Upgrading Bridge Rails on Low-Volume Roads in Iowa

Center for Transportation Research and Education

Final Report
June 2016

IOWA STATE UNIVERSITY
Institute for Transportation

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

About InTrans

The mission of the Institute for Transportation (InTrans) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.

About CTRE

The mission of the Center for Transportation Research and Education (CTRE) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, and reliability while improving the learning environment of students, faculty, and staff in transportation-related fields.

Disclaimer Notice

ISU Non-Discrimination Statement

Iowa DOT Statements

The preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its "Second Revised Agreement for the Management of Research Conducted by Iowa State University for the Iowa Department of Transportation" and its amendments.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
IHRB Project TR-679		

4. Title and Subtitle	5. Report Date
Upgrading Bridge Rails on Low-Volume Roads in Iowa	June 2016
	6. Performing Organization Code
7. Author(s) Zachary Hans, Basak Aldemir Bektas, Emmanuel Nketah, and Brent Phares (orcid.org/0000-0003-0649-9124, orcid.org/0000-0002-0866-6216, orcid.org/0000-0001-6678-5128, and orcid.org/0000-0001-5894-4774)	8. Performing Organization Report No. InTrans Project 14-508
9. Performing Organization Name and Address Institute for Transportation Iowa State University 2711 South Loop Drive, Suite 4700 Ames, IA 50010-8664	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Organization Name and Address Iowa Highway Research Board Iowa Department of Transportation 800 Lincoln Way Ames, IA 50010	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code IHRB Project TR-679

15. Supplementary Notes

Visit www.intrans.iastate.edu for color pdfs of this and other research reports.

16. Abstract

Building on previous research, the goal of this project was to identify significant influencing factors for the Iowa Department of Transportation (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—specifically, factors that might be significant for the bridge rail rating system component of I.M. 3.213.

A literature review was conducted of policies and guidelines in other states and, specifically, of studies related to traffic barrier safety countermeasures at bridges in several states. In addition, a safety impact study was conducted to evaluate possible non-driver-related behavior characteristics of crashes on secondary road structures in Iowa using road data, structure data, and crash data from 2004 to 2013. Statistical models (negative binomial regression) were used to determine which factors were significant in terms of crash volume and crash severity.

The study found 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), and bridges older than 25 years (both paved and unpaved).

No specific roadway or bridge characteristic was found to contribute to more serious crashes. The study also confirmed previous research findings that crashes with bridges on secondary roads are rare, low-severity events. Although the findings of the study support the need for 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.

17. Key Words	18. Distribution Statement
bridge barrier rails—bridge guardrails—crash severity mitigation—low-volume roads—safety countermeasures—secondary road bridges	No restrictions.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified.	Unclassified.	56	NA

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

UPGRADING BRIDGE RAILS ON LOW-VOLUME ROADS IN IOWA

Final Report
June 2016

Principal Investigator
Zachary Hans, Research Engineer
Center for Transportation Research and Education, Iowa State University

Co-Principal Investigators
Basak Aldemir Bektas, Research Scientist
Center for Transportation Research and Education, Iowa State University
Brent Phares, Director
Bridge Engineering Center, Iowa State University

Research Assistant
Emmanuel Nketah

Authors
Zachary Hans, Basak Aldemir Bektas, Emanuel Nketah, and Brent Phares

Sponsored by
the Iowa Highway Research Board and
the Iowa Department of Transportation
(IHRB Project TR-679)

Preparation of this report was financed in part
through funds provided by the Iowa Department of Transportation
through its Research Management Agreement with the
Institute for Transportation
(InTrans Project 14-508)

A report from
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.intrans.iastate.edu

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

This research project was sponsored by the Iowa Department of Transportation and the Iowa Highway Research Board. The authors would like to thank the Technical Advisory Committee for their input and effort on the project.

EXECUTIVE SUMMARY

The goal of this project was to identify significant influencing factors for the Iowa Department of Transportation (Iowa DOT) to consider in future updates of its Instructional Memorandum (I.M.) 3.213 (Iowa DOT 2013), which provides guidelines for determining the need for traffic barriers (guardrail and bridge rail) at secondary roadway bridges—specifically, factors that might be significant for the bridge rail rating system component of I.M. 3.213.

Background

A previous study for the Iowa Highway Research Board (IHRB TR-592) provided an overview of the nation's bridge and approach rail state of practice and of a statewide crash analysis of bridge rails and approach guardrails on low-volume road (LVR) bridges in Iowa. The study found that LVR bridge crashes were rare events, occurring more frequently on bridges with widths of less than 24 ft. Crash rates were found to be higher on bridges with a narrower width compared to the approach roadway width.

Partly as a result of TR-592, changes were made to the guardrail exceptions in I.M. 3.213 to increase the average daily traffic (ADT) exception from 200 vehicles per day (vpd) to 400 vpd and add an exception for bridges with widths greater than the approach roadway width. However, no significant changes were made to the detailed bridge rail rating system component of I.M. 3.213, which is used to determine necessary bridge rail upgrades by assigning points to bridges based on crash history, ADT, width, length, and type of bridge rail. Thus, the current study was a follow-up to, and builds upon, the results of TR-592.

Research Methodology

A literature review was conducted of policies and guidelines in other states and, specifically, of studies related to traffic barrier safety countermeasures at bridges. Bridge railing and guardrails are a Group 3 (high-severity) fixed object/hazard (Stephens 2005). In general, however, for certain roadway characteristics such as LVRs, it may not be necessary or desirable to design bridge railing or guardrail countermeasures to full AASHTO standards. Also, the *Guidelines for Geometric Design of Very Low-Volume Local Roads* (ADT ≤400 vpd) (AASHTO 2001) recommend that safety improvements should be initiated only when a safety problem exists at a site.

To identify safety problems at bridges on Iowa's LVRs, a safety impact study was conducted. The impact study evaluated possible non-driver-related behavior characteristics of crashes on secondary road structures in Iowa using roadway data, structure data, and crash data from 2004 to 2013. Negative binomial regression models were used to determine which factors were significant in terms of crash frequency; an ordered probit regression model was used to determine the influence of roadway and structure characteristics on the severity of crashes involving bridge components. In the 10-year study period, 846 crashes were retained and used in the analyses.

First, a combined sample set involving the entire secondary road network (statewide) to investigate the effects of the explanatory variables (road and structure characteristics) on the expectancy of bridge crashes for the entire network as a whole was analyzed. Then, separate samples from only paved roads and unpaved roads, respectively, were analyzed. Splitting the network into paved and unpaved secondary systems allowed for more specific parameter estimation for the paved and unpaved systems, which may have exclusive policies and characteristics that cannot be specified as variables.

Several characteristics were identified as possible factors correlated with bridge crashes: traffic volume and percentage of heavy vehicles, roadway cross-section features factors such as lane/shoulder widths and structure length, roadway alignment factors such as the presence of horizontal/vertical curvature, and weather conditions factors such as the presence of rain/snow or low visibility settings. Several factors were excluded from the study for various reasons, leaving the following factors to be considered in the final analyses: traffic volume (ADT), bridge width, bridge length, and bridge age.

Key Findings

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).

No specific roadway or bridge characteristic, including paved or unpaved, was found to contribute to more serious crashes.

Conclusions

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.

INTRODUCTION

In March 2010, the Iowa Highway Research Board (IHRB) sponsored project “Bridge Rail and Approach Railing for Low-Volume Roads In Iowa” (TR-592) (Bigelow et al. 2010) was completed. TR-592 provided an overview of the nation’s bridge and approach rail state of practice as well as results of a statewide crash analysis of bridge rails and approach guardrails on low-volume road (LVR) bridges in Iowa. Primary analysis findings were that LVR bridge crashes were rare events, occurring on bridges with very low volumes and width less than 24 ft. Additionally, crash rates were higher on bridges with a narrower width compared to the approach roadway width.

The Iowa Department of Transportation (DOT) used the TR-592 findings, in part, in the July 18, 2013, update of Instructional Memorandum (I.M.) 3.213 (found in Appendix A) which provides guidelines for determining the need for traffic barriers (guardrail and bridge rail) at roadway bridges. Specifically, the following changes were made to the guardrail exceptions: (1) the average daily traffic (ADT) exception was increased from 200 vehicles per day (vpd) to 400 vpd and (2) an exception was added for bridges with a width greater than the approach roadway width. However, no significant changes were made to the bridge rail rating system component of I.M. 3.213. This system is used to determine necessary bridge rail upgrades by assigning points to bridges based on crash history, ADT, width, length, and type of bridge rail.

The existing bridge barrier rail rating system is somewhat detailed, with limited documentation regarding the basis for point assignment, categories, and thresholds employed. For example, a combination of different crash severities and frequencies dictates crash history-based point assignment. However, if minimum equivalent crash costs are estimated for these different combinations, resulting costs may overlap among categories. A wide range of values may also exist within any given category. Using the Iowa DOT’s Traffic Safety Improvement Program (TSIP) benefit cost worksheet, the minimum equivalent cost for a bridge receiving 10 points can be in excess of $300,000, while minimum costs for bridges receiving 15 and 20 points range from approximately $15,000 to $4.8M and $22,000 to $4.8M, respectively. That said, I.M. 3.213’s bridge barrier rail rating system still supports the essential role of promoting traffic safety on local roads, ensuring motorists adequate protection from more hazardous objects.

This project builds on previously completed research, including TR-592, through comprehensive, rigorous analysis of crash experience at or on secondary road bridges in Iowa. A primary objective is to investigate and identify significant influencing factors that may be considered in future updates of I.M. 3.213, balancing traffic safety and practical application of bridge rail guidelines.

LITERATURE REVIEW

Policies and Guidelines

Modern highway design concepts essentially began in the 1940s; however, roadside safety design did not start until the 1970s (AASHTO 2011). Sometimes referred to as "off-pavement" design, roadside design is often defined as the design of the area outside the traveled way. Today, many roadways built prior to 1970 have reached their useful designed lifespan and are prime candidates for reconstruction—an opportunity to update and improve their "off-pavement" designs. National- and state-level roadway design guidelines have been established to be used by states and local agencies as acceptable design standards/guidance and are regularly revised/refined over time. Released in 1967, the *Highway Design and Operational Practices Related to Highway Safety* was the first official report that focused attention on hazardous roadside elements and suggested appropriate treatments for them (AASHTO 2011). The document was later revised and updated in 1974 with the introduction of roadside concepts by the American Association for State Highway Officials. In 1989, AASHTO published the first edition of the *Roadside Design Guide*. Through years of experience and research, the design guide has been modified over time to include sequential options for reducing crashes involving roadside obstacles. The following, in order of preference, are techniques suggested for reducing crashes and crash severity:

1. Remove the obstacle.
2. Redesign the obstacle so it can be safely traversed.
3. Relocate the obstacle to a point where it is less likely to be struck.
4. Reduce impact severity by using an appropriate breakaway device.
5. Shield the obstacle with a longitudinal traffic barrier designed for redirection or use a crash cushion.
6. Delineate the obstacle if the previous alternatives are not appropriate.

Often, the removal or relocation of such roadside obstacles may be impractical or unavoidable. Along roadways where the shortest lateral distance (i.e., horizontal clearance) to a roadside fixed objects is considered "insufficient" or hazardous to user safety, some common cost-effective countermeasures include the installation of obstacle protective devices such as cable/traffic barriers, guardrails, or impact attenuators (crash cushions), the installation of "on-the-pavement" edge safety features such as shoulder rumble strips/stripes, or a combination of both to help errant vehicles recover after diverging from its traveled way before colliding with a roadside obstacle. In many cases, these counteragents may be appropriate and have been proven beneficial toward the reduction of the severity and possibly frequency of run-off-road crashes. Nonetheless, they do not completely explain the problem of serious injuries associated with roadway departure crashes involving roadside objects.

