Iowa Department of Transportation
Research Project Number TPF-5(193) Supplement #131

IN-SERVICE PERFORMANCE EVALUATION OF CONCRETE SLOPED END TREATMENTS IN IOWA

Submitted by

Jessica L. Lingenfelter, B.S.M.E.
Former Graduate Research Assistant

Cody S. Stolle, Ph.D., E.I.T.
Research Assistant Professor

Robert W. Bielenberg, M.S.M.E., E.I.T.
Research Engineer

Khyle Clute, B.S.C.E., P.E.
Research Engineer
Iowa Department of Transportation

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln

Main Office
Prem S. Paul Research Center at Whittier School
Room 130, 2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-0965

Outdoor Test Site
4630 N.W. 36th Street
Lincoln, Nebraska 68524

Submitted to

Iowa Department of Transportation
800 Lincoln Way
Ames, Iowa 50010

MwRSF Research Report No. TRP-03-421-20

October 12, 2020

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	**2. Government Accession No.**	**3. Recipient's Catalog No.**
TRP-03-421-20		

4. Title and Subtitle In-Service Performance Evaluation of Concrete Sloped End Treatments in Iowa	**5. Report Date** October 12, 2020 **6. Performing Organization Code**
7. Author(s) Lingenfelter, J.L., Stolle, C.S., Bielenberg, R.W., and Clute, K.	**8. Performing Organization Report No.** TRP-03-421-20
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) Nebraska Transportation Center University of Nebraska-Lincoln Main Office: Prem S. Paul Research Center at Whittier School Room 130, 2200 Vine Street Lincoln, Nebraska 68583-0853 Outdoor Test Site: 4630 N.W. 36th Street Lincoln, Nebraska 68524	**10. Work Unit No.** **11. Contract** TPF-5(193) Supplement #131
12. Sponsoring Agency Name and Address Iowa Department of Transportation 800 Lincoln Way Ames, Iowa 50010	**13. Type of Report and Period Covered** Final Report: 2018 – 2020 **14. Sponsoring Agency Code**

15. Supplementary Notes
Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

Sloped end treatments were historically developed as low-cost, low-maintenance end treatments for rigid features like concrete barriers and bridge rails. Crash testing indicated that sloped end treatments are associated with significant instability and rollover risk for impacting vehicles. However, the in-service performance of these features has not been evaluated. An in-service performance evaluation (ISPE) was performed to evaluate vehicle crashes with sloped end treatments in Iowa between 2008 and 2017. Researchers generated a geographic inventory of sloped end treatment locations, reviewed crash narratives and scene diagrams for crashes near these sloped end treatments, and calculated an estimated crash rate and crash cost for these sloped end treatments. A total of 30 crashes were identified which involved sloped end treatments, including one fatal crash and one severe injury crash.

Thirteen of the 30 crashes resulted in vehicle rollover (43%), and the estimated crash cost for sloped end treatments was approximately $178,260 per crash. For comparison, crash costs for other fixed objects in the same vicinity as sloped end treatments, typically associated with roads with higher speed limits, averaged $67,449 per crash. Benefit-cost analyses were calculated for replacing select groups of sloped end treatments with various crash cushions.

Because nineteen of the crashes occurred on a total of seven bridges, indicating most impacts were in "black spot" locations, researchers recommended a sloped end treatment removal and replacement prioritization based on crash history. Further research is necessary to determine if Iowa crash results are extrapolatable to other states, as well as what safety treatments are preferred in challenging locations such as limited right-of-way or adjacent to intersections.

17. Key Words	**18. Distribution Statement**
In-Service Performance Evaluation, End Treatment, Concrete Barriers, MASH, Injury Analysis, Benefit-to-Cost Ratio	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	402	

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

DISCLAIMER STATEMENT

This material is based upon work supported by the Federal Highway Administration, U.S. Department of Transportation and the Iowa Department of Transportation under TPF-5(193) Supplement #131. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the University of Nebraska-Lincoln, Iowa Department of Transportation nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names, which may appear in this report, are cited only because they are considered essential to the objectives of the report. The United States (U.S.) government and the State of Nebraska do not endorse products or manufacturers.

ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Iowa Department of Transportation for funding the research effort and supplying crash data, locations, narratives, and scene diagrams with researchers; (2) Drs. George Hunt and Ayse Kilic for technical assistance with crash report mapping software; (3) Drs. Faller and Rasmussen for being members of the thesis committee; and (4) MwRSF students and staff for contributing to this research project.

Acknowledgement is also given to the following individuals who contributed to the completion of this research project.

Midwest Roadside Safety Facility

R.K. Faller, Ph.D., P.E., Research Professor & MwRSF Director
J.D. Reid, Ph.D., Professor
J.C. Holloway, M.S.C.E., E.I.T., Assistant Director – Physical Testing Division
K.A. Lechtenberg, M.S.M.E., E.I.T., Research Engineer
S.K. Rosenbaugh, M.S.C.E., E.I.T., Research Engineer
J.D. Rasmussen, Ph.D., P.E., Research Associate Professor
J.S. Steelman, Ph.D., P.E., Associate Professor
M. Asadollahi Pajouh, Ph.D., P.E., Research Assistant Professor
A.T. Russell, B.S.B.A., Testing and Maintenance Technician II
E.W. Krier, B.S., Construction and Testing Technician II
S.M. Tighe, Construction and Testing Technician I
D.S. Charroin, Construction and Testing Technician I
R.M. Novak, Construction and Testing Technician I
T.C. Donahoo, Construction and Testing Technician I
J.T. Jones, Construction and Testing Technician I
J.E. Kohtz, B.S.M.E., CAD Technician
E.L. Urbank, B.A., Research Communication Specialist
Z.Z. Jabr, Engineering Technician
Undergraduate and Graduate Research Assistants

Iowa Department of Transportation

Khyle Clute, Research SPR/Pooled Fund Lead
Brian Smith, Bridge Maintenance and Condition Reporting
Stuart Nielsen, Road Design Methods Lead
Daniel Harness, Road Design Methods
Mike Thiel, Road Design Methods Personnel
Jesse Peterson, Bridge Design Methods Lead
Edward Engle
Kimball Olson

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in.	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short ton (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE & PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliter	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or “metric ton”)	1.103	short ton (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE & PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

Concrete barrier sloped end treatments (SETs) are used in many states, such as Iowa, for terminating the ends of concrete barriers. Historically, sloped end treatments offered a safety benefit as compared to terminating concrete barriers with blunt ends. Sloped end treatments are also generally inexpensive to install and require no routine maintenance and minimal repair. Sloped end treatments can be cast in place, horizontally doweled into an existing concrete barrier end, attached to a concrete road or bridge surface, and installed in conjunction with a curb. Examples of sloped end treatments from the state of Iowa, collected using Google Earth and Street View [1], are shown in Figure 1.

Figure 1. Examples of Concrete Sloped End Treatments in Iowa [1]

Sloped end treatments are also referred to as "sloped ends," "concrete barrier turn-downs," "tapered ends," or "tapers." For this report, all sloped or tapered terminations for concrete barriers will be referred to as "sloped end treatments."

Since the adoption of the National Cooperative Highway Research Program (NCHRP) Report No. 350 [2] and the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (MASH) [3], many sloped end treatments were removed due to concerns regarding impacting vehicle instabilities and replaced with newer, crashworthy end treatment options. However, sloped end treatments are still preferred in some locations with:

- low average daily traffic (ADT) and low crash history;
- limited space due to intersections, driveways, or other fixed obstacles;
- curbs and gutters which could adversely affect crashworthiness of other features; or
- end treatments that are difficult to perform maintenance on or repair.

Although some sloped end treatments have been successfully full-scale crash tested, typical test conditions consist of level, flat terrain, and test vehicles typically experience significant roll angle displacements during the tests [4-8], which can lead to vehicle rollover. It is uncertain what risk, if any, is posed to occupants of vehicles during crashes with real distributions of impact conditions and roadside geometries because an in-service performance evaluation (ISPE) of these features has not been conducted. ISPEs have been used to evaluate the safety and cost-effectiveness of some roadside safety hardware after being installed on roadsides. However, full-scale testing of these features on level, flat terrain may not be indicative of the safety performance when installed in conjunction with bridge ends or adjacent to slopes.

The Iowa Department of Transportation (DOT) funded research to perform an ISPE of existing concrete sloped end treatments and recommend warrants for replacing sloped end treatments based on factors such as cost-effectiveness, site limitations, or crash history.

1.2 Objective

The objective of this research was to perform an ISPE of Iowa's crash data and determine if action is warranted to shield, retrofit, or remove sloped end treatments. If severe crashes were observed and determined to be caused at least in part by the concrete barrier sloped end treatments, researchers would evaluate causes of those severe crashes and determine if simple modifications could be made to reduce the frequency or likelihood of these crash types occurring in the future. If severe crash outcomes were not observed, researchers would attempt to determine if results indicate that the sloped end treatments were not a safety risk, and by extension, not a priority for further treatment and consideration.

1.3 Scope

The research plan was to be completed in up to three phases. Phase I consisted of the ISPE of sloped end treatments in the state of Iowa using crash record analysis. Depending on the completion and outcome of Phase I, if further analysis was recommended, Phase II was to be conducted to complete the ISPE. As well, Phase II would identify potential retrofits, modifications, or low-cost replacement evaluation if the sloped end treatments were determined to be cost-effective to treat and replace or if sufficient crash severity and history was observed. Phase III was intended to perform crash testing of any novel solution identified or recommended during Phase II.

Phase I, summarized in this report, focused on the preliminary ISPE of sloped end treatment performance in Iowa. The MwRSF research team successfully completed the ISPE and benefit-to-cost analysis aspects of the project. The project tasks were:

1. Project Planning and Correspondence
    a. General project planning and documentation
    b. Literature search of concrete sloped end treatments
2. Crash Data Analysis
    a. Acquire, process, and geographically locate crash data and road data from Iowa DOT, which include:
        i. Posted speed limit (PSL)
        ii. Road names
        iii. Average daily traffic (ADT)
        iv. Barrier information
        v. Summary crash database of all crashes
    b. Identify sites with concrete barrier sloped end treatments in Iowa
        i. Bridges and concrete barriers in urban and suburban locations
        ii. Low-volume or lower PSL roadways
        iii. Verify the use of sloped end treatments using Google Earth, roadside hardware inventory, site tour, etc.
    c. Extract all crash data within proximity of concrete barrier sloped end treatments
    d. Review crash data
        i. Determine if changes are required to first harmful event (FHE) and most harmful event (MHE) fields in crash report database
        ii. Determine significance of sloped end treatment on crash outcome
        iii. Evaluate crash attributes and determine relationships (weather, road conditions, vehicle data, PSL, ADT, etc.)
        iv. Compare severities of crashes related to sloped end treatments to crashes in near vicinity which are not related to sloped end treatments
3. Reporting and Project Deliverables
    a. Compile Phase I summary report to document research effort, including literature search, crash data analysis, and recommendations for further research.

2 LITERATURE REVIEW

2.1 Overview

The research study consisted of the accumulation, analysis, and recommendations based on crash data related to sloped end treatments in the state of Iowa. Before acquiring the crash data, researchers performed a literature review of: (1) ISPE topics, methods, and analysis results; (2) design, development, and full-scale crash testing of guardrail turned-down terminals; (3) design, development, and full-scale crash testing of concrete barrier end treatments, including concrete barrier sloped end treatments and MASH-eligible and NCHRP Report No. 350-accepted crash cushions; and (4) short-radius guardrail systems.

2.2 In-Service Performance Evaluations

ISPEs have been used to: differentiate risk and rollover rates for concrete barrier profiles such as New Jersey shape, F-shape, and vertical shape barriers [9]; estimate rates of unreported collisions [10]; and evaluate factors associated with penetration, rollover, and severe crash outcomes with cable barrier impacts [11].

Iowa State University (ISU) performed a cost-effectiveness study of end treatments in Iowa using crash reports and *Roadside Safety Analysis Program v3* regarding life cycle costs of various end treatments [12]. However, sloped end treatments were not considered in that study. To date, no ISPEs have been conducted to evaluate the real-world severities of concrete sloped end treatment crashes. NCHRP Report No. 490, *In-Service Performance of Traffic Barriers*, details the importance of ISPEs and outlines the ISPE procedure [13].

2.2.1 ISPE Purpose

ISPEs are a valuable step within the roadside hardware development process, as illustrated in Figure 2. Before implementation, hardware is evaluated with full-scale crash testing. However, crash testing evaluates a limited number of vehicles and impact conditions. An ISPE determines if the roadside hardware performs satisfactorily in all real-world conditions with a large variety of vehicles. If the ISPE finds that interaction with the roadside hardware causes a large number of severe injuries, design changes can be made and the development process can begin again.

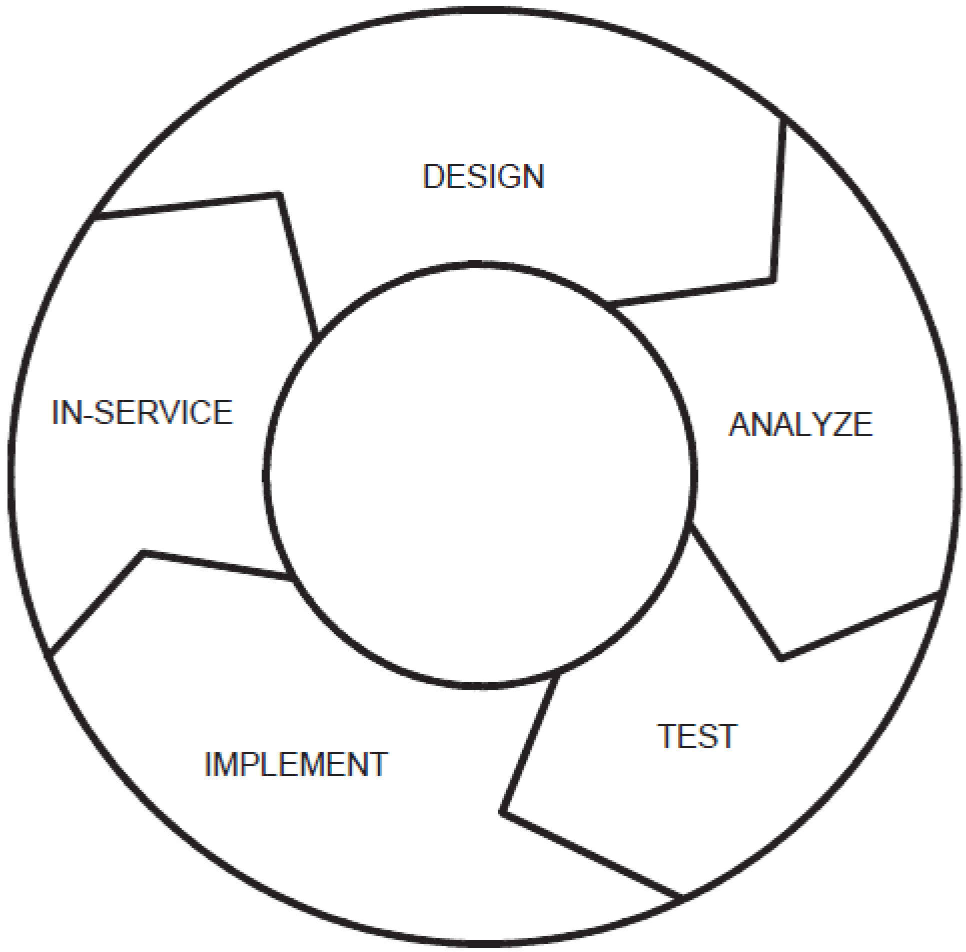


Figure 2. Roadside Hardware Development Process [13]

2.2.2 ISPE Procedure

A procedure manual for ISPEs was published by the NCHRP, in the appendix of the *In-Service Performance of Traffic Barriers* report [13]. The three phases involved in ISPEs include (1) planning and preparation, (2) data collection, and (3) analysis. The recommended procedure for executing an ISPE is shown schematically in Figure 3.

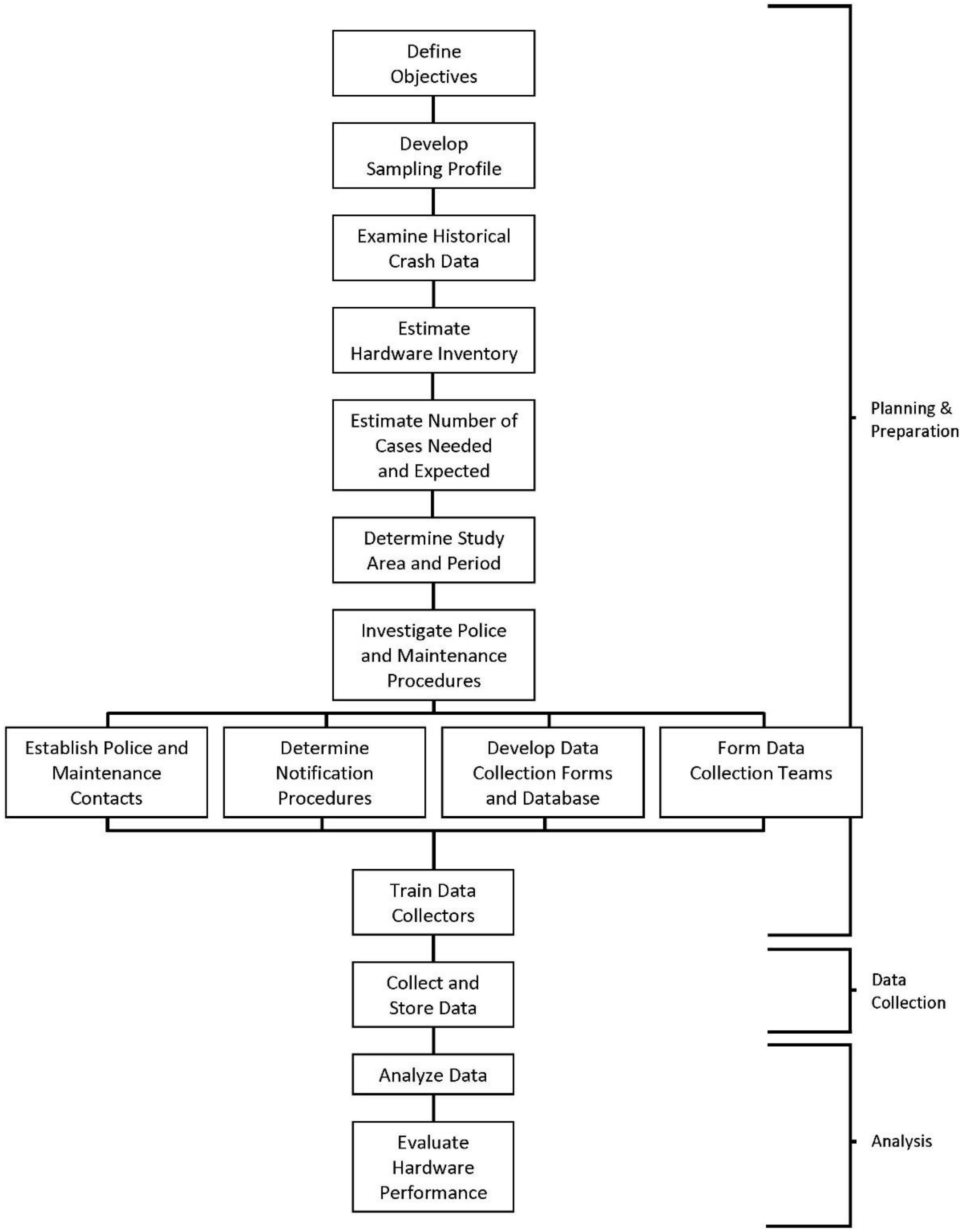


Figure 3. ISPE Steps [13]

Methods and procedures described in this manual were considered throughout this research effort. A sampling profile, or archetype, of crashes to investigate was developed to identify which crashes involved sloped end treatments. In addition, a hardware inventory estimate was completed and utilized in this research, crash exposure was calculated, and a study period and area were established. Only off-site data collection was performed, which involved analyzing police crash reports. No other data was examined. No crash site investigations were performed, and no information regarding unreported collisions was collected. Finally, analysis was performed to determine the in-service performance of concrete sloped end treatments.

2.3 Guardrail Attachments to Concrete Barriers

Concrete barrier blunt ends are rigid, fixed hazards located adjacent to the roadway, and are often treated using crashworthy end treatments to reduce the likelihood of injury. These end treatments vary in length based on the construction of the attachment. Concrete barrier end treatments which use guardrail typically consist of a guardrail to barrier attachment, stiffness transition, guardrail length of need (LON), and end terminal with end anchorage [14]. For downstream or trailing guardrail systems, the end treatment may not be energy-absorbing, but many upstream guardrail end terminals utilize energy-absorbing elements to slow and stop a vehicle. Most tangent guardrail end treatments require considerable length, approximately 75 ft, upstream from a concrete barrier to develop tensile anchorage and to provide a safe stiffness transition [15]. Because sloped end treatments are often used in locations with narrow offsets from other road features, including intersecting roads and driveways, replacing sloped end treatments with guardrail end treatments is typically not possible for Iowa DOT. Therefore, researchers focused primarily on two guardrail end treatments: W-beam guardrail turn-down terminals, due to their similarity to the concrete barrier sloped end treatments; and short-radius guardrail for use near intersecting roadways.

2.3.1 Guardrail Turn-Down Terminals

Guardrail turn-down terminals, as shown in Figure 4, were a common means of anchoring and terminating guardrail ends for many years. Before many crashworthy end terminals were introduced, the turn-down end was a cost-effective option for terminating guardrail installations. The short overall length of the turn-down influenced future guardrail transition designs. Similar to concrete sloped end treatments, turn-down ends were a sloped terminating option for guardrail installations.

Figure 4. Guardrail Turn-Down [16]

Evidence reported to many states indicated that W-beam turn-down terminals were contributing to an abnormally high rate of vehicle rollover and serious crashes (severe injury and fatality crashes) [17]. Many agencies sought to improve the performance of these terminals using crash testing. The Texas Transportation Institute (TTI) located at Texas A&M University (TAMU) conducted several crash testing modification efforts to improve rail release by modifying connections and lengthening the sloped turn-down end [18-19]. Although results were positive, the two studies denoted considerable vehicle instability when traversing the turn-down ends and recommended long turn-down lengths and weak post-to-rail connections during the turn-down transition. Additional studies conducted at the University of Nebraska-Lincoln (UNL) in 1989 and 1992 described some improvements to reduce the likelihood of rollover due to the turn-down ends based on crash test data and static testing results for post-to-rail connections, but crash test no. NETD-1 resulted in rollover [20-21]. Subsequent analysis utilized finite element analysis (FEA) of turn-down ends and evaluated alternative rail sections for the turn-down region, but crash test nos. NETD-2 and NETD-3 [22] still resulted in rollover and unacceptable performance according to NCHRP Report No. 230 [23].

2.3.2 Guardrail Turn-Down Terminal ISPE

ISPEs of guardrail system and end termination impacts provided additional evidence that the end treatments were contributing to an excessive number of vehicle rollovers. Guardrail turn-down terminals were evaluated in the state of New York, and it was concluded that turn-down terminals likely contributed to some severe crash results and at least one rollover in 1983 [24]. Investigations into the turn-down ends installed and impacted in the state of Texas were conducted in the late 1980s and early 1990s, and it was observed that out of a quasi-random sample of non-fatal crashes involving guardrails, approximately 15% (152 out of 987 crashes) involved a turn-down end; in contrast, for fatal crashes, 32% (32 out of 100 fatal crashes) involved the turn-down ends, and most fatalities occurred due to rollover [25]. Despite some concerns regarding data validity and collection methodology, results suggested that turn-down ends produced more severe injury results, on average, than the remainder of the guardrail system.

2.3.3 Short Radius Guardrail

For some situations, such as bridge rails near entrances and entrance ramps with no sidewalks, short radius guardrail may be a potential concrete barrier end treatment option. A short radius guardrail system, as shown in Figure 5, was developed at the Midwest Roadside Safety Facility (MwRSF) and evaluated according to MASH Test Level 3 (TL-3) criteria [26]. Although this system was determined to be unsuccessful at MASH TL-3, analysis indicated the system was likely to be successful when impacted at MASH TL-2 conditions.

Figure 5. Short Radius Guardrail [26]

TTI conducted a MASH-equivalency study on the Yuma County short-radius guardrail system which had previously been tested in accordance with AASHTO's *Guide Specifications for Bridge Railings* [27]. The study suggested that the Yuma County system had a strong likelihood to perform satisfactorily if subjected to full-scale crash testing and some entities consider it to be crashworthy [28]. The installation is shown in Figure 6. Subsequently, TTI developed a new short-radius guardrail system which utilized a thrie beam short-radius guardrail combined with a short sand barrel array [29]. Several full-scale crash tests were performed, and the system adequately captured the impacting vehicles. The system is shown in Figure 7.

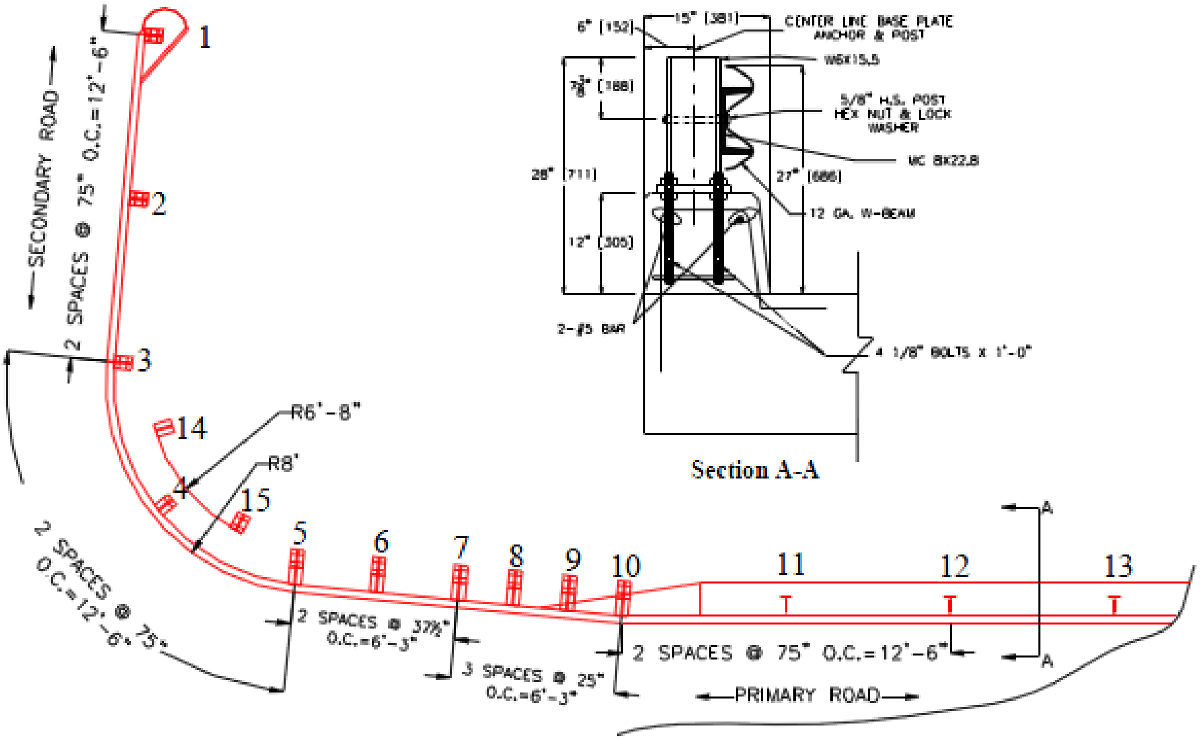


Figure 6. Yuma County Short Radius System [28]

Figure 7. TTI MASH TL-3 Short Radius Guardrail [29]

2.4 Concrete Barrier End Treatments Attached Directly to Barrier Ends

Numerous end treatments exist which can be attached directly to concrete barrier ends, including concrete sloped end treatments and various crash cushions. Concrete sloped end treatments have been successfully full-scale crash tested according to NCHRP Report No. 230, NCHRP Report No. 350, and MASH criteria, despite high vehicle instability observed during the tests [4-8]. Alternatives to concrete sloped end treatments, including various crash cushions, have also been full-scale crash tested according to NCHRP Report No. 350 and MASH evaluation criteria [32]. Despite their tendency to induce greater vehicle instability compared to crash cushions, concrete sloped end treatments are installed on roadways in Iowa due to smaller size, no attachment hardware, cost, and simplicity. Nevertheless, various crash cushions were researched and are discussed in the following sections.

Three end treatments for concrete barriers were considered: blunt or untreated ends, sloped end treatments, and energy-absorbing end treatments [4]. When impacting blunt ends, vehicles and occupants may experience high accelerations as they are brought to a sudden stop. Sloped end treatments were designed to eliminate the longitudinal impact and snag from the exposed vertical face of the barrier's blunt end by redirecting the vehicle to the top surface or back side of the barrier.

Most energy-absorbing concrete barrier end treatments consist of crash cushions, which may be connected to a barrier face, or use a standalone backup structure adjacent to the concrete barrier's blunt end. Energy-absorbing crash cushions may be categorized as redirecting or non-redirecting, but most capture vehicles during end-on impacts through material deformation and conversion of vehicle kinetic energy into material strain or fracture energy.

The following sections describe full-scale crash testing of sloped end treatments and energy-absorbing end treatments. No safety research has been performed to date regarding the full-scale crash testing of blunt end treatments; hence, their impact performance is not discussed here.

2.4.1 Sloped End Treatment Full-Scale Crash Testing

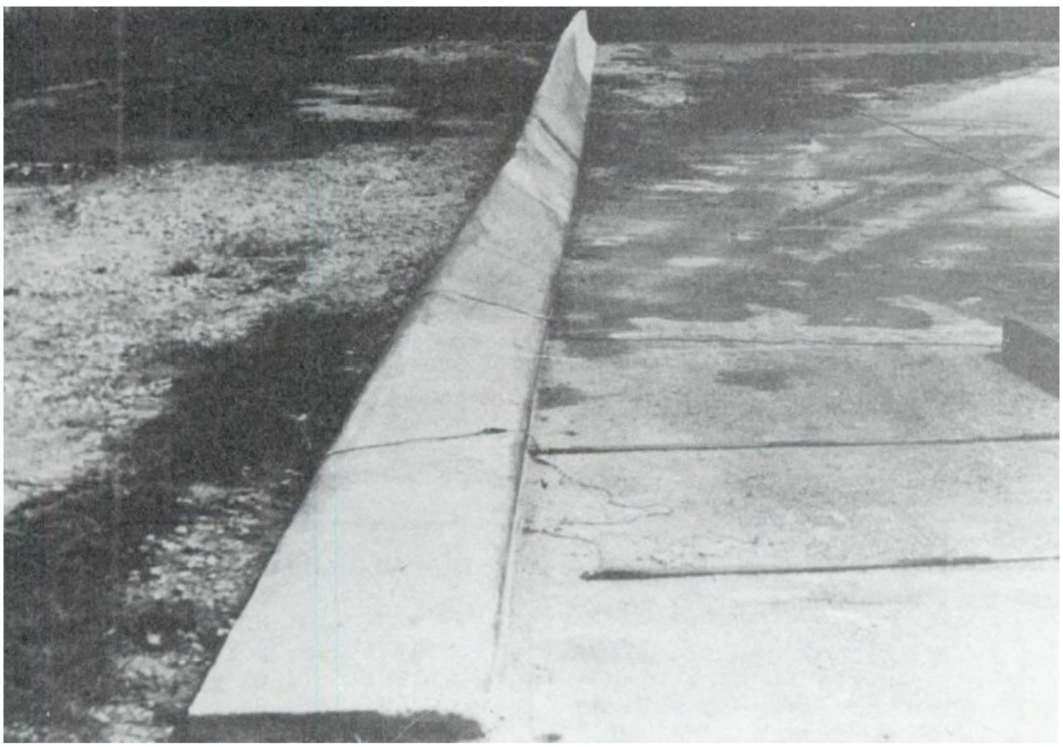
Several configurations of sloped end treatments have been successfully full-scale crash tested to NCHRP Report No. 230 [23], NCHRP Report No. 350 [2], and MASH [3] criteria. During some of these tests, vehicles experienced high roll angles, instability, or rollover, and some vehicles came to rest on the non-traffic side of the sloped end treatment. Although sloped end treatments are not traditionally defined as gating terminals, vehicle traversal to the non-traffic side face of the system was nonetheless deemed acceptable.

2.4.1.1 New Jersey Sloped End Treatment

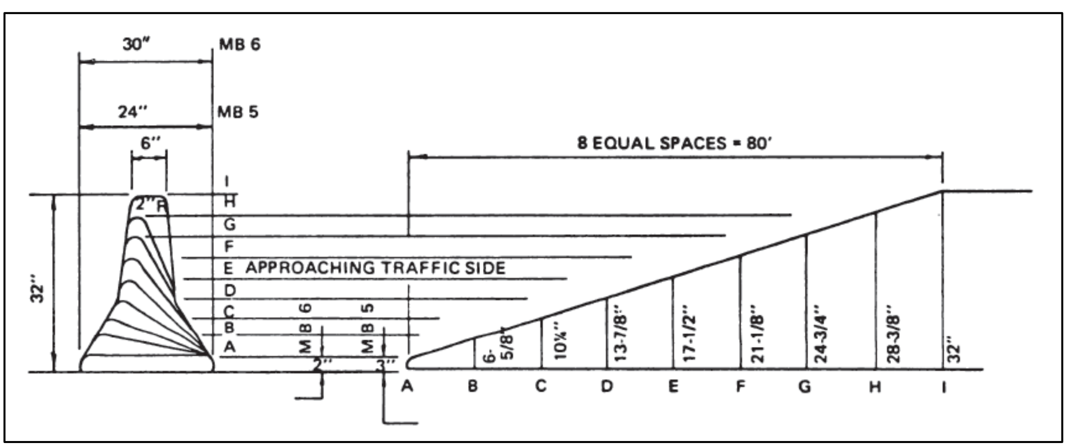
Testing was conducted at the Southwest Research Institute (SwRI) in the 1970s according to NCHRP Report No. 230 to evaluate the New Jersey sloped end treatment (NJSET), as shown in Figure 8 [5]. Two full-scale crash tests were performed to evaluate the NJSET's performance at low impact angles.

Test no. CMB-17A featured the NJSET impacted 30 ft from the leading end by a 4,500-lb sedan at a speed of 59.6 mph and an angle of 7 degrees. The small impact angle was chosen to lower the chance of vehicle rollover in order to evaluate the end treatment's redirecting capabilities. During the test, the vehicle impacted the NJSET, slid along the top of the barrier until the barrier installation ended, and regained contact with the ground. The vehicle was judged to be on the threshold of rollover during this test but received minimal damage to the undercarriage.