The AASHTO *Manual for Assessing Safety Hardware* (MASH) is the new state-of-the-practice for the crash testing of safety hardware devices for use on the National Highway System (NHS). Federal Highway Administration (FHWA) policy requires that all roadside appurtenances such as traffic barriers, barrier terminals and crash cushions, bridge/approach (guard) railings, sign and light pole supports, and work zone hardware used on the NHS (or federally funded projects) shall meet full-scale crash performance criteria contained in the *National Cooperative Highway Research Program (NCHRP) Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* (Ross et al. 1993) or AASHTO's MASH (AASHTO 2009). Bridge railings are very important components of roadway safety systems and play an important role in preventing and mitigating crash severity. Since their primary purpose is to prevent penetration, bridge railings must be strong enough to redirect an impacting vehicle. MASH presents specific test level (TL) impact conditions at various speeds for conducting vehicle crash tests. However, because of concerns with high speed conditions, test level 3 (TL-3), tested at 100 km/h (62 mph), devices are considered standard by many highway agencies (AASHTO 2009). Table 1 shows the test matrix for traffic barrier systems.

Table 1. Example of MASH test matrix for traffic barrier Systems

Test Level	Test Vehicle Designation and Type	Test Conditions		
		Vehicle Weight kg [lb]	Speed km/h [mph]	Angle Degree
1	1100C (Passenger Car)	1,100 [2,420]	50 [31]	25
	2270P (Pickup Truck)	2,270 [5,000]	50 [31]	25
2	1100C (Passenger Car)	1,100 [2,420]	70 [44]	25
	2270P (Pickup Truck)	2,270 [5,000]	70 [44]	25
3	1100C (Passenger Car)	1,100 [2,420]	100 [62]	25
	2270P (Pickup Truck)	2,270 [5,000]	100 [62]	25
4	1100C (Passenger Car)	1,100 [2,420]	100 [62]	25
	2270P (Pickup Truck)	2,270 [5,000]	100 [62]	25
	10000S (Single Unit Truck)	10,000 [22,000]	90 [56]	15
5	1100C (Passenger Car)	1,100 [2,420]	100 [62]	25
	2270P (Pickup Truck)	2,270 [5,000]	100 [62]	25
	36000V (Tractor/Van Trailer)	36,000 [79,300]	80 [50]	15
6	1100C (Passenger Car)	1,100 [2,420]	100 [62]	25
	2270P (Pickup Truck)	2,270 [5,000]	100 [62]	25
	36000T (Tractor/Tanker Trailer)	36,000 [79,300]	80 [50]	15

Source: AASHTO 2009

In many instances, TL-3 devices work for both TL-1 and TL-2 conditions as well as for high speed conditions. The FHWA reviews test results and issues worthiness letters for each bridge rail that is tested according to the evaluation criteria.

The FHWA believes that the most responsible method for determining (bridge) roadway design standard is based on a consistent design approach, guided by past crash history and a cost-effectiveness analysis. The *Roadside Design Guide* provides guidance to help local agencies develop consistent design approaches for determining the widths of clear zones along roadways based on speed, traffic volume, roadside slope, and curvature (AASHTO 2011). The design guide also recommends clear zone ranges based on a width of 30 to 32 ft for flat, level terrain adjacent to a straight section of a 60 mph highway with an average daily traffic of 6,000 vehicles. For steeper slopes on a 70 mph roadway the clear zone range increases to 38 to 46 ft, and on a low speed, low-volume roadway the clear zone range drops to 7 to 10 ft. For horizontal curves the clear zone can be increased by up to 50%. Another AASHTO publication, *A Policy on Geometric Design of Highways and Streets* (also known as the Green Book), recommends a 10-foot minimum clear zone on collectors without curbs, low-speed rural collectors, and rural local roads (AASHTO 2004). For local roads and streets, a minimum clear zone of 7 to 10 ft is considered desirable on sections without curb. As a practical matter, the clear zone dimensions may be limited by available right-of-way; the location, frequency, and nature of roadside objects; the presence of valued resources such as wetlands; or the need to provide for pedestrians (AASHTO 2004). Thus, railing or guardrail countermeasures designed to full AASHTO standards may not be necessary/desirable for certain roadway characteristics such as LVRs. Also, the *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤400 vpd)* (AASHTO 2001) recommends that safety improvements should be initiated only when a safety problem exists at a site. Furthermore, the design guide states that a one-lane bridge can be used for roads with traffic volumes of less than 100 vpd.

Roadside crash fatality rate for rural roads is estimated to be nearly three times the average roadside fatal crash rate for all roads in the United States (Ross et al. 1993), and these types of roads typically have very restricted rights-of-way, little to no clear zones, and substandard design features. Because of their low traffic volumes, drivers are more likely to become distracted and fatigued. Nonetheless, this is still a concern on all roads. The *Manual on Uniform Traffic Control Devices* (MUTCD) requires that post/sign supports within the clear zone be made breakaway or shielded by a barrier (FHWA 2009). All existing supports located on highways posted at 50 mph or greater shall meet this criterion by January 2013. On roads posted at speeds 45 mph or lower, the breakaway criterion may be met when upgrading sign retroreflectivity or by 2019, whichever comes first. Based on an urban roadside safety study conducted by Dixon et al. (2009) on arterial and collector-type facilities in urban areas with speeds up to 50 mph, the authors assessed corridors of urban roadside conditions and compared 6 years of historic crash data with roadside features and noted that "restricted right-of-way with a greater demand for functional use of the space adjacent to urban roads makes the maintenance of a wide clear zone impractical."

Engineering is not a science; it is an art. As an art, its practice precedes its theory. Thus, per design standard, most countermeasures are routinely installed based on a subjective analysis of their benefits to the motorist. However, on occasion, the benefits gained from a specific safety design or treatment may not be immediately obvious; thus, engineering judgement is also required to decide how, where, and when funds are spent to achieve maximum benefit. Addressing safety on local and rural roads presents several challenges including the actuality that 1) safety issues are often random on local and rural roads and 2) strategies to address local and rural road safety are diverse and draw from several safety areas. Consequently, per AASHTO's *Load and Resistance Factor Design* (LRFD) manual, agencies are required to develop their warrants for bridge installations (or upgrades) per site (FHWA 2001). They are also encouraged to upgrade existing safety hardware that has not been accepted either during a bridge's reconstruction or resurfacing, rehabilitation, or restoration (3R) projects or when the system is damaged beyond repair. The Roadside Safety Analysis Program (RSAP) offers an example of one methodological approach typically used for accomplishing a benefit/cost analysis of various countermeasure alternatives.

Previous Studies

Supplemental to national-level guidance, several agencies have analyzed the design and safety countermeasures of bridges through various research efforts. Nonetheless, it is impossible for regression models to account for each and every factor associated with crash occurrences (Persaud and Dzbik 1993). As the first crash frequency modelers to analyze multilane roadways, Persaud and Dzbik investigated the relationship between freeway crashes and traffic volumes (Chengye and Ranjitkar 2013). In design, most focus is typically placed on the crashworthiness of the guardrail/bridge rail connections and end treatments; hence, very few studies were found to be directly related to the objectives of this research. Table 2 shows summaries of findings related to traffic barrier safety countermeasures in design and traffic safety characteristics.

Table 2. Summary of studies related to traffic barrier safety countermeasures

Author(s)	State	Scope	Major Finding(s)
Stephens (2005)	(All)	Barrier warrants, selection, and design	Traffic volume, speed, roadway characteristics, including grade and curvature, all affect the odds of a crash.
Mehta et al. (2015)	Alabama	Bridge components safety performance	High presence of trucks and use of transition railings were found to be significant noncontributory factors associated with bridge crashes.
Zou et al. (2014)	Indiana	Traffic barriers safety performance	Guardrails should be preferred over concrete barriers, and cable barriers should be preferred over guardrails where geometric conditions allow.
Bigelow et al. (2010)	Iowa	Guardrail and bridge rail performance	Frequency of vehicular crashes are more prevalent on bridges with smaller widths in relation to roadway width.
Seitz and Salfrank (2014)	Kansas	Guardrail and bridge rail design	Railings installed on new bridges could be of a non-tested design if the structure meets the set of conditions.
Gates and Noyce (2006)	Minnesota	Guardrail barrier effectiveness	Guardrails installed at all four quadrants of a bridge have a B/C ratio ranging from 3.99 to 6.62 and are cost-effective at ADT greater than 400 vpd.
Dare (1992)	Missouri	Guardrail barrier effectiveness	Roads with ADT of 400 vpd, at 60 mph and 2-ft lateral offset do not have sufficient traffic volumes to warrant approach guardrail.
Turner (1984)	Texas	Bridge components safety performance	Structures became "safer" as one moves from negative to positive relative widths of bridges.
Lee and Mannering (1999)	Washington	Safety performance of roadside objects	Perhaps, roadside recovery space is the most important factor in reducing crash severity in presence of narrower lane and shoulder widths.

All States

Many fixed objects present some degree of risk if struck but are not serious enough to consider removal or shielding countermeasures. It is important to first understand the philosophy of roadside design concepts to better apply their criteria and processes. According to Stephens (2005), warranting of roadside barriers is difficult to quantify, particularly for low-volume, low-speed roads. They require processes to ensure that all important issues are addressed rather than a "cookbook" approach. Thus he suggests special, practical considerations be taken for such road classification per condition situations. Relative to this study, they include consideration for speed, hazard offset, and special design considerations for aesthetics and severe conditions. Table 3 lists hazards and their potential severity.

Table 3. Fixed object potential hazards

Potential Hazard	Group 1 (Low Severity)	Group 2 (Moderate Severity)	Group 3 (High Severity)
Bridge piers, abutments, and railing ends			X
Boulders, less than 0.3 m (1 ft) in diameter		X	
Boulders, 0.3 m (1 ft) in diameter or larger			X
Non-breakaway sign and luminaire supports		X	
Individual trees, greater than 100 mm (4 in.) and less than 200 mm (8 in.) diameter	X		
Individual trees, greater than 200 mm (8 in.) diameter		X	
Groups of trees, individually greater than 100 mm (4 in.) diameter*			X
Utility poles		X	

*Because of driver expectancy, a group of trees at a consistent offset for lengthy distances may experience lower encroachment rates, even though the offset may be within the clear zone. In such instances, it may be appropriate to consider the trees a Group 2 hazard.

Source: Stephens 2005

Severity increases from 1 to 3, with Group 3 being the most severe. Furthermore, Stephens noted that considerations should also take into account both the cost of a barrier and the expected crashes into that barrier. Often, local conditions, policies, and resources are also considered. In all, these considerations lead to a list of technically acceptable barriers for a specific site. Figure 1 presents an example bridge rail end that is unshielded since no hazard from Table 3 is warranted.

Stephens 2005

Figure 1. Unshielded bridge rail end

Similarly, within the perspective of traffic operations, the concepts of probability and severity must be understood to effectively evaluate roadside safety alternatives. Stephens (2005) suggested that the probability (or likely frequency) of a vehicle striking any roadside object or condition (including barriers) should be determined by a complex set of variables, including the following:

- Traffic volume
- Speed
- Roadway characteristics (number and width of lanes, shoulders, divided or not, etc.)
- Horizontal curvature
- Grade
- Size and offset of the hazard or barrier
- Rate of encroachment (affected by familiarity of drivers, driver distractions, driver expectancy and design consistency of the roadway)

Alabama

A recent study conducted by Mehta et al. aimed to develop safety performance functions for overall crashes and single-vehicle crashes involving bridges in Alabama (Mehta et al. 2015). The study focused on 1,122 bridge structures located on state and interstate highways, including ramps. Of the structures considered, 9,985 crashes along the structures' overpasses were associated and used as bridge crash incidents (crash incidents that occur on/near a bridge) for the analysis. The study used negative binomial regression to estimate crash frequency involving bridges in addition to identifying factors associated with bridge crashes. Best fitting models were chosen using log-likelihood and AIC (Akaike Information Criterion) values. Of all variables considered, annual average daily traffic (AADT), bridge length, shoulder width, and the use of approach railings/guardrail-ends were identified to be significant contributing factors to increase the expected number of bridge crashes, whereas high presence of trucks and use of transition railings were found to be significant noncontributory factors likely to decrease the expected number of bridge crashes. It was also found that the predictive capability of the final model (using all significant variables) was not much different from the predictive capability of similar model using only AADT, bridge length, and truck percentage. Moreover, the authors noted that, if available, the variables related to the presence of bridge railings or guardrails may be included but are not essential.

Indiana

Another study conducted by Zou et al. (2014) analyzed the severity of injuries sustained by vehicle occupants when colliding with several types of roadside barriers along freeways. The study focused on the safety performance of road barriers in Indiana in reducing the risk of injury. In so doing, the study compared the risk of injury among different hazardous events faced by an occupant in a single-vehicle crash. The studied hazardous events included rolling over, striking three types of barriers (guardrails, concrete barrier walls, and cable barriers) with different barrier offsets to the edge of the traveled way, and striking various roadside objects. A total of 2,124 single-vehicle crashes (3,257 occupants) that occurred between 2008 and 2012 on 517 pair-matched homogeneous barrier and non-barrier segments were analyzed. The findings indicated that crashes involving barriers such as guardrails or cable barriers are typically less severe than crashes with poles or rollover crashes. More specifically, the study found that the likelihood of occupant injury was reduced significantly across several crash barrier types as offset distance increased depending on the barrier struck. For example, odds of injury decrease 43% when colliding with a guardrail within 15–18 ft rather than colliding with a median concrete barrier within the same lateral offset distance. Further injury reductions were observed when compared to a concrete barrier within 7–14 ft of the traveled way. The study claimed that guardrails should be preferred over concrete barriers, and cable median barriers should be preferred over guardrails where geometric conditions allow. The study noted, however, that there was a certain degree of invariability across vehicle characteristics in regards to crash severity sustained and general interactions between barrier types during collisions.

Iowa

The most recent study in the state of Iowa concerning LVR traffic barriers was conducted by Bigelow et al. (2010) to determine criteria and guidelines used by states for bridge and approach guardrail implementation on low-volume roads. The primary objective of the study was to provide information about the use of bridge rail and approach guardrail on LVR in Iowa. Statistical and economic analyses were used to aid the investigation. The authors found that, based on a survey of non-Iowa bridge owners, most agencies tend to not use ADT as a requirement for bridge barriers; however, a majority did use protective treatments other than W-beam as effective countermeasures. Regardless, the criteria for determining traffic barrier use for most agencies have not changed over the past 10 years. Within the Iowa structure and crash databases, the analyses revealed that crash rate decreased as bridge traffic volume (or bridge width) increased; both the crash frequency and crash rate were higher for bridges with lower traffic volumes.

A previous study led by Schwall (1989) in the state of Iowa in 1988 looked at the cost-effectiveness of approach guardrails on primary-system roads. Schwall found that, to obtain a B/C ratio of 1.0 or better, a traffic volume of at least 1,400 vpd with a guardrail offset of 2 ft is required.

Currently, the Iowa DOT recommends upgrade standards provided in its Instructional Memorandums (I.M.s) to Local Public Agencies that warrant bridge railing upgrades based on scoring of five criteria (Iowa DOT 2013):

1. Crash History (in the past 5 years)
2. ADT (current year annual daily traffic)
3. Bridge Width (curb-to-curb) in ft
4. Bridge Length (in ft)
5. Bridge Type

Kansas

A study by Seitz and Salfrank (2014) aimed to maximize the safety benefits of low-cost bridge design for low-volume local roads in Kansas given the limited funding. The study consisted primarily of bridge/approach guardrail crash-cost analyses. In conclusion, the authors recommended that bridge rails installed on new or rehabilitated bridges utilizing federal funds could be of a non-tested design if the structure meets the set of conditions. This non-tested design should be constructed of a W-beam guardrail section mounted on standard guardrail posts that are fastened to the bridge structure either by welding or a bolted connection. In addition, no approach guardrail will be required on these bridges. Nonetheless, Seitz and Salfrank noted that, although the findings would support a policy that does not require installation of bridge rails on structures between 20 ft and 50 ft on roads functionally classified as Local Roads with less than 50 vpd), it is recognized that there are benefits of the rail that cannot be evaluated by this effort.

In support, an earlier study in the state of Kansas (Russell and Rys 1998) compared the probabilities and expected cost of crashes at bridge and culvert locations with bridge rails and headwalls versus the expected cost of crashes with bridge rails and culvert headwalls removed. Russell and Rys concluded that the expected costs of these crashes were less with the concrete rails and headwalls removed for ditch depths of 2.4 meters or less.

Minnesota

A study led by Gates and Noyce (2005) analyzed characteristics of 96 run-off-road, rural-area crashes that occurred on the approach or departure railings of low-volume state-aid highway bridges in Minnesota over a 14-year period from 1988 to 2002. The objective of the study was to determine the ADT at which the B/C ratio suggests that installation of guardrails at the bridge approach is cost-effective (i.e., B/C > 1.0). On the basis of statistical and benefit-cost analyses, the study confirmed that crashes that occurred at bridges with approach guardrails were significantly less severe than crashes that occurred at bridges without guardrails. Crashes involving bridges with approach guardrails were more likely to result in property damage only. More precisely, approach guardrails installed at all four quadrants of a bridge had a B/C ratio ranging from 3.99 to 6.62 and are cost-effective at traffic volumes greater than or equal to 400 vpd, according to Gates and Noyce. The study recommended to the Minnesota DOT that a minimum threshold of 400 vpd be a requirement for the installation of a bridge guardrail on LVRs, which is consistent with current roadside clear zone guidelines suggested by AASHTO for local LVRs. The authors furthermore suggest that bridges with ADT volumes between 150 to 400 vpd be reviewed individually because bridges with unique circumstances (bridges along curves and/or bridges with narrow widths) may warrant guardrails. Installing guardrails along bridges serving ADT less than 150 vpd is considered probably not cost-effective by Gates and Noyce; nonetheless, if a guardrail is installed, it should be on all four corners of the bridge.

Missouri

The Missouri DOT (MoDOT) concluded from a study by Dare (1992) that roads with an ADT of 400 vpd at 60 mph speed limit and 2-ft lateral guardrail offset do not have sufficient traffic volumes to warrant approach guardrail. The same study also provided higher thresholds values for 40 and 50 mph speeds and lateral offsets of 8 and 10 ft, respectively.

Texas

A similar study conducted by Turner (1984) aimed to identify hazardous structures, evaluate potential safety treatments, predict bridge accidents, and set priorities for improvement at bridges in Texas. Rural, two-lane two-way bridge crashes were the focus of the study. The investigation was narrowed to a statistically consistent sample of 2,849 crashes that occurred at or near 2,087 structures during a 4-year period. The research led to emphasis on three key variables: (1) width of a bridge (bridge width minus road width), (2) ADT, and (3) width of the approach roadway. These variables were used to develop a probability table for collision prediction. Results showed that the structures became “safer” as one moves from negative to positive relative widths of bridges.

Washington

One study conducted by Lee and Mannering (1999) investigated the relationships among roadway geometry, roadside characteristics, and run-off-roadway accidents and concluded that temporal, environmental, driver-related, roadway, and roadside geometric characteristics all play a role in roadside crash severity. However, the study also declared that perhaps roadside recovery space is the most important factor in reducing crash severity. Other factors such as driver inattention, lack of experience, and impaired driving create higher risks of severe injury crashes. The authors acknowledged that due to the cost associated with roadside data collection, it is difficult to develop effective models for the relationship between run-off-road crashes and crashes involving fixed objects. Some notable findings included the following: decreased crash severity when narrow shoulders are present, increased probability of fatal crashes on or near bridges, increased crash severity in the presence of tree groups, and decreased probability of incapacitating (or fatal) crash severity when utility poles are present. It would seem counterintuitive that crashes in the presence of utility poles would lower probability of severe injury; nonetheless, Lee and Mannering suggested that this could be due to the increased distance (recovery space) from the outside edge of traveled lane to the utility pole.

DATA COLLECTION METHODOLOGY

In order to conduct a safety impact study to evaluate possible non-driver-related behavior characteristics of crashes on secondary road structures in Iowa, a statewide analysis of crashes occurring during the period from January 2004 to December 2013 was performed. The primary sources of data for this analysis included the Iowa DOT Geographic Information Management System (GIMS) and the Iowa Crash Data. A statewide query and integration of all data from 2004 to 2013 was performed using ArcGIS 10.2 software program.

From the GIMS database, two sets of records were of interest: the Base Record Road Data and the Structure Data. In conjunction with these two GIMS records were the Crash Record Data that came from the Iowa Crash Data for the same years (2004–2013).

Roadway Database

The Base Record Road database included all public road records in Iowa. However, given the scope of the research, only roadways under county jurisdiction (secondary roads) were considered in the analysis. Roadways classified as interstate, major U.S./state route, municipal, or institutional roads were excluded. Of those roadways included in the study, roadway characteristics were associated with the structures along the network, including the following key characteristics:

- Annual average daily traffic volume of the road
- Speed limit of the road
- Roadway geometry (in terms of width and number of lanes serving the roadway)
- Surface type of the roadway (paved versus unpaved)

On the basis of these criteria, approximately 75% (88,000 miles) of the public road network were considered local, secondary roads. Moreover, 80% of the secondary roadway network had unpaved surface type and 20% paved.

Structure Data

The Structure database included all National Bridge Inventory (NBI) structures in the state of Iowa, specifically, those structures of a minimum length of 20 ft, located along secondary roadways and serving vehicular traffic on the bridge. Structures serving railroads and other non-vehicular modes were excluded from the analysis. Of the nearly 26,000 recorded structures in the database, 20,791 (79.2%) of them were vehicular bridge structures on a secondary roadway. Those also included box-culverts of 20 ft or longer along secondary roads. Of those structures retained, some of the key structure characteristics included were the structure number/ID, the structure geometry (i.e., bridge length and bridge width), and structure construction or reconstruction year. As previously noted, roadway characteristics were also associated with each structure. Furthermore, the selected structures were then divided into two samples: those situated on a paved road network system (n = 5,704) and those situated on an unpaved road network system (n = 15,087).

Crash Data

The crash database includes reported and recorded crashes on all public roads resulting in an injury or minimum estimated property damage of $1,500. In the 10-year analysis period from 2004 to 2013, there were a total of 547,654 automobile crashes reported and recorded in the state of Iowa; however, of those recorded, less than 1% (5,377) were crashes involving a vehicle striking a bridge or bridge rail on a secondary roadway overpass. Furthermore, based on the premise that all crashes of interest may or may not be geospatially accurate and providing that all structures (including those less than 20 ft in length) are not geospatially located in the structure database, the preliminary 5,377 “bridge” crashes of interest were then examined and refined.

In an attempt to minimize possible errors in the crash coding/selection procedure, bridge crashes within 50 m (164 ft) of either inventoried structures in the database or streams/rivers intersecting secondary roadways were initially retained. The spatial proximity of 50 m was employed to address changes (improvements) in the spatial accuracies of the roadway, structures, and crash database throughout the analysis period and not neglect crashes located at non-inventoried structures. However, due to lack of extensive information about these non-inventoried structures, corresponding crashes were ultimately excluded from analysis. The majority of crashes 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. Thus, upon final revision of the refined crashes, the locations of 846 crashes involving vehicles striking a bridge or bridge component were retained and used in the succeeding analysis.

Of the crashes included in the study, key crash characteristics were noted and associated to the nearest structure to each crash. Key crash characteristics included the following: a unique crash key (and case number) for each crash, the severity level of the crash (in terms of number of fatalities and injuries), number of vehicles involved in a crash, location and time of the crash, and other environmental and weather conditions during the time of collision. These 846 crashes occurred at 729 structures, with some structures involved in more than one crash during the analysis period. Table 4 shows the distribution of structures ranging from 20,062 structures with zero crashes to 1 structure with 6 crashes.

Table 4. Distribution of number of structures per number of crashes

Road Network	Number of Structures per Number of Crashes on the Structure						
	Zero Crashes	One Crash	Two Crashes	Three Crashes	Four Crashes	Five Crashes	Six Crashes
Paved	5312	332	44	11	3	1	1
Unpaved	14750	313	16	7	1	0	0

Figure 2 shows an example of the bridge struck more than once during the analysis period.

©2016 Google

Figure 2. Example of a bridge structure struck more than once

Data Processing

Within the analysis period, in order to correct for potential temporal differences in the GIMS data each year, crashes of any given year were linked to the Structure and Road database of the year the crash record occurred, as illustrated in Figure 3.