Test no. CMB-17B was performed with a 4,500-lb vehicle impacting the NJSET 26 ft from the leading end at a speed of 64.1 mph and an angle of 10 degrees. The vehicle rode over the end treatment and landed behind the barrier, nearly rolling in the process. The vehicle received minor damage on the lower driver's side, spanning from the wheel to the rear door, due to regaining contact with the ground.



(a)



(b)

Figure 8. New Jersey Sloped End Treatment, (a) Image and (b) Drawing [5]

For both test nos. CMB-17A and CMB-17B, the test vehicles experienced significant roll displacement and instability, but test results were considered successful because rollovers did not occur. It was determined from these tests, despite the low impact angle, that the long tapered approach resulted in marginally stable vehicles. Additional length did not result in more stable vehicles compared to shorter installations, therefore it was recommended that taper length be shortened to reduce costs.

Within this report, sloped end treatment designs from Arizona, Colorado, Michigan, Idaho, Washington state, and Oklahoma were collected, but not full-scale crash tested. Sloped end treatment drawings are shown in Figures 9 through 14, respectively.

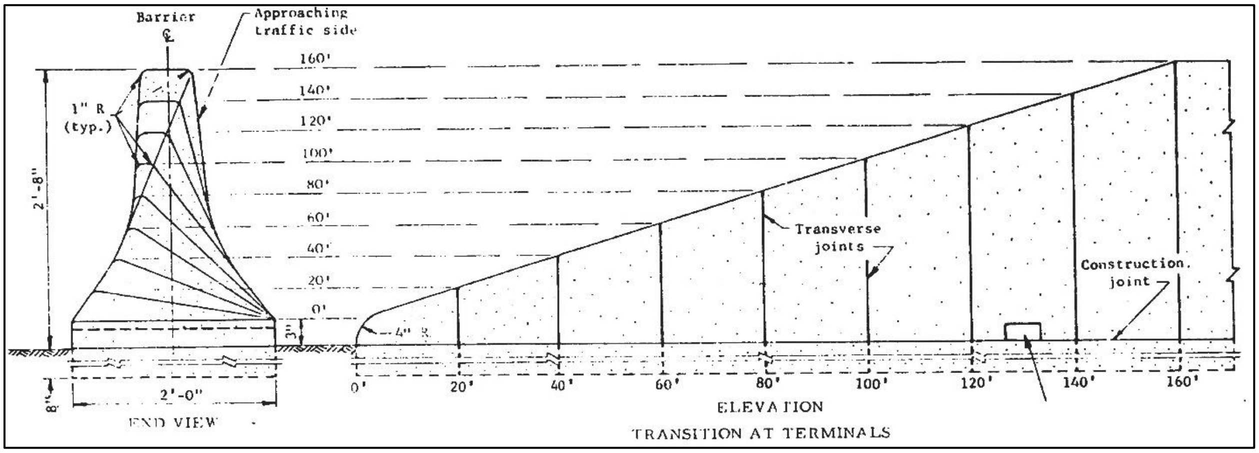


Figure 9. Arizona Sloped End Treatment Drawing [5]

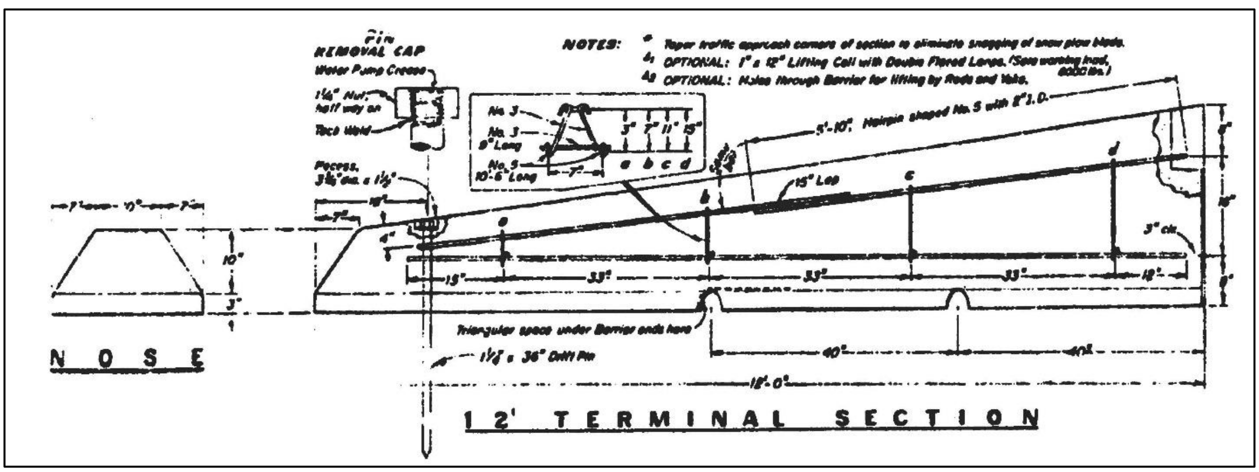


Figure 10. Colorado Sloped End Treatment Drawing [5]

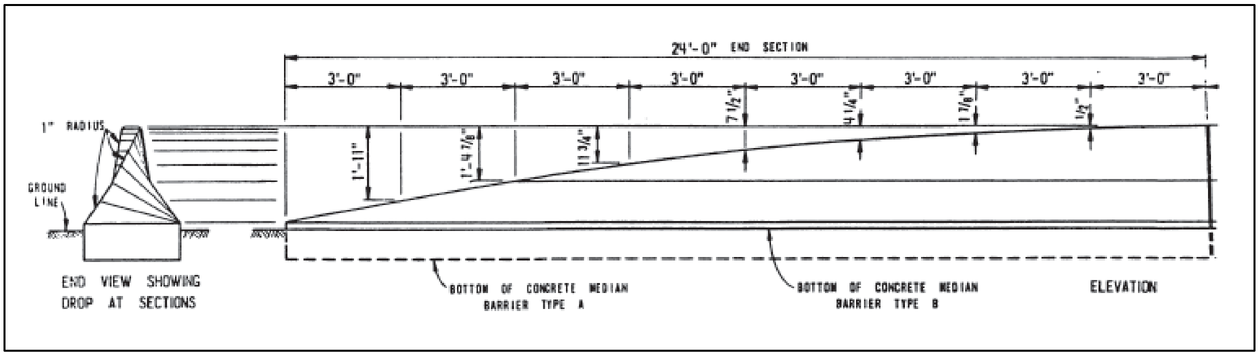


Figure 11. Michigan Sloped End Treatment Drawing [5]

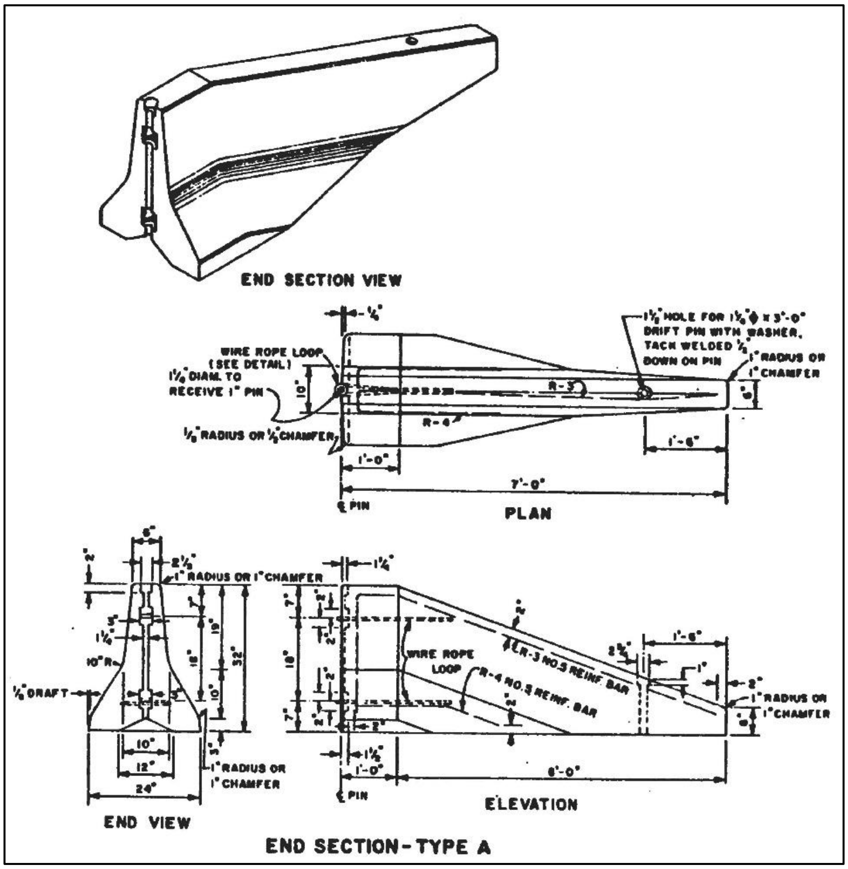


Figure 12. Idaho Sloped End Treatment Drawing [5]

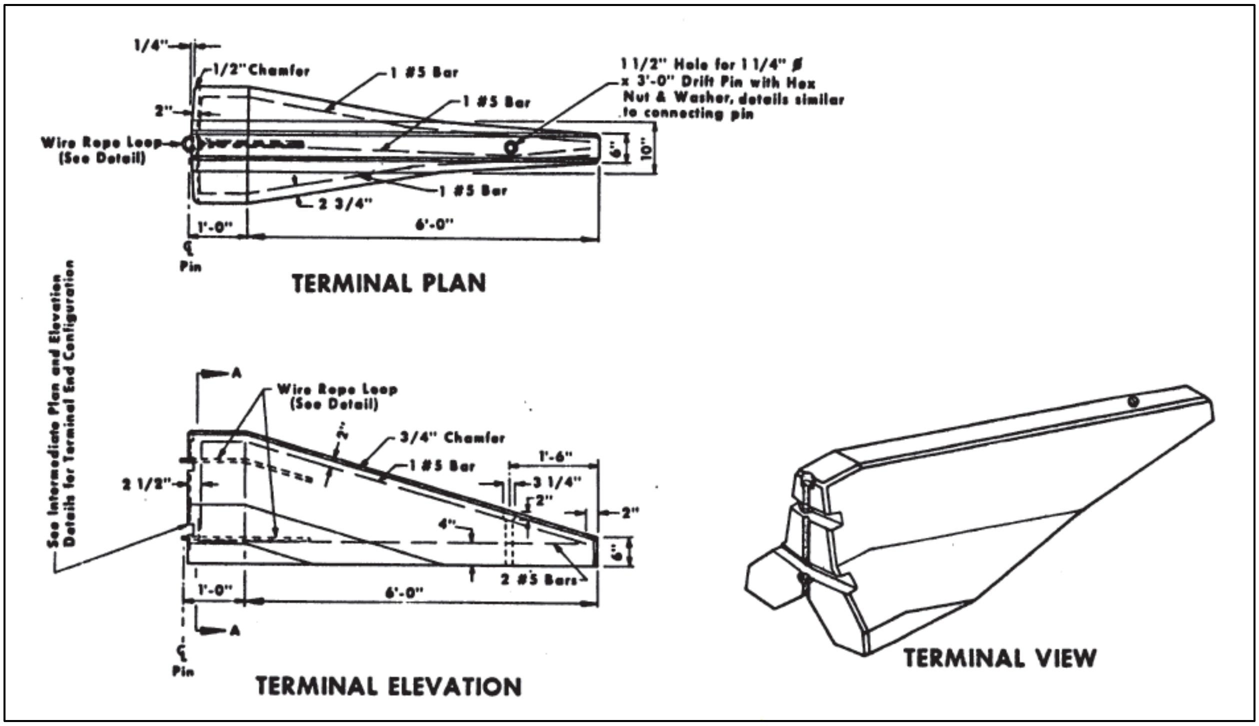


Figure 13. Washington State Sloped End Treatment Drawing [5]

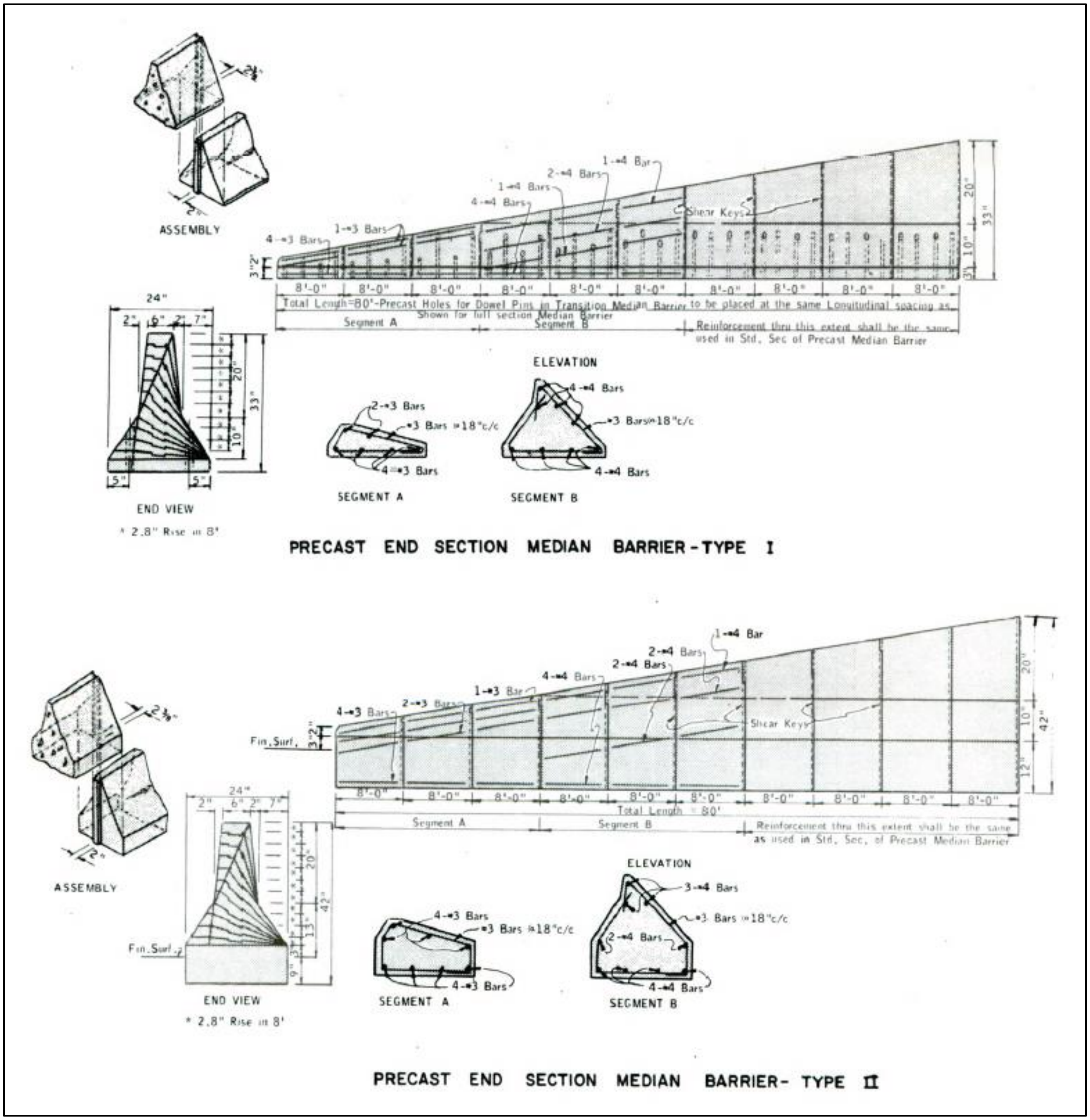
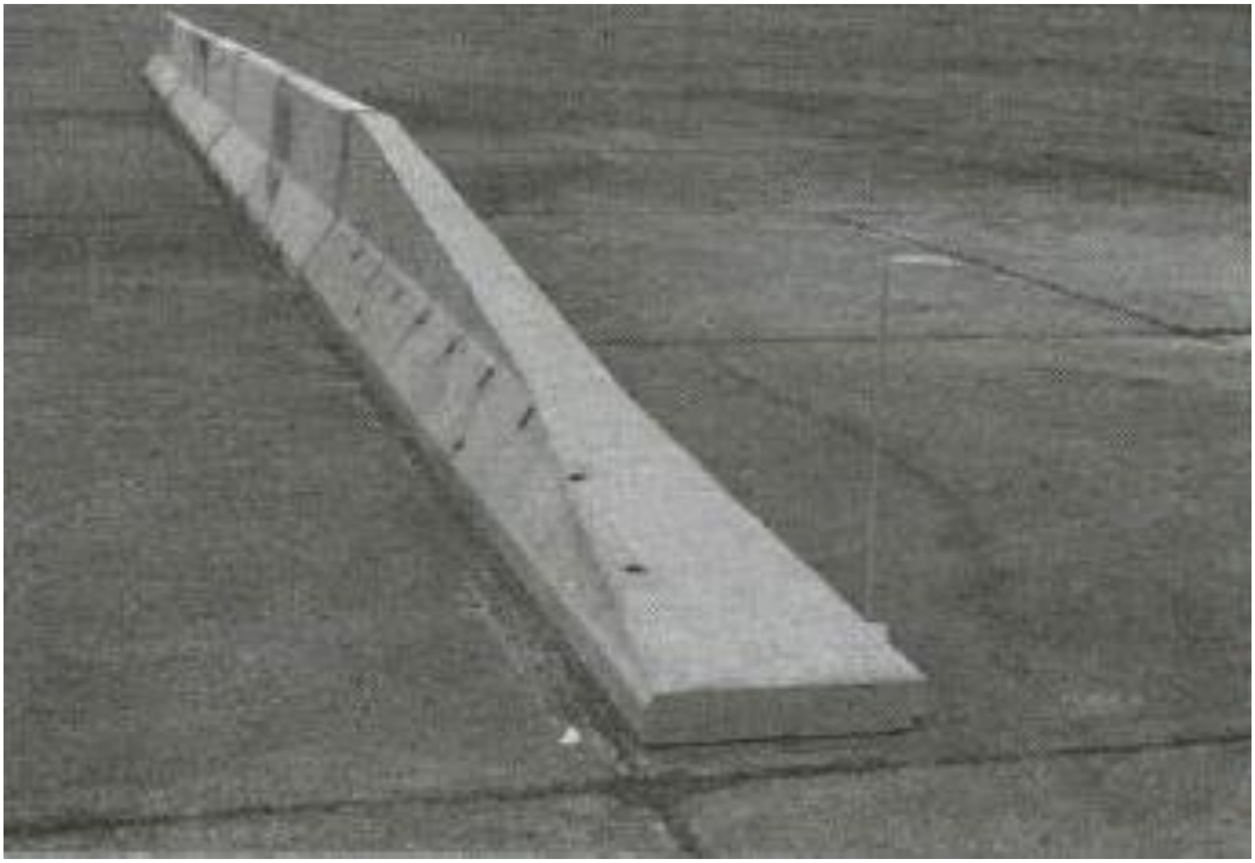


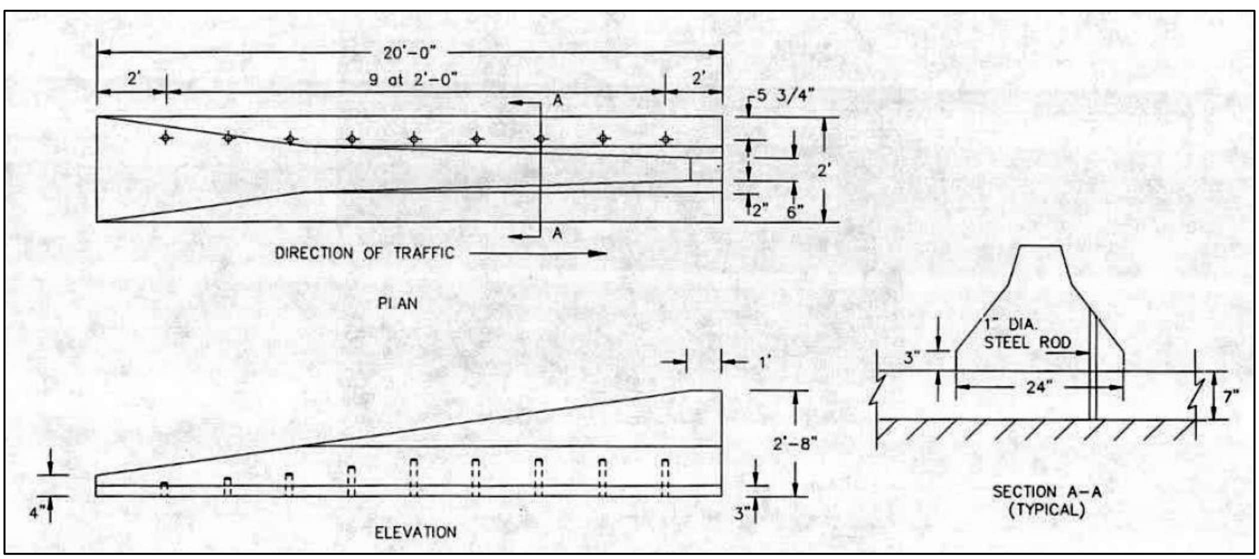
Figure 14. Oklahoma Sloped End Treatment Drawing [5]

2.4.1.2 Conventional and New York Sloped End Treatments

In NCHRP Report No. 358 [6], which was published in 1994, a series of work zone and temporary barrier applications were evaluated. Full-scale crash tests and simulations were conducted on two types of concrete barrier sloped end treatments: a conventional sloped end treatment (CSET), as shown Figure 15, and the New York sloped end treatment (NYSET), as shown in Figure 16.

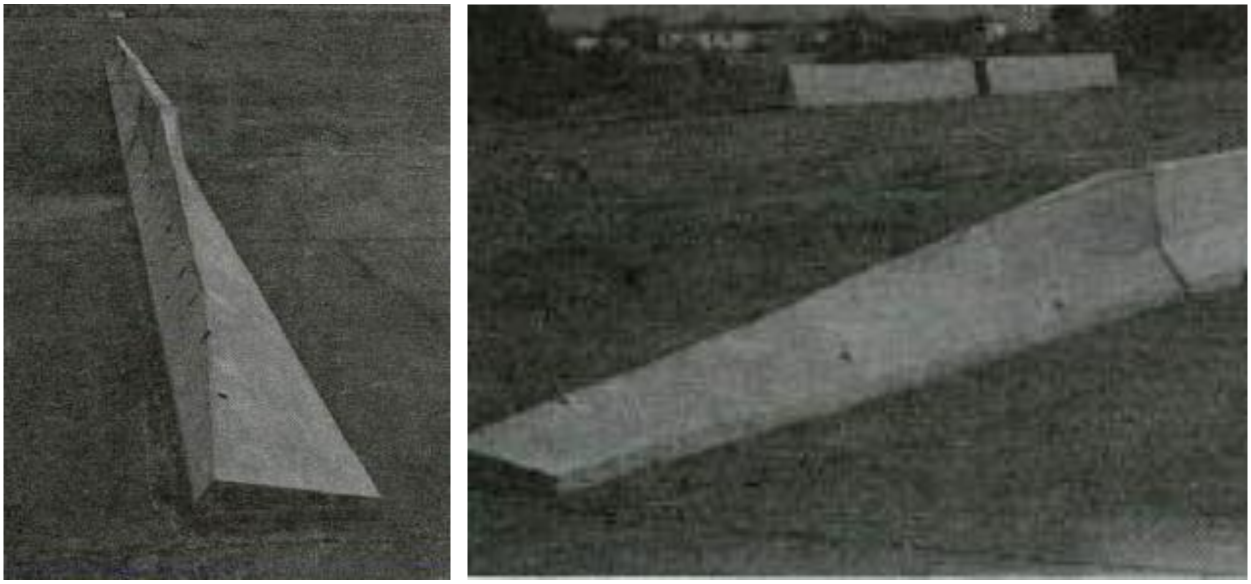


(a)

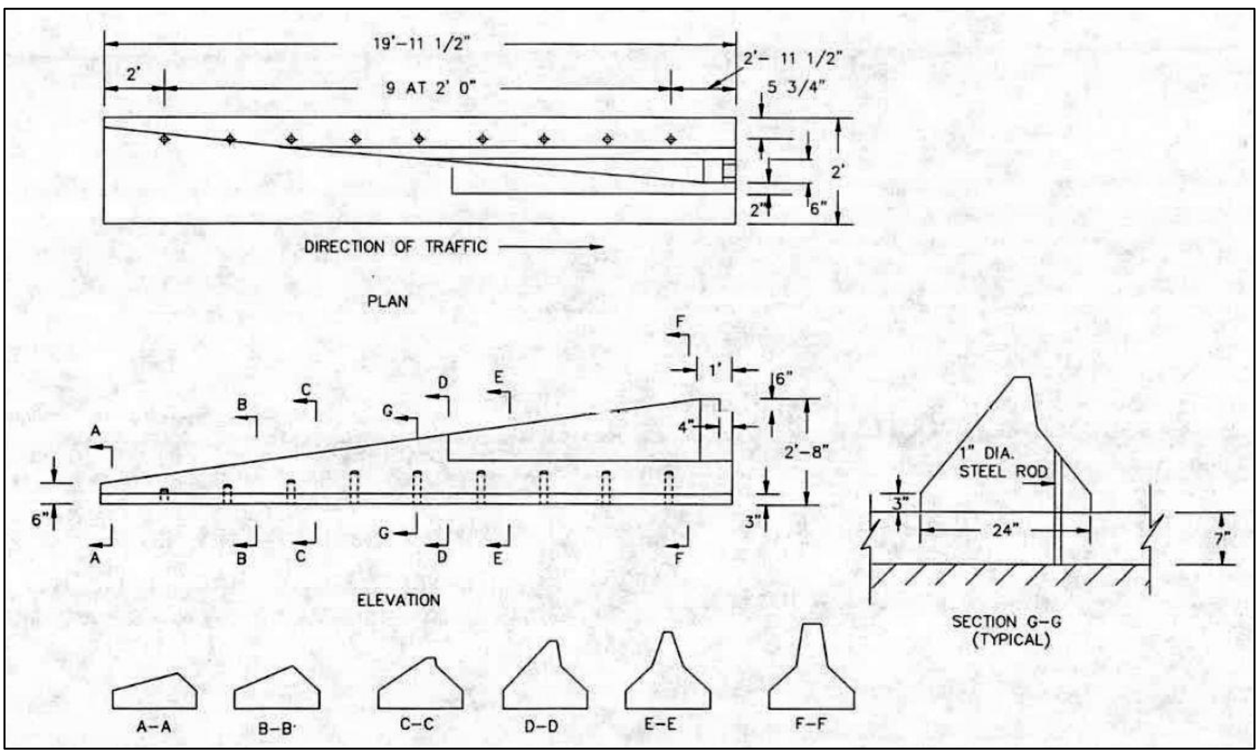


(b)

Figure 15. Conventional Sloped End Treatment, (a) Image and (b) Drawing [6]



(a)



(b)

Figure 16. New York Sloped End Treatment, (a) Image and (b) Drawing [6]

Full-scale crash tests were performed with small cars, weighing approximately 1,970 lb, due to their greater instability compared to larger cars. A summary of test conditions and results are shown in Table 1. Three tests were performed with the CSET, and three were performed with the NYSET. Impact speeds ranged between 30 and 45 mph, and impact angles were either 0 or 30 degrees. Two of the six tests involved impacts at the upstream end of the sloped end treatment and four impacted 2 ft downstream from the leading end.

Four of the six tests resulted in vehicle rollover. The remaining two tests, nos. 7110-5 and 7110-8, both of which impacted the sloped end treatment end-on, resulted in marginally stable vehicles. After reviewing these tests, it was found that the guide plate attached to the right-front wheel contacted the pavement before the wheel, which reduced the likelihood of rollover. Simulations were utilized to determine the validity of this finding: simulations with the guide plate predicted no rollover and those without predicted rollover. Researchers concluded that an end-on impact at 45 mph with a sloped end treatment would result in vehicle rollover.

Table 1. Summary of Sloped End Treatment Tests Conducted for NCHRP Report 358 [6]

Test No.	**Test Article**	**Speed mph**	**Angle deg**	**Impact Location: Distance from Leading End ft**	**Vehicle Stability**
7110-5	NYSET	45.0	0.00	0	Marginal
7110-6	NYSET	45.5	30.2	2	Overturn
7110-8	CSET	45.8	0.00	0	Marginal
7110-9	CSET	45.3	29.6	2	Overturn
7110-11	CSET	30.4	31.2	2	Overturn
7110-12	NYSET	30.1	29.1	2	Overturn

Researchers conducted computer simulations using additional impact conditions for the CSET model because it was simpler than the NYSET model but had similar test outcomes. A 1,800-lb test vehicle was simulated impacting CSETs of varying taper lengths at varying impact angles, locations, and speeds for a total of 84 simulations, as summarized in Table 2. All simulations which involved the vehicle impacting the sloped end treatment at 30 degrees resulted in vehicle rollover, and all simulations utilizing a 15-degree impact angle were deemed unstable. Head-on impacts resulted in stable vehicles at 30 and 37 mph when the taper length was 20 and 25 ft long. From simulation results, it was recommended that sloped end treatments be at least 20 ft long and be used on roadways with speed limits less than or equal to 45 mph.

Table 2. Summary of Simulations Conducted for NCHRP Report No. 358 [6]

Impact Angle deg	Impact Location: Distance from Leading End	Impact Speed mph	Vehicle Action at Taper Length (L)			
			10 ft	15 ft	20 ft	25 ft
0	0	30	Overturn	Overturn	Stable	Stable
0	0	37	Overturn	Overturn	Stable	Stable
0	0	45	Overturn	Overturn	Overturn	Stable
15	0.1L	30	Climbs	Rides	Rides	Ran Over
15	0.1L	37.5	Climbs	Ran Over	Overturn	Overturn
15	0.1L	45	Ran Over	Ran Over	Overturn	Overturn
15	0.2L	30	Climbs	Rides	Redirects	Redirects
15	0.2L	37.5	Rides	Overturn	Rides	Climbs
15	0.2L	45	Climbs	Rides	Rides	Rides
15	0.3L	30	Rides	Redirects	Redirects	Redirects
15	0.3L	37.5	Overturn	Overturn	Climbs	Climbs
15	0.3L	45	Overturn	Overturn	Ran Over	Rides
30	0.1L	30	Overturn	Overturn	Overturn	Overturn
30	0.1L	37.5	Overturn	Overturn	Overturn	Overturn
30	0.1L	45	Overturn	Overturn	Overturn	Overturn
30	0.2L	30	Overturn	Overturn	Overturn	Overturn
30	0.2L	37.5	Overturn	Overturn	Overturn	Overturn
30	0.2L	45	Overturn	Overturn	Overturn	Overturn
30	0.3L	30	Overturn	Overturn	Overturn	Overturn
30	0.3L	39.5	Overturn	Overturn	Overturn	Overturn
30	0.3L	45	Overturn	Overturn	Overturn	Overturn

2.4.1.3 Low-Profile Sloped End Treatment

TTI developed a low-profile concrete barrier and associated low-profile sloped end treatment (LPSET) for the Texas Department of Transportation (TxDOT) in the early 1990s [4]. The barrier was 20 in. tall, utilized a rectangular profile, and is shown in Figure 17.

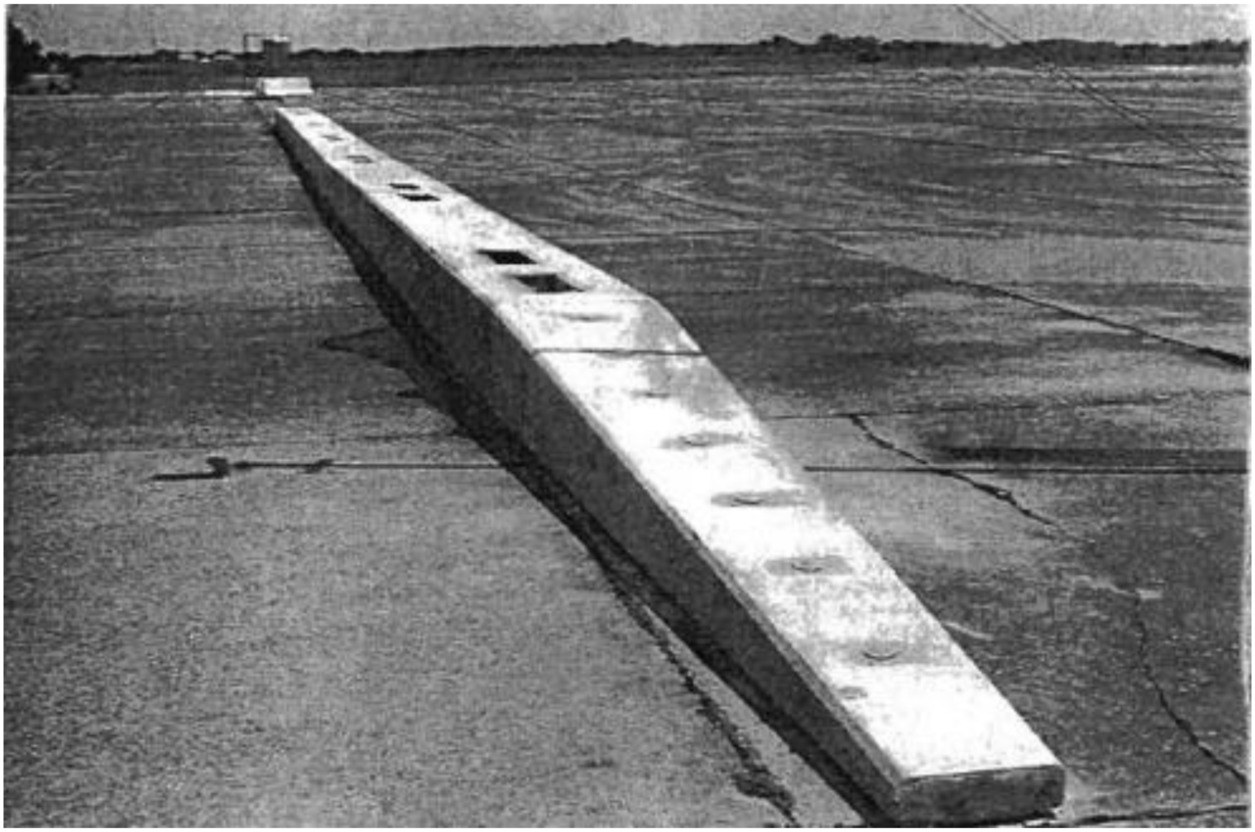


Figure 17. Low-Profile Sloped End Treatment [4]

2.4.1.3.1 LPSET Full-Scale Crash Testing – 1992

Three full-scale crash tests were performed on the LPSET in the early 1990s [4] according to crash test conditions consistent with NCHRP Report No. 230 at "work zone speeds" of 45 mph.