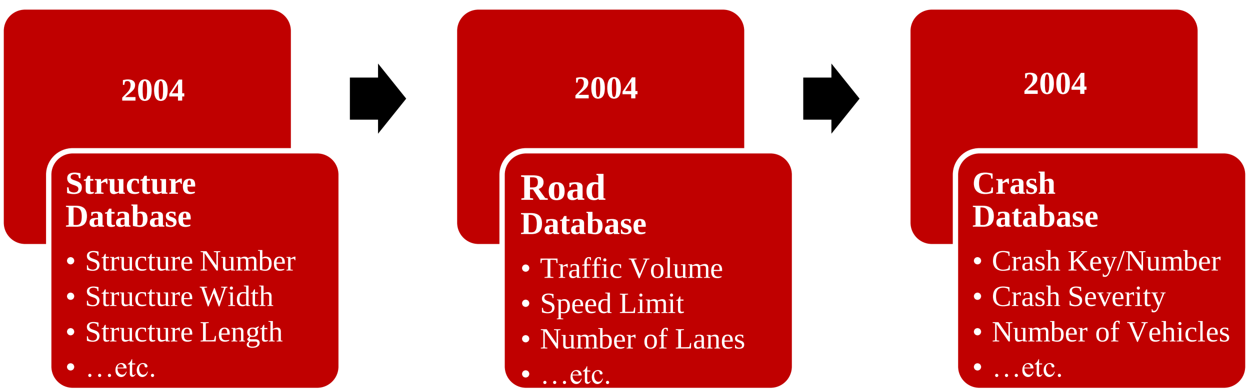


Figure 3. Diagram showing crashes of any given year linked to the databases of that year

For example, if a crash occurred in 2004, its Structure and Road Data were based on the 2004 record for which the crash occurred. Furthermore, in any instance where a structure experienced no crash in the analysis period, its Structure and Road data were based on the middle year GIMS snapshot record (2008–2009). In any instance where a structure experienced multiple crashes in different years (or same year) in the analysis period, the averages of the Structure and Road Data were used to avoid over representation of structures with multiple crashes in the final analysis.

DATA ANALYSIS METHODOLOGY

In an effort to apply the most appropriate methods that best reflect the data distribution to produce effective model results, a number of sampling approaches were considered for various statistical modeling approaches (i.e., negative binomial regression model vs. Poisson regression). Sampling adjustments were also made based on the advice from the project's technical advisory committee (TAC) to improve the study variables for a better representation of local roads and bridges and to have variables that conform to potential policy decisions. Final decisions on the selection of the statistical models were based on the data set and analysis results.

Data Sampling and Descriptive Statistics

Initially, based on advice from the project's TAC, only selected counties (shown in Table 5) were included in the data sample.

Table 5. Distribution of structures and "bridge" crashes by county for the top 5 plus technical advisory committee counties

County Number	County Name	Number of Structures	Number of "Bridge" Crashes
31	Dubuque	259	35
94	Webster	203	31
78	Pottawattamie	396	30
85	Story	238	29
16	Cedar	279	28
96	Winneshiek	335	28
54	Keokuk	178	7
72	Osceola	165	7
99	Wright	169	5
-	Other 90 Counties	18,569	646
	Total	**20,791**	**846**

These were the top five counties, including one tie, which experienced the most bridge crashes (Dubuque, Webster, Pottawattamie, Story, Cedar, and Winneshiek) in addition to three counties represented by the TAC (Keokuk, Osceola, and Wright). However, due to the small sampling size of 200 crashes within these counties, the analysis was expanded to include all counties to improve the results and have sufficient number of observations for the statistical analysis.

Moving forward, the analysis was implemented in three parts. First, a combined sample set involving the entire secondary road network (statewide) to investigate the effects of the explanatory variables (road and structure characteristics) on the expectancy of bridge crashes for the entire network as a whole was analyzed. Then, separate samples involving only paved roads and unpaved roads, respectively, were analyzed. Splitting the network into paved and unpaved secondary systems allows for more specific parameter estimation for the paved and unpaved systems, which may have exclusive policies and characteristics that cannot be specified as variables. Table 6 shows the distribution of bridge crashes and number of structures represented in the three models.

Table 6. Distribution of structures and "bridge" crashes by paved and unpaved secondary road network system

	Statewide Sample		Paved Sample		Unpaved Sample	
	Statewide Road Network		Paved Road Network		Unpaved Road Network	
Number/% of Crashes	846	100%	477	56%	369	44%
Number/% of Structures	20,791	100%	5,704	27%	15,087	73%

Based on the descriptive statistics of the sample data and previous literature, a few characteristics stood out to be factors correlated with bridge crashes and were considered initially in this analysis. Those characteristics included traffic volume and percentage of heavy vehicles, roadway cross-section features factors such as lane/shoulder widths and structure length, roadway alignment factors such as the presence of horizontal/vertical curvature, and weather conditions factors such as the presence of rain/snow or low visibility settings.

However, based on the project objectives/scope, data availability, and expected effect on the model outcomes, not all aforementioned variables were used as explanatory variables to estimate bridge crashes. For example, characteristics such as weather-related factors were excluded from the analysis due to their seasonal effects, and roadway alignment factors involving curvatures were also excluded due to lack of their availability in the database.

As a starting point, factors and thresholds used from the current I.M. 3.213 criteria (i.e., ADTs, bridge widths, and bridge lengths) were considered for the analysis. Descriptive statistics and the distribution of the variables were used to refine the variables considered for the analysis.

Traffic Volume

A majority (73%) of the structures in the database were on the unpaved road network. These structures also were typically located on roadways of less than or equal to 400 vpd. On the paved road network, 37% of the structures service roadways of less than or equal to 400 vpd. Figure 4 shows the distribution of traffic volume for both the paved and unpaved road structures.

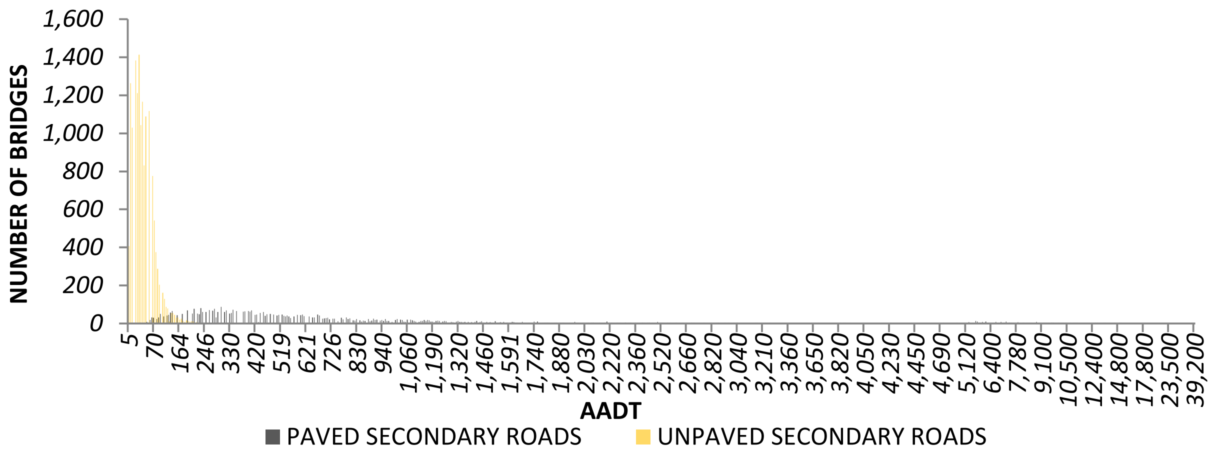


Figure 4. Distribution of structures along the paved and unpaved secondary roadways by traffic volume (AADT)

As evident, there are more structures on the unpaved network than the paved network; however, there are more crashes and higher traffic volumes on the paved system than the unpaved system.

Bridge Width

Among several variables that pertain to bridge and roadway width, bridge roadway width was preferred as a variable, in lieu of surface lane or shoulder widths. This was preferred given that, the bridge width is the face-to-face or curb-to-curb minimum distance measurement between the structure railings which would include both lane and shoulder widths (and medians when indicated) and also bridge roadway width was the most consistently collected variable. For structures with closed or no medians, the bridge width is the sum of the most restrictive minimum distances for all roadways carried by the structure. In an effort to simplify the analysis and account for median presence, an alternative variable as relative bridge width (the algebraic difference between bridge and approach roadway widths) was used. Figure 5 shows an example of a typical roadway bridge cross-section with respect to its approach, surface, and bridge widths.

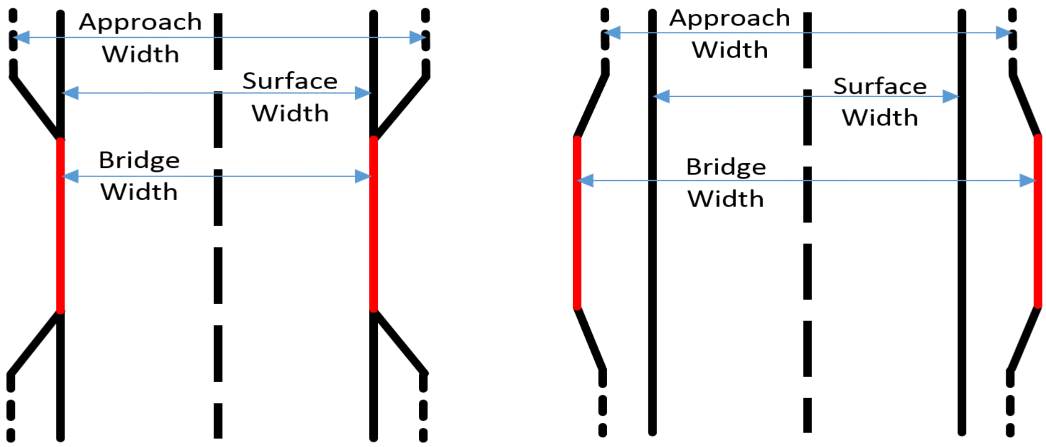


Figure 5. Examples of typical roadway cross-sections with negative relative (narrow) bridge width (left) and positive relative (wider) bridge width (right)

Relative bridge width of negative value indicates bridge structures that are narrower than the traveled way. Both the bridge and approach widths include shoulder and median widths. Also, the cases with missing values for bridge roadway width were removed from consideration to consistently analyze the effects of these variables. Figure 6 shows the distribution of bridge roadway widths for both the paved and unpaved bridge structures.