Test no. 1949A-1 impacted the sloped end treatment 6.5 ft from the end of the treatment at an angle of 16.3 degrees and a speed of 44.7 mph. The sloped end treatment redirected the vehicle, and the vehicle exited the system at a speed of 37.4 mph and an angle of 6.1 degrees. Test no. 1949A-2 impacted the sloped end treatment end-on at a speed of 45.1 mph with the centerline of the right wheels aligned with the centerline of the sloped end treatment. The right-side wheels of the vehicle rode along the top of the concrete barrier, as shown in Figure 18, then the vehicle lost contact with the barrier and exited the system. Test no. 1949A-3 impacted the sloped end treatment end-on at a speed of 46.5 mph with the centerline of the vehicle aligned with the centerline of the sloped end treatment. The vehicle rode atop the barrier, as shown in Figure 19, before coming to rest. Thus, the sloped end treatment was determined to be successful according to NCHRP Report No. 230 test criteria.

Figure 18. Right Side of Vehicle Riding Along Top of Concrete Barrier, Test No. 1949A-2 [4]

Figure 19. Vehicle Riding Along Top of Concrete Barrier, Test No. 1949A-3 [4]

2.4.1.3.2 LPSET Full-Scale Crash Testing – 1998

TTI re-evaluated the LPSET according to NCHRP Report No. 350 Test Level 2 (TL-2) criteria in 1998 [7]. Test no. 414038-1 was performed with a 1990 Ford Festiva impacting the sloped end treatment 3 ft from the end at a speed of 44.1 mph and an angle of 15.8 degrees. During the test, the right rear tire became trapped on the non-impact side of the barrier, as shown in Figure 20. The vehicle eventually came to rest on the traffic side of the barrier.

Test no. 414038-2 consisted of a 1990 Ford Festiva impacting the leading end of the LPSET at an angle of 15.1 degrees and a speed of 42.8 mph. The vehicle traveled up the end treatment and came to rest on the non-traffic side of the concrete barrier, as shown in Figure 21. Thus, the low-profile sloped end treatment was determined to be successful according to NCHRP Report No. 350 TL-2 test criteria.

Figure 20. Vehicle Rear Tires on Top of Concrete Barrier, Test No. 414038-1 [7]

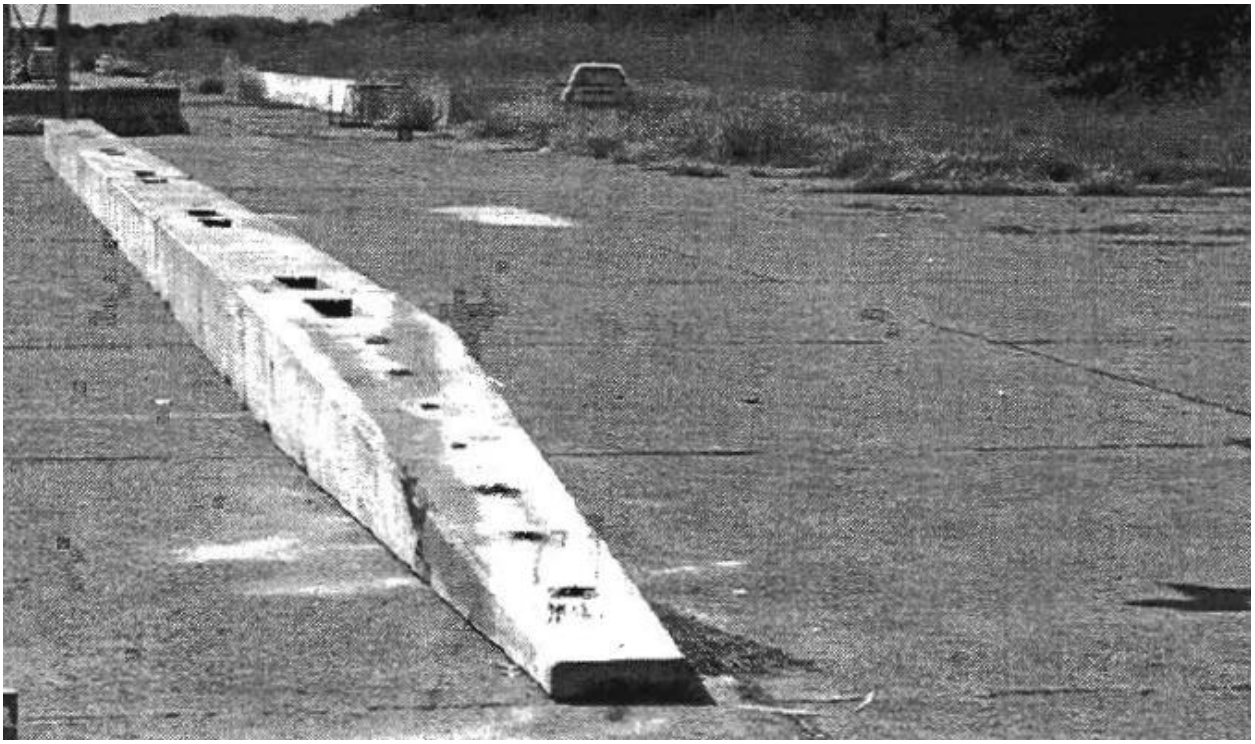


Figure 21. Vehicle Final Position, Test No. 414038-2 [7]

2.4.1.3.3 Non-Pinned LPSET Full-Scale Crash Testing – 2013

In 2013, TTI re-tested a modified, non-pinned version of the sloped end treatment according to MASH TL-2 impact conditions [8]. Test no. 490023-5 was performed with the car impacting the sloped end treatment 33 in. from the end at a speed of 43.9 mph and an angle of 15.2 degrees. During this test, the vehicle rode up the end treatment, shown in Figure 22, and came to rest on the non-traffic side of the barrier.

Test no. 490023-7 was performed with a 2270P pickup truck impacting the sloped end treatment at a speed of 45.0 mph and an angle of 25.3 degrees. The impact location was 78.0 in. upstream from the splice location, coinciding with where the sloped end treatment reached a height of 18 in. The vehicle was successfully redirected and came to rest on the traffic side of the barrier. Thus, the low-profile sloped end treatment was determined to be successful according to MASH impact conditions.

Figure 22. Vehicle Riding Up Sloped End Treatment, Test No. 490023-5 [8]

2.4.2 Crash Cushions

Information about energy-absorbing crash cushions was collected and is shown in the following sections. Federal Highway Administration (FHWA) eligibility letters for barrier terminals and crash cushions which were tested to either MASH [30] or NCHRP Report No. 350 [31] criteria were reviewed to collect all viable treatments that could be used in place of concrete sloped end treatments. This information was summarized in the FHWA Crash Cushion Chart [32].

2.4.2.1 MASH

A total of seven crash cushions rated to MASH TL-1, TL-2, or TL-3 evaluation criteria are shown in Table 3. These crash cushions are classified as redirective or non-redirective and either gating or non-gating. According to MASH 2016, redirective crash cushions are designed to reduce the severity of head-on impacts with a fixed object and function as a longitudinal barrier during impacts on the side of the device [3]. A non-redirective device is designed to safely accommodate vehicles striking the front of the cushion, but they have no capability to redirect vehicles impacting near the rear of the device. A gating device allows controlled penetration by a vehicle when impacted upstream from the beginning of the LON, while a non-gating device is designed to capture vehicles striking the end of the device and safely decelerate them to a stop. Most crash cushions received FHWA eligibility letters, which are listed with their corresponding device. The height, width, and length of each device is also listed. Images of each crash cushion are shown in Figures 23 through 29.

Table 3. MASH Crash Cushions

Device Name	Ref.	Performance	FHWA Eligibility Letter	Test Level	Height in.	Width in.	Length ft – in.
QuadGuard M10	33	Redirective, Non-Gating	CC-112 CC-112A CC-112B CC-112C CC-121	TL-3	32.2	24	22 – 0
ABSORB-M	34	Non-Redirective	None	TL-2	42	24	Not Listed
			None	TL-3	42	24	21 – 0
TAU-M	35	Redirective, Non-Gating	CC-146	TL-2	32.6	30	14 – 2
			CC-147	TL-3	32.6	30	22 – 9
SLED	36	Non-Redirective, Gating	None	TL-1	42	22.5	12 – 7
			None	TL-2	42	22.5	18 – 11
			CC-131	TL-3	42	22.5	25 – 3
SLED Mini	37	Non-Redirective, Gating	CC-144	TL-2	32	23	12 – 0
Hercules	38	Redirective, Non-Gating	None	TL-3	35	23	19 – 1
Smart Cushion	39	Redirective, Non-Gating	CC-85A	TL-2	34	24	13 – 6
			CC-85 CC-128	TL-3	34 (864)	24 (610)	21 – 6

2.4.2.1.1 QuadGuard M10

The QuadGuard M10, shown in Figure 23, is classified as a redirective, non-gating crash cushion. It was evaluated to MASH TL-3 and received FHWA eligibility letter nos. CC-112, CC-112A, CC-112B, CC-112C, and CC-121. The device is manufactured by Trinity Highway and is 32.2 in. tall, 24 in. wide, and 22 ft long.

Figure 23. QuadGuard M10 [33]

2.4.2.1.2 ABSORB-M

The ABSORB-M crash cushion is manufactured by Barrier Systems, was tested according to MASH TL-2 and TL-3 evaluation criteria, and is shown in Figure 24. The device dimensions are 42 in. tall, 24 in. wide, and the TL-3 version is 21 ft long.

Figure 24. ABSORB-M [34]

2.4.2.1.3 TAU-M

Barrier Systems manufactures the TAU-M crash cushion, shown in Figure 25, which is classified as a redirective, non-gating device. It received FHWA eligibility letter nos. CC-146 and CC-147 after being evaluated to MASH TL-2 and TL-3, respectively. The TL-2 version of the TAU-M device is 14 ft – 2 in. long, the TL-3 version is 22 ft – 9 in. long, and both are 32.6 in. tall and 30 in. wide.

Figure 25. TAU-M [35]

2.4.2.1.4 SLED

The sentry longitudinal energy dissipater (SLED) device, manufactured by TrafFix Devices, is shown in Figure 26. It was crash tested to MASH TL-3 criteria and received FHWA eligibility letter no. CC-131. The device is classified as a non-redirective, gating crash cushion, with dimensions 42 in. tall, 22.5 in. wide, and 25 ft – 3 in. long. TL-1 and TL-2 versions are also available, with lengths of 12 ft – 7 in. and 18 ft – 11 in., respectively.

Figure 26. SLED [36]

2.4.2.1.5 SLED Mini

The SLED Mini, shown in Figure 27 and manufactured by TrafFix Devices, is classified as a non-redirective, gating crash cushion. It received FHWA eligibility letter no. CC-144 after being tested to MASH TL-2 evaluation criteria. The device is 32 in. tall, 23 in. wide, and 12 ft long.

Figure 27. SLED Mini [37]

2.4.2.1.6 Hercules

The Hercules redirective, non-gating crash cushion is shown in Figure 28. It is manufactured by Safety Modular Absorber (SMA) and was evaluated according to MASH TL-3. The device is 35 in. tall, 23 in. wide, and 19 ft – 1 in. long.

Figure 28. Hercules [38]

2.4.2.1.7 Smart Cushion

The Smart Cushion, a redirective, non-gating crash cushion, is manufactured by Hill & Smith and shown in Figure 29. The MASH TL-2 version received FHWA eligibility letter no. CC-85A and has dimensions 34 in. tall, 24 in. wide, and 13 ft – 6 in. long. FHWA eligibility letter nos. CC-85 and CC-128 were awarded to the MASH TL-3 version of the device, which has the same height and width as the TL-2 version and is 21 ft – 6 in. long. The Smart Cushion was also evaluated to NCHRP Report no. 350 criteria.

Figure 29. Smart Cushion [39]

2.4.2.2 NCHRP Report No. 350

Crash cushions and end terminals evaluated to NCHRP Report No. 350 criteria are listed in Table 4. Pictures of the devices are shown in Figures 30 through 58.

Table 4. NCHRP Report No. 350 Crash Cushions

Device Name	Ref.	Performance	FHWA Eligibility Letter	Test Level	Height in.	Width in.	Length ft – in.
QuadGuard	32, 40	Redirective, Non-Gating	None	TL-1	32	24	9 – 0
			CC-35C	TL-2	32	24	13 – 1.5
			CC-35 CC-35B CC-35D CC-35H CC-35J CC-35L CC-35M CC-45	TL-3	32	24	21 – 0
QuadGuard Elite	32, 41	Redirective, Non-Gating	CC-57A CC-57C	TL-2	32	24	23 – 10
			CC-57 CC-57B CC-57D CC-57E	TL-3	32	24	26 – 9
QuadGuard HS	32, 42	Redirective, Non-Gating	CC-35E	TL-3	32	24	30 – 0

Table 5. NCHRP Report No. 350 Crash Cushions (Cont.)

Device Name	Ref.	Performance	FHWA Eligibility Letter	Test Level	Height in.	Width in.	Length ft – in.
QuadGuard II	32, 43	Redirective, Non-Gating	CC-35I	TL-2	32	24	9 – 11
			CC-35J	TL-3	32	24	19 – 0
REACT 350	32, 44	Redirective, Non-Gating	None	TL-1	51.5	36	28 – 9
			CC-26B CC-26C	TL-2	51.5	36	29 – 9
			CC-26 CC-26A CC-26C CC-26I CC-26K	TL-3	51.5	36	30 – 9
REACT 350 II	45	Redirective, Non-Gating	CC-26J	TL-3	51.5	46.75	19 – 5
REACT 350 Wide	32, 46	Redirective, Non-Gating	CC-73C	TL-1	46	60	10 – 7
			CC-73B	Tl-2	46	60	17 – 6
			CC-73 CC-73A	TL-3	46	60	30 – 7
TRACC	47, 32	Redirective, Non-Gating	CC-54 CC-54A CC-54C CC-54E CC-54G CC-54I	TL-3	32	24	21 – 3
FasTRACC	32, 48	Redirective, Non-Gating	CC-54B CC-54H	TL-3	32	34	26 – 0
ShorTRACC	32, 49	Redirective, Non-Gating	CC-54F	TL-2	32	24	14 – 3
WideTRACC	32, 50	Redirective, Non-Gating	None	TL-2	32	58	Not Listed
			CC-54D	TL-3	32	58	21 – 0
QUEST	32, 51	Redirective, Non-Gating	CC-87B	TL-2	31	24	21 – 0
			CC-87 CC-87C CC-87D	TL-3	31	24	27 – 0
N-E-A-T	32, 52	Non-Redirective, Gating	CC-25	TL-2	32	22.5	9 – 8
ACZ-350	53	Non-Redirective, Gating	CC-110	TL-2	33	22	18 – 4
			None	TL-3	33	22	31 – 7
ADIEM	32, 54	Redirective, Gating	CC-16 CC-38	TL-3	49	32	30 – 0

Table 6. NCHRP Report No. 350 Crash Cushions (Cont.)

Device Name	Ref.	Performance	FHWA Eligibility Letter	Test Level	Height in.	Width in.	Length ft – in.
CAT 350	55	Energy Absorbing End Terminal	CC-08 CC-14 CC-33 CC-33A	TL-3	27.75	29	31 – 3
HEART	56	Redirective, Non-Gating	CC-89 CC-89A	TL-3	32	36	26 – 0
ABSORB 350	57	Non-Redirective, Gating	None	TL-1	32	24	Not Listed
			CC-66A	TL-2	32	24	14 – 5
			CC-66 CC-66C	TL-3	32	24	32 – 0
TAU-II	58	Redirective, Non-Gating	CC-75	TL-2	31.5	27	15 – 5
			CC-75 CC-75A CC-75B	TL-3	31.5	27	23 – 10
TAU-II-R	59	Redirective, Non-Gating	CC-75D	TL-2	31.5	27	11 – 5.5
			CC-75D	TL-3	31.5	27	23 – 10
X-TENuator	60	Redirective, Non-Gating	CC-109 CC-109A CC-109B	TL-3	31.1875	22	24 – 9
X-MAS	61	Redirective, Non-Gating	None	TL-3	28	22.5	37 – 6
Compressor	62	Redirective, Non-Gating	CC-95 CC-95A CC-95B CC-95C	TL-3	53	48	21 – 9
SMA 110P/TL 3	63	Redirective	None	TL-3	30.3	33.9	19 – 8.6
BEAT-SSCC	32, 64	Redirective, Gating	CC-69B CC-69D CC-69E	TL-3	28	24	28 – 0
CIAS	32, 65	Redirective, Gating	CC-77	TL-3	48	150	25 – 6
NCIAS	32, 65	Redirective, Gating	CC-58	TL-3	48	36	Not Listed
FastBrake	66	Redirective, Non-Gating	CC-82	TL-3	Not Listed	19	32 – 0
EASI-Cell	32	Non-Redirective, Gating	CC-71	TL-1	39	51.5	8 – 6
QuadTrend	32, 67	Redirective, Gating	CC-49	TL-3	32	15	20 – 0

2.4.2.2.1 QuadGuard

The QuadGuard, a redirective, non-gating crash cushion, is shown in Figure 30. It is manufactured by Trinity Highway and is available in NCHRP Report No. 350 TL-1, TL-2, and TL-3 versions, all of which are 32 in. tall and 24 in. wide. The TL-1 version is 9 ft long. The TL-2 version is 13 ft – 1.5 in. long and received FHWA eligibility letter no. CC-35C. The TL-3 version is 21 ft long and received FHWA eligibility letter nos. CC-35, CC-35B, CC-35D, CC-35H, CC-35J, CC-35L, CC-35M, and CC-45.

Figure 30. QuadGuard [40]

2.4.2.2.2 QuadGuard Elite

The QuadGuard Elite, shown in Figure 31, is a redirective, non-gating crash cushion manufactured by Trinity Highway. FHWA eligibility letter nos. CC-57A and CC-57C were awarded to the TL-2 version of the QuadGuard Elite and letter nos. CC-57, CC-57B, CC-57D, and CC-57E were awarded to the TL-3 version. Both QuadGuard Elite devices are 32 in. tall and 24 in. wide. The TL-2 version is 23 ft – 10 in. long and the TL-3 version is 26 ft – 9 in. long.

Figure 31. QuadGuard Elite [41]

2.4.2.2.3 QuadGuard HS

The QuadGuard High Speed (HS), shown in Figure 32, is a redirective, non-gating crash cushion manufactured by Trinity Highway. The device was tested according to NCHRP Report No. 350 TL-3 criteria and received FHWA eligibility letter no. CC-35E. Dimensions for the QuadGuard HS are 32 in. tall, 24 in. wide, and 30 ft long.

Figure 32. QuadGuard HS [42]

2.4.2.2.4 QuadGuard II

Trinity Highway manufactures the QuadGuard II, a redirective, non-gating crash cushion, shown in Figure 33. The TL-2 and TL-3 versions received FHWA eligibility letter nos. CC-35I and CC-35J. Both versions are 32 in. tall and 24 in. wide, where the TL-2 version is 9 ft – 11 in. long and the TL-3 version is 19 ft long.

Figure 33. QuadGuard II [43]

2.4.2.2.5 REACT 350

The reusable energy absorbing crash terminal (REACT) 350 is manufactured by Trinity Highway and shown in Figure 34. It is classified as a redirective, non-gating crash cushion. This device is available for TL-1, TL-2, and TL-3 applications, and is 51.5 in. tall and 36 in. wide. The TL-1 version is 28 ft – 9 in. long. The TL-2 version is 29 ft – 9 in. long and received FHWA eligibility letter nos. CC-26B and CC-26C. The TL-3 version received FHWA eligibility letter nos. CC-26, CC-26A, CC-26C, CC-26I, and CC-26K and is 30 ft – 9 in. long.

Figure 34. REACT 350 [44]

2.4.2.2.6 REACT 350 II

The REACT 350 II, shown in Figure 35, is a redirective, non-gating crash cushion manufactured by Trinity Highway. FHWA eligibility letter no. CC-26J was awarded to the REACT 350 II device, which was evaluated to NCHRP Report No. 350 TL-3. The device is 51.5 in. tall, 46.75 in. wide, and 19 ft – 5 in. long.

Figure 35. REACT 350 II [45]

2.4.2.2.7 REACT 350 Wide

Trinity Highway manufactures the REACT 350 Wide, a redirective, non-gating crash cushion, shown in Figure 36. The TL-1 version received FHWA eligibility letter no. CC-73C and is 10 ft – 7 in. long. The TL-2 version is 17 ft – 6 in. long and received FHWA eligibility letter no. CC-73B. The TL-3 version is 30 ft – 7 in. and received FHWA eligibility letter nos. CC-73 and CC-73A. All versions of the REACT 350 Wide crash cushion are 46 in. tall and 60 in. wide.

Figure 36. REACT 350 Wide [46]

2.4.2.2.8 TRACC

Trinity Highway manufactures the Trinity Attenuating Crash Cushion (TRACC), shown in Figure 37. The device is classified as a redirective, non-gating crash cushion which received FHWA eligibility letter nos. CC-54, CC-54A, CC-54C, CC-54E, CC-54G, and CC-54I for NCHRP Report No. 350 TL-3 evaluation criteria. Dimensions for the TRACC device are 32 in. tall, 24 in. wide, and 21 ft – 3 in. long.

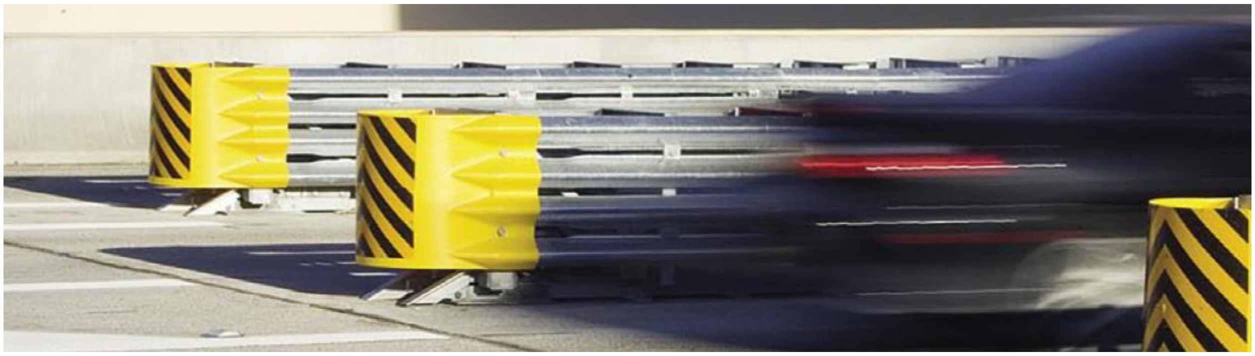


Figure 37. TRACC [47]

2.4.2.2.9 FasTRACC

The fast version of the TRACC device (FasTRACC) is a redirective, non-gating device manufactured by Trinity Highway and shown in Figure 38. It was evaluated to NCHRP Report No. 350 TL-3 evaluation criteria and received FHWA eligibility letter nos. CC-54B and CC-54H. The device dimensions are 32 in. tall, 34 in. wide, and 26 ft long.

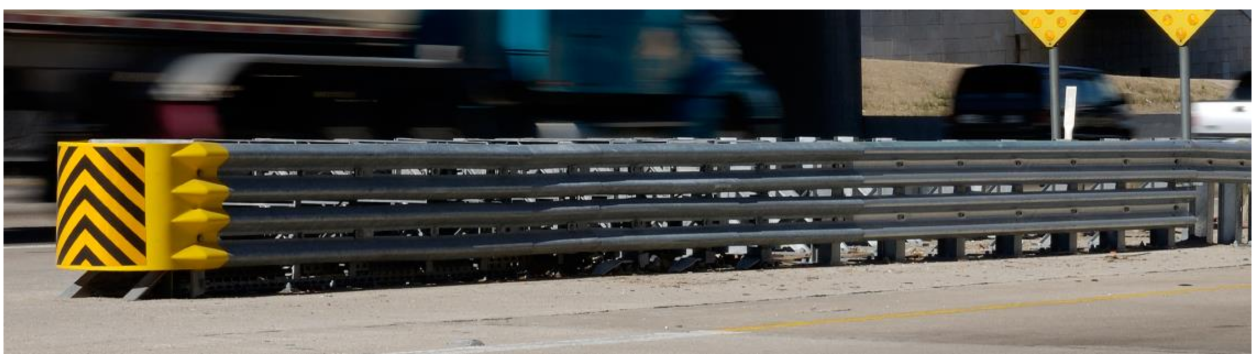


Figure 38. FasTRACC [48]

2.4.2.2.10 ShorTRACC

The short version of the TRACC device (ShorTRACC), shown in Figure 39, is manufactured by Trinity Highway and is classified as a redirective, non-gating device. It received FHWA eligibility letter no. CC-54F after being evaluated to NCHRP Report No. 350 TL-2 criteria. The ShorTRACC crash cushion is 32 in. tall, 24 in. wide, and 14 ft – 3 in. long.

Figure 39. ShorTRACC [49]

2.4.2.2.11 WideTRACC

A wide version of the TRACC device (WideTRACC), manufactured by Trinity Highway, is shown in Figure 40. It is classified as a redirective, non-gating device and is available in TL-2 and TL-3 versions. The TL-2 version has dimensions 32 in. tall and 58 in. wide, and the length was not available. The TL-3 version, which received FHWA eligibility letter no. CC-54D, has dimensions 32 in. tall, 58 in. wide, and 21 ft tall.

Figure 40. WideTRACC [50]

2.4.2.2.12 QUEST

The QUEST crash cushion, shown in Figure 41, is classified as a redirective, non-gating device and is manufactured by Trinity Highway. Two versions, TL-2 and TL-3, have received FHWA eligibility letter no. CC-87B and nos. CC-87, CC-87C, and CC-87D, respectively. Both versions of the QUEST crash cushion are 31 in. tall and 24 in. wide. The TL-2 version is 21 ft long and the TL-3 version is 27 ft long.

Figure 41. QUEST [51]

2.4.2.2.13 N-E-A-T

A non-redirective, gating crash cushion manufactured by Trinity Highway, named N-E-A-T, is shown in Figure 42. It is approved for TL-2 applications according to FHWA eligibility letter no. CC-25. Device dimensions are 32 in. tall, 22.5 in. wide, and 9 ft – 8 in. long.

Figure 42. N-E-A-T [52]

2.4.2.2.14 ACZ-350

The ACZ-350 crash cushion, a non-redirective, gating device, is manufactured by Trinity Highway and is shown in Figure 43. The TL-2 version of the ACZ-350 crash cushion received FHWA eligibility letter no. CC-110 and no letter was written for the TL-3 version. Device dimensions are 33 in. tall, 22 in. wide, 18 ft – 4 in. tall for the TL-2 version, and 31 ft – 7 in. tall for the TL-3 version.

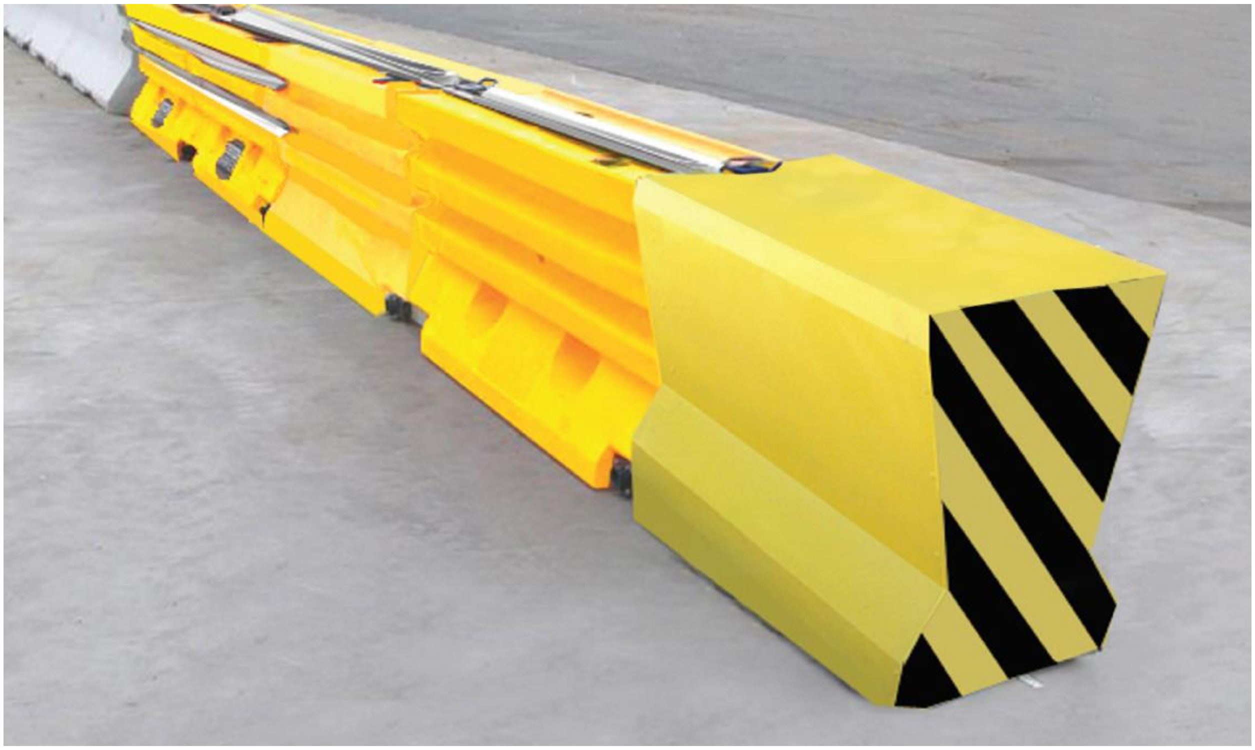


Figure 43. ACZ-350 [53]

2.4.2.2.15 ADIEM

The Advanced Dynamic Impact Extension Module (ADIEM) is a redirective, gating crash cushion manufactured by Trinity Highway and shown in Figure 44. The device received FHWA eligibility letter nos. CC-16 and CC-38 and was evaluated according to NCHRP Report No. 350 TL-3 criteria. The ADIEM is 49 in. tall, 32 in. wide, and 30 ft long.

Figure 44. ADIEM [54]

2.4.2.2.16 CAT 350

The Crash Cushion Attenuating Terminal (CAT) is an energy absorbing end treatment manufactured by Trinity Highway and shown in Figure 45. It was evaluated to NCHRP Report No. 350 TL-3 evaluation criteria and received FHWA eligibility letter nos. CC-08, CC-14, CC-33, and CC-33A. The CAT 350 is 27.75 in. tall, 29 in. wide, and 31 ft – 3 in. long.

Figure 45. CAT 350 [55]

2.4.2.2.17 HEART

The Hybrid Energy Absorbing Reusable Terminal (HEART) crash cushion is a redirective, non-gating device manufactured by Trinity Highway. It is shown in Figure 46 and its dimensions are 32 in. tall, 36 in. wide, and 26 ft long. FHWA eligibility letter nos. CC-89 and CC-89A were awarded to the HEART crash cushion which was evaluated according to NCRHP Report No. 350 TL-3 criteria.

Figure 46. HEART [56]

2.4.2.2.18 ABSORB 350

The ABSORB 350, a non-redirective, gating crash cushion, shown in Figure 47, is manufactured by Barrier Systems. Three versions of this device were evaluated according to NCHRP Report No. 350 test conditions, and each has a height of 32 in. and a width of 24 in. The length of the TL-1 version was not listed. The TL-2 version received FHWA eligibility letter no. CC-66A and has a length of 14 ft – 5 in. The TL-3 version is 32 ft long and received FHWA eligibility letter nos. CC-66 and CC-66C.

Figure 47. ABSORB 350 [57]

2.4.2.2.19 TAU-II

The TAU-II redirective, non-gating crash cushion, shown in Figure 48, is manufactured by Barrier Systems. The TL-2 version of the system received FHWA eligibility letter no. CC-75 and the TL-3 version received FHWA eligibility letter nos. CC-75, CC-75A, and CC-75B. Both have dimensions of 31.5 in. tall and 27 in. wide, where the TL-2 version is 15 ft – 5 in. long and the TL-3 version is 23 ft – 10 in. long.

Figure 48. TAU-II [58]

2.4.2.2.20 TAU-II-R

The TAU-II-R crash cushion, shown in Figure 49, is a redirective, non-gating device manufactured by Barrier Systems. Both the TL-2 and TL-3 versions of the device received FHWA eligibility letter no. CC-75D. The crash cushion is 31.5 in. tall, 27 in. wide, and the TL-2 version is 11 ft – 5.5 in. long while the TL-3 version is 23 ft – 10 in. long.

Figure 49. TAU-II-R [59]

2.4.2.2.21 X-TENuator

The redirective, non-gating crash cushion manufactured by Barrier Systems and named X-TENuator is shown in Figure 50. It was evaluated according to NCHRP Report No. 350 TL-3 criteria and received FHWA eligibility letter nos. CC-109, CC-109A, and CC-109B. The device dimensions are 31.1875 in. tall, 22 in. wide, and 24 ft – 9 in. long.

Figure 50. X-TENuator [60]

2.4.2.2.22 X-MAS

The X-Tension Median Attenuator System (X-MAS) is a redirective, non-gating device shown in Figure 51. It is manufactured by Barrier Systems and rated to TL-3. The system dimensions are 28 in. tall, 22.5 in. wide, and 37 ft – 6 in. long.

Figure 51. X-MAS [61]

2.4.2.2.23 Compressor

TrafFix Devices manufactures the Compressor, shown in Figure 52. It is a redirective, non-gating crash cushion which received FHWA eligibility letter nos. CC-95, CC-95A, CC-95B, and CC-95C for NCHRP Report No. 350 TL-3. The system dimensions are 53 in. tall, 48 in. wide, and 21 ft – 9 in. long.

Figure 52. Compressor [62]

2.4.2.2.24 SMA 110P/TL 3

The SMA 110P/TL 3, shown in Figure 53, is manufactured by SMA. It is classified as a redirective crash cushion and rated to TL-3. The device is 30.3 in. tall, 33.9 in. wide, and 19 ft – 8.6 in. long.

Figure 53. SMA 110P/TL 3 [63]

2.4.2.2.25 BEAT-SSCC

The Bursting Energy-Absorbing Terminal Single-Sided Crash Cushion (BEAT-SSCC), shown in Figure 54, is manufactured by Road Systems, Inc. It received FHWA eligibility letter nos. CC-69B, CC-69D, and CC-69E and is classified as a redirective, gating device. Various lengths are available, with the shortest being 28 ft. The BEAT-SSCC is 28 in. tall and 24 in. wide.

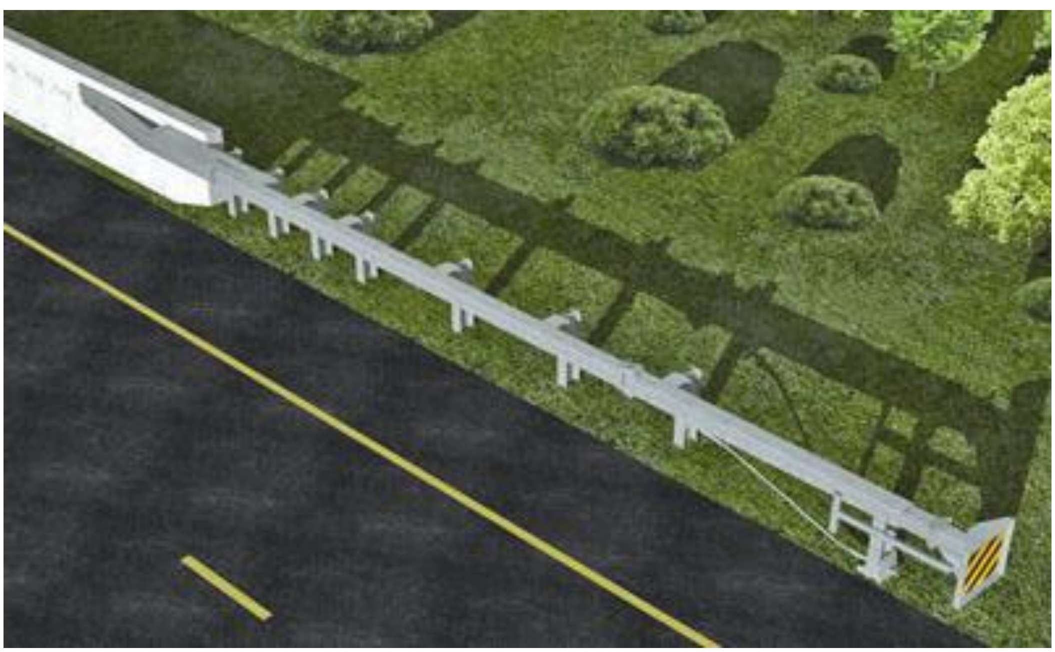


Figure 54. BEAT-SSCC [64]

2.4.2.2.26 CIAS and NCIAS

The Connecticut DOT developed two crash cushions, the Connecticut Impact Attenuating System (CIAS) and the Narrow CIAS (NCIAS), both non-proprietary designs. The CIAS device, shown in Figure 55, is 48 in. tall, 150 in. wide, and 25 ft – 6 in. long. The NCIAS is 48 in. tall, 36 in. wide, and the length was not listed. A drawing of the NCIAS device is shown in Figure 56. Both devices are classified as redirective and gating.

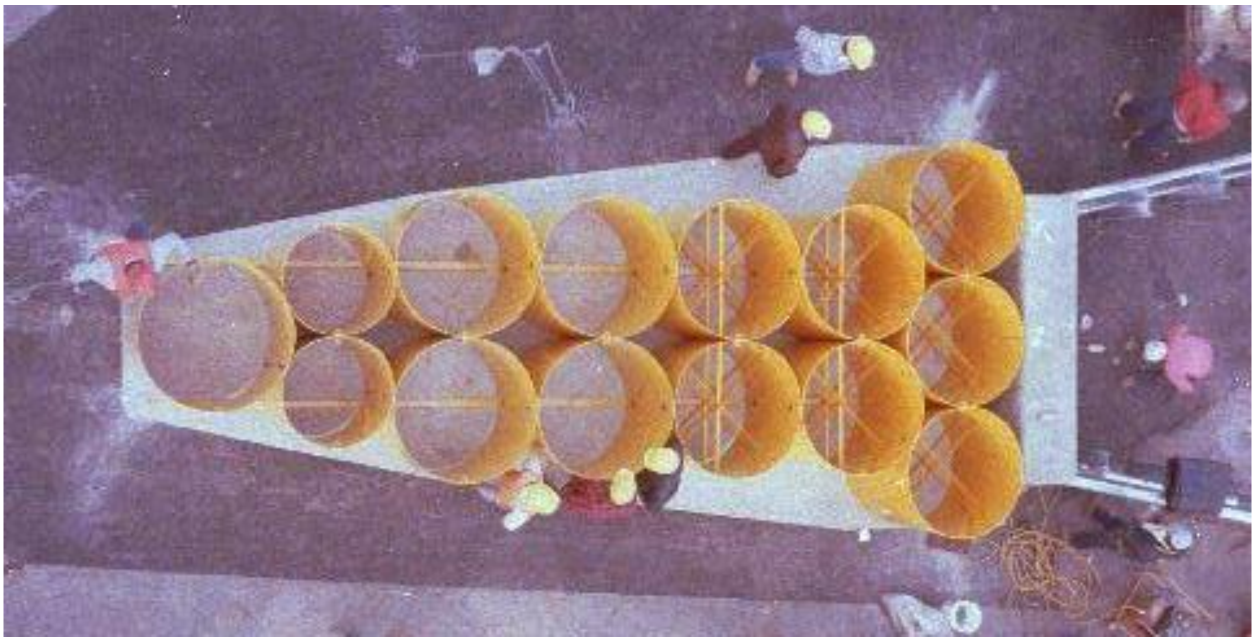


Figure 55. CIAS [65]

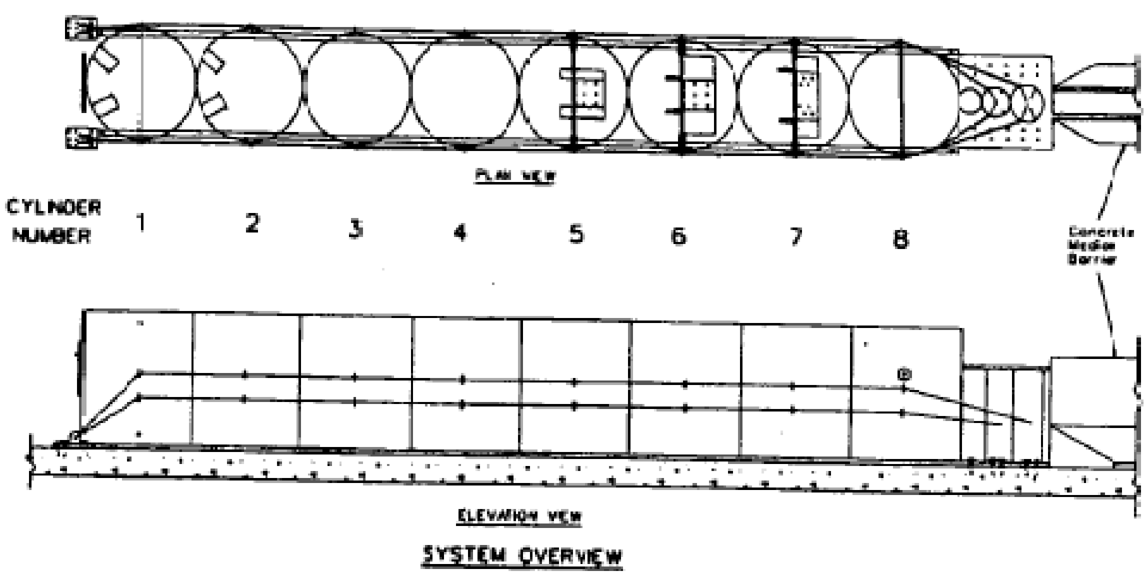


Figure 56. NCIAS [65]

2.4.2.2.27 FastBrake

The FastBrake impact attenuator received FHWA eligibility letter no. CC-82 for NCHRP Report No. 350 TL-3. The device is 19 in. wide and 32 ft long [66]. No additional information regarding the FastBrake impact attenuator was found.

2.4.2.2.28 EASI-Cell

The crash cushion EASI-Cell, shown in Figure 57, is a non-redirective, gating device designed by Energy Absorption Systems, Inc. It received FHWA eligibility letter no. CC-71 for TL-1 test conditions. The EASI-Cell is 39 in. tall, 51.5 in. wide, and 8 ft – 6 in. long.

Figure 57. EASI-Cell [32]

2.4.2.2.29 QuadTrend

The QuadTrend device, shown in Figure 58, is a redirective, gating end terminal. It is designed for TL-3 situations and received FHWA eligibility letter no. CC-49. The QuadTrend is 32 in. tall, 15 in. wide, and 20 ft long.

Figure 58. QuadTrend [67]

3 SLOPED END TREATMENTS IN IOWA

An ISPE was conducted regarding the safety performance of slope end treatments in Iowa by investigating vehicle crashes into sloped end treatments. First, the locations of sloped end treatments were determined using virtual roadway tours and aerial views. Those locations were compared to Iowa DOT databases, and a selection filter was applied. Lastly, each feature was located, identified, labeled, and logged for further reference and analysis.

3.1 Sloped End Treatment Locations

An inventory of sloped end treatments in the state of Iowa was not available for this research, there were no fields on crash reports which were deemed conducive to describe sloped end treatments, and creating an all-inclusive inventory by virtual inspection was not within the scope of this project. Therefore, based on recommendations from Iowa DOT, a visual site survey using Google Street View [1] and Iowa's feature inventory of bridge ends were used to generate an index of sloped end treatments. Researchers investigated common sloped end treatment locations to provide a narrow focus for the research.

3.1.1 Visual Survey Using Google Earth and Street View

Initially, researchers utilized Google Earth and Street View [1] to virtually tour every road in Johnson, Polk, and Linn counties in Iowa to identify locations of sloped end treatments. Researchers annotated the locations, types of road characteristics, and features connected to the sloped end treatments (i.e., concrete barriers). For these three counties, it was found that 93 percent of sloped end treatments were located on bridges or overpasses, 5 percent were located on entrance or exit ramps, and 2 percent were located on other roadways.

Note that sloped end treatments were overwhelmingly located in conjunction with bridge features. Further, Iowa DOT's bridge inventory tracked features, such as sloped end treatments, when used in conjunction with bridge ends. Therefore, researchers focused this ISPE study on sloped end treatments located in conjunction with bridges.

3.1.2 Sloped End Treatment Geometry

Many variations of sloped end treatments were found in Iowa during the Google Earth and Street View visual survey [1]. Taper geometries were either straight or round, and overall sloped end treatment length varied. Sloped end treatments with rounded tapers are shown in Figure 59 (a) and sloped end treatments with straight tapers are shown in Figure 59 (b).

(a)

(b)

Figure 59. Sloped End Treatment Geometry – (a) Round Tapers and (b) Straight Tapers [1]

3.1.3 Iowa DOT Standard Road Plans

Current standard road plans for the state of Iowa are available on the Iowa DOT website [68]. The drawing for concrete sloped end treatments, titled Concrete Barrier Tapered End Section (BA-108), is show in Figure 60. General details for bridge approach sections (BR-101) are shown in Figure 61. Detail "C" features the low-speed bridge rail end section, a sloped end treatment which can be installed on various bridge approach sections in Iowa. The bridge approach section standard plans, for both Portland cement concrete (PCC) and hot mix asphalt (HMA), which call out the general details (BR-101) are listed in Table 7 and shown in Appendix A.

On average, Iowa DOT noted that sloped end treatments cost approximately $2,500 to install, which includes materials and labor. Variations in design and construction were not considered, as that information was not available. Therefore, the average value was assumed for all sloped end treatment installations.

Table 7. Iowa DOT Bridge Approach Section Standard Road Plans [68]

Standard Road Plan	Description
BR-102	Bridge Approach Section (Two-Lane, Abutting PCC Pavement)
BR-103	Bridge Approach Section (Two-Lane for Bridge Reconstruction, PCC Pavement)
BR-104	Bridge Approach Section (at Existing Bridges, PCC Pavement)
BR-105	Bridge Approach Section (Two-Lane, HMA Pavement)
BR-106	Bridge Approach Section (Two-Lane for Bridge Reconstruction, HMA Pavement)
BR-107	Bridge Approach Section (at Existing Bridges, HMA Pavement)
BR-112	Bridge Approach Details (in Conjunction with Bridge Deck Overlay)

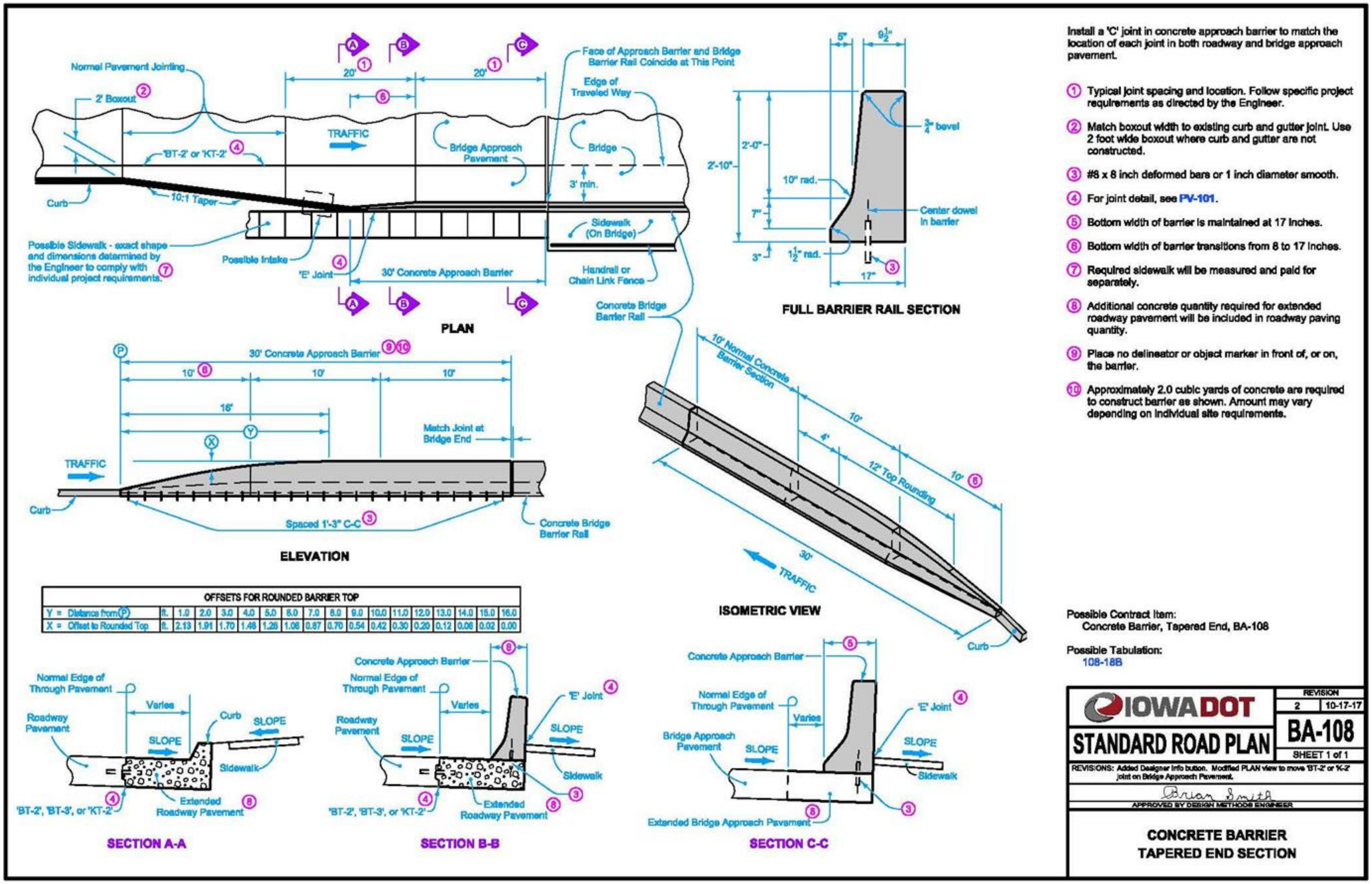


Figure 60. Iowa DOT Standard Road Plan BA-108 – Concrete Barrier Tapered End Section [68]

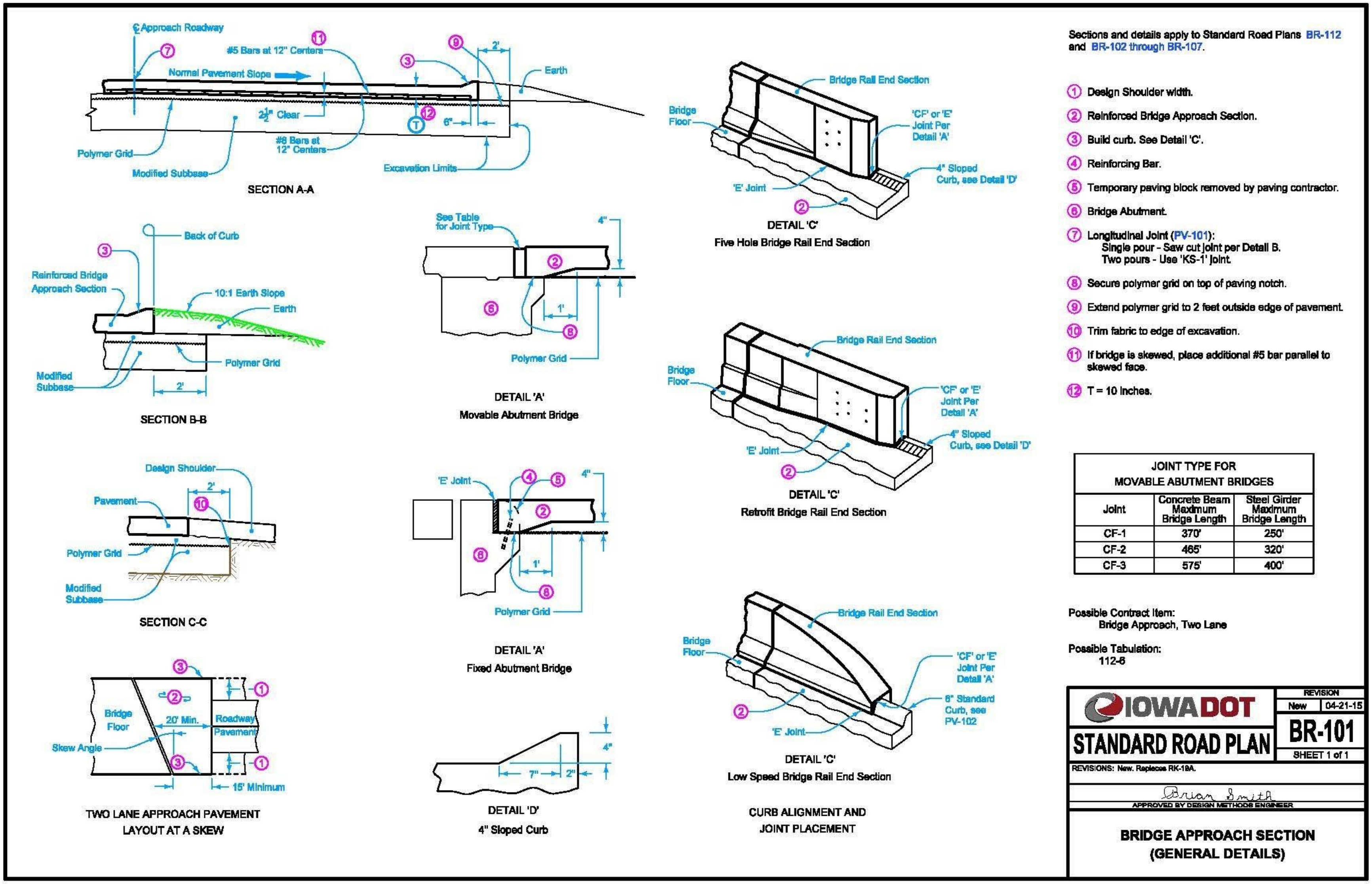


Figure 61. Iowa DOT Standard Road Plan BR-101 – Bridge Approach Section (General Details) [68]

3.1.4 Iowa DOT Bridge Inventory

Iowa DOT provided researchers access to four state-owned bridge inventory datasets, which included bridge number, latitude, longitude, and features and structures in conjunction with each bridge. Two datasets contained state-owned bridges with sloped end treatments which had been identified, one by a maintenance asset management activity and one by a bridge inspection activity. Two additional datasets were provided, one containing all state bridges which do not feature guardrail on one approach, and the other containing all state bridges which do not feature guardrail on either approach.

Each dataset was reviewed using Google Earth and Street View [1] to determine which bridges featured concrete sloped end treatments. A total of 183 bridges were identified that featured one or more sloped end treatments. In addition, some interstate entrance and exit ramps near the identified bridges featured sloped end treatments and were included in the inventory. A total of 658 individual sloped end treatments were located. The geo-terrestrial mapping software ArcGIS was used to tabulate the locations and unique indices of each identified sloped end treatment, and each location is marked with a black dot, as shown in Figure 62.

The global positioning system (GPS) location of each sloped end treatment can be found in Table B-1, in Appendix B. Overhead images of each bridge, taken from Google Earth [1], with the identified sloped end treatments, can also be found in Appendix B.

For each sloped end treatment, additional information was noted, including the number of lanes and traffic flow (one-way or two-way). The type of road associated with each sloped end treatment was noted, such as bridge, median, entrance ramp, or exit ramp. It was also noted if the sloped end treatment was located on the approach or departure end of the closest lane. This information was utilized to calculate sloped end treatment exposure to passing vehicles.

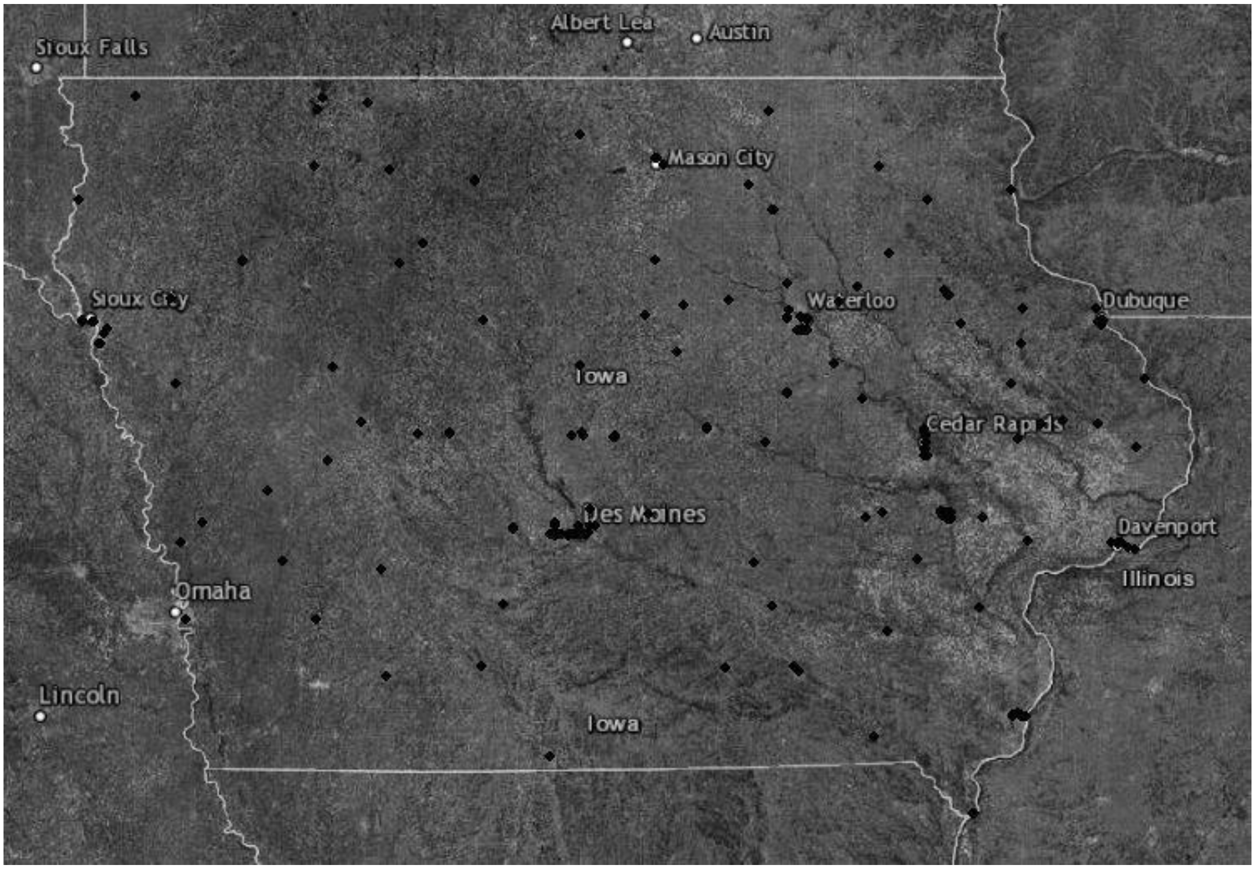
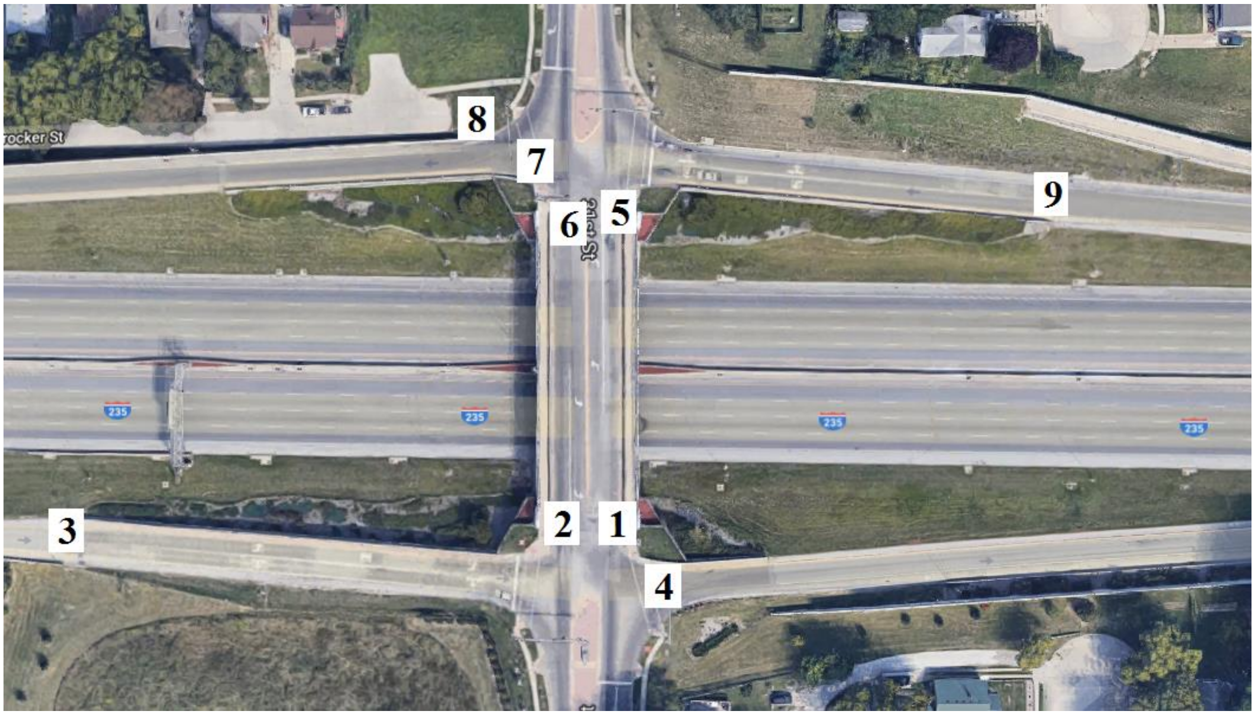


Figure 62. State-Owned Sloped End Treatments in Iowa

3.2 Type of Roadway

Sloped end treatments were located on one of three types of roadways: ramps, bridges with ramps, or bridges without ramps, as shown in Figure 63(a), (b), and Figure 64(c), respectively. The type of roadway was collected for all sloped end treatments identified for this research, as shown in Figure 65. Seventy-one percent of sloped end treatments were located on bridges which feature no ramps. Bridges with ramps accounted for 25 percent of sloped end treatment installations. Twenty-five sloped end treatment installations were located on ramps (4 percent).

(a)



(b)

Figure 63. Roadways – (a) Ramps, (b) Bridge with Ramps [1]

(c)

Figure 64. Roadways – (c) Bridge without Ramps [1]

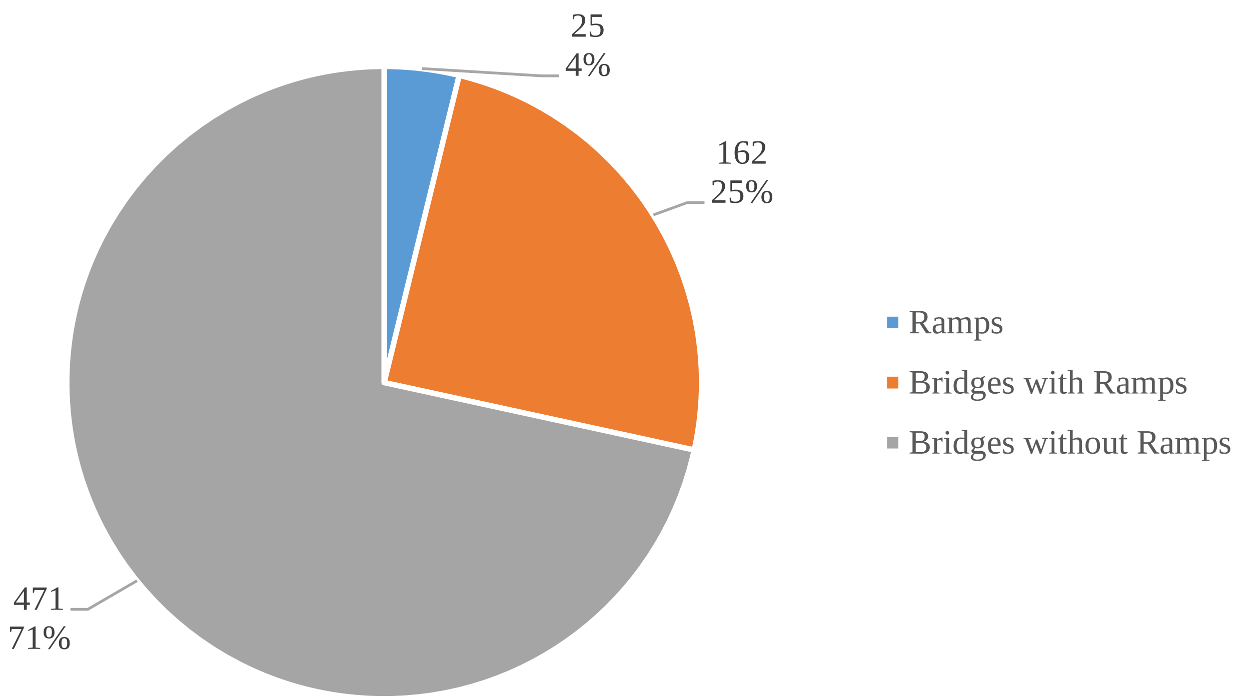


Figure 65. Sloped End Treatments – Type of Roadway

3.3 Average Annual Daily Traffic

The average annual daily traffic (AADT) for roadways which feature sloped end treatment installations are shown in Figure 66, with AADTs sorted into “bins” or ranges of AADTs. As AADT increased, the number of sloped end treatment installations decreased.

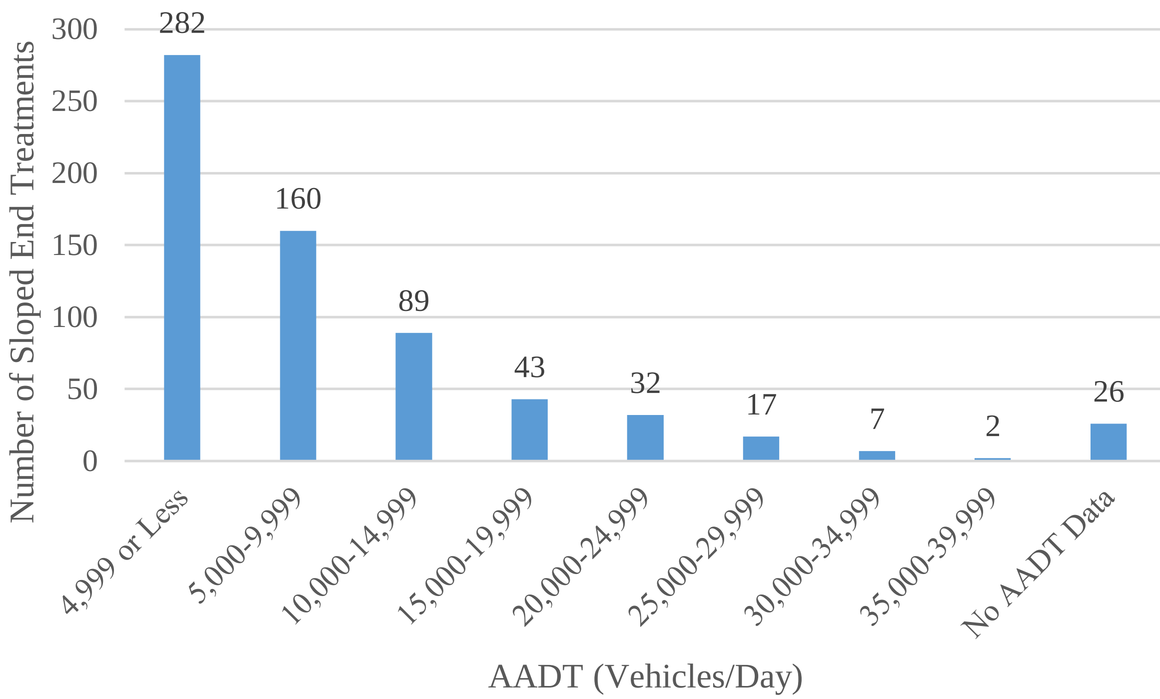


Figure 66. Sloped End Treatments – AADT

3.4 Miles of Sloped End Treatments in Iowa

In 2017, the state of Iowa featured 235,048 lane miles of public roads [69]. Lane miles are calculated by multiplying the centerline mileage of a road by the number of lanes of that road. Sloped end treatments, according to Iowa DOT Standard Road Plan BA-108, are 10 ft long. Therefore, the 658 identified sloped end treatments account for approximately 6,580 ft (1.25 miles) of lane miles, or 0.00053 percent.

3.5 Sloped End Treatment Exposure

Researchers investigated the crash risk associated with sloped end treatments. Crash risk was calculated using exposure, or number of opportunities for vehicles to engage a sloped end treatment. Many factors affected the calculation of sloped end treatment exposure:

- Many bridges were associated with more than one sloped end treatment; it was believed that in a potential crash, only one of these features would be struck. Therefore, the cumulative sum of the exposure of all four sloped end treatments per day was equal to the total average daily traffic (ADT) of that road segment.