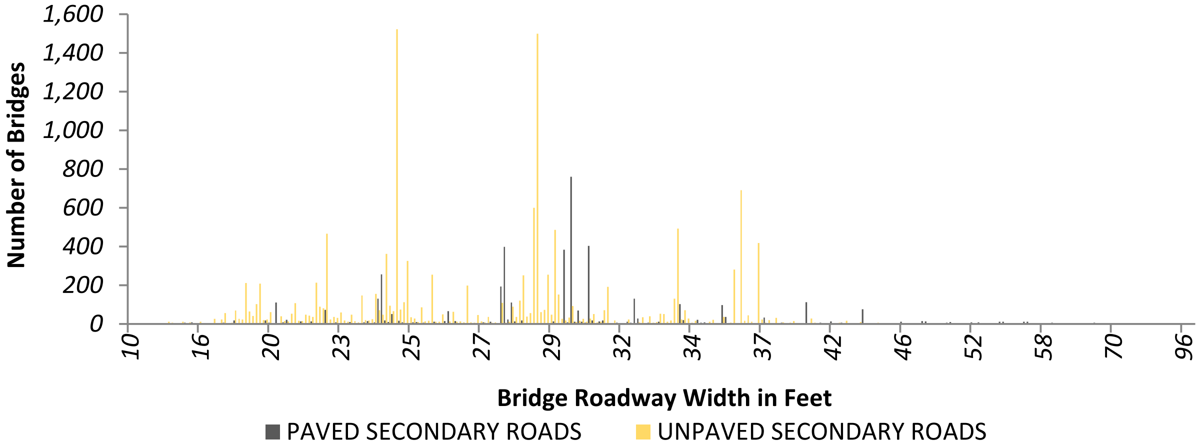
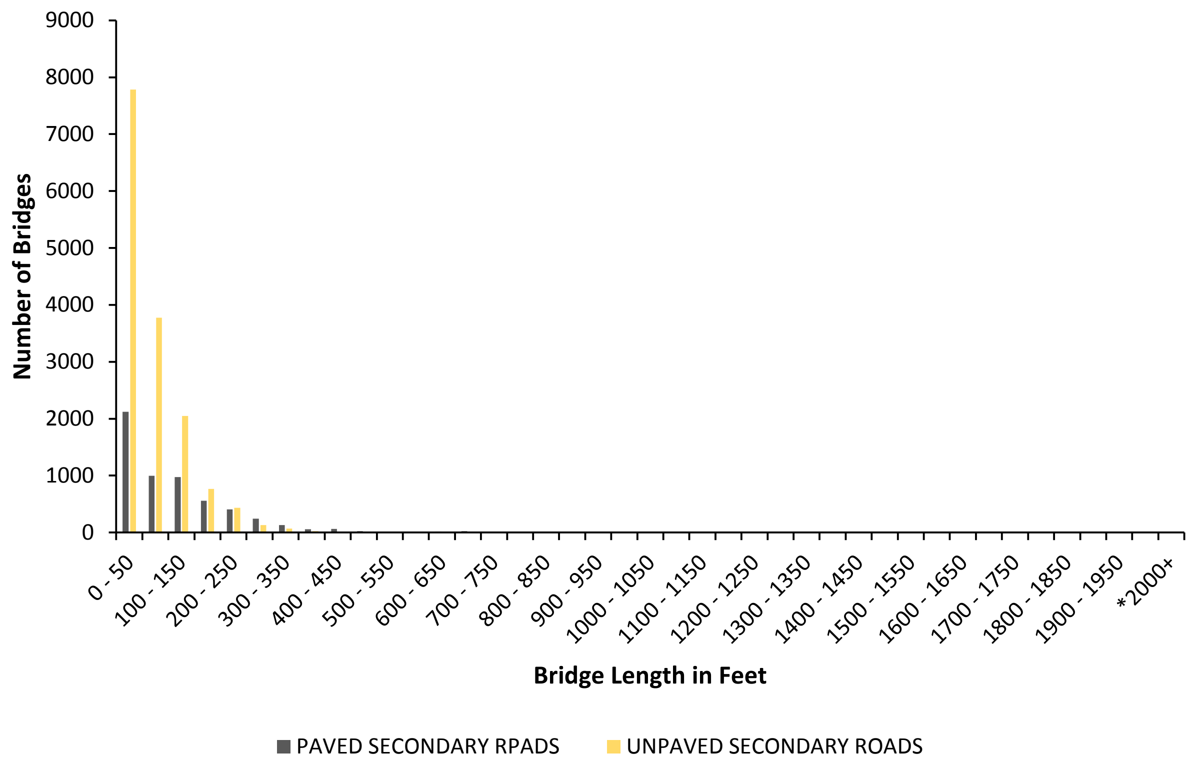


Figure 6. Distribution of structures along the paved and unpaved secondary roadways by width

Bridge Length

A majority (52%) of the structures on the unpaved road network are structures less than or equal to 50 ft long, whereas, on the paved road network, 72% of the structures are less than or equal to 150 ft long. Figure 8 shows the distribution of structure length for both the paved and unpaved road bridge structures.



* 3 bridges longer than 2,000 ft are 2,080, 3,579, and 7,311 ft long

Figure 7. Distribution of structures along the paved and unpaved secondary roadways by length

Bridge Age

In an effort to better understand the range of construction (or reconstruction) year of bridges on the paved and unpaved road networks, bridge age was calculated with respect to the year of crash, or middle year in cases of no crash. Figure 8 shows the age distribution of all structures along the secondary road networks.

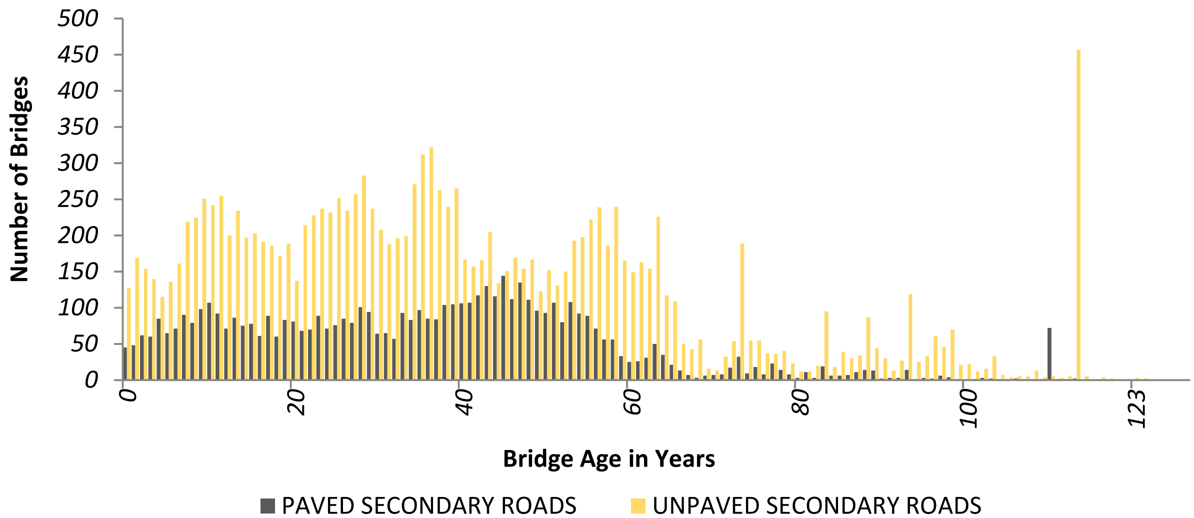


Figure 8. Distribution of structures along the paved and unpaved secondary roadway by age

As shown, over half (51%) of the structures on paved and unpaved road networks are over the age of 35; these were structures last designed or reconstructed prior to 1980.

Tables 7 through 10 show the descriptive and summary statistics respectively for all variables considered in the analysis.

Table 7. Descriptive statistics of model variables

Variable	Description
Number of Crashes (in 10 years)	The sum of crashes from 2004 to 2013 involving bridges (per structure).
Crash Severity (1 = Fatal; 5 = PDO)	1 = Fatal, 2 = Major, 3 = Minor, 4 = Possible/Unknown, 5 = (Property Damage Only (PDO) crashes
Structure Length (ft)	The length of a structure (bridge) in ft.
Bridge Roadway Width (ft)	The curb-to-curb distance (width) between the structure railings (in ft).
Approach Roadway Width (ft)	The width of usable roadway approaching the structure (in ft).
Relative Approach Width (ft)	The algebraic difference in bridge and approach roadway widths (in ft).
Narrow Approach Indicator	An indicator variable for structure narrower than approach: 1 = narrow; 0 otherwise.
Bridge Age (Years)	The average (or middle year) age of the structure at time of crash.
AADT (vehicles per day)	The annual average number of vehicles using the structure roadway each day.
Speed Limit (MPH)	The posted speed limit of the roadway the structure is on (in miles per hour).
Surface Lane Width (ft)	The width of roadway surface (excluding shoulder and median widths).
Median Width (ft)	The width of roadway median in ft.
Paved Road Indicator	An indicator variable for structure on paved road: 1 = paved; 0 otherwise.
Number of Lanes	The number of lanes serving the roadway the structure is on.
Average Shoulder Width (ft)	The algebraic average of the right and left shoulder widths of the roadway.
Number of Observations	The total number of secondary road structures considered.

Table 8. Distribution of number of structures by crash Severity

Road Network	Number of Structures by Crash Severity				
	Property Damage Only	Possible/ Unknown	Minor Injury	Major Injury	Fatal
Paved	274	100	74	23	6
Unpaved	191	74	70	26	8

Table 9. Descriptive statistics of the statewide secondary roads used in the statewide sample

		Statewide (Secondary) Road Network			
	Variable	**Min**	**Mean**	**Std. Dev.**	**Max**
CRASH DATABASE	Number of Crashes (in 10 years)	0	0.04	0.23	6
	Crash Severity (1 = Fatal; 5 = PDO)	1	4.21	1.03	5
STRUCTURE DATABASE	Structure Length (ft)	18	86.38	107.58	3580
	Bridge Roadway Width (ft)	12	24.82	6.75	113
	Approach Roadway Width (ft)	8	27.66	6.67	137
	Relative Approach Width (ft)	-38	-2.74	5.12	46
	Narrow Approach Indicator	0	0.68	0.47	1
	Bridge Age (Years)	0	39.07	25.92	142
ROAD DATABASE	AADT (vehicles per day)	5	433.49	1675.94	30300
	Speed Limit (MPH)	5	52.78	7.32	55
	Surface Lane Width (ft)	10	23.53	3.82	75
	Median Width (ft)	0	0.05	1.06	40
	Paved Road Indicator	0	0.27	0.45	1
	Number of Lanes	1	2.03	0.25	6
	Average Shoulder Width (ft)	0	1.86	2.01	15
	Number of Observations	20,791			

Table 10. Descriptive statistics of the paved and unpaved secondary roads used in the paved and unpaved samples

		Paved (Secondary) Road Network				Unpaved (Secondary) Road Network			
	Variable	**Min**	**Mean**	**Std. Dev.**	**Max**	**Min**	**Mean**	**Std. Dev.**	**Max**
CRASH DATABASE	Number of Crashes (in 10 years)	0	0.08	0.34	6	0	0.02	0.17	4
	Crash Severity (1 = Fatal; 5 = PDO)	1	4.29	0.98	5	1	4.12	1.08	5
STRUCTURE DATABASE	Structure Length (ft)	20	125.82	174.59	3580	18	71.46	60.09	855
	Bridge Roadway Width (ft)	12	30.66	8.63	113	12	22.81	4.46	60
	Approach Roadway Width (ft)	8	33.63	8.83	137	9	25.42	3.68	63
	Relative Approach Width (ft)	-38	-3.06	6.81	46	-27	-2.63	4.39	38
	Relatively Narrow Approach Width (%)	0	0.63	0.48	1	0	0.70	0.46	1
	Bridge Age (Years)	0	35.99	22.14	113	0	40.24	27.12	142
ROAD DATABASE	AADT (vehicles per day)	5	1439.75	2957.46	30300	5	52.37	177.39	6000
	Speed Limit (MPH)	10	48.19	11.47	55	5	54.52	3.60	55
	Surface Lane Width (ft)	12	24.31	5.79	75	10	23.23	2.67	38
	Median Width (ft)	0	0.20	2.01	40	0	0.00	0.00	0
	Number of Lanes	1	2.09	0.46	6	1	2.00	0.01	2
	Avg. Shoulder Width (ft)	0	4.03	2.73	15	0	1.03	0.53	10
	Number of Observations	5,704				15,087			

As can be seen in Table 10, on average more crashes occur on paved roads than on unpaved roads, probably due to exposure. Nonetheless, though paved roads experience higher traffic volumes, they also experience more non-injury crashes on average compared to unpaved roads. The summary statistics also revealed that, of those structures with no missing values, there are more narrow structures on unpaved roads (70%) than on paved roads (63%). Whereas, on average, structures on paved roads are relatively younger in age in comparison to structures on unpaved roads (Figure 8).

Statistical Models

Crash Frequency

Among various statistical modeling approaches suitable for count data models (i.e., negative binomial vs. Poisson regression), negative binomial regression was selected for this study since the number of crashes was overdispersed (the variance of the number of crashes was larger than the mean). Negative binomial regression variance term includes a dispersion parameter vector (α) that is different than zero; so selection between negative binomial regression and Poisson regression models depends on the significance of the overdispersion parameter. Equation (1) shows the expected number of crash events (y_i) per structure (i) per period of time using a negative binomial regression.

$$E[y_i] = \exp(\beta_0 + \textstyle\sum_{i=1}^{n} \beta_i X_i + \varepsilon_i) \qquad or \qquad \ln(E[y_i]) = \beta_0 + \textstyle\sum_{i=1}^{n} \beta_i X_i + \varepsilon_i \tag{1}$$

where: $E[y_i]$ = the expected crash frequency per structure (i) in 10 years,
β_0 = the intercept term,
β_i = the (estimated) parameter coefficient per variable X,
X_i = the explanatory variables (traffic volume, length, widths, age), and
ε_i = the disturbance term.