- Only vehicles traveling toward an upstream sloped end treatment would be considered. No reverse-direction impacts were considered. Thus, only traffic exposed to the upstream end were included in exposure calculations.

- Two-directional traffic flow was assumed to be equally distributed, with half of the traffic passing by the feature in one travel direction, and half in the opposite direction. Thus, for two-directional traffic flow, the exposure for each end of the bridge would be one half the total ADT.

    - For one- and two-directional traffic, it was assumed that left- and right-side departures would be equally weighted (50 percent).

Note that based on discussions with Iowa DOT, it was anticipated that the distribution of right- and left-side departures would be 60% and 40%, respectively, but for purposes of simplicity, both sides were weighted equally; exposure results did not vary significantly using either distribution. The exposure for each sloped end treatment was calculated and used to find the average sloped end treatment exposure as well as the total, cumulative exposure. The equation utilized to calculate exposure is shown in Equation 1. The subscript "R" indicates a term determined by the roadway and the subscript "i" indicates a term determined by the individual sloped end treatment.

$$Exposure_i = (AADT)_R * \ (Traffic\ Factor)_R \ * (Side\ Factor)_i * Time \qquad \text{Equation 1}$$

Where:

$Exposure_i =$ number of opportunities to crash into the i^{th} sloped end treatment

$AADT_R =$ annualized average daily traffic at sloped end treatment (vehicles/day)

$(Traffic\ Factor)_R =$ for road adjacent to i^{th} sloped end treatment:

2-way traffic: 0.5

1-way traffic: 1.0

$(Side\ Factor)_i =$ run-off-road risk per sloped end treatment:

treatments on left or right side: 0.5

treatments located behind medians on divided roads: 0

$Time =$ years of traffic data (days) = 3,653

An ArcGIS map, named Iowa Traffic Counts, featuring average annual daily traffic (AADT) for the state of Iowa, was utilized to collect AADT values for each roadway that features identified sloped end treatments [70]. The map is available on the ArcGIS online hub and was created using information from the Iowa DOT open data website.

A total of 658 sloped end treatments were identified throughout the state of Iowa, located on and near 183 bridges. Various configurations of sloped end treatments were found, and exposure calculations for each are discussed in Sections 3.5.1 through 3.5.4. Sloped end treatments, sorted by configuration, are listed in Table B-1, and images of bridges with sloped end treatments labeled are shown in Appendix B, Figures B-1 through B-183.

3.5.1 Two-Way Traffic

3.5.1.1 Four Treatments

Bridge no. 1710.2S122 was located on a two-way, undivided road with sloped end treatments located on the upstream and downstream ends of both sides of the concrete bridge rails, and is shown in Figure 67. A total of 98 bridges featured sloped end treatments in this configuration, for a total of 392 individual sloped end treatments.

Exposure calculations for sloped end treatments located on bridge no. 1710.2S122 are shown in Table 8. Exposure calculations for the total 392 sloped end treatments featuring the four treatments, two-way traffic configuration, are shown in Table C-1, in Appendix C.

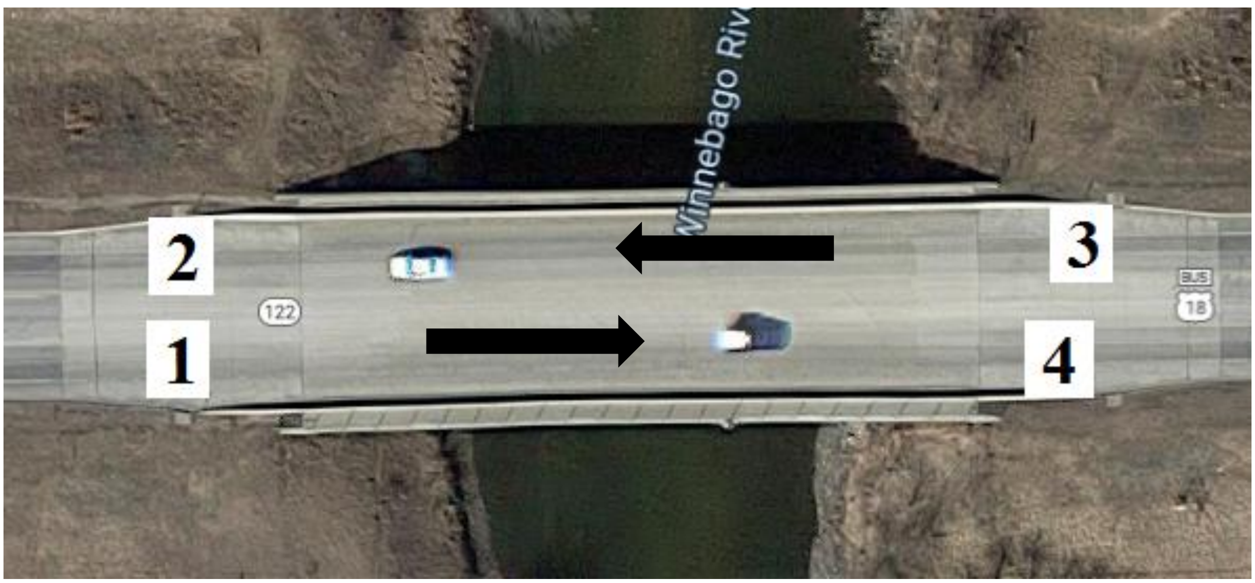


Figure 67. Bridge No. 1710.2S122 [1]

Table 8. Exposure Calculations for Bridge No. 1710.2S122

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(\text{Traffic Factor})_R$	$(\text{Side Factor})_i$	Time (Days)	Exposure (Vehicles)
1	6,800	0.5	0.5	3,653	6,210,100
2	6,800	0.5	0.5	3,653	6,210,100
3	6,800	0.5	0.5	3,653	6,210,100
4	6,800	0.5	0.5	3,653	6,210,100
Total Exposure for Bridge					**24,840,400**

3.5.1.2 Three Treatments

Eight bridges featured a total of three sloped end treatments, two located on one bridge end and one located on the other bridge end, in conjunction with a two-way, undivided road. An example of this configuration is shown in Figure 68, bridge no. 4287.7S175. Exposure calculations for the 24 sloped end treatments with this configuration are listed in Table C-15, and calculations for bridge no. 4287.7S175 are shown in Table 9.

Figure 68. Bridge No. 4287.7S175 [1]

Table 9. Exposure Calculations for Bridge No. 4287.7S175

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(Traffic\ Factor)_R$	$(Side\ Factor)_i$	Time (Days)	Exposure (Vehicles)
1	3,740	0.5	0.5	3,653	3,415,555
2	3,740	0.5	0.5	3,653	3,415,555
3	3,740	0.5	0.5	3,653	3,415,555
Total Exposure for Bridge					**10,246,665**

3.5.1.3 One Bridge End

Ten bridges, including bridge no. 2521.1S006, shown in Figure 69, featured a total of two sloped end treatments located on one end of the bridge in conjunction with a two-way, undivided road. Exposure calculations for bridge no. 2521.1S006 are shown in Table 10, and calculations for the 20 one bridge end, two-way traffic sloped end treatments are shown in Table C-16.

Figure 69. Bridge No. 2515.1S006 [1]

Table 10. Exposure Calculations for Bridge No. 2515.1S006

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	8,300	0.5	0.5	3,653	7,579,975
2	8,300	0.5	0.5	3,653	7,579,975
Total Exposure for Bridge					**15,159,950**

3.5.1.4 Treatments Adjacent to One Lane

Bridge no. 8336.8S037 is shown in Figure 70, which featured two sloped end treatments located along one traffic lane (on each bridge end) with two-way traffic. Exposure calculations for this bridge are shown in Table 11. A total of 17 bridges feature this sloped end treatment configuration, with a total of 34 sloped end treatments. Exposure calculations for each are shown in Table C-17 in Appendix C.

Figure 70. Bridge No. 8336.8S037 [1]

Table 11. Exposure Calculations for Bridge No. 8336.8S037

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	1,150	0.5	0.5	3,653	1,050,238
2	1,150	0.5	0.5	3,653	1,050,238
Total Exposure for Bridge					**2,100,476**

3.5.1.5 One Treatment

A total of five bridges with two-way traffic featured a single-sloped end treatment. Bridge no. 5753.4O030 is shown in Figure 71, and the exposure calculation for the sloped end is shown in Table 12. Calculations for exposure of the five single sloped end treatments are shown in Table C-19.

Figure 71. Bridge No. 5753.4O030 [1]

Table 12. Exposure Calculation for Bridge No. 5753.4O030

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	11,900	0.5	0.5	3,653	10,867,675
Total Exposure for Bridge					**10,867,675**

3.5.1.6 Special Cases

Some bridges featured unique sloped end treatment configurations, which were different from those already discussed. Special cases, which were located on two-way traffic roads, are discussed in Sections 3.5.1.6.1 through 3.5.1.6.7. Exposure calculations for the two-way traffic, special case sloped end treatment configurations are listed in Table C-20.

3.5.1.6.1 One Bridge End and Median

Bridge no. 0743.1S057 consisted of a two-way road with a median barrier located between travel directions. Three sloped end treatments were used on one end of the bridge, two on the sides of the road and one in the median, as shown in Figure 72. Exposure calculations are shown in Table 13. For the *(Side Factor)$_i$* values for each sloped end treatment, it was assumed that there was an equal chance of impacting sloped end treatment nos. 1 and 2, which would be greater than the chance of impacting sloped end treatment no. 3. Therefore, *(Side Factor)i* for sloped end treatment nos. 1 and 2 was 50 percent and *(Side Factor)i* for sloped end treatment no. 3 was 0 percent.

Figure 72. Bridge No. 0743.1S057 [1]

Table 13. Exposure Calculations for Bridge No. 0743.1S057

Sloped End No.	AADT$_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	15,200	0.5	0.5	3,653	13,881,400
2	15,200	0.5	0.5	3,653	13,881,400
3	15,200	0.5	0.0	3,653	0
Total Exposure for Bridge					**27,762,800**

3.5.1.6.2 Four Corners and Sidewalk

Bridge no. 1900.5S346 featured a total of five sloped end treatments, as shown in Figure 73. Four of the sloped end treatments were located at the upstream and downstream ends of the bridge rails, and an additional sloped end treatment was located along a sidewalk. Exposure calculations are shown in Table 14.

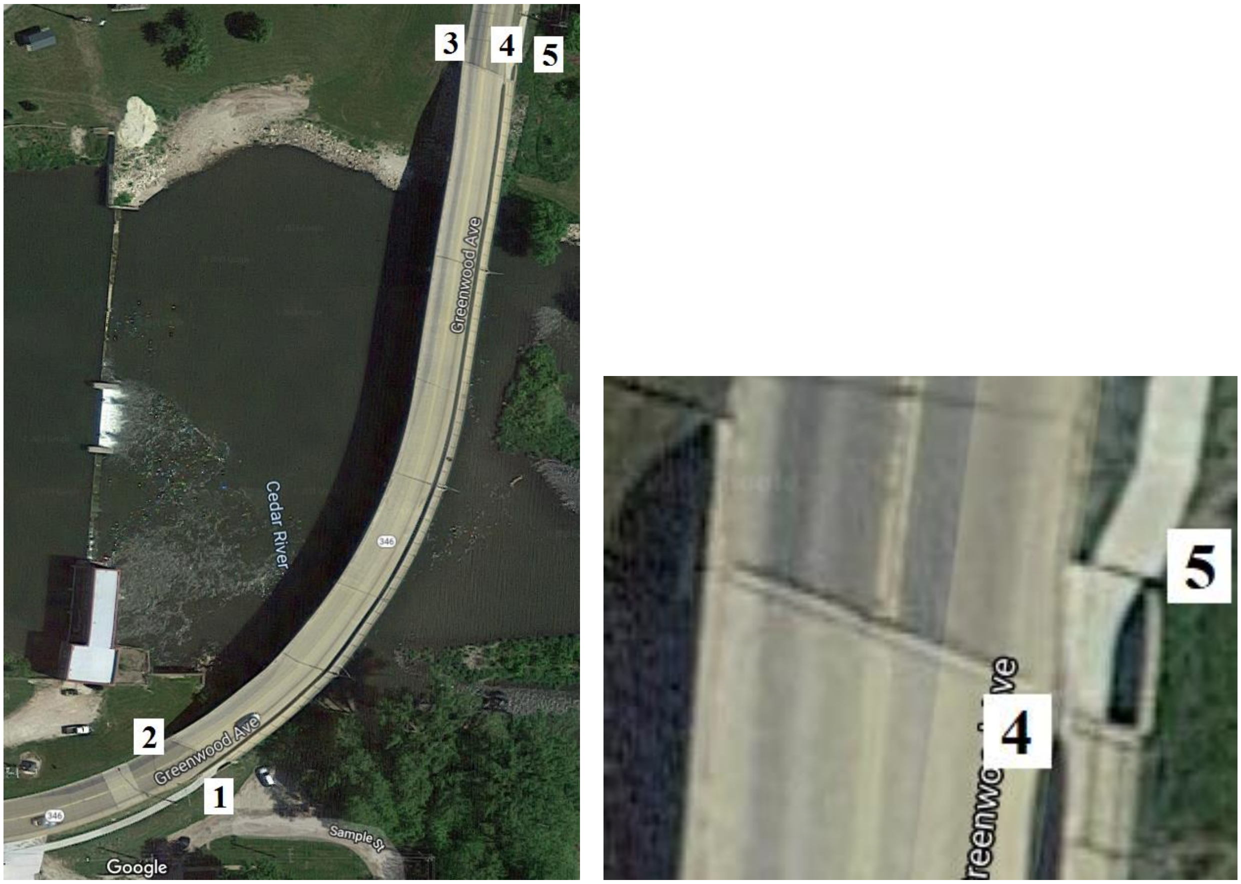


Figure 73. Bridge No. 1900.5S346 [1]

Table 14. Exposure Calculations for Bridge No. 1900.5S346

Sloped End No.	**$AADT_R$ (Vehicles/Day)**	**$(Traffic Factor)_R$**	**$(Side Factor)_i$**	**Time (Days)**	**Exposure (Vehicles)**
1	3,750	0.5	0.5	3,653	3,424,688
2	3,750	0.5	0.5	3,653	3,424,688
3	3,750	0.5	0.5	3,653	3,424,688
4	3,750	0.5	0.5	3,653	3,424,688
5	3,750	0.5	0.5	3,653	3,424,688
Total Exposure for Bridge					**17,123,440**

3.5.1.6.3 Six Treatments on Extended Bridge

Bridge no. 3021.8S071 featured a total of six sloped end treatments in conjunction with a two-lane, two-way, undivided road. Four were located on the upstream and downstream ends of the bridge rails, and two were located along one lane near the middle of the bridge, near the rest area, as shown in Figure 74. Exposure calculations for bridge no. 3021.8S071 are shown in Table 15.

Figure 74. Bridge No. 3021.8S071 [1]

Table 15. Exposure Calculations for Bridge No. 3021.8S071

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(\text{Traffic Factor})_R$	$(\text{Side Factor})_i$	Time (Days)	Exposure (Vehicles)
1	15,500	0.5	0.5	3,653	14,155,375
2	15,500	0.5	0.5	3,653	14,155,375
3	15,500	0.5	0.5	3,653	14,155,375
4	15,500	0.5	0.5	3,653	14,155,375
5	15,500	0.5	0.5	3,653	14,155,375
6	15,500	0.5	0.5	3,653	14,155,375
Total Exposure for Bridge					**84,932,250**

3.5.1.6.4 Four Treatments with Ramps

Five bridges featured the four sloped end treatments configuration with additional sloped end treatment(s) located on nearby entrance and/or exit ramps. Bridge nos. 3145.1O052, 7704.4O235, 7705.4O235, 7706.2O235, and 7718.3S028 are shown in Figures 75, 76, 77, 78, and 79, respectively, and exposure calculations are shown in Tables 16, 17, 18, 19, and 20, respectively.

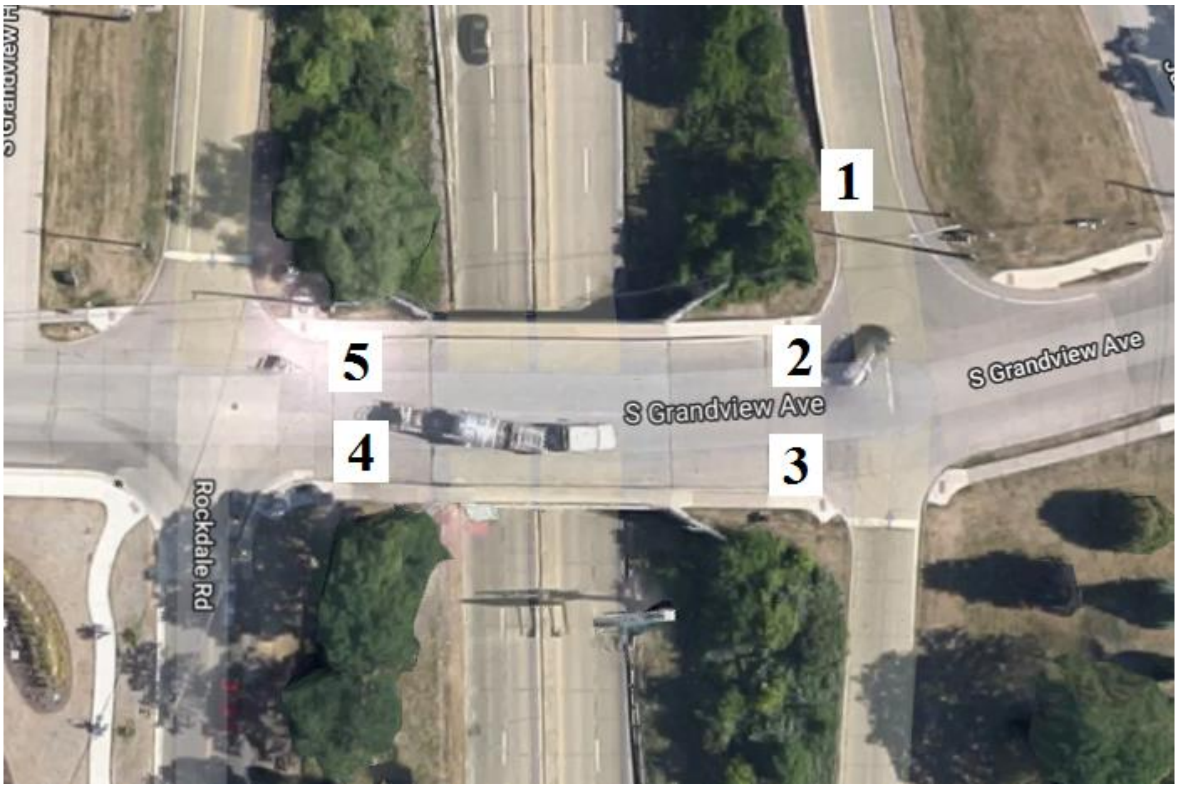


Figure 75. Bridge No. 3145.1O052 [1]

Table 16. Exposure Calculations for Bridge No. 3145.1O052

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	1,450	1.0	0.5	3,653	2,648,425
2	5,800	0.5	0.5	3,653	5,296,850
3	5,800	0.5	0.5	3,653	5,296,850
4	5,800	0.5	0.5	3,653	5,296,850
5	5,800	0.5	0.5	3,653	5,296,850
Total Exposure for Bridge					**23,835,825**

Figure 76. Bridge No. 7704.4O235 [1]

Table 17. Exposure Calculations for Bridge No. 7704.4O235

Sloped End No.	**$AADT_R$ (Vehicles/Day)**	**(Traffic Factor)$_R$**	**(Side Factor)$_i$**	**Time (Days)**	**Exposure (Vehicles)**
1	9,500	0.5	0.5	3,653	8,675,875
2	3,880	1.0	0.5	3,653	7,086,820
3	9,500	0.5	0.5	3,653	8,675,875
4	9,500	0.5	0.5	3,653	8,675,875
5	9,500	0.5	0.5	3,653	8,675,875
Total Exposure for Bridge					**41,790,320**

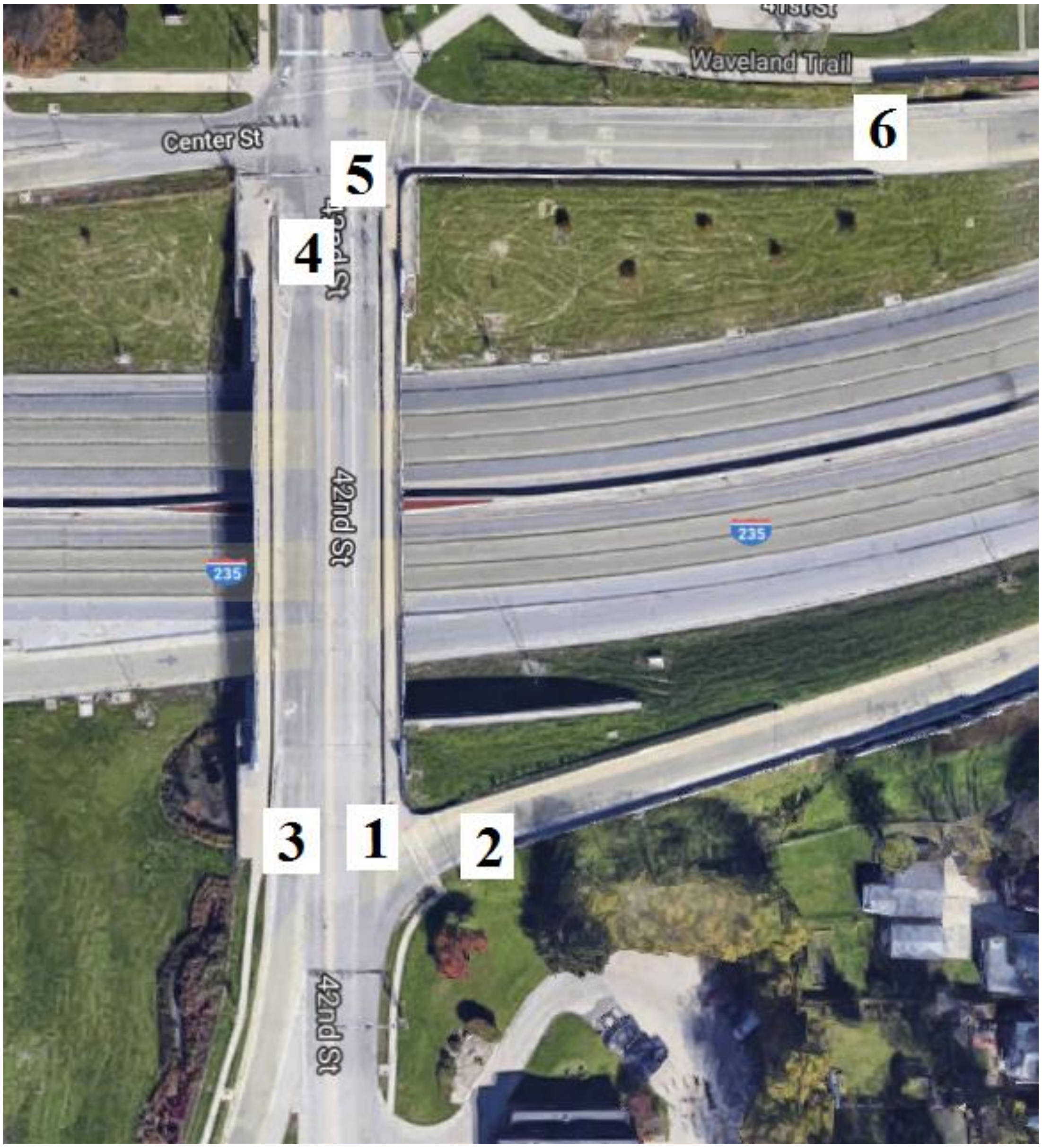


Figure 77. Bridge No. 7705.4O235 [1]

Table 18. Exposure Calculations for Bridge No. 7705.4O235

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	13,300	0.5	0.5	3,653	12,146,225
2	1,090	1.0	0.5	3,653	1,990,885
3	13,300	0.5	0.5	3,653	12,146,225
4	13,300	0.5	0.5	3,653	12,146,225
5	13,300	0.5	0.5	3,653	12,146,225
6	4,170	1.0	0.5	3,653	7,616,505
Total Exposure for Bridge					**58,192,290**

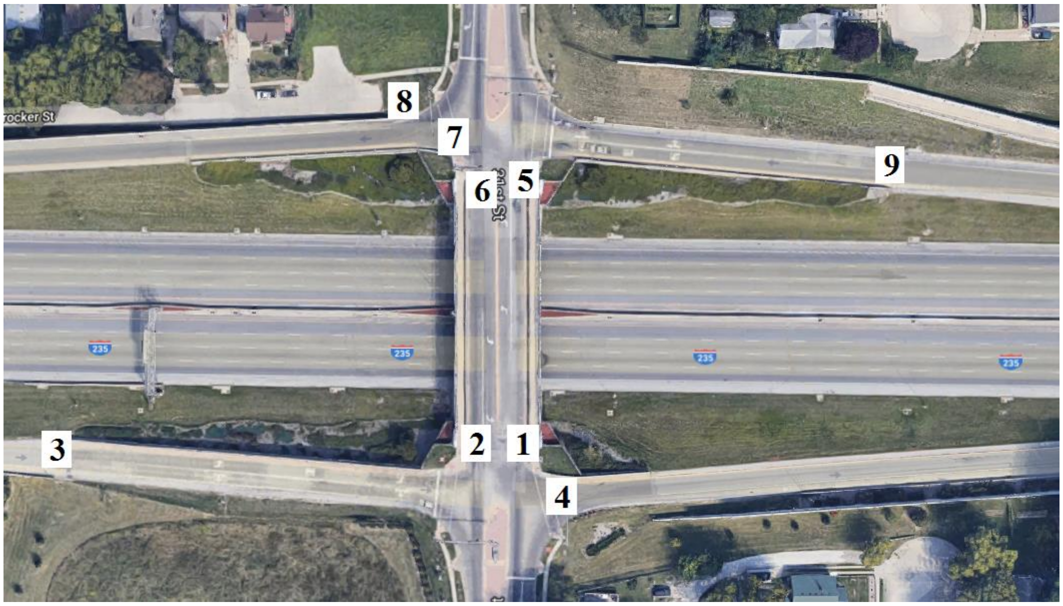


Figure 78. Bridge No. 7706.2O235 [1]

Table 19. Exposure Calculations for Bridge No. 7706.2O235

Sloped End No.	**$AADT_R$ (Vehicles/Day)**	**$(Traffic Factor)_R$**	**$(Side Factor)_i$**	**Time (Days)**	**Exposure (Vehicles)**
1	14,900	0.5	0.5	3,653	13,607,425
2	14,900	0.5	0.5	3,653	13,607,425
3	5,500	1.0	0.5	3,653	10,045,750
4	5,200	1.0	0.5	3,653	9,497,800
5	14,900	0.5	0.5	3,653	13,607,425
6	14,900	0.5	0.5	3,653	13,607,425
7	5,700	1.0	0.5	3,653	10,411,050
8	5,700	1.0	0.5	3,653	10,411,050
9	5,700	1.0	0.5	3,653	10,411,050
Total Exposure for Bridge					**105,206,400**

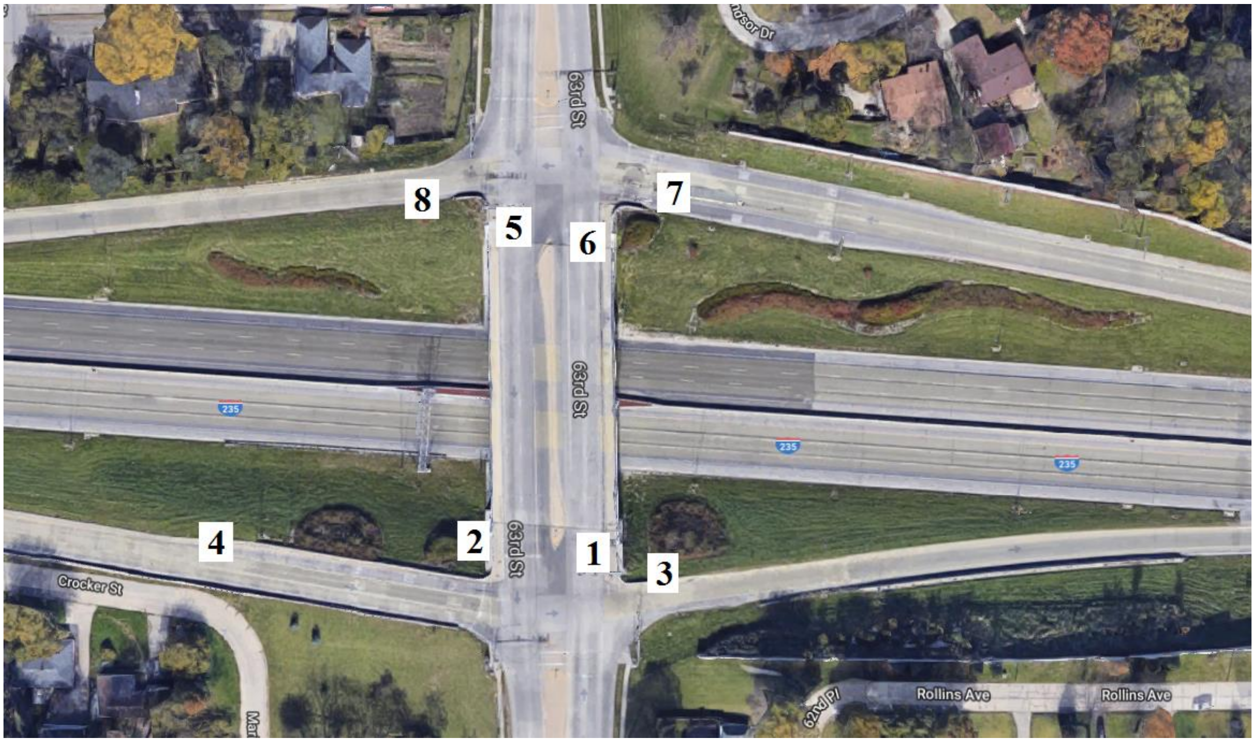


Figure 79. Bridge No. 7718.3S028 [1]

Table 20. Exposure Calculations for Bridge No. 7718.3S028

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	23,100	0.5	0.5	3,653	21,096,075
2	23,100	0.5	0.5	3,653	21,096,075
3	9,500	1.0	0.5	3,653	17,351,750
4	6,800	1.0	0.5	3,653	12,420,200
5	23,100	0.5	0.5	3,653	21,096,075
6	23,100	0.5	0.5	3,653	21,096,075
7	9,000	1.0	0.5	3,653	16,438,500
8	6,800	1.0	0.0	3,653	0
Total Exposure for Bridge					**130,594,750**

3.5.1.6.5 Divided Road with Six Treatments

Bridge no. 5285.9L001, shown in Figure 80, featured a total of six sloped end treatments, located on three corners of the bridge and medians. For sloped end treatment nos. 1, 2, 3, and 4, it was assumed vehicles had an equal chance of exiting the road to the right or middle, and a smaller chance of exiting to the far right (sloped end treatment no. 4). Therefore, the *(Side Factor)i* for sloped end treatment nos. 1, 2, and 3 was 50 percent and the *(Side Factor)i* for sloped end treatment no. 4 was 0 percent. Exposure calculations for the sloped end treatments located on bridge no. 5285.9L001 are shown in Table 21.

Figure 80. Bridge No. 5285.9L001 [1]

Table 21. Exposure Calculations for Bridge No. 5285.9L001

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(Traffic Factor)_R$	$(Side Factor)_i$	Time (Days)	Exposure (Vehicles)
1	26,100	0.5	0.5	3,653	23,835,825
2	26,100	0.5	0.5	3,653	23,835,825
3	26,100	0.5	0.5	3,653	23,835,825
4	26,100	0.5	0.0	3,653	0
5	26,100	0.5	0.5	3,653	23,835,825
6	26,100	0.5	0.5	3,653	23,835,825
Total Exposure for Bridge					**119,179,125**

3.5.1.6.6 Three Treatments with Entrance Ramp

One bridge featured the “three corners” configuration with an additional sloped end treatment located on a nearby entrance ramp, shown in Figure 81. Exposure calculations for bridge no. 5722.7O380 are shown in Table 22.

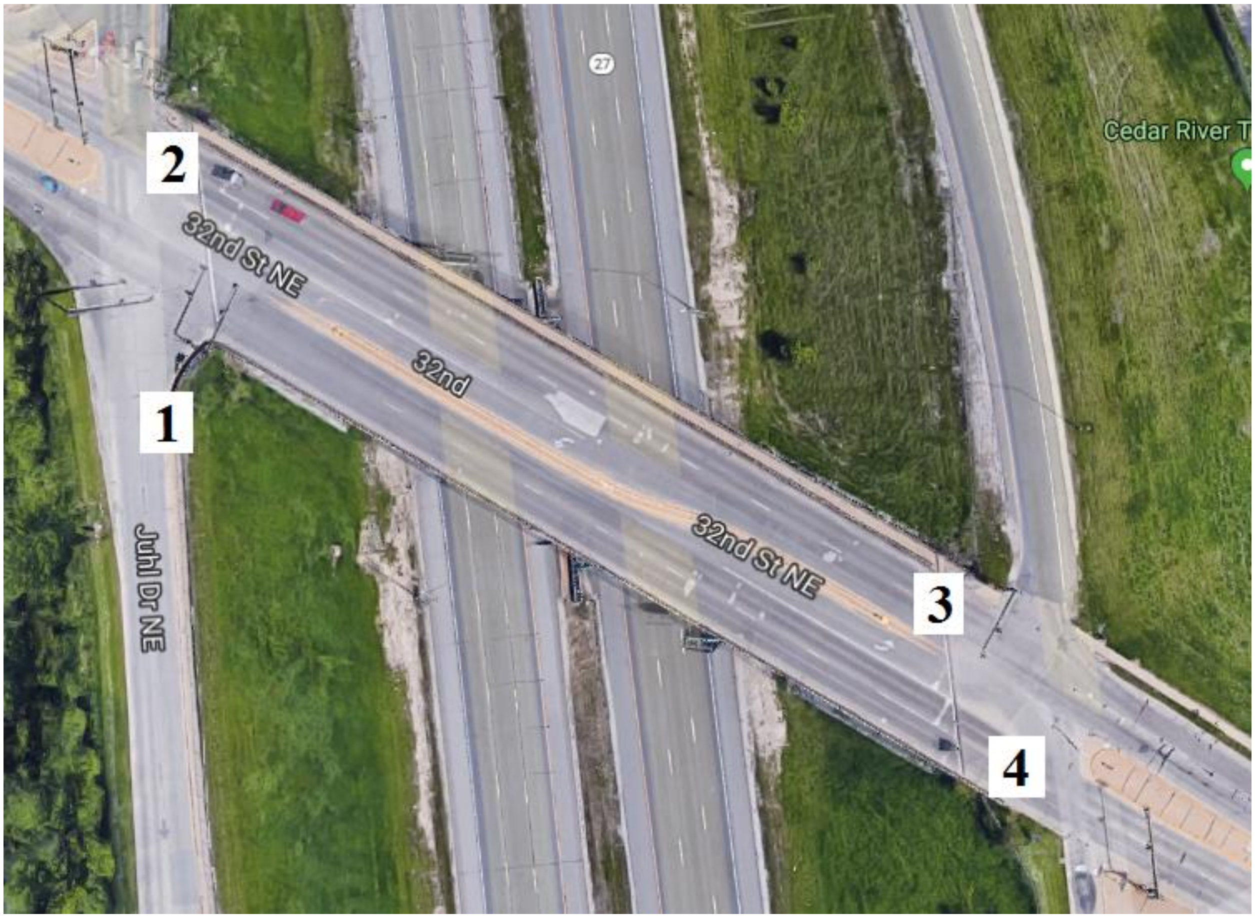


Figure 81. Bridge No. 5722.7O380 [1]

Table 22. Exposure Calculations for Bridge No. 5722.7O380

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	12,100	1.0	0.5	3,653	22,100,650
2	12,100	0.5	0.5	3,653	11,050,325
3	12,100	0.5	0.5	3,653	11,050,325
4	12,100	0.5	0.5	3,653	11,050,325
Total Exposure for Bridge					**55,251,625**

3.5.1.6.7 Diagonal Corner

Two bridges, with a total of four sloped end treatments, featured two sloped ends on diagonal corners of the bridge, with two-way traffic. Bridge no. 7702.4S160, which features this configuration, is shown in Figure 82, and exposure calculations are shown in Table 23.

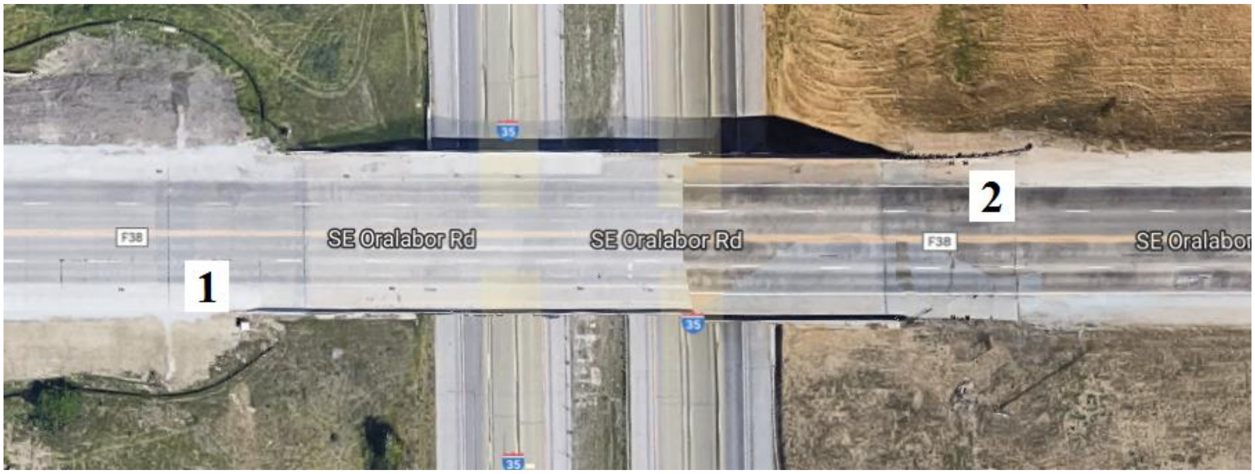


Figure 82. Bridge No. 7702.4S160 [1]

Table 23. Exposure Calculations for Bridge No. 7702.4S160

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(\text{Traffic Factor})_R$	$(\text{Side Factor})_i$	Time (Days)	Exposure (Vehicles)
1	23,500	0.5	0.5	3,653	21,461,375
2	23,500	0.5	0.5	3,653	21,461,375
Total Exposure for Bridge					**42,922,750**

3.5.2 One-Way Traffic

3.5.2.1 Four Treatments

Bridge no. 7708.0O235, as shown in Figure 83, was located on a one-way road with sloped end treatments located on the upstream (sloped end treatment nos. 1 and 2) and downstream (sloped end treatment nos. 3 and 4) ends of the concrete bridge rails, with respect to traffic flow. Exposure calculations for bridge no. 7708.0O235 are shown in Table 24, and calculations for the 24 four treatment, one-way traffic sloped end treatments are shown in Table C-22.

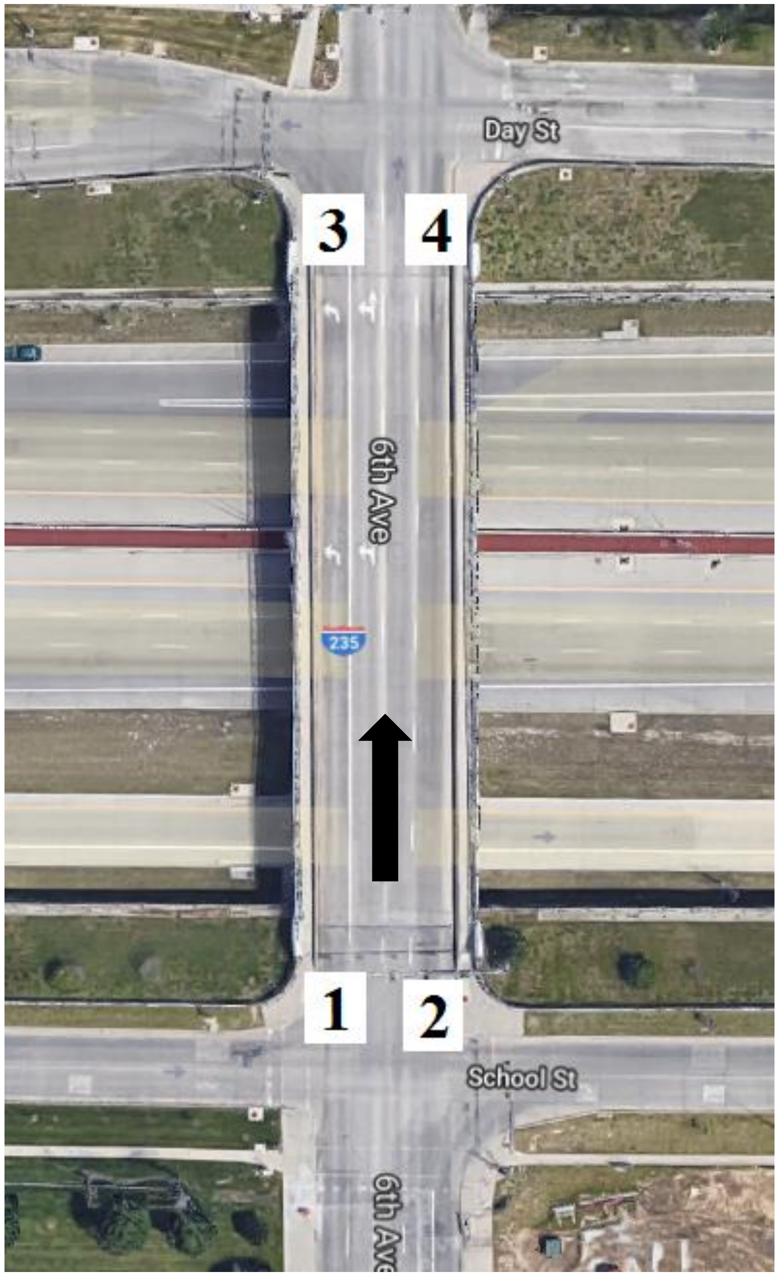


Figure 83. Bridge No. 7708.0O235 [1]

Table 24. Exposure Calculations for Bridge No. 7708.0O235

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	10,200	1.0	0.5	3,653	18,630,300
2	10,200	1.0	0.5	3,653	18,630,300
3	10,200	1.0	0.0	3,653	0
4	10,200	1.0	0.0	3,653	0
Total Exposure for Bridge					**37,260,600**

3.5.2.2 One Bridge End

Five bridges featured two sloped end treatments on one end of the bridge located in conjunction with a one-way road. An example of this configuration, for bridge no. 8220.1R061, is shown in Figure 84. Exposure calculations for the two sloped end treatments located on bridge no. 8220.1R061 are shown in Table 25, and exposure calculations for the sloped end treatments located on one bridge end, one-way traffic bridges are shown in Table C-23.

Figure 84. Bridge No. 8220.1R061 [1]

Table 25. Exposure Calculations for Bridge No. 8220.1R061

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(Traffic\ Factor)_R$	$(Side\ Factor)_i$	Time (Days)	Exposure (Vehicles)
1	21,300	1.0	0.5	3,653	38,904,450
2	21,300	1.0	0.5	3,653	38,904,450
Total Exposure for Bridge					**77,808,900**

3.5.2.3 Special Cases

Some bridges featured sloped end treatment configurations, which were different from those already discussed. Special cases, which were located on one-way traffic roads, are discussed in Sections 3.5.2.3.1 through 3.5.2.3.5. Exposure calculations for the one-way traffic, special case sloped end treatment configurations are listed in Table C-24.

3.5.2.3.1 Entrance and Exit Ramps

Three bridges did not feature sloped end treatments, but nearby entrance and/or exit ramps did. Bridge nos. 2963.7A034, 7708.1A235, and 7710.0A235 are shown in Figures 85, 86, and 87, respectively, and exposure calculations are shown in Tables 26, 27, and 28, respectively.

Figure 85. Bridge No. 2963.7A034 [1]

Table 26. Exposure Calculations for Bridge No. 2963.7A034

Sloped End No.	**$AADT_R$ (Vehicles/Day)**	**(Traffic Factor)$_R$**	**(Side Factor)$_i$**	**Time (Days)**	**Exposure (Vehicles)**
1	1,040	1.0	0.5	3,653	1,899,560
2	1,040	1.0	0.5	3,653	1,899,560
Total Exposure for Bridge					**3,799,120**

Figure 86. Bridge No. 7708.1A235 [1]

Table 27. Exposure Calculation for Bridge No. 7708.1A235

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(Traffic Factor)_R$	$(Side Factor)_i$	Time (Days)	Exposure (Vehicles)
1	7,300	1.0	0.5	3,653	13,333,450
Total Exposure for Bridge					**13,333,450**

Figure 87. Bridge No. 7710.0A235 [1]

Table 28. Exposure Calculations for Bridge No. 7710.0A235

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(Traffic Factor)_R$	$(Side Factor)_i$	Time (Days)	Exposure (Vehicles)
1	10,500	1.0	0.5	3,653	19,178,250
2	10,500	1.0	0.5	3,653	19,178,250
3	10,500	1.0	0.0	3,653	0
Total Exposure for Bridge					**38,356,500**

3.5.2.3.2 Two Along One Lane

Bridge no. 5723.8O380 featured two sloped end treatments located along the far right lane on each side of the bridge, as shown in Figure 88. Exposure calculations are shown in Table 29.

Figure 88. Bridge No. 5723.8O380 [1]

Table 29. Exposure Calculations for Bridge No. 5723.8O380

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	2,390	1.0	0.5	3,653	4,365,335
2	2,390	1.0	0.0	3,653	0
Total Exposure for Bridge					**4,365,335**

3.5.2.3.3 Two Treatments Adjacent to One Lane with Ramps

Bridge nos. 7707.2O235 and 7708.2O235 featured sloped end treatments along one lane in addition to sloped end treatments on entrance and/or exit ramps, as shown in Figures 89 and 90, respectively. Exposure for sloped end treatments located on bridge no. 7707.2O235 are shown in Table 30. Bridge no. 7708.2O235 featured three sloped end treatments, and exposure for each is shown in Table 31.

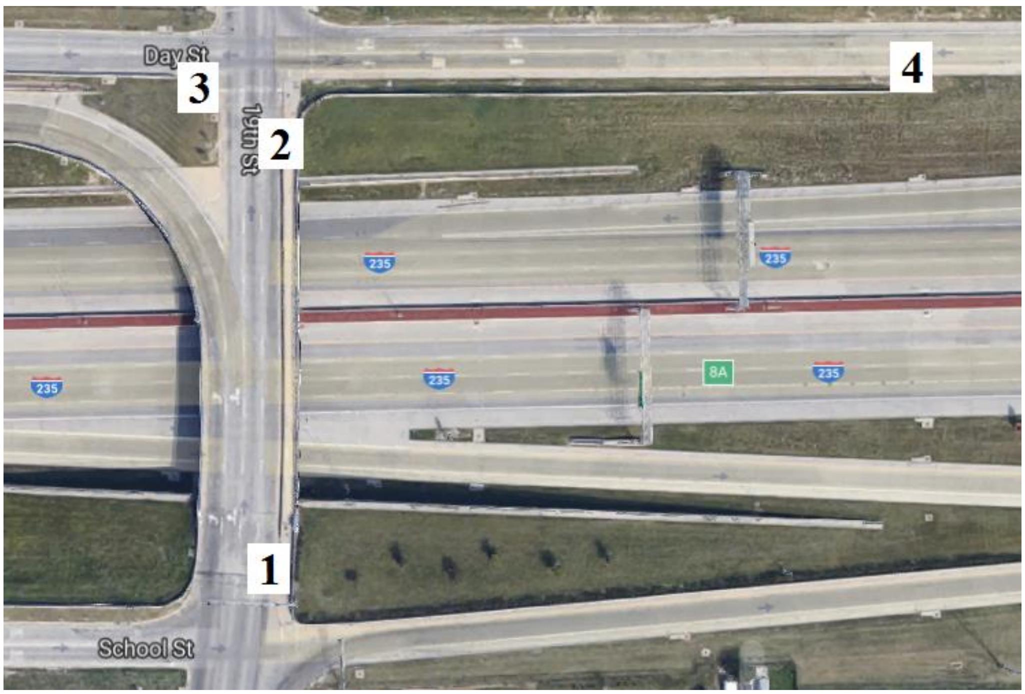


Figure 89. Bridge No. 7707.2O235 [1]

Table 30. Exposure Calculations for Bridge No. 7707.2O235

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	19,600	1.0	0.5	3,653	35,799,400
2	9,300	1.0	0.0	3,653	0
3	5,800	1.0	0.5	3,653	10,593,700
4	7,400	1.0	0.5	3,653	13,516,100
Total Exposure for Bridge					**59,909,200**

Figure 90. Bridge No. 7708.2O235 [1]

Table 31. Exposure Calculations for Bridge No. 7708.2O235

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(Traffic Factor)_R$	$(Side Factor)_i$	Time (Days)	Exposure (Vehicles)
1	11,900	1.0	0.5	3,653	21,735,350
2	2,840	1.0	0.5	3,653	5,187,260
3	11,900	1.0	0.0	3,653	0
Total Exposure for Bridge					**26,922,610**

3.5.2.3.4 Three Treatments with Ramp

Bridge no. 7708.3O235, shown in Figure 91, featured sloped end treatments located on three bridge rail ends in addition to a sloped end treatment located at the start of an entrance ramp. Exposure calculations for bridge no. 7708.3O235 are shown in Table 32.

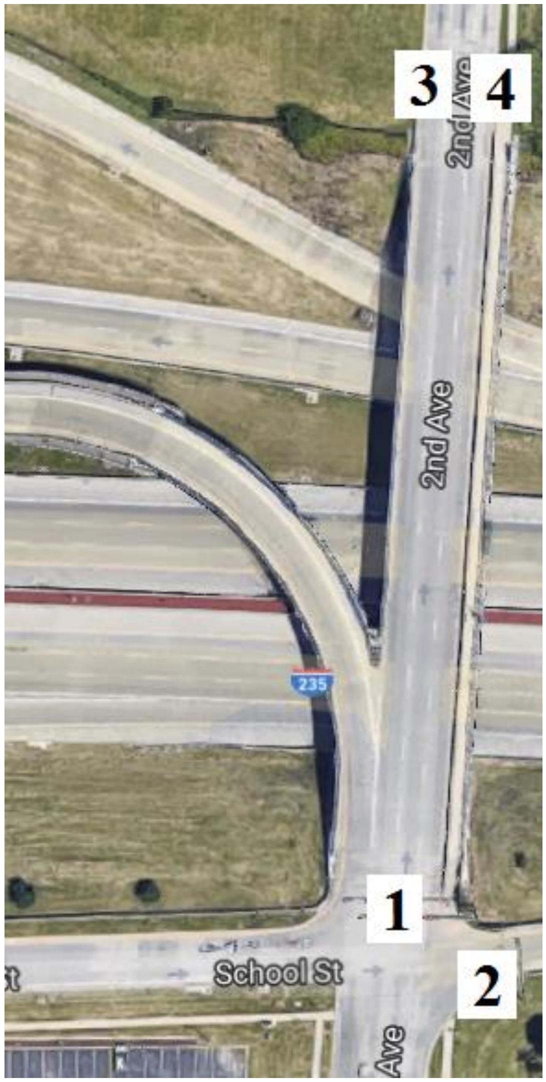


Figure 91. Bridge No. 7708.3O235 [1]

Table 32. Exposure Calculations for Bridge No. 7708.3O235

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	8,600	1.0	0.5	3,653	15,707,900
2	5,600	1.0	0.5	3,653	10,228,400
3	8,600	1.0	0.0	3,653	0
4	8,600	1.0	0.0	3,653	0
Total Exposure for Bridge					**25,936,300**

3.5.2.3.5 Four Treatments and Ramp

Bridge no. 7785.5S069, shown in Figure 92, featured a four sloped end treatments configuration with an additional sloped end treatment located on a nearby entrance ramp. The exposure calculations for the sloped ends located on and near bridge no. 7785.5S069 are shown in Table 33.

Figure 92. Bridge No. 7785.5S069 [1]

Table 33. Exposure Calculations for Bridge No. 7785.5S069

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(\text{Traffic Factor})_R$	$(\text{Side Factor})_i$	Time (Days)	Exposure (Vehicles)
1	13,700	1.0	0.5	3,653	25,023,050
2	13,700	1.0	0.5	3,653	25,023,050
3	8,800	1.0	0.5	3,653	16,073,200
4	13,700	1.0	0.0	3,653	0
5	13,700	1.0	0.0	3,653	0
Total Exposure for Bridge					**66,119,300**

3.5.3 Divided Bridges with Two-Way Traffic

A total of seven bridges were located in conjunction with divided, two-way roads with medians. As a result, both lanes of travel had individual bridges and bridge rails, which were assigned two separate bridge numbers. These bridges were analyzed and exposure for each sloped end treatment located on them was calculated. Exposure calculations for all split number bridges are listed in Table C-25.

3.5.3.1 Treatments Adjacent to One Lane and Medians

Bridge nos. 5244.3O080 and 5244.4O080 featured two sloped end treatments along one lane with three additional sloped end treatments located on medians, as shown in Figure 93. The exposure calculations for bridge nos. 5244.3O080 and 5244.4O080 are shown in Table 34.

Bridge nos. 8544.7O030 and 8544.8O030, shown in Figure 94, featured a total of six sloped end treatments, with two located along one lane and four located on medians. Exposure calculations for bridge nos. 8544.7O030 and 8544.8O030 are shown in Table 35.

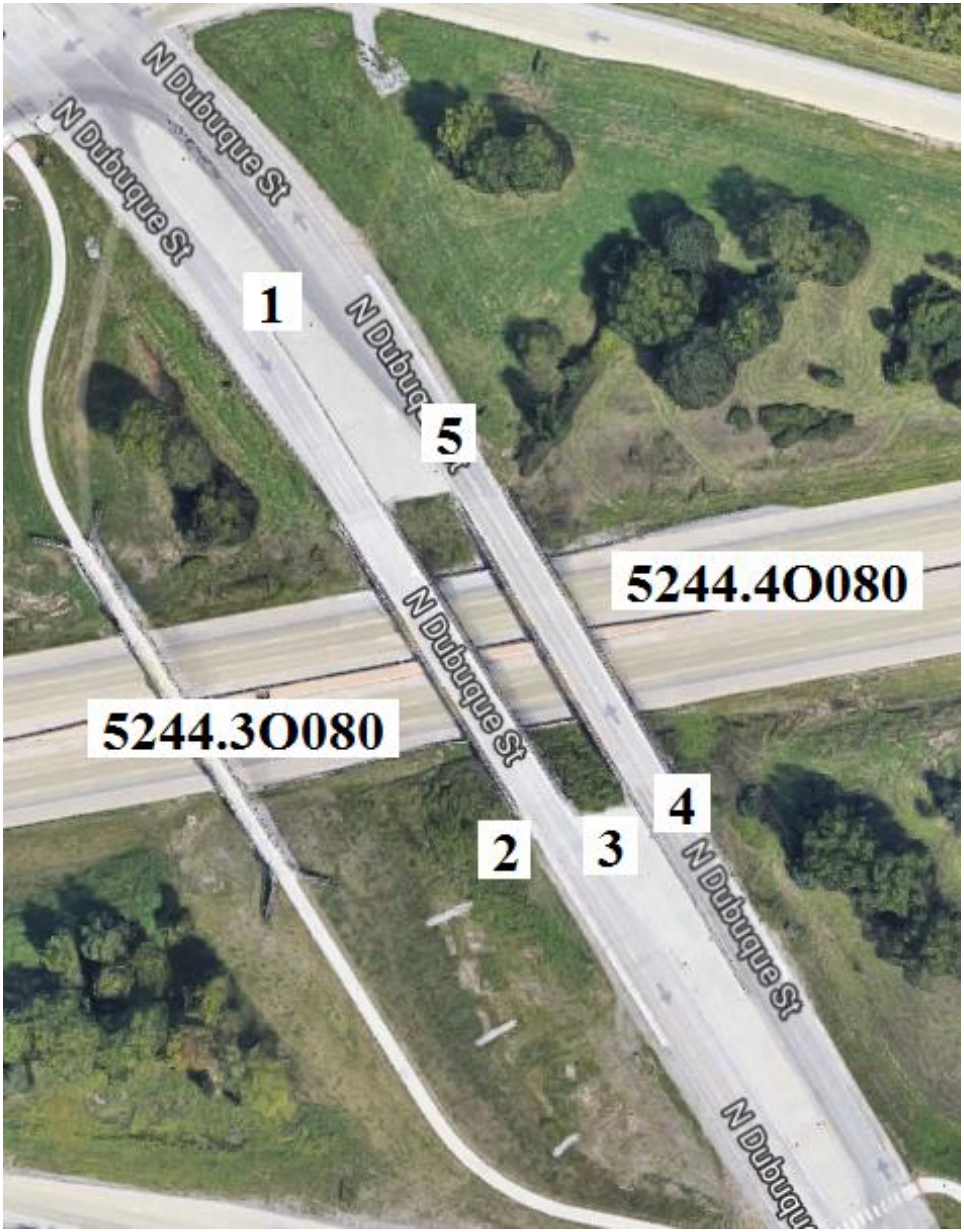


Figure 93. Bridge Nos. 5244.3O080 and 5244.4O080 [1]

Table 34. Exposure Calculations for Bridge Nos. 5244.3O080 and 5244.4O080

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(\text{Traffic Factor})_R$	$(\text{Side Factor})_i$	Time (Days)	Exposure (Vehicles)
1	17,800	0.5	0.5	3,653	16,255,850
2	17,800	0.5	0.0	3,653	0
3	17,800	0.5	0.5	3,653	16,255,850
4	17,800	0.5	0.5	3,653	16,255,850
5	17,800	0.5	0.0	3,653	0
Total Exposure for Bridge					**48,767,550**

Figure 94. Bridge Nos. 8544.7O030 and 8544.8O030 [1]

Table 35. Exposure Calculations for Bridge Nos. 8544.7O030 and 8544.8O030

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(Traffic Factor)_R$	$(Side Factor)_i$	Time (Days)	Exposure (Vehicles)
1	9,900	0.5	0.5	3,653	9,041,175
2	9,900	0.5	0.5	3,653	9,041,175
3	9,900	0.5	0.0	3,653	0
4	9,900	0.5	0.5	3,653	9,041,175
5	9,900	0.5	0.5	3,653	9,041,175
6	9,900	0.5	0.0	3,653	0
Total Exposure for Bridge					**36,164,700**

3.5.3.2 Four Treatments with Two Along One Lane

Bridge nos. 6401.9S014 and 6402.0S014, shown in Figure 95, featured a total of six sloped end treatments. Four were located at the corners and two treatments were located along the bridge. Exposure calculations are shown in Table 36.

Figure 95. Bridge Nos. 6401.9S014 and 6402.0S014 [1]

Table 36. Exposure Calculations for Bridge Nos. 6401.9S014 and 6405.0S014

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(Traffic\ Factor)_R$	$(Side\ Factor)_i$	Time (Days)	Exposure (Vehicles)
1	13,900	0.5	0.5	3,653	12,694,175
2	13,900	0.5	0.5	3,653	12,694,175
3	13,900	0.5	0.5	3,653	12,694,175
4	13,900	0.5	0.5	3,653	12,694,175
5	13,900	0.5	0.5	3,653	12,694,175
6	13,900	0.5	0.5	3,653	12,694,175
Total Exposure for Bridge					**76,165,050**

3.5.3.3 Four Treatments

Three bridges with split bridge numbers featured the four treatments configuration on two-way traffic bridges. Bridge nos. 7705.0O235 and 7705.1O235, shown in Figure 96, featured four sloped end treatments located on a two-way traffic bridge. Exposure calculations are shown in Table 37. Exposure calculations for bridge nos. 8619.1L063, 8619.1R063, 9401.5L926, and 9401.5R926 are shown in Table C-25.

Figure 96. Bridge Nos. 7705.0O235 and 7705.1O235 [1]

Table 37. Exposure Calculations for Bridge Nos. 7705.0O235 and 7705.1O235

Sloped End No.	$AADT_R$ (Vehicles/Day)	(Traffic Factor)$_R$	(Side Factor)$_i$	Time (Days)	Exposure (Vehicles)
1	8,900	0.5	0.5	3,653	8,127,925
2	8,900	0.5	0.0	3,653	0
3	8,900	0.5	0.5	3,653	8,127,925
4	8,900	0.5	0.0	3,653	0
Total Exposure for Bridge					**16,255,850**

3.5.3.4 Three Treatments with Ramp and Medians

Bridge nos. 9700.2S077 and 9700.3S077, shown in Figure 97, featured a total of nine sloped end treatments, with one located on an entrance ramp, three located on medians, and five located along the outside lanes of the bridge. Exposure calculations for all sloped end treatments located on bridge nos. 9700.2S077 and 9700.3S077 are shown in Table 38.

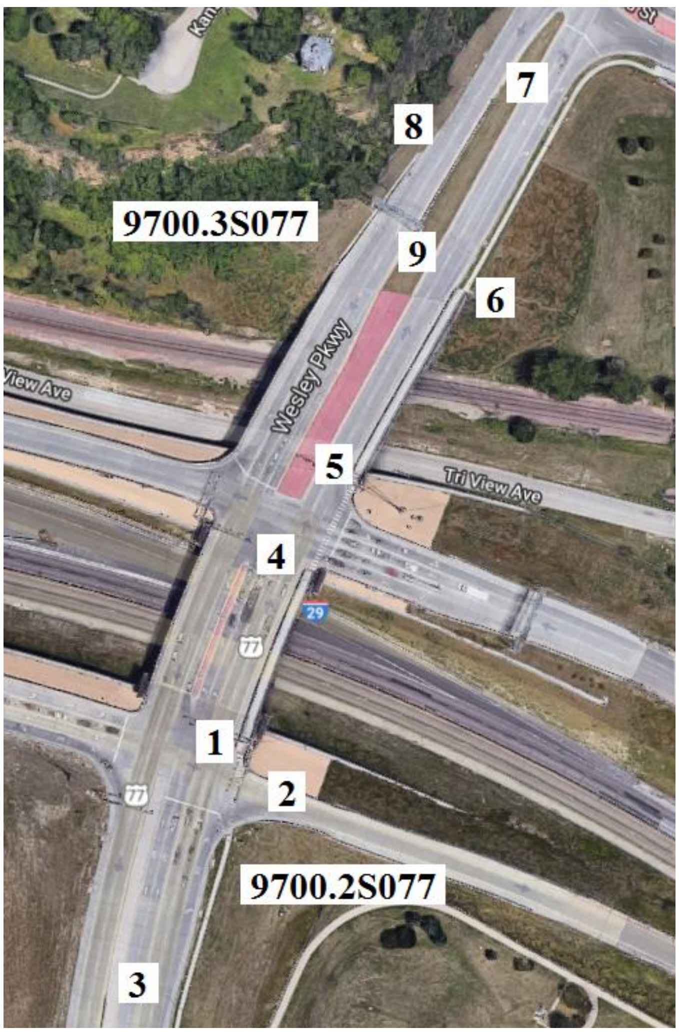


Figure 97. Bridge Nos. 9700.2S077 and 9700.3S077 [1]

Table 38. Exposure Calculations for Bridge Nos. 9700.2S077 and 9700.3S077

Sloped End No.	$AADT_R$ (Vehicles/Day)	$(Traffic\ Factor)_R$	$(Side\ Factor)_i$	Time (Days)	Exposure (Vehicles)
1	20,200	0.5	0.5	3,653	18,447,650
2	4,030	1.0	0.5	3,653	7,360,795
3	20,200	0.5	0.5	3,653	18,447,650
4	20,200	0.5	0.5	3,653	18,447,650
5	20,200	0.5	0.5	3,653	18,447,650
6	20,200	0.5	0.0	3,653	0
7	20,200	0.5	0.5	3,653	18,447,650
8	20,200	0.5	0.5	3,653	18,447,650
9	20,200	0.5	0.5	3,653	18,447,650
Total Exposure for Bridge					**136,494,345**

3.5.4 No AADT Data

AADT data was not available for seven of the 183 bridges which feature sloped end treatments. Therefore, it was not possible to calculate exposure for the 26 sloped end treatments located on these bridges. These bridges are listed in Table C-27.

3.5.5 Total Exposure

A total of 658 sloped end treatments were identified for this research, located on or near 183 bridges. AADT data was not available for seven of these bridges, which featured 26 sloped end treatments. Therefore, exposure, average exposure, and exposure rate were determined utilizing the 632 sloped end treatments located on or near the 176 bridges for which AADT data was available.

The total exposure for the identified sloped end treatments with AADT data is equal to 4,915,096,889 vehicles. The average exposure per bridge was calculated by dividing the total exposure by the total number of bridges with AADT data (176 bridges), which found an average exposure of 27,926,687 per bridge. An average exposure of 7,777,052 per sloped end treatment was found by dividing the total exposure by 632 (number of sloped end treatments with AADT data).

An estimated total exposure of 5,117,300,242 vehicles was calculated by scaling the total exposure by 1.04 (658/632). The estimated average exposure per bridge was equal to 27,963,389 vehicles, found by dividing the estimated total exposure by the total number of bridges featuring sloped end treatments (183 bridges). An estimated average exposure per sloped end treatment of 7,777,052 was calculated.

4 CRASH DATA

Iowa DOT crash reports did not contain a descriptor that identified sloped end treatment impacts. In order to determine the ISPE of sloped end treatments, researchers paired crash reports involving any fixed object and its crash location with the database of sloped end treatments, as discussed in Chapter 3. Crash data involving impact with at least one roadside fixed object was provided by Iowa DOT in a geo-located dataset in ArcGIS format. Crash data was filtered to remove any crash which was noted to occur more than 1,000 ft away from any noted sloped end treatment. Then, crash narratives and scene diagrams were reviewed to identify the crashes which could have impacted sloped end treatments.

4.1 Crash Database

Iowa DOT supplied a crash database which contained the crash information listed in Table 39 for all reported crashes in Iowa between 2008 and 2017. Additional information, including the database element name and data type for each data element, is listed in Appendix D.

Table 39. Iowa DOT Crash Database Data Elements

Data Category	Data Element
Identification	Case Number Law Enforcement Case Number Report Type
Date	Crash Data Crash Day Time of Crash in String Format
Location	County FHWA Urban Area Code Base Records City Number Literal Description of Location Latitude Longitude

Table 40. Iowa DOT Crash Database Data Elements (Cont.)

Data Category	Data Element
Road	Type of Roadway Junction/Feature Road Classification Road System Paved or Not Speed Limit Intersection Class Route Overpass/Underpass Information Traffic Controls Mainline or Ramp Roadway Contributing Circumstances Surface Conditions
Environment	Environmental Contributing Circumstances Weather Conditions 1-2 Derived Light Conditions Vision Obscurement
Events	Manner of Crash Sequence of Events 1-4 First Harmful Event Location of First Harmful Event Most Harmful Event Major Cause Fixed Object Struck Emergency Status Emergency Vehicle Type Property Damage
Injury	Crash Severity Injured Gender Injured Age Injury Status Number of Injuries Number of Unknown Injuries Number of Possible Injuries Number of Minor Injuries Number of Major Injuries Number of Fatalities Occupant Trapped? Airbag Deployment Ejection Ejection Path

Table 41. Iowa DOT Crash Database Data Elements (Cont.)

Data Category	Data Element
Driver/Occupants	Total Number of Occupants Occupants in Vehicle Person Number Seating Position Occupant Protection Driver Contributing Circumstances 1-2 Driver Gender Driver Age Driver Age by Primarily 5 Year Bins Driver Charged? Driver Condition Driver's License State Drug or Alcohol Related Alcohol Test Results Drug Test Results
Non-Motorist	Non-Motorist Type Non-Motorist Condition Non-Motorist Action Non-Motorist Contributing Circumstances Non-Motorist Location Non-Motorist Safety Equipment
Vehicle	Number of Vehicles Vehicle Unit Number Vehicle Make Vehicle Model Vehicle Style Vehicle Configuration Cargo Body Type Vehicle Year License Plate State License Plate Year Vehicle Action Vehicle Defect Point of Initial Impact Extent of Damage Most Damaged Area Approximate Repair Cost Initial Direction of Travel Cardinal Direction of Vehicles
Work Zone	Work Zone Related? Work Zone Location Work Zone Type Workers Present?

The crash set was filtered to remove crashes in which a fixed object was not struck. These crashes typically involved vehicle-to-vehicle collisions, vehicle-to-animal collisions, or rollovers. From 2008 through 2017, a total of 534,246 crashes occurred in Iowa, and 91,445 involved striking a fixed object (17 percent). The fixed object struck crashes were imported into ArcGIS, as shown in Figure 98. The different colors represent crash data from different years.