The (gamma-distributed) disturbance term ε_i has the mean of 1 and variance of α. The addition of this term allows the variance of the distribution to differ from the mean within a negative binomial regression as shown in equation (2).

$$VAR[y_i] = \mathrm{E}[y_i]\big[1 + \alpha E[y_i]\big] = E[y_i] + \alpha E[y_i]^2 \tag{2}$$

Crash Severity

Table 11 shows the distribution of bridge crashes by severity on both paved and unpaved roads.

Table 11. Distribution of "bridge" crashes by severity for the paved and unpaved road network systems

	Statewide Road Network		Paved Road Network		Unpaved Road Network	
Crash Severity	**Crash Count**	**%**	**Crash Count**	**%**	**Crash Count**	**%**
No Injury (PDO)	465	55%	274	57%	191	52%
Possible/Unknown Injury	174	21%	100	21%	74	20%
Minor Injury	144	17%	74	16%	70	19%
Major Injury	49	6%	23	5%	26	7%
Fatal Injury	14	2%	6	1%	8	2%
TOTAL	846	100%	477	56%	369	44%

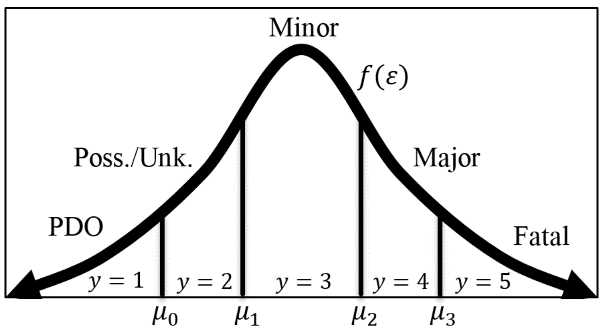
An ordered probability model (probit or logit) was used for the crash severity analysis in this study. Equation (3) shows the specified (z) function, defined as an unobserved latent variable used for the basis of modeling each observed ordinal-injury severity of a crash event (y) with ε random disturbance.

$$z = \beta X + \varepsilon \tag{3}$$

where: $z =$ a latent variable used for the basis of modeling observed ordinal-injury severities,
$\beta =$ the (estimated) parameter coefficient per variable X,
$X =$ the explanatory variables (traffic volume, length, widths, age), and
$\varepsilon =$ the disturbance term.

Figure 9 illustrates an ordered probability parameter threshold using equation (3) for the observed ordinal severity dataset (y) per crash defined as the following:

$$\begin{array}{lll} y = 5 & \text{If} & z > \mu_3 \\ y = 4 & \text{If} & \mu_2 < z \le \mu_3 \\ y = 3 & \text{If} & \mu_1 < z \le \mu_2 \\ y = 2 & \text{If} & \mu_0 < z \le \mu_1 \\ y = 1 & \text{If} & z \le \mu_0 \end{array}$$



after Washington et al. 2011

Figure 9. Illustration of ordered probability regression with μ_i as parameter thresholds

Goodness of Fit Measures

Numerous goodness-of-fit statistics are used to assess the overall fit of regression model results. The coefficient of determination (R^2) is a commonly used fundamental statistic. It serves as a numerical value ranging from zero to one which summarizes the overall strength of the model, with zero indicating a model with no predictive power and one indicating a model with perfect predictive power (Hu et al. 2006). This statistic can be interpreted as a proportion of the variance that can be predicted (explained) given a set of explanatory/independent variables within a model (compared to its constant-only model).

For nonlinear regressions (Poisson, negative binomial models), numerous statistics (entropy-based or variance-based), including pseudo-R^2 and McFadden R^2, can be used to summarize their predictive strength (Hu et al. 2006). The likelihood ratio test is one common test used to assess two competing models. It provides evidence in support of one model, usually a full or complete model, over another competing model that is restricted by having a reduced number of parameters (Washington et al. 2011). For this analysis, the McFadden pseudo-R^2 (written as ρ^2) is utilized as the preferred statistic and is calculated using equation (4):

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \tag{4}$$

where $LL(\beta)$ represents the maximum log likelihood function estimate at convergence (of the finalized "restricted" model) with coefficient vector β, and $LL(0)$ represents the maximum log likelihood function estimate for its constant-only "unrestricted" model (with all parameters set at zero) (Washington et al. 2011). Similar to simple linear regression, a perfect nonlinear regression model also has a test-statistic equal to one.

STATISTICAL ANALYSIS

Crash Frequency Results

Prior to the development of the final model results, Pearson's correlation analysis was done to check for multicollinearity. Moreover, all variables conveying strong correlations with others were carefully reviewed and were not included in the same model. Tables 12 through 14 show the correlation matrix of variables considered in the models. Variables considered correlated with one another are shaded in red.

Table 12. Pearson's correlation matrix for explanatory variables used in the statewide sample

Statewide Road Structures	AADT	Length	Appr. Width	Surface Width	Shoulder Width	Median Width	Bridge Age	Speed Limit	No. of Lanes
AADT	-								
Length	0.324	-							
Appr. Width	0.053	-0.080	-						
Surface Width	0.333	0.185	0.399	-					
Shoulder Width	0.106	0.225	-0.114	0.451	-				
Median Width	0.366	0.125	-0.066	0.161	0.006	-			
Bridge Age	-0.077	-0.108	-0.342	-0.415	-0.081	-0.030	-		
Speed Limit	-0.379	-0.174	-0.052	-0.121	0.035	-0.096	0.001	-	
No. of Lanes	0.713	0.217	0.071	0.224	-0.040	0.462	-0.051	-0.231	-

Table 13. Pearson's correlation matrix for explanatory variables used in the paved sample

Paved Road Structures	AADT	Length	Appr. Width	Surface Width	Shoulder Width	Median Width	Bridge Age	Speed Limit	No. of Lanes
AADT	-								
Length	0.285	-							
Appr. Width	0.108	-0.103	-						
Surface Width	0.272	0.026	0.290	-					
Shoulder Width	-0.226	0.012	-0.196	0.254	-				
Median Width	0.363	0.128	-0.094	0.204	-0.069	-			
Bridge Age	-0.116	-0.132	-0.207	-0.334	-0.057	-0.054	-		
Speed Limit	-0.308	-0.079	-0.130	0.153	0.526	-0.079	-0.061	-	
No. of Lanes	0.713	0.214	0.116	0.242	-0.223	0.457	-0.089	-0.207	-

Table 14. Pearson's correlation matrix for explanatory variables used in the unpaved sample

Unpaved Road Structures	AADT	Length	Appr. Width	Surface Width	Shoulder Width	Median Width	Bridge Age	Speed Limit	No. of Lanes
AADT	-								
Length	0.129	-							
Appr. Width	-0.026	-0.036	-						
Surface Width	0.060	0.088	0.632	-					
Shoulder Width	0.116	0.148	0.020	0.146	-				
Median Width	0.000	0.000	0.000	0.000	0.000	-			
Bridge Age	-0.023	-0.083	-0.428	-0.505	-0.054	0.000	-		
Speed Limit	-0.113	-0.030	0.015	-0.034	-0.046	0.000	-0.023	-	
No. of Lanes	0.007	-0.007	0.010	0.002	0.020	0.000	-0.001	-0.002	-

Table 15 shows the crash frequency analysis results for the statewide database of crashes involving bridge structures along secondary roadways.

Table 15. Negative binomial regression results for the overall (statewide) model

Statewide Road Network	Explanatory Variable	Coefficient	t-statistic
	Constant	-7.27404***	-21.88
Natural log of Traffic Volume (vpd)	LN_AADT	0.41100***	8.96
Natural log of Structure Length (ft)	LN_LENG	0.29639***	5.07
Paved Road Indicator	PAVED_1	-0.46166***	-3.17
Relative Approach Width (ft)	REL_AWID	-0.04636***	-6.02
Average Shoulder Width (ft)	AVGSHDWD	0.11458***	5.24
Square-root of Bridge Age (years)	BRI_AGE2	0.08378***	4.11
Overdispersion	α	3.09598***	7.33
Number of Observations	N	18138	
Log-likelihood at Zero	LL(0)	-3655.85	
Log-likelihood at Convergence	LL(β)	-2866.21	
Goodness of Fit	ρ^2	0.215994	

Note: *** ==> Significance at 1% level.

The results reveal six roadway characteristics that are significantly correlated with the expected number of crashes involving bridges on secondary roadways. The associated test-statistic (student's t-statistic) acknowledges some variables as more significant than others. In order of significance, those include the natural log of the traffic volume, the width of the approach lane(s) relative to the width of the bridge, the average width of the shoulders (if any), the natural log of the length of the structure, the squared-root of the age of the structure, and pavement type (paved or unpaved) of the structure. All variables included in this analysis, and subsequent models, were significant at least at the 95% confidence level. Positive parameter estimates indicate expectancy of higher number of crashes with increasing values of a particular variable while negative parameter estimates indicate lower number of crashes.

In conjunction with previous studies (Bigelow et al. 2010) and (Mehta et al. 2015), these results confirm that higher number of crashes are observed on structures serving higher traffic volumes and structures that are longer in length. A possible explanation could be increased exposure, meaning the more (or longer) vehicles traverse through a given structure, the more they become susceptible to vehicular crashes. Furthermore, these results also concur that bridge crashes are observed more frequently on structures that are older and structures that have shoulders along their approaches (Mehta et al. 2015). This may appear counterintuitive given that shoulder lanes provide extra area to maneuver; nonetheless, shoulder lanes are also largely present on higher traffic volume roads.

The analysis results also indicate that lower number of crashes are expected on structures that are on paved roadways and structures that are relatively wider than the travel way, as also reported in earlier studies (Turner 1984, Bigelow et al. 2010).

The approach roadway width was defined as the normal width of the roadway approaching a structure, which includes both roadway and shoulder/median widths when present. The surface width was defined as the width of the traveled way approaching a structure, not accounting for shoulders. Based on the results, roadways with detectable shoulders preceding a structure tend to increase the likelihood of a bridge crash. This relationship can be attributed to most structures in the database with shoulders located on higher traffic volume (paved) roads, as shown in the data summary. Nevertheless, it is much easier to detect surface/shoulder markings on paved roads than unpaved roads which may influence how vehicles navigate through the structures. Lastly, due to higher correlation between traffic volume and surface width, the roadway approach width, which also accounted for the effects of both shoulders and medians, was preferred as a variable.

Numerous studies suggest thresholds at which the installation or upgrade of proper bridge railing/guardrail is observed to be most beneficial for both the safety of the road users and structures. Nonetheless, this analysis initially considered variables as in both continuum and interval values using logical and statistical groupings suggested by the data distributions. Ranges of variables similar to existing I.M. were also included in an effort to investigate significant relationship between expected crash frequency and these different ranges. The objective of this effort was to quantify the difference in expected crash frequency across the ranges of variables and determine whether the ranges had sufficient impact on expected crash frequency to warrant policy decisions. However, taking into account recommendations from the literature, and advice from the TAC, thresholds for study variables that could make a significant difference in expected crash frequency or a threshold for a policy decision were analyzed to ascertain practical limits for implementing countermeasures. As previously mentioned, studies (Gates and Noyce 2005, Dare 1992) recommended that guardrails be installed on structures serving traffic volumes of 400 or more vehicles per day. Also, with respect to structure length, another study (Seitz and

Salfrank 2014) suggested that structures less than 50 ft (but greater than 20 ft) long on local roadways serving traffic volumes of less than 50 vpd do not warrant bridge railings or guardrails. Nevertheless, the authors chose to not disregard that there are potential safety benefits of bridge railing that cannot be statistically evaluated. Consequently, there may be special cases when structures on very low-volume roads are justified in having proper railings regardless of traffic exposure. Table 16 and Table 17 show the log-likelihood and AIC values of several categorical thresholds considered for both the paved and unpaved secondary roads crash frequency models, respectively.