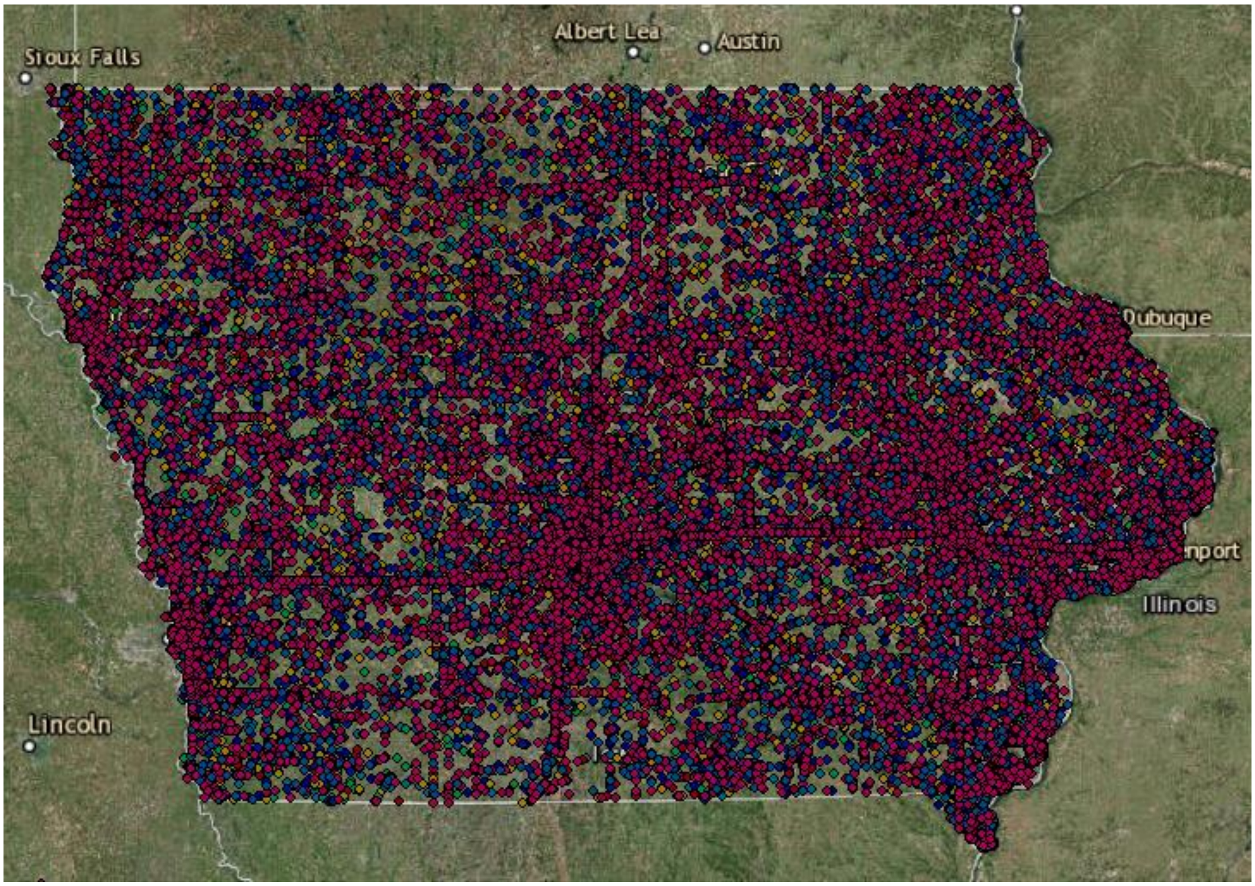


Figure 98. Iowa Crashes with a Fixed Object Struck from 2008 to 2017

It should be noted that the "Fixed Object Struck" category of Iowa DOT's crash database was populated to be consistent with the Model Minimum Uniform Crash Criteria (MMUCC) [71], and the MMUCC guidelines do not specifically identify concrete barrier sloped end treatments. Ambiguity regarding how sloped end treatments were categorized using available categories, as well as the potential for data coding errors, required a more detailed evaluation of crash circumstances to identify which crashes involved sloped end treatments.

4.2 ArcGIS Proximity Filter

Both the sloped end treatment locations and fixed object struck crash locations were imported into ArcGIS. Utilizing the buffer feature, a radius of 1,000 ft was drawn around each sloped end treatment, as shown in Figure 99. This buffer zone was chosen to ensure all crashes which involved the identified sloped end treatments were collected. Note that it was assumed that crash GPS locations could be taken at the responding officer's vehicle location during crash reporting, which may be located far from the initial crash location.

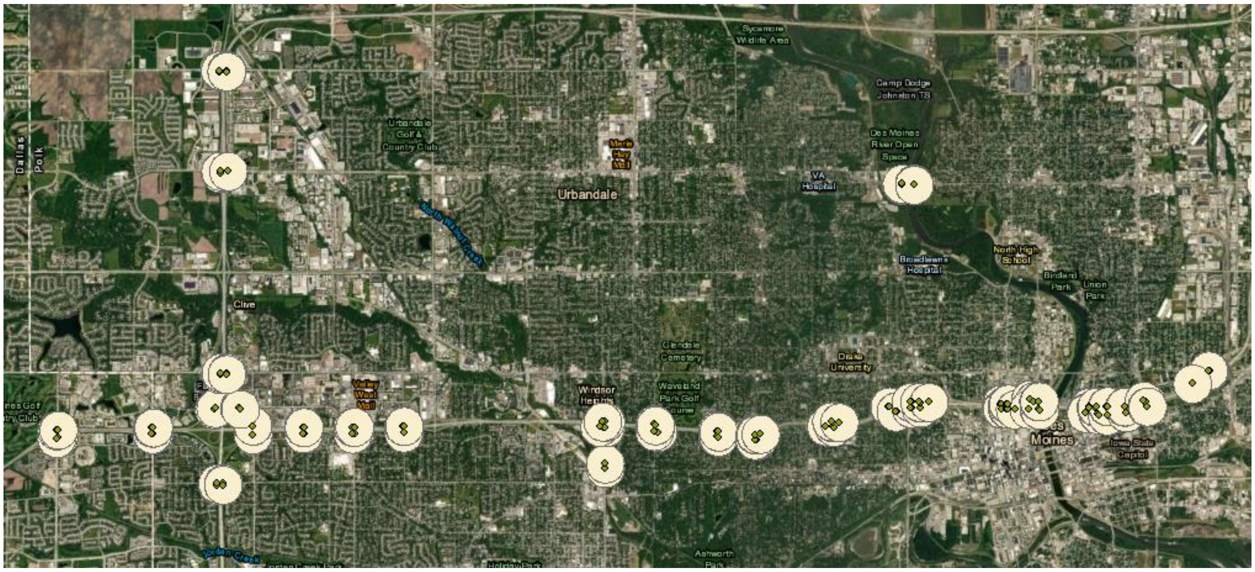


Figure 99. 1,000-ft Radius Buffer Zone

Next, the intersect feature was used to collect all crashes which occurred within these proximity zones, resulting in a total of 2,835 crashes, as shown in Figure 100. To determine which crashes involved a sloped end treatment, the narrative police reports were required.

It was anticipated that by using a large proximity filter, most of the crashes which involved one of the known sloped end treatments would be identified. In addition, non-sloped end treatment crashes, which were identified using the proximity filter dataset, would serve as a reference ("baseline") crash database to determine the relative risk of the sloped end treatments on roads with similar attributes, weather conditions, and traffic flows.

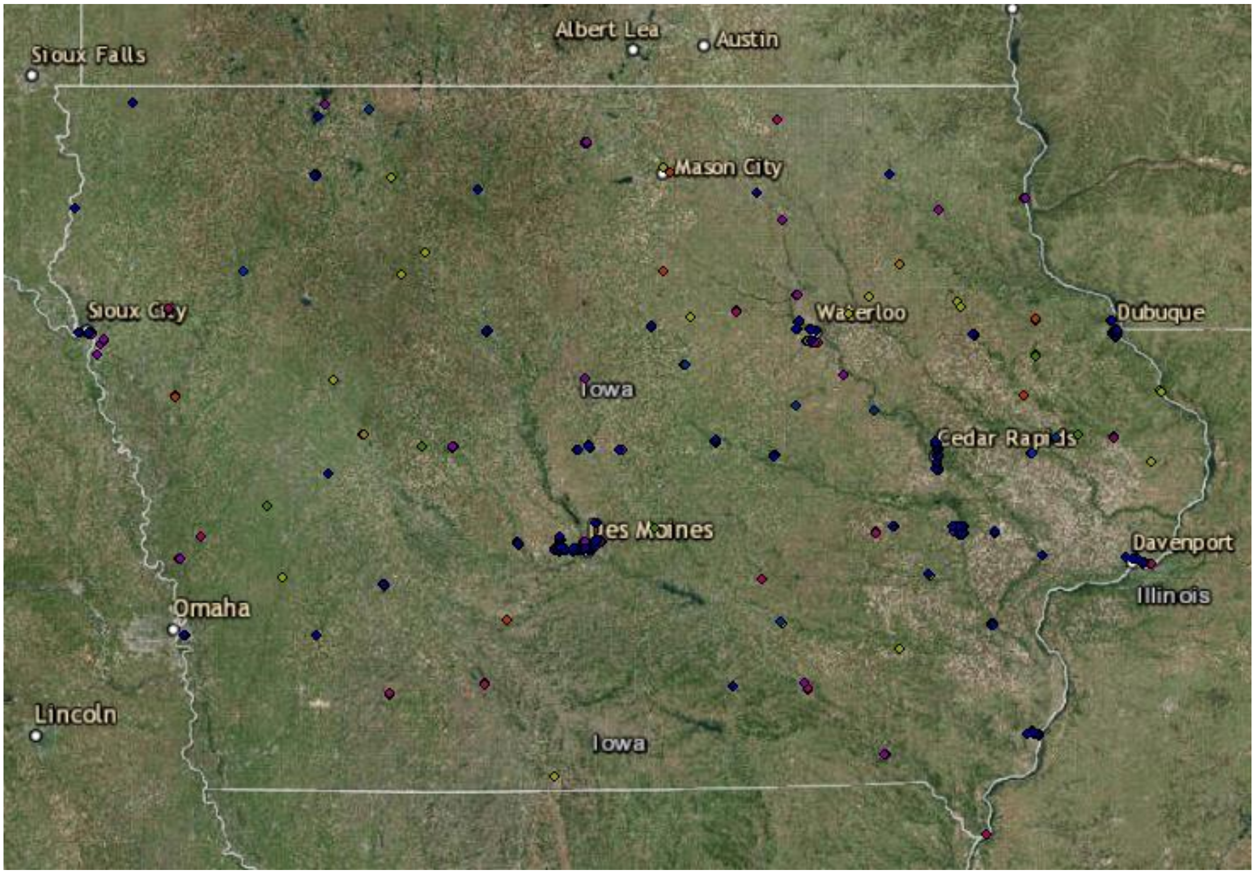


Figure 100. 2008-2017 Crashes within Buffer Zones

4.3 Crash Narrative Reports

Responding officers often provide crash narratives which summarize major events of the crashes when crash reports are filed. Iowa DOT provided crash narratives for the 2,835 crashes in the vicinity of the sloped end treatments.

Each crash narrative was reviewed and classified based on the probability that the crash involved a sloped end treatment. A subjective scale consisting of "likely," "probably," "possibly," "unlikely," and "unknown" fields was utilized. A crash coded "likely" specifically mentioned a sloped end treatment or described the vehicle "riding up" on the barrier. Accidents coded "probably" suggested the end of the barrier was impacted, but the narrative did not specify if a sloped end treatment was impacted. "Possible" crashes referenced impacts with barriers or barrier-like features but did not specify if a sloped end treatment was impacted or if the impact occurred at the end of the barrier. An "unlikely" crash includes crashes with objects other than a sloped end treatment (tree, utility pole, building, cable barrier, etc.) or clearly denoted the crash remained within a bridge rail LON. A crash was coded "unknown" if no narrative report was available. Crashes designated "unlikely" were omitted from further consideration, leaving 1,059 potential sloped end treatment crashes which required further review. The number of crashes placed within each category, sorted by year, is shown in Table 42.

Table 42. Crashes Categorized from Narrative Reports

Year	Narrative Report Classification					Total (from Buffer Zones)
	Likely	Probably	Possible	Unlikely	Unknown	
2008	3	3	104	180	43	333
2009	1	1	9	198	36	245
2010	2	2	97	164	19	284
2011	1	1	48	201	28	279
2012	1	1	80	160	24	266
2013	1	0	33	188	22	244
2014	0	0	28	168	97	293
2015	4	0	126	148	8	286
2016	2	0	102	195	7	306
2017	6	0	113	174	6	299
Total	**21**	**8**	**740**	**1,776**	**290**	**2,835**
Percentage	**0.7%**	**0.3%**	**26%**	**63%**	**10%**	**100%**

4.4 Crash Scene Diagrams

Iowa DOT provided scene diagrams for the database of 1,059 crashes rated “likely,” “probably,” “possibly,” and “unknown” impact with sloped end treatments. A total of 73 crashes involved scene diagrams which were not consistent with narratives or for which scene diagrams were not available, and these crashes were excluded. The scene diagrams for the remaining crashes were reviewed. Crashes were excluded when the sequence of events clearly indicated no end treatment was impacted. Researchers also excluded crashes in which the scene diagram and narrative were not sufficiently detailed to determine if the crash involved the sloped end treatment. A total of 30 crashes were confirmed to involve a sloped end treatment as one of the sequence of events. Crash results are summarized in Table 43. It is important to note some crashes involving sloped end treatments may not have been collected for this ISPE study, had the sloped end treatment been impacted and replaced with some other end treatment before the bridge inventory was updated.

Table 43. Sloped End Treatment Crashes by Year [72]

Year	Number of Sloped End Treatment Crashes	Total Yearly Crashes	Percent of Crashes Involving Sloped End Treatments
2008	3	59,918	0.005%
2009	0	55,494	0.000%
2010	6	54,396	0.011%
2011	5	48,793	0.010%
2012	4	47,882	0.008%
2013	0	50,009	0.000%
2014	3	52,102	0.006%
2015	2	54,624	0.004%
2016	2	55,848	0.004%
2017	5	55,180	0.009%
Total	**30**	**534,246**	**0.006%**
Annual Average	**3**	**53,425**	**0.006%**

4.5 Exposure Rate

The exposure rate of sloped end treatments was calculated by comparing the total exposure to the total number of sloped end treatment crashes. Therefore, the exposure rate of sloped end treatments is 4,915,096,889 to 30, or 163,836,563 to 1. When factoring for roads without ADT data, the estimated exposure rate for sloped end treatments was 5,117,300,242 to 30, or 170,576,675 to 1.

4.6 Analysis of Crash Frequency

For the ten years of crash data, sloped end treatment crashes accounted for 0.006 percent of all crashes or an average of three sloped end treatment crashes per year. In comparison, an average of 53,425 reported crashes occurred annually in Iowa.

5 ANALYSIS OF CRASH RESULTS

Researchers used the results of the exposure analysis, crash identification, and "baseline" dataset to determine the ISPE of the sloped end treatments. The baseline dataset included crashes that were within 1,000 ft of a sloped end treatment but did not involve a sloped end treatment, also denoted as non-sloped end treatment crashes. In order to determine if the baseline crash data set was representative of the conditions associated with sloped end treatment crashes, data such as speed limits, weather and road conditions, and vehicle distributions were compared.

5.1 Speed Limit

All of the sloped end treatment crashes occurred on roads with speed limits between 25 and 60 mph, whereas the non-sloped end treatment crashes, 2,805 crashes, occurred on roads with speed limits ranging from 5 to 70 mph. Crashes which occurred on roadways with speed limits which were unknown, less than 25 mph, or greater than 60 mph were removed from both datasets. These crashes occurred on private drives, low-access roads, or freeways, and were not representative of roads with sloped end treatments. As a result, 2,376 crashes were analyzed as the data set; 2,346 of these crashes did not feature sloped end treatments (non-sloped end treatment crashes) and 30 featured sloped end treatments (sloped end treatment crashes). The total dataset is shown in Table 44, sorted by speed limit.

Table 44. Number of Crashes by Speed Limit

Speed Limit (mph)	Number of Crashes	Percent
25	422	18%
30	226	9%
35	494	21%
40	41	2%
45	231	10%
50	23	1.0%
55	584	24%
60	355	15%
Total	**2,376**	**100%**

A total of 416 non-sloped end treatment crashes (18 percent) occurred in 25 mph zones, 220 (9 percent) occurred in 30 mph zones, 481 (20 percent) occurred in 35 mph zones, 40 (2 percent) occurred in 40 mph zones, 229 (10 percent) occurred in 45 mph zones, 23 (1.0 percent) occurred in 50 mph zones, 582 (25 percent) occurred in 55 mph zones, and 355 (15 percent) occurred in 60 mph zones, as shown in Figure 101.

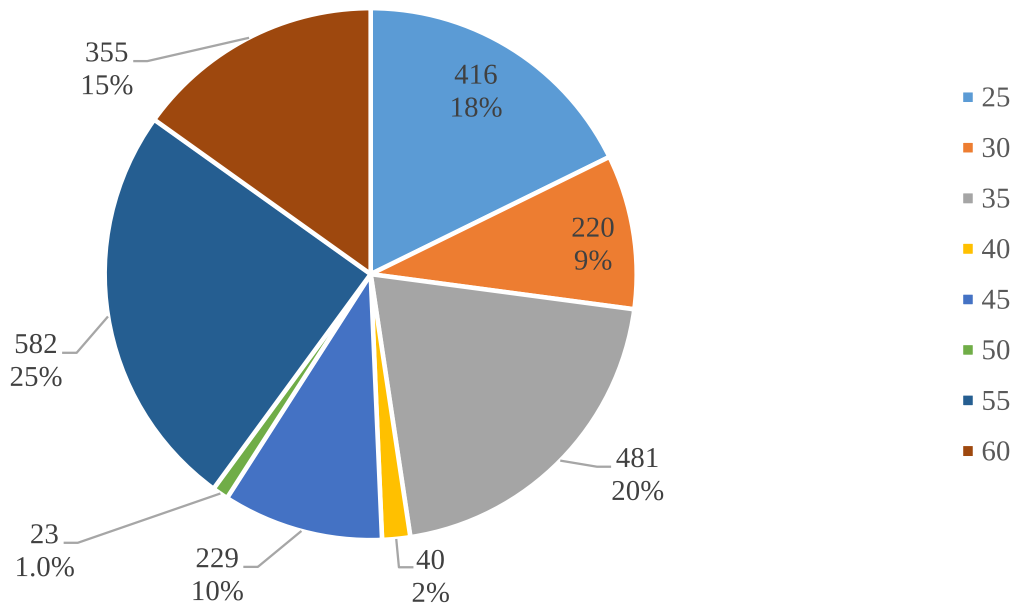


Figure 101. Non-Sloped End Treatment Crashes – Speed Limit

A total of six sloped end treatment crashes (20 percent) occurred in 25 mph zones, 6 (20 percent) occurred in 30 mph zones, 13 (43 percent) occurred in 35 mph zones, one (3 percent) occurred in a 40 mph zone, two (7 percent) occurred in 45 mph zones, and two (7 percent) occurred in 55 mph zones, as shown in Figure 102.

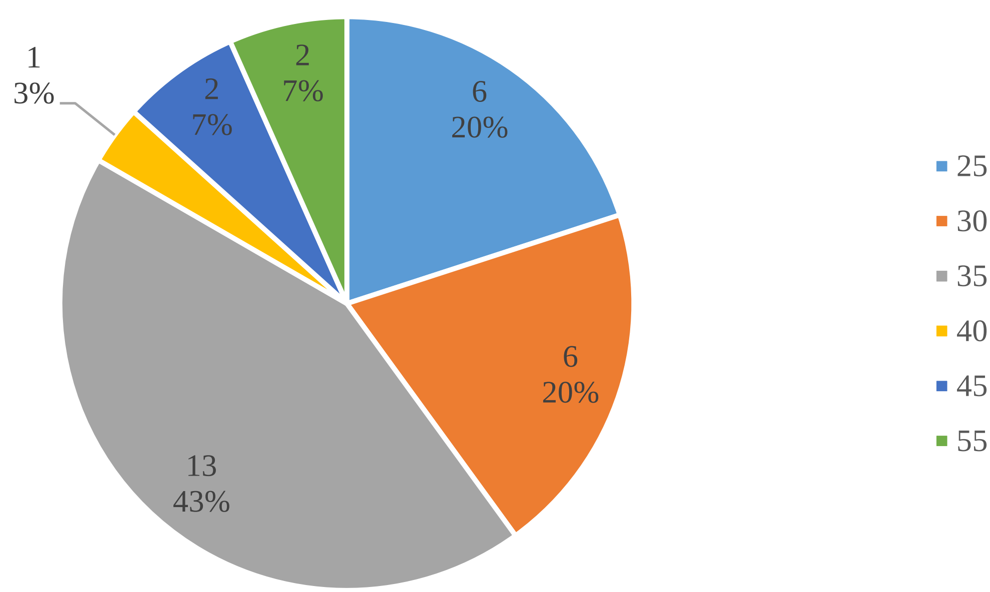


Figure 102. Sloped End Treatment Crashes – Speed Limit

The percentage of non-sloped end treatment and sloped end treatment crashes within each speed limit category are shown in Figure 103. A total of 48 percent of non-sloped end treatment crashes occurred on roads with speed limits less than or equal to 35 mph, while 83 percent of sloped end treatment crashes occurred on roads with speed limits less than or equal to 35 mph. Sloped end treatment crashes occurred on disproportionately low-speed roads compared to non-sloped end treatment crashes. It should be noted that the distribution of all sloped end treatment installations by speed limit was not known as speed limits were only collected data for the sloped end treatments struck. However, additional crash characteristics were reviewed to determine if the two datasets were comparable.

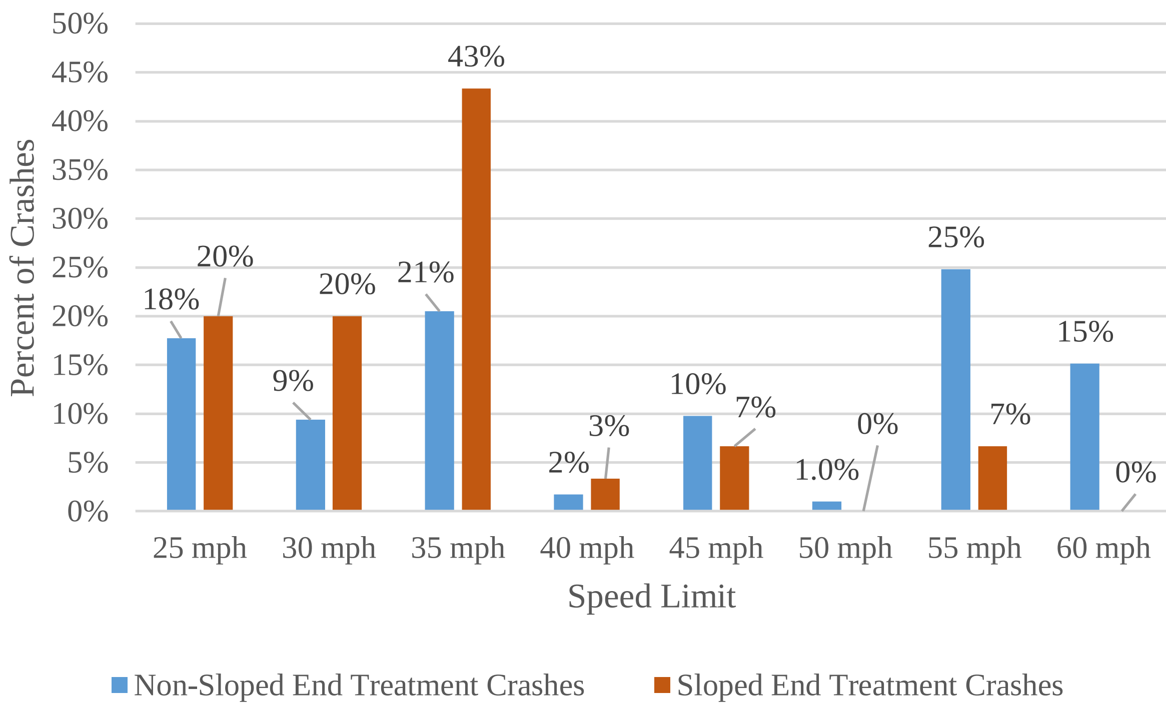


Figure 103. Percentage of Non-Sloped End Treatment and Sloped End Treatment Crashes – Speed Limit

5.2 Weather

Weather conditions for crashes were coded as one of: clear, cloudy, rain, snow, wind/blowing material, hail, fog/smoke, or other. Crashes denoted as "other" did not have additional information to clarify the circumstances. However, crashes with sloped ends were only recorded as one of: clear, cloudy, or rain. Table 45 shows crashes sorted by weather.

Table 45. Number of Crashes by Weather

Weather	Number of Crashes	Percent
Clear	1,040	44%
Cloudy	674	28%
Rain	249	10%
Snow	321	14%
Wind/Blowing Material	9	0.4%
Hail	50	2%
Fog/Smoke	12	0.5%
Other	21	0.9%
Total	**2,376**	**100%**

The weather was clear for 1,025 non-sloped end treatment crashes (44 percent), cloudy for 666 (28 percent), rain for 242 (10 percent), snow for 321 (14 percent), wind/blowing material for 9 (0.4 percent), hail for 50 (2 percent), fog/smoke for 12 (0.5 percent), and other for 21 (0.9 percent), as shown in Figure 104.

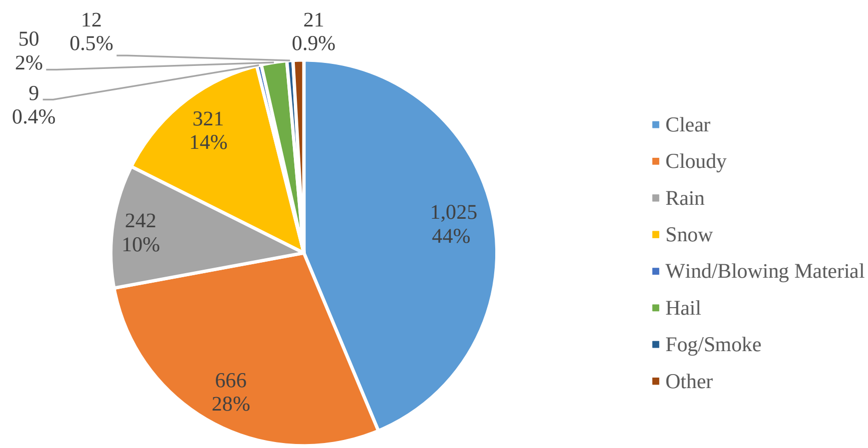


Figure 104. Non-Sloped End Treatment Crashes – Weather Conditions

A total of 15 sloped end treatment crashes (50 percent) occurred with clear weather, eight (27 percent) occurred with cloudy weather, and seven (23 percent) occurred with rain, as shown in Figure 105.

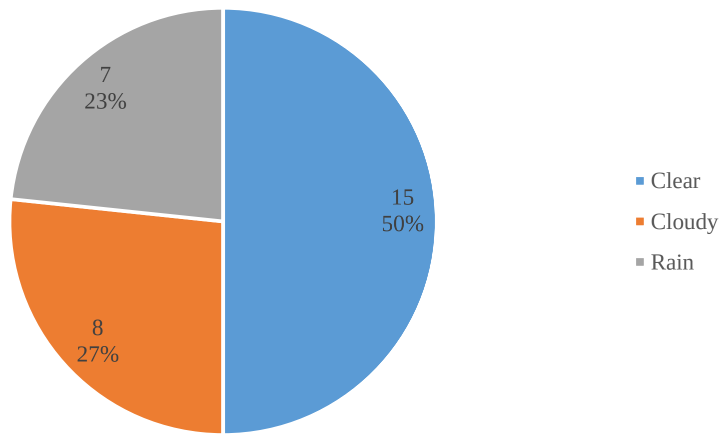


Figure 105. Sloped End Treatment Crashes – Weather Conditions

Percentages of non-sloped end treatment and sloped end treatment crashes within each weather condition category are shown in Figure 106. "Non-adverse" weather includes clear and cloudy conditions, which were present for 72 percent of non-sloped end treatment crashes and 77 percent of sloped end treatment crashes. "Adverse" conditions, which include rain, snow, wind/blowing material, hail, fog/smoke, and other, were present for 28 percent of non-sloped end treatment crashes and 23 percent of sloped end treatment crashes.

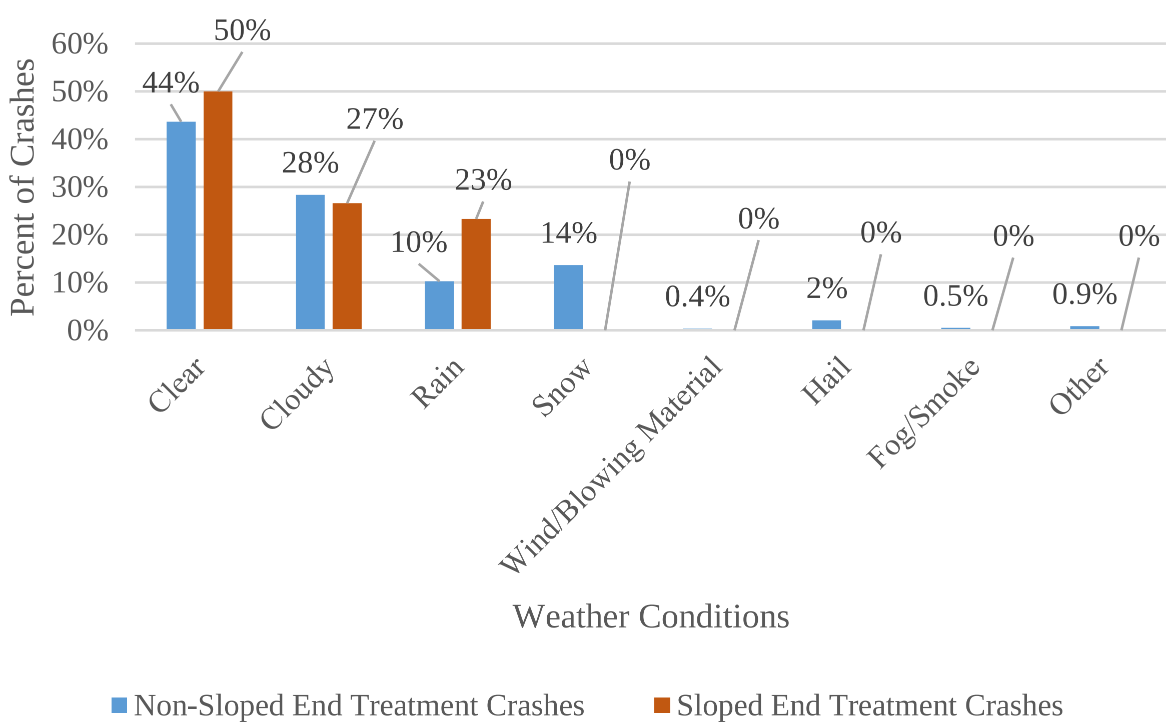


Figure 106. Percentage of Non-Sloped End Treatment and Sloped End Treatment Crashes – Weather Conditions

5.3 Road Conditions

Road conditions for sloped end treatment crashes include dry, wet, and slush. The non-sloped end treatment crashes featured these conditions in addition to snow, ice, mud/dirt/gravel/sand, water, and other. The other category includes other, unknown, and not reported conditions. Road conditions sorted by these conditions for all crashes are shown in Table 46.

Table 46. Number of Crashes by Road Conditions

Road Conditions	Number of Crashes	Percent
Dry	1,307	55%
Wet	411	17%
Slush	60	3%
Snow	335	14%
Ice	226	10%
Mud/Dirt/Gravel/Sand	8	0.3%
Water	3	0.1%
Other	26	1.1%
Total	**2,376**	**100%**

Road conditions were dry for 1,286 non-sloped end treatment crashes (55 percent), wet for 403 (17 percent), slush for 59 (3 percent), snow for 335 (14 percent), ice for 226 (10 percent), mud/dirt/gravel/sand for 8 (0.3 percent), water for 3 (0.1 percent), and other for 26 (1.1 percent), shown in Figure 107.

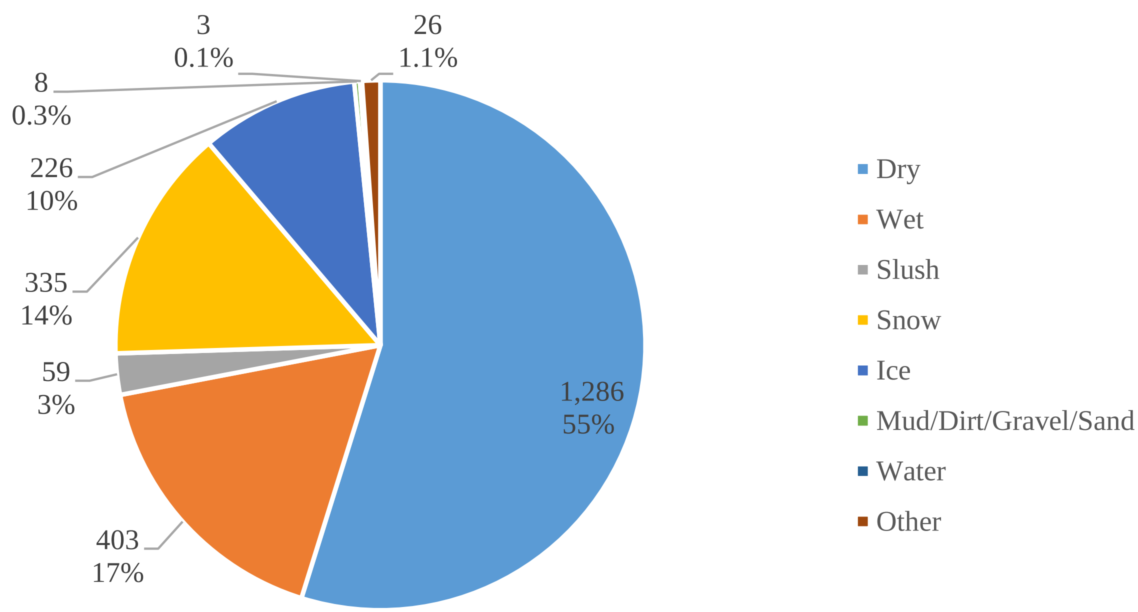


Figure 107. Non-Sloped End Treatment Crashes – Road Conditions

Road surface conditions for the sloped end treatment crashes are shown in Figure 108. A total of 21 sloped end crashes (70 percent) occurred on dry roads, 8 (27 percent) occurred on wet roads, and 1 (3 percent) occurred on slush.