Table 16. Log-likelihood and AIC values of variables at various thresholds for the paved sample

AADT	LL(β)	AIC
250	1411	2834
400	1399	2811
750	1403	2819
1000	1407	2825
1200	1414	2841

LENGTH	LL(β)	AIC
50	1400	2812
100	1403	2819
150	1399	2810
200	1405	2823
250	1402	2817

AGE	LL(β)	AIC
25	1399	2810
35	1400	2812
50	1401	2815

Table 17. Log-likelihood and AIC values of variables at various thresholds for the unpaved sample

AADT	LL(β)	AIC
50	1524	3061
100	1531	3074
150	1567	3146
200	1567	3146
250	1574	3161

LENGTH	LL(β)	AIC
25	1527	3066
35	1524	3061
50	1526	3065
100	1528	3069
150	1528	3068

AGE	LL(β)	AIC
25	1524	3061
35	1526	3065
50	1526	3065

Thresholds with the lowest values (highlighted in red) were selected as desired breakpoints. The statistical distribution of each variable was considered in conjunction with significance of thresholds in the analysis for the final selection of analysis thresholds.

Table 18 and Table 19 show the negative binomial regression model results for the paved and unpaved samples, respectively.

Table 18. Negative binomial regression results for the paved model using paved sample

Paved Road Network	Explanatory Variable	Coefficient	t-statistic
	Constant	-3.85375***	-22.09
Traffic Volume > 400 (vpd)	AADT_400	0.79603***	5.83
Structure Length > 150 (ft)	LENG_150	0.59590***	5.18
Relative Approach Width < 0 (ft)	AWID_0_	0.66012***	5.19
Bridge Age > 25 (years)	B_AGE25	0.27754**	2.14
Overdispersion	α	2.64864***	6.10
Number of Observations	N	4617	
Log-likelihood at Zero	LL(0)	-1731.82	
Log-likelihood at Convergence	LL(β)	-1399.47	
Goodness of Fit	ρ^2	0.191908	

Note: ***==> Significance at 1% level.

Table 19. Negative binomial regression results for the unpaved model using unpaved sample

Unpaved Road Network	Explanatory Variable	Coefficient	t-statistic
	Constant	-5.14073***	-27.84
Traffic Volume > 50 (vpd)	AADT_50	1.33423***	11.45
Structure Length > 35 (ft)	LENG_35	0.54635***	3.88
Bridge Width < 20 (ft)	BRIWID20	0.89289***	7.07
Bridge Age > 25 (years)	B_AGE25	0.27715**	1.98
Overdispersion	α	3.96598***	4.61
Number of Observations	N	13898	
Log-likelihood at Zero	LL(0)	-1768.80	
Log-likelihood at Convergence	LL(β)	-1524.94	
Goodness of Fit	ρ^2	0.137867	

Note: ***, ** ==> Significance at 1% and 5% levels, respectively.

Complying with previous literature and the statewide model (Table 15), traffic volumes greater than 400 vehicles per day on paved roads and greater than 50 vehicles per day on unpaved roads were significantly correlated with higher number of crashes. Also, structures longer than 150 ft on paved roads or longer than 35 ft on unpaved roads were significantly correlated with higher number of crashes. The selected thresholds of 150 and 35 ft for the paved and unpaved models respectively seemed permissible given the distribution of structure lengths in both cases. More than half (52%) of the structures on the unpaved roads were 50 ft long or less, and nearly three-quarters (72%) of the structures on the paved roads were 150 ft long or less.

Due to the uncertainty of detecting surface/shoulder markings (widths) on unpaved roads as opposed to paved roads, bridge width equivalent to two typical 10-foot lanes was substituted in place of calculating bridge relative width in the unpaved model. As a result, structures narrower than the approach on paved roads and structures narrower than 20-ft in total width on unpaved roads were correlated with higher number of crashes.

For both paved and unpaved roads, higher number of crashes were expected on structures that exceed the age of 25 years. Indirectly, this could be attributed to old structures being designed using outdated standards, methods, and/or styles; narrower widths are common in older structures.

Crash Severity Results

Crash severity analysis was also done for the data sets with the objective of also using the results ultimately in a cost-efficiency assessment. An ordered probit regression was used to best ascertain the influences of roadway and structure characteristics on the maximum severity sustained by vehicle occupants in the likely outcome of a crash involving bridge components. Basis of the analysis was first developed using the KABCO severity scale as shown in Figure 10 (from No Injury coded as 5 to Fatal Injury coded as 1).

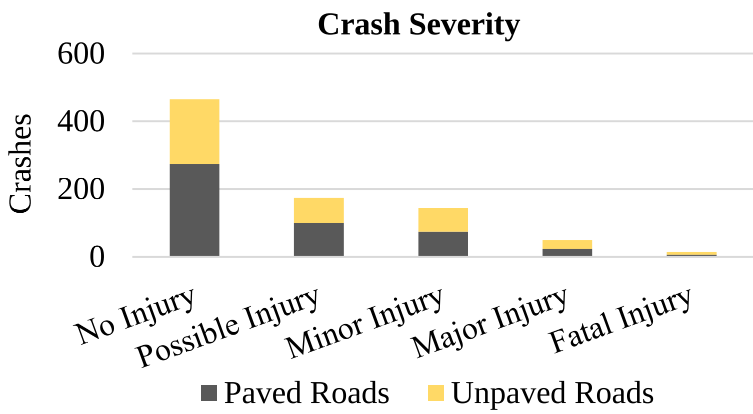


Figure 10. Distribution summary of bridge crashes by severity

Given the very limited number of observations within each severity group, grouping of injury versus no-injury crashes was also considered. Nevertheless, results from both approaches showed no statistical significance of roadway and structure characteristics on crash severity, particularly for the separated paved and unpaved samples. Therefore crash severity could not be addressed further within this project due to data limitations.

Results Implications

The negative binomial regression analysis results for paved and unpaved samples, as discussed above, presented parameter estimates for the relationship between selected ranges of traffic volume, structure length, relative approach width, bridge age, and expected crash frequency. These variables and ranges together present four conditions that group the bridges in Iowa. For example, a structure may carry more than 400 vpd, have a relative approach width of 2 ft, a length of 100 ft, and 15 years of age. In this case, the expected bridge crash frequency on this structure increases only due to the traffic it carries. Another structure with the same characteristics except a relative width of -2 ft will have a higher expected bridge crash frequency since an additional condition holds. In order to better quantify and present the impact of these variables and thresholds on the expected bridge crash frequencies for the bridge groups in Iowa, expected crash frequencies for the paved and unpaved roads were estimated for a 10-year period for different combinations of the conditions and are presented in Table 20 and Table 21, respectively.

Table 20. Threshold rankings based on effect on expected crashes on paved secondary roads

	Expected Bridge Crash Frequency per 10-year Period	No. of Structures "At-risk"	Percent Change in Frequency	TRAFFIC CONDITION	STRUCTURE GEOMETRIC CHARACTERISTICS		
				Exposed Structures	Narrow Structures	Long Structures	Old Structures
				(vpd)	(ft)	(ft)	(years)
RANK	$E[y_i]$	n	**%Δ**	**AADT > 400**	**AWID < 0**	**LENGTH > 150**	**AGE > 25**
1	0.21780	515	-	x***	x***	x***	x**
2	0.19950	776	-8.40%	x***	x***	x***	
3	0.19159	693	-12.04%	x***		x***	x***
4	0.18229	747	-16.30%		x***	x***	x**
5	0.16839	1,109	-22.69%		x***	x***	
6	0.16703	1,168	-23.31%	x***		x***	
7	0.16426	970	-24.58%			x***	x***
8	0.15976	1,279	-26.65%	x***	x***		x
9	0.15236	1,754	-30.05%	x***	x***		
10	0.14570	1,606	-33.10%			x***	

Note: ***, ** ==> Significance at 1% and 5% levels, respectively.

Each row in Table 20 presents a group of bridges based on traffic volume and structure characteristics and the corresponding individual negative binomial regression model. The number of structures that fall under each group is shown in the same row along with the expected bridge crash frequency per a 10-year period. These groups are not mutually exclusive; same structures can fall under several groups as long as the conditions hold. The groups are ranked from the highest expected crash frequency to the least, and only the top 10 groups are shown in the table. The marks in the variable columns show which conditions hold for the group of bridges and the significance level of the correlation between expected crash frequency and the particular condition. The main purpose for this effort is to quantify the difference between these groups in expected crash frequency. Although the variables are all significantly correlated in expected crash frequency, the difference in expected number of crashes between these groups may potentially be used to determine if exclusive policy decisions are warranted.

As shown, structures which have high exposure/traffic, narrow widths, and long lengths, in addition to those that are 'older' (ranked 1), have the highest number of expected crashes. That being said, structures fitting such criteria (rank 1) influence a small subset (515) of all structures (5,705) on the paved road network, and only one crash is expected on each bridge in 45.9 years.

The second ranked group excludes the age variable and has slightly more number of structures (776) and the expected number of crashes is slightly less, i.e., one crash in 50.1 years. While there is a difference between the two groups, both expectancies are rare. A crash is expected in 68.6 years for the structures in group 10. In general, crash expectancy was relatively similar among the 10 models. The number of potentially impacted structures ranged from nine to approximately 30% of the paved secondary road bridges.

Table 21 presents the same ranking for unpaved roads.

Table 21. Threshold rankings based on effect on expected crashes on unpaved secondary roads

	Expected Bridge Crash Frequency per 10-year Period	**No. of Structures "At-risk"**	**Percent Change in Frequency**	**TRAFFIC CONDITION**	**STRUCTURE GEOMETRIC CHARACTERISTICS**		
				Exposed Structures (vpd)	**Narrow Structures (ft)**	**Long Structures (ft)**	**Old Structures (years)**
RANK	$\boldsymbol{E[y_i]}$	$\boldsymbol{n}$	**%Δ**	**AADT > 50**	**BRIWID < 20**	**LENGTH > 35**	**AGE > 25**
1	0.12367	362	-	x***	x***	x***	x**
2	0.11841	407	-4.26%	x***	x***	x***	
3	0.10688	551	-13.58%	x***	x***		x*
4	0.10270	611	-16.96%	x***	x***		
5	0.06448	1,885	-47.86%	x***		x***	x***
6	0.05627	2,838	-54.50%	x***		x***	
7	0.05566	2,783	-55.00%	x***			x***
8	0.04977	1,961	-59.76%		x***	x***	x**
9	0.04858	4,220	-60.72%	x***			
10	0.04789	2,311	-61.28%		x***	x***	

Note: ***, **, * ==> Significance at 1%, 5%, and 10% levels, respectively.

Crashes are even rarer for unpaved roads. For the group ranked 1, a crash is expected in 80 years. For the second group, a crash is expected in 84.5 years whereas it is expected in 209 years for the structures in group 10. Those structures experiencing higher crash tendencies represent a fraction of all secondary roadway structures statewide. The group of structures in rank 1 constitute only 2.4% of the 15,087 structures on unpaved roads. Structures with the lowest crash expectancy represented approximately 15% of the unpaved structures and 61% fewer expected crashes.

CONCLUSION

A primary objective of this study was to identify factors which are significantly correlated with crash frequency that may be considered in future updates of I.M. 3.213, while balancing traffic safety and practical application of bridge rail guidelines. This study confirms previous research findings that crashes with bridges on secondary roads are rare, low-severity events, yet crashes are more frequent on bridges possessing certain characteristics.

Six roadway characteristics were significantly correlated with the expected number of crashes involving bridges on secondary roadways. These characteristics, in order of significance, were the natural log of the traffic volume, the width of the approach lane/s relative to the width of the bridge, the average width of the shoulders (if any), the natural log of the length of the structure, the squared-root of the age of the structure, and pavement type (paved or unpaved) of the structure.

Negative binomial regression models, utilizing threshold values for model explanatory variables, indicated that the following characteristics were significantly correlated with higher number of crashes:

- Traffic volume: greater than 400 vpd (paved), greater than 50 vpd (unpaved)
- Bridge length: greater than 150 ft (paved), greater than 35 ft (unpaved)
- Bridge width: narrower than its approach (paved), narrower than 20 ft (unpaved)
- Bridge age: older than 25 years (paved, unpaved)

However, no specific roadway or bridge characteristic(s) contributed to more serious crashes.

The individual statistical models developed to convey the impact of different combinations of the statistically significant explanatory roadway and structure characteristics on crash expectancy and corresponding structures revealed that older structures with higher traffic volumes, narrow widths, and long lengths have the highest number of expected crashes. Corresponding bridges on paved secondary roads expected only one crash in nearly 46 years, while corresponding unpaved road bridges expected only one crash in 80 years. These bridges represented only 9% and 2% of the secondary paved and unpaved bridges, respectively. Other combinations of roadway and structure characteristics had varying levels of impact on the expected number of crashes (approximately 30 to 60% fewer) and resulting bridges (approximately 30% of the paved network and 15% of the unpaved network).

While bridge crashes on secondary roads are infrequent and low severity, the findings of this study support the need for appropriate use of bridge rails. For example, the low-severity nature of these crashes may be indicative of bridge rails serving their purpose, protecting motorists from more hazardous objects. Furthermore, because expected crash experience is higher for bridges possessing certain characteristics, consideration may be given to, or emphasis placed on, these characteristics. That said, 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. Lastly, since a relatively small proportion of secondary road bridges may possess these characteristics, impacts on the responsible local jurisdictions may be limited.

REFERENCES

AASHTO. 2001. *Guidelines for Geometric Design of Very Low-volume Local Roads (ADT < 400vpd).* Washington, DC: American Association of State Highway and Transportation Officials.

AASHTO. 2004. *A Policy on Geometric Design of Highways and Streets (Green Book, 2004 edition).* Washington DC: American Association of State and Highway Transportation Officials.

AASHTO. 2009. *Manual for Assessing Safety Hardware (MASH).* Washington, DC: American Association of State and Highway Transportation Officials.

AASHTO. 2011. *Roadside Design Guide, 4th Edition.* Washington DC: American Association of State and Highway Transportation Officials.

Bigelow, J., Z. Hans, and B. Phares. 2010. *Bridge Rail and Approach Railing for Low-Volume Roads in Iowa.* Ames, IA: Bridge Engineering Center, Institute for Transportation, Iowa State University.

Chengye, P., and P. Ranjitkar. 2013. Modelling Motorway Accidents using Negative Binomial Regression. *Journal of the Eastern Asia Society for Transportation Studies*. Volume 10: pp. 1946-1963.

Dare, C. E. 1992. *Guidelines for Guardrail Installation on Embankments and at Bridges Ends: Low-Volume Roads in Missouri*. Jefferson City, MO: Missouri Highway and Transportation Department.

Dixon, K. K., M. T. Liebler, and M. P. Hunter. 2009. Urban Roadside Safety: Cluster-Crash Evaluation. *Transportation Research Record: Journal of the Transportation Research Board*. No. 2120: pp. 74-81.

FHWA. 2001. *Load and Resistance Factor Design (LRFD) for Highway Bridge Substructures Reference Manual and Participant Workbook.* Washington, DC: Federal Highway Administration.

FHWA. 2009. *Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD).* Washington, DC: Federal Highway Administration.

Gates, T. J., and D. A. Noyce. 2005. *The Safety and Cost-Effectiveness of Bridge-Approach Guardrail for County-State-Aid (CSAH) Bridges in Minnesota*. St. Paul, MN: Minnesota Department of Transportation.

Hu, B., J. Shao, and M. Palta. 2006. Pseudo-R square in Logistic Regression Model. *Statistica Sinica*. Volume 16.

Iowa DOT. 2013. *Instructional Memorandum 3.213*. Ames, IA: Iowa Department of Transportation.

Lee, J. J., and F. L. Mannering. 1999. *Analysis of Roadside Accident Frequency and Severity and Roadside Safety Management.* Seattle, WA: Washington State Transportation Commission and Federal Highway Administration.

Mehta, G., J. Li, R. T. Fields, Y. Lou, and S. Jones. 2015. Safety Performance Function Development for Analysis of Bridges. *Journal of Transportation Engineering*. Volume 141 (Issue 8).

Persaud, B., and L. Dzbik. 1993. Accident prediction models for freeways. *Transportation Research Record: Journal of the Transportation Research Board*. No. 1401: pp. 55-60.

Ross, H. E., Jr., D. L. Sicking, R. A. Zimmer, and J. D. Michie. 1993. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features.* Washington, DC: National Cooperative Highway Research Program.

Russell, E. R., and M. J. Rys. 1998. Guidelines for Developing a Guardrail Manual for Low-Volume Roads. *Transportation Conference Proceedings.* Ames, IA. Iowa State University. pp. 22-25.

Schwall, W. A. 1989. *Upgrading of Bridge Approach Guardrail on Primary Roads in Iowa.* Ames, IA: Federal Highway Administration, Iowa Division.

Seitz, R. J., and T. Salfrank. 2014. *Guardrail and Bridge Rail Recommendations for Very Low-Volume Local Roads in Kansas*. Topeka, KS: Kansas Department of Transportation.

Stephens, L. B., Jr. 2005. *Barrier Guide for Low Volume and Low Speed Roads.* Lakewood, CO: Central Federal Lands Highway Division.

Turner, D. S. 1984. Prediction of Bridge Accident Rates. *Journal of Transportation Engineering*. Volume 110 (No. 1): pp. 45-54.

Washington, S. P., M. G. Karlaftis, and F. L. Mannering. 2011. *Statistical and Econometric Methods for Transportation Data Analysis.* Second Edition. Boca Raton, FL.: Chapman & Hall/CRC Press.

Zou, Y., A. P. Tarko, E. Chen, and M. A. Romero. 2014. Effectiveness of Cable Barriers, Guardrails, and Concrete Barrier Walls in Reducing the Risk of Injury. *Accident Analysis & Prevention.* Volume 72: pp. 55-65.

APPENDIX A

This appendix includes Iowa DOT Instructional Memorandum (I.M.) No. 3.213 and Attachment A, which is the Bridge Barrier Rail Rating System form.

INSTRUCTIONAL MEMORANDUMS

To Local Public Agencies

To:	Counties and Cities	Date: July 18, 2013
From:	Office of Local Systems	I.M. No. 3.213
Subject:	Traffic Barriers (Guardrail and Bridge Rail)	

Contents: This Instructional Memorandum (I.M.) provides guidelines for determining the need for traffic barriers at roadway bridges and culverts. This I.M. also provides guidelines for upgrading bridge barrier rails. This I.M. includes the following attachments:

Attachment A - Bridge Barrier Rail Rating System (Word)

Other obstructions, within the right-of-way and clear zone, should be reviewed for removal, relocation, or installation of a traffic barrier; or the "do nothing" option based on a cost-effectiveness approach. Refer to I.M. 3.215, Clear Zone Guidelines.

APPROACH GUARDRAIL

In general, approach guardrail should be installed at the following:

1. On newly constructed bridges on the Farm-to-Market system, guardrail should be installed on all 4 corners; except bridges located within an established speed zone of 35 mph or less.

2. On Federal-aid bridges constructed or rehabilitated on rural local roadways, guardrail should be installed on the approach corner in both directions (right side in each direction); except bridges located within an established speed zone of 35 mph or less. Consideration should be given to shielding the trailing corner (left side in each direction) if it is located on the outside edge of a curve. Approach guardrail shall also be upgraded when bridge barrier rail is upgraded.

3. On 3R projects on the Farm-to-Market System, all four corners 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 standards.

4. Culverts with spans greater than 6 feet (circular pipe culverts greater than 72 inches in diameter), if it is impractical to extend beyond the clear zone and grates are not utilized.

The FHWA will participate in guardrail, including at all four corners of a bridge, if desired by the county.

Design Exceptions

Design exceptions (refer to I.M. 3.218, Design Exception Process) to not install guardrail at bridges or culverts will be considered if all of the following conditions exist:

1. Current average daily traffic (ADT) at structure is less than 400 vehicles per day.

2. Structure width is 24 feet or greater.

3. Structure is on tangent alignment.

4. Benefit/cost Ratio is less than 0.80.

5. Bridge width is wider than the approach roadway width.

Design exceptions are also possible for guardrail installations that may not be considered crashworthy. For example, standard approach guardrail may not be feasible for a structure located in close proximity to an intersection or entrance, so the guardrail may need to be curved around the radius. Depending on the radius, such an installation might not be considered crashworthy. However, compared to placing a crash cushion or doing nothing, curving the guardrail around the radius may provide the best compromise of cost and safety.

Work with the appropriate Administering Office for more guidance on these issues.

BRIDGE BARRIER RAIL

On newly constructed bridges, the bridge barrier rail shall be constructed to the current acceptable standards (includes SL-1 type rail on structures with less than 1000 vpd).

On Federal-aid bridge rehabilitation projects involving the superstructure, any substandard bridge barrier rail, as well as approach guardrail, shall be upgraded. For Federal-aid bridge rehabilitation projects that do not involve the superstructure, it is strongly recommended that the bridge barrier rail, as well as approach guardrail, be upgraded to the current acceptable standards.

Bridge barrier rail that is coded 0 on Item 36A, Bridge Railings, on the SI&A form of the National Bridge Inspection Standards (NBIS), does not meet current acceptable standards and shall be reviewed for upgrading as part of the 3R projects. Use the “Bridge Barrier Rail Rating System”, see Attachment A to this I.M., to assist in determining if a bridge barrier rail should be upgraded with the 3R project and to what extent it should be upgraded. Any bridge which is programmed in the County Five Year Plan for replacement or rehabilitation may not require upgrading as part of the 3R roadway project.

The Bridge Barrier Rail Rating System assigns points to five factors (Crashes, ADT, Width, Length and Type of bridge rail). The sum of these factors will indicate the degree or amount of upgrading required, if any. The crash factor involves crashes (property damage only, personal injury, and fatality) in the last 5 years. The types of bridge barrier rail are from various county bridge standards. If the existing bridge barrier rail is not an old standard, then determine which type it is similar to and assign the corresponding points.

Consideration should 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 attaching the guardrail as per the Iowa DOT Standard Road Plans or constructing an end post.

BRIDGE BARRIER RAIL RATING SYSTEM

Name: ______________________________ Date: ______________________________

Bridge ID: ______________________________ County / City: ______________________________

FHWA No.: ______________________________ ADT: ______________________________

Main Span Materials & Design (Item 43): ______________________________

Location: ______________________________

An upgrade to the bridge barrier rails is not required when the “Total Points” are under 25. The following is a list of the required upgrade to the bridge barrier rails relative to the “Total Points”:

25 - 50 Points - delineation according to Iowa DOT Standard Road Plans
51 - 75 Points - block out with Thrie-Beam to curb edge

> 75 Points - retrofit

	POINTS	POINTS GIVEN
1. Crashes (in the past 5 years):		
A. None	0	
B. 1 Property Damage Only (PDO)	5	
C. 1 Personal Injury (PI)	10	
D. 1 Fatality (F), 2 PDO, or 1 PI and 1 PDO	15	
E. ≥ 2 F, ≥ 2 PI, or ≥ 3 PDO	20	______
2. ADT (current year):		
A. <200	0	
B. 200-299	5	
C. 300-399	10	
D. 400-750	15	
E. >750	20	______
3. Bridge width (curb-to-curb) (feet):		
A. ≥ 30	0	
B. 28	5	
C. 24	10	
D. 22	15	
E. ≤ 20	20	______
4. Bridge Length (feet):		
A. <50	0	
B. 50-99	5	
C. 100-149	10	
D. 150-200	15	
E. > 200	20	______
5. Type:		
A. Aluminum Rail (1967 Standard)	0	
B. Steel Box Rail (1964 Standard)	5	
C. Formed Steel Beam Rail (1951 or 1957 Standards)	10	
D. Steel Rail (1941 Standard) or Concrete Rail (1928 Standard)	15	
E. Angle Handrail (1928 Standard)	20	______
Total Points =		______