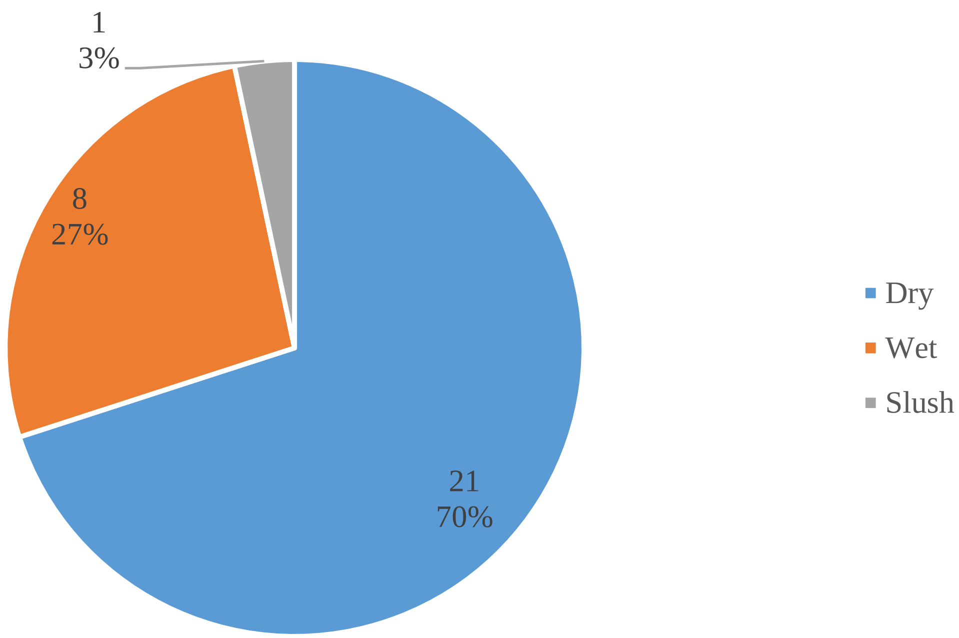


Figure 108. Sloped End Treatment Crashes – Road Conditions

Figure 109 shows a percentage comparison of non-sloped end treatment and sloped end treatment crashes within each road condition category. A higher percentage of sloped end treatment crashes occurred on dry and wet roads compared to non-sloped end treatment crashes. The same percentage of non-sloped end and sloped end treatment crashes occurred on roads with slush. Higher percentages of non-sloped end treatment crashes occurred on roads with snow, ice, mud/dirt/gravel/sand, water, and other conditions.

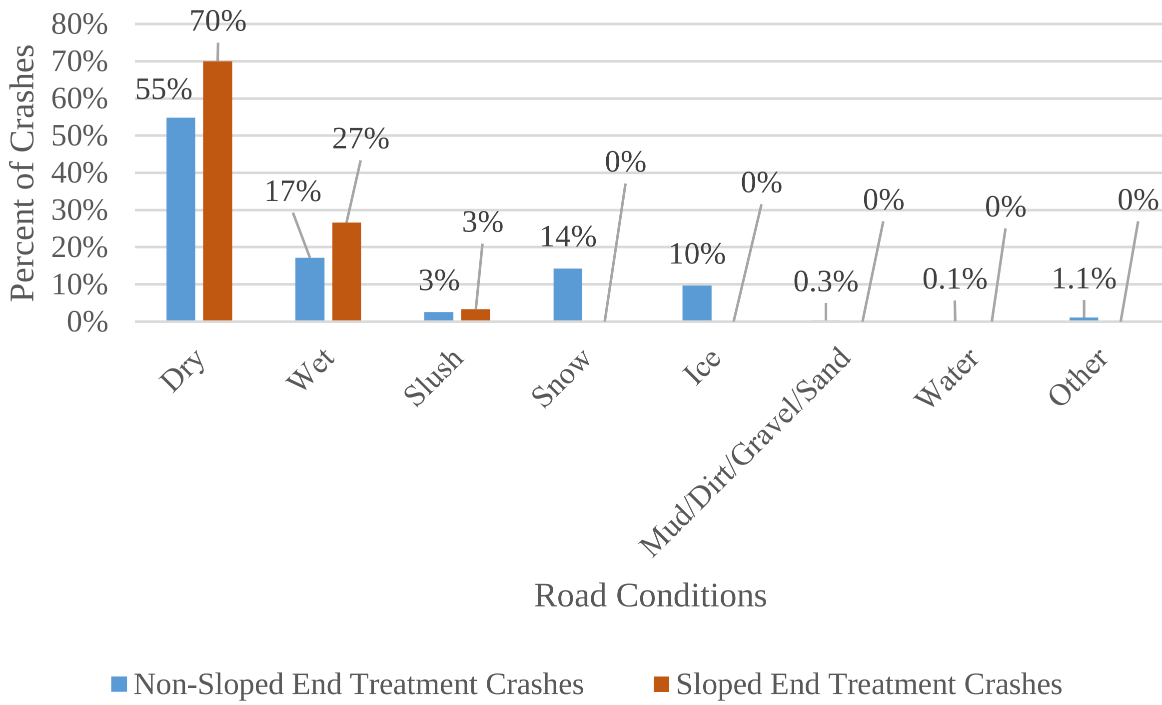


Figure 109. Percentage of Non-Sloped End Treatment and Sloped End Treatment Crashes – Road Conditions

5.4 Vehicle

Vehicles were categorized as one of four types: car, light truck, large vehicle, or other vehicle, as shown in Table 47. No subdivisions of vehicles types were provided for cars, although light truck vehicles were subdivided into classifications of pickup truck, sport utility vehicles (SUVs), and van. Therefore, the distribution of cars was plotted against light trucks, and the distribution of vehicle types within the light truck class were identified. Large vehicles include single unit trucks, tractor-trailers, motor homes, and buses. Other vehicles include farm tractor, motorcycle, mopeds, and unknown vehicles.

When crashes involved multiple vehicles, two vehicle statistics were collected. First, all vehicles involved in each crash were collected, resulting in “all vehicles” statistics. Then, for the second vehicle statistic, only one vehicle per crash was collected. For the sloped end treatment crashes, the vehicle which impacted the sloped end treatment was collected and, for most crashes, this was listed as unit one. For the non-sloped end treatment crashes, the vehicle labeled unit one was collected.

Table 47. Vehicle Classifications

Analysis Vehicle Classification	**Iowa Vehicle Categories**
Car	Passenger Car
Light Truck (SUV, Pickup, Van)	Sport Utility Vehicle Four-Tire Light Truck (Pick-Up) Cargo/Panel Van Passenger Van (seats < 9) Passenger Van (seats 9-15)
Large Vehicle	Single-Unit Truck (2-Axle, 6 Tire) Single-Unit Truck (>= 3 Axles) Tractor/Doubles Tractor/Semi-Trailer Truck Tractor (Bobtail) Truck/Trailer Motor Home/ RV Other Small Bus (seats 9-15) Other Bus (seats > 15)
Other	Farm Tractor Motorcycle Moped Not Reported Unknown

5.4.1 All Vehicles

For all crashes, a total of 2,968 vehicles were involved in the 2,376 crashes, as shown in Table 48. Vehicle ages for all vehicles involved in the non-sloped and sloped end treatment crashes are shown in Table 49. This was calculated by subtracting the vehicle year from the crash year, which resulted in a negative vehicle age if the vehicle was brand new at the time of the crash.

Table 48. Number of Crashes by All Vehicles

Vehicle	**Number of Crashes**	**Percent**
Cars	1,634	55%
Large Vehicles	131	4%
Other	91	3%
Light Trucks	1,112	38%
Total	**2,968**	**100%**

Table 49. Non-Sloped End and Sloped End Treatment Crashes – All Vehicle Ages

Vehicle Age	**Non-Sloped End Treatment Crashes**		**Sloped End Treatment Crashes**	
	Number	**Percent**	**Number**	**Percent**
-1	6	0.2%	0	0%
0	73	3%	0	0%
1	92	3%	4	13%
2	106	4%	0	0%
3	128	4%	0	0%
4	135	5%	0	0%
5	127	4%	2	7%
6	147	5%	1	3%
7	179	6%	2	7%
8	187	6%	0	0%
9	224	8%	3	10%
10	211	7%	3	10%
11	211	7%	2	7%
12	171	6%	1	3%
13	161	6%	4	13%
14	155	5%	1	3%
15	123	4%	1	3%
16	92	3%	3	10%
17	95	3%	1	3%
18	55	2%	0	0%
19	52	2%	0	0%
20	29	1.0%	1	3%
21	19	0.6%	0	0%
22	20	0.7%	1	3%
23	12	0.4%	0	0%
24	13	0.4%	0	0%
25	5	0.2%	0	0%
26	8	0.3%	1	3%
27	3	0.1%	0	0%
28	2	0.1%	0	0%
29	2	0.1%	0	0%
30	1	0.0%	0	0%
33	2	0.1%	0	0%
34	1	0.0%	0	0%
35	1	0.0%	0	0%
37	1	0.0%	0	0%
38	2	0.1%	0	0%
Unknown	86	3%	0	0%
Total	**2,937**	**100%**	**31**	**100%**

A total of 2,937 vehicles were involved in the 2,346 non-sloped end treatment crashes. Cars were involved in 1,619 crashes (55 percent), large vehicles were involved in 130 (4 percent), other vehicles were involved in 91 (3 percent), and light trucks were involved in 1,097 (38 percent). Recall that light trucks comprise pickup trucks, SUVs (which includes compact utility vehicles, or CUVs), and vans. A total of 557 (19 percent) vehicles in the light trucks category were SUVs, 376 (13 percent) were pickups, and 164 (6 percent) were vans, as shown in Figure 110.

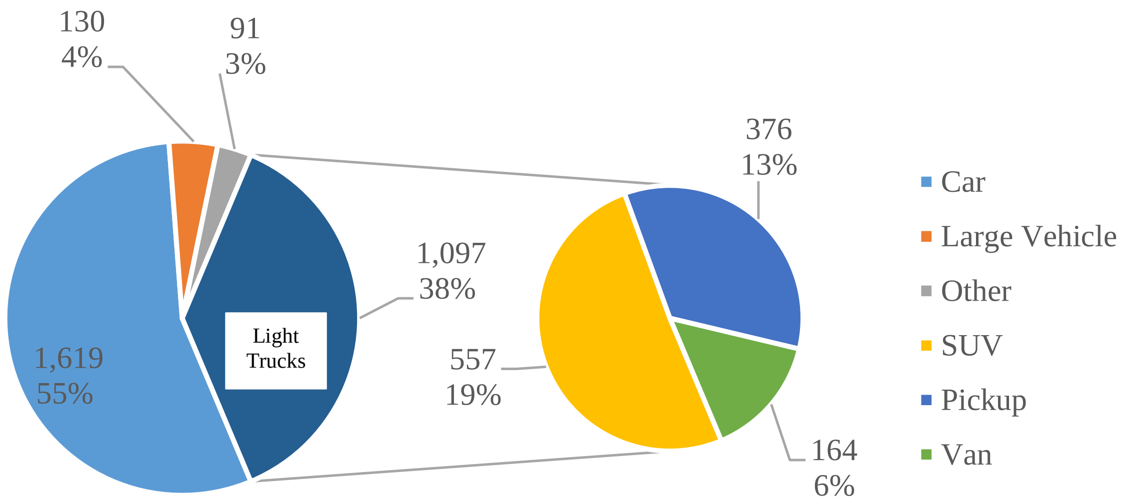


Figure 110. Non-Sloped End Treatment Crashes – All Vehicles

Vehicles involved in sloped end treatment crashes were collected and are shown in Figure 111. A total of 15 (48 percent) were cars, 1 (3 percent) was a large vehicle, 0 were other, and 15 (49 percent) were light trucks, comprising 7 (23 percent) SUVs, 5 (16 percent) pickups, and 3 (10 percent) vans.

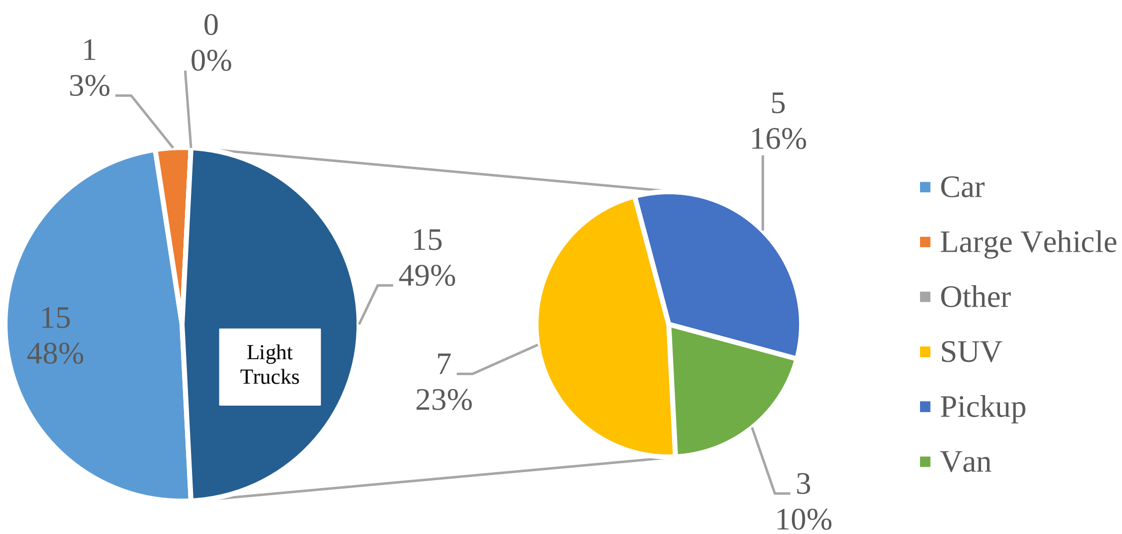


Figure 111. Sloped End Treatment Crashes – All Vehicles

Percentage comparisons of vehicles involved in non-sloped end treatment and sloped end treatment crashes are shown in Figure 112. A higher percentage of non-sloped end treatment crashes involved cars, large vehicles, and other vehicles. Sloped end treatment crashes involved a higher percentage of SUVs, pickups, and vans compared to non-sloped end treatment crashes.

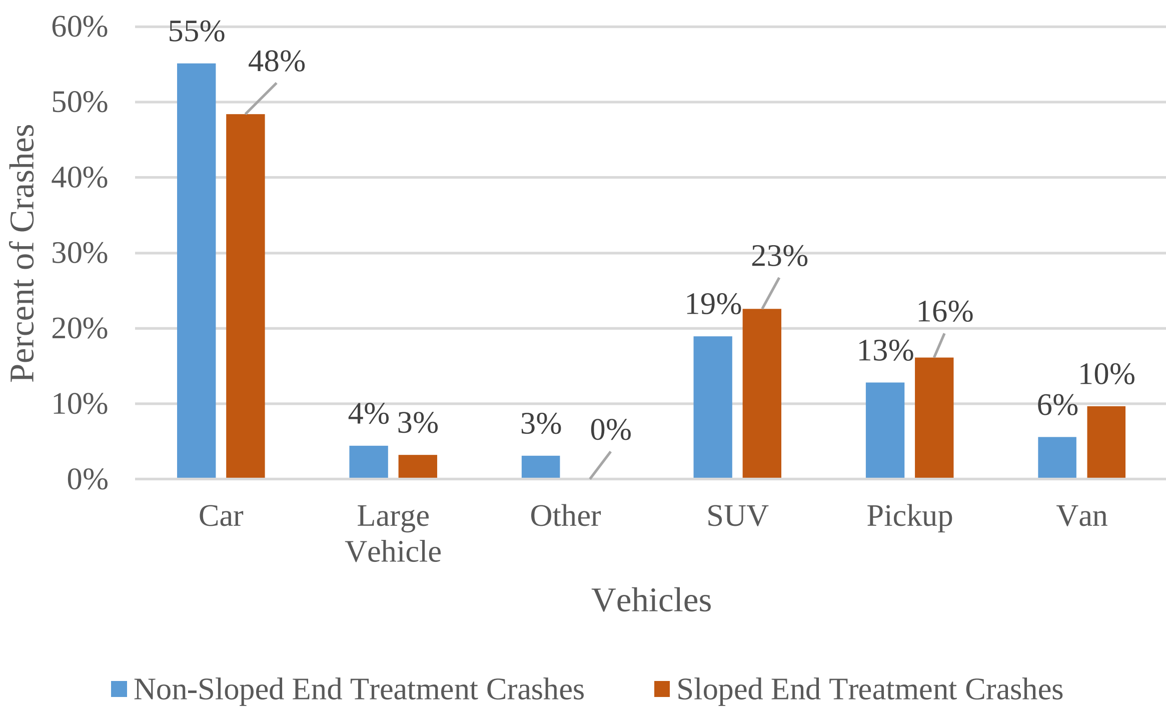


Figure 112. Percentage of Non-Sloped End Treatment and Sloped End Treatment Crashes – All Vehicles

5.4.2 Principal Vehicles

The second vehicle statistic involved only one vehicle per crash. For sloped end treatment crashes, this was the vehicle which impacted the treatment. For non-sloped end treatment crashes, this was the vehicle labeled "unit one" in the crash report. Principal vehicles for the crashes are shown in Table 50.

Table 50. Number of Crashes by Principal Vehicles

Vehicle	Number of Crashes	Percent
Cars	1,328	56%
Large Vehicles	97	4%
Other	69	3%
Light Trucks	882	37%
Total	**2,376**	**100%**

Figure 113 shows unit one vehicles involved in non-sloped end treatment crashes. A total of 1,313 crashes (56 percent) involved cars, 96 (4 percent) involved large vehicles, 69 (3 percent) involved other vehicles, and 868 (37 percent) involved light trucks. Within the light trucks category, 444 (19 percent) involved SUVs, 299 (13 percent) involved pickups, and 125 (5 percent) involved vans.

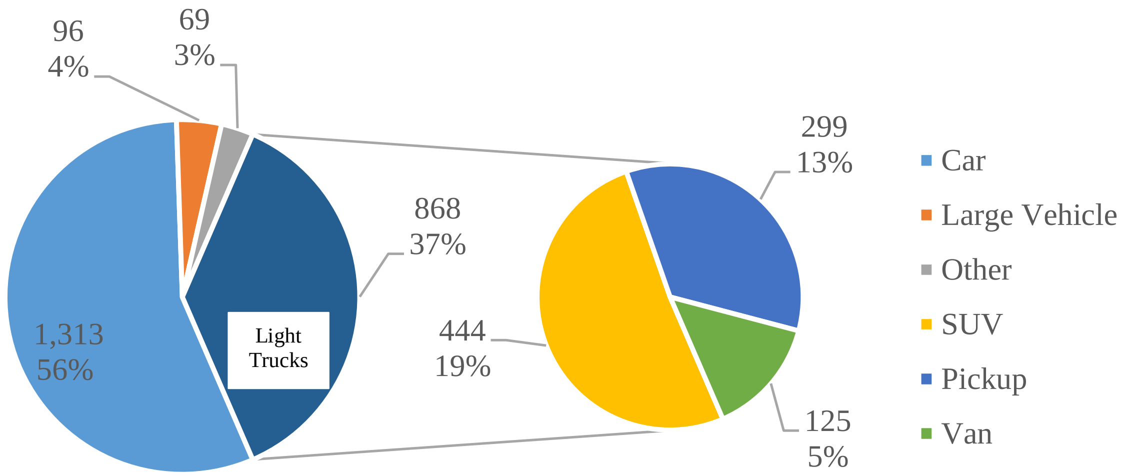


Figure 113. Non-Sloped End Treatment Crashes – Unit One Vehicles

A total of 30 vehicles impacted sloped end treatments in the sloped end treatment crash data set. Fifteen vehicles (50 percent) were cars, 1 (3 percent) was a large vehicle, 0 (0 percent) were other, and 14 (47 percent) were light trucks, shown in Figure 114. For light trucks, 7 (23 percent) were SUVs, 4 (14 percent) were pickups, and 3 (10 percent) were vans.

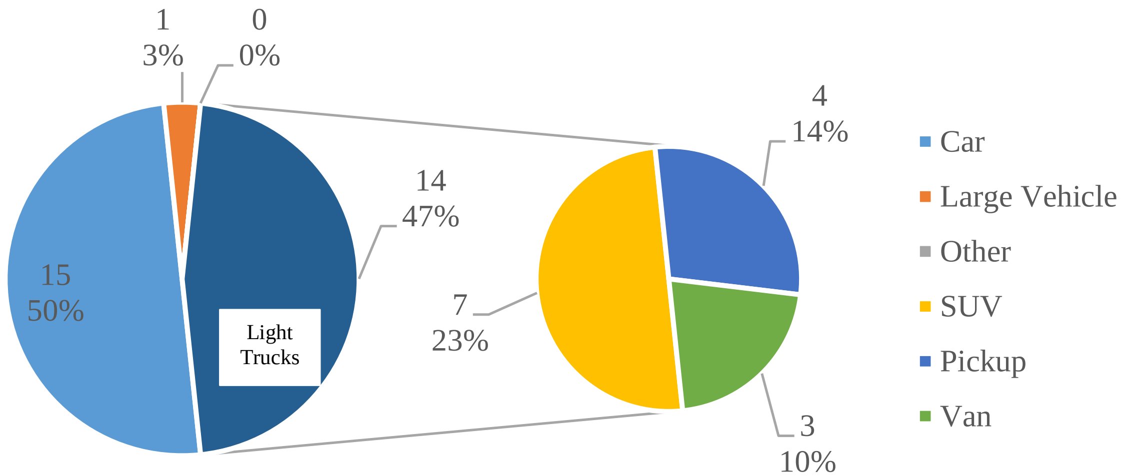


Figure 114. Sloped End Treatment Crashes – Impact Vehicles

Percentage of principal vehicles involved in non-sloped end treatment and sloped end treatment crashes are shown in Figure 115. A higher percentage of non-sloped end treatment crashes involved cars, large vehicles, and other vehicles compared to sloped end treatment crashes. A higher percentage of sloped end treatment crashes involved light trucks, which included SUVs, pickups, and vans.

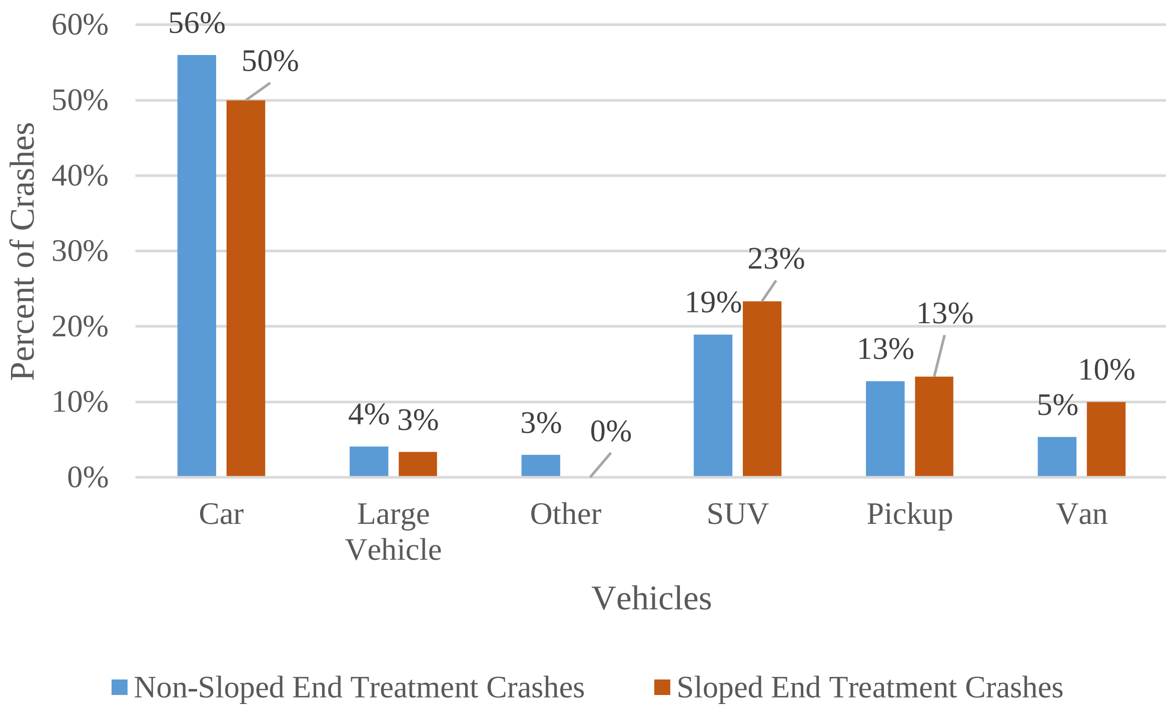


Figure 115. Percentage of Non-Sloped End Treatment and Sloped End Treatment Crashes – Principal Vehicles

5.5 Discussion

A comparison of speed limit distributions indicated there were differences between sloped end treatment and non-sloped end treatment crashes. Crashes with sloped end treatments overwhelmingly occurred on roads with speed limits less than or equal to 35 mph, a total of 25 out of the 30 sloped end treatment crashes (83 percent). In contrast, 48 percent of non-sloped end treatment crashes occurred on roads with speed limits of 35 mph or less. Recall that only crashes on similar roads and in the vicinity of sloped end treatments were selected as baseline crashes; this suggests that other fixed object crashes were less likely to occur on lower-speed limit roads. Results may suggest that crashes involving fixed objects located far from the roadway require a higher vehicle initial speed and larger lateral offset for a crash to occur. However, this explanation alone does not indicate why so few sloped end treatment crashes occurred on higher-speed limit roads. Bridge rails would have a comparable lateral offset from the travel way, and other features, such as utility poles, trees, fire hydrants, and utility boxes were more likely to be located farther away from the roadway based on results from the visual survey of SET locations. Results suggest that, on average, impact speeds for sloped end treatment crashes were likely lower than for non-sloped end treatment, fixed object crashes. However, speed limits are only a surrogate measure of approximate speed, and they do not define the actual vehicle travel speeds [73]. Furthermore, no estimated actual speeds were recorded in the crash database.

Weather and road conditions were very similar for non-sloped and sloped end treatment crashes. Results were consistent with other ISPE studies regarding weather pattern distributions associated with crashes in Midwestern Plains states [11]. More crashes occurred on dry roads and in clear conditions than other road and weather conditions, which have been associated with increased average travel speeds previously, and therefore higher average crash severities [11].

Few differences were observed between the vehicle distributions for non-sloped end treatment and sloped end treatment crashes. This suggests that the class or make of the vehicle was not strongly related to the type of roadside fixed object crash that occurred.

The proximity-based, fixed-object baseline crash data (non-sloped end treatment crashes) contained information from many different types of fixed objects, and it was not intended to offer a comparison of sloped end treatments vs. other end treatment options. Instead, the data was investigated to determine if crashes had similar attributes for non-sloped end treatment and sloped end treatment crashes in similar locations (geography) with similar ADT, exposure, crash data evaluation duration, and weather patterns. Results confirmed that the baseline crashes had similar attributes as sloped end treatment crashes, although baseline crashes occurred on higher-speed limit roads and were therefore assumed to have higher average crash impact speeds.

Therefore, an injury analysis was conducted comparing results of the sloped end treatment crashes to the non-sloped end treatment fixed object crashes and is discussed in the next chapter.

6 INJURIES AND CRASH COSTS

After determining that the non-sloped and sloped end treatment crashes were comparable, injuries and crash costs from both datasets were computed and analyzed.

6.1 Injuries

Injuries reported on the Iowa DOT Accident Report Form, as shown in Appendix E, include property damage only (PDO), unknown, possible, minor, major, and fatal, which was labeled the "Iowa Injury Classification Scale." To compare injury statistics collected for sloped end treatments to other ISPE studies and other state crash data, the Iowa injury classification scale was converted to the KABCO injury scale, which is shown in Table 51. Therefore, two injury classifications were analyzed and compared for non-sloped end and sloped end treatment crashes.

The Iowa injury classification scale categories were classified as approximated KABCO injury categories, as shown in Table 51. The Iowa injury classification of "minor" is ambiguous and could fit into either C or B injury categories within the KABCO scale. Researchers estimated that approximately three times as many C-injuries would occur as B-injuries; therefore, the "minor" injuries were distributed as 75 percent to C-injury and 25 percent to B-injury.

Table 51. Injury Classification – KABCO and Iowa

KABCO Injury Classification	Iowa Injury Classification
O (no injury)	PDO + Unknown
C (possible injury)	(0.75*Minor) + Possible
B (non-incapacitating injury)	0.25*Minor
A (incapacitating injury)	Major
K (fatal)	Fatal

Furthermore, some crashes resulted in multiple injuries. Therefore, two injury statistics were collected: all injuries per crash and most severe injury per crash. In total, four injury statistics were collected: (1) all injuries per crash by the Iowa injury classification scale; (2) most severe injury per crash by the Iowa injury classification scale; (3) all injuries per crash by the KABCO injury classification scale; and (4) most severe injury per crash by the KABCO injury classification scale.

6.1.1 All Injuries – Iowa Injury Classification Scale

All injuries for all non-sloped and sloped end treatment crashes according to the Iowa injury classification scale are shown in Table 52. A total of 2,589 injurie severities were identified in conjunction with 2,376 crashes. Non-sloped end treatment crashes are shown in Figure 116, and sloped end treatment crashes are shown in Figure 117.

Table 52. Number of Total Injuries by Iowa Injury Classification Scale

Injuries	Injury Severity	Percent
No Injury (PDO)	1,549	60%
Possible/Unknown	575	22%
Minor	359	14%
Major	82	3%
Fatal	24	0.9%
Total	**2,589**	**100%**

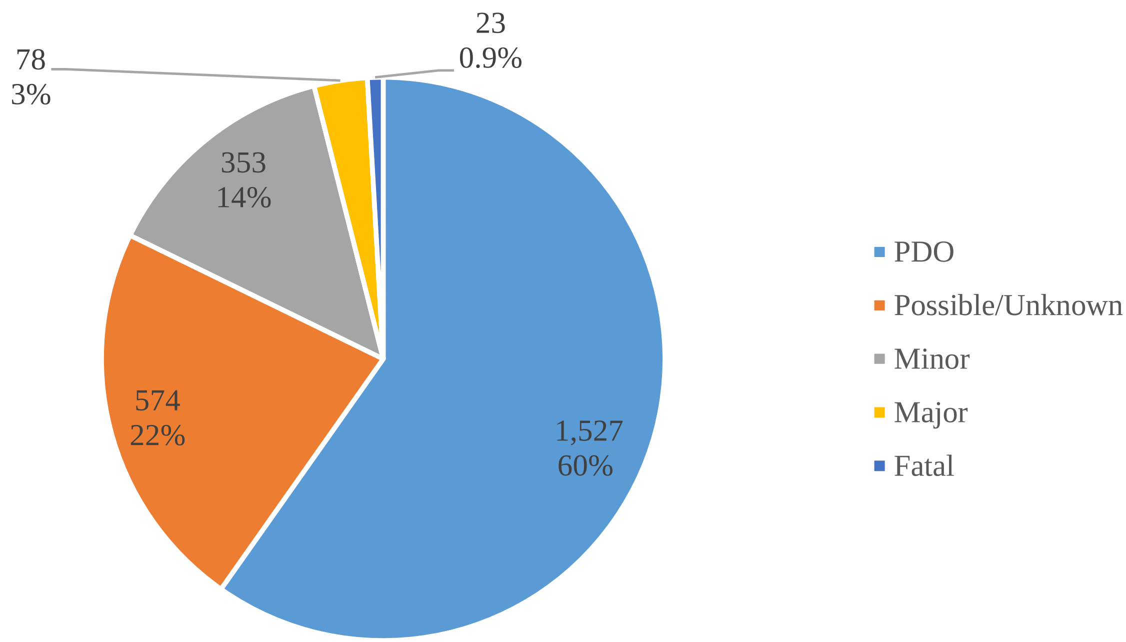


Figure 116. Non-Sloped End Treatment Crashes – All Injuries by Iowa Scale

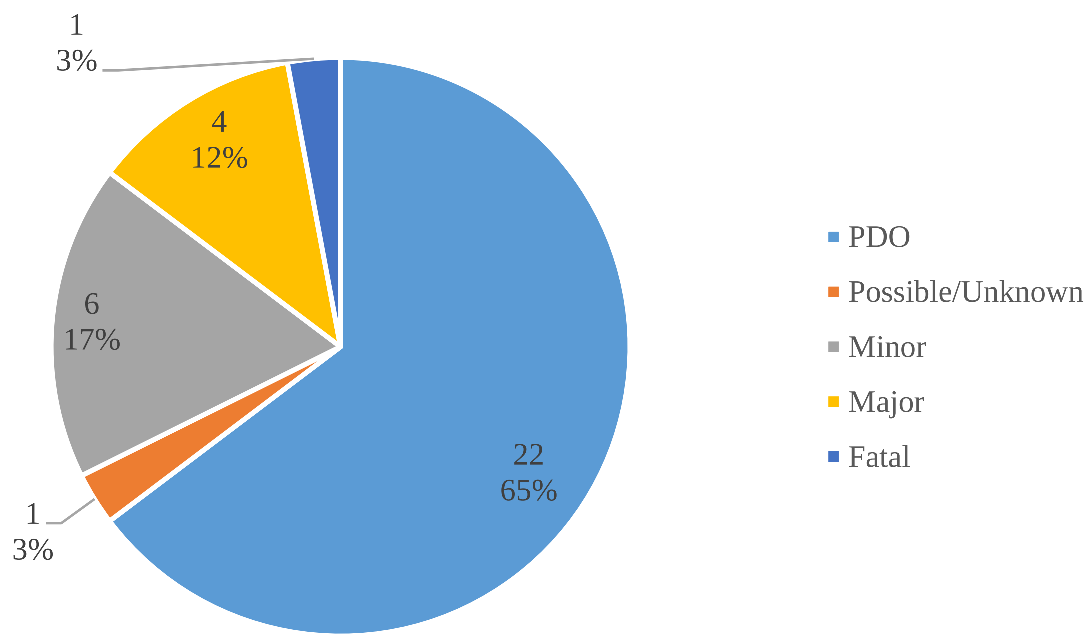


Figure 117. Sloped End Treatment Crashes – All Injuries by Iowa Scale

6.1.2 Most Severe Injury– Iowa Injury Classification Scale

For the 2,376 crashes, the most severe injury per crash was collected and are shown in Table 53. Non-sloped end treatment crashes are shown in Figure 118, and sloped end treatment crashes are shown in Figure 119. Note that it is unknown if the most severe injury resulted from impacting the sloped end treatment or as a result of a separate event in the crash sequence of events.

Table 53. Number of Most Severe Injuries by Iowa Injury Classification Scale

Injuries	Number of Injuries	Percent
PDO	1,549	65%
Possible/Unknown	441	19%
Minor	294	12%
Major	71	3%
Fatal	21	0.9%
Total	**2,376**	**100%**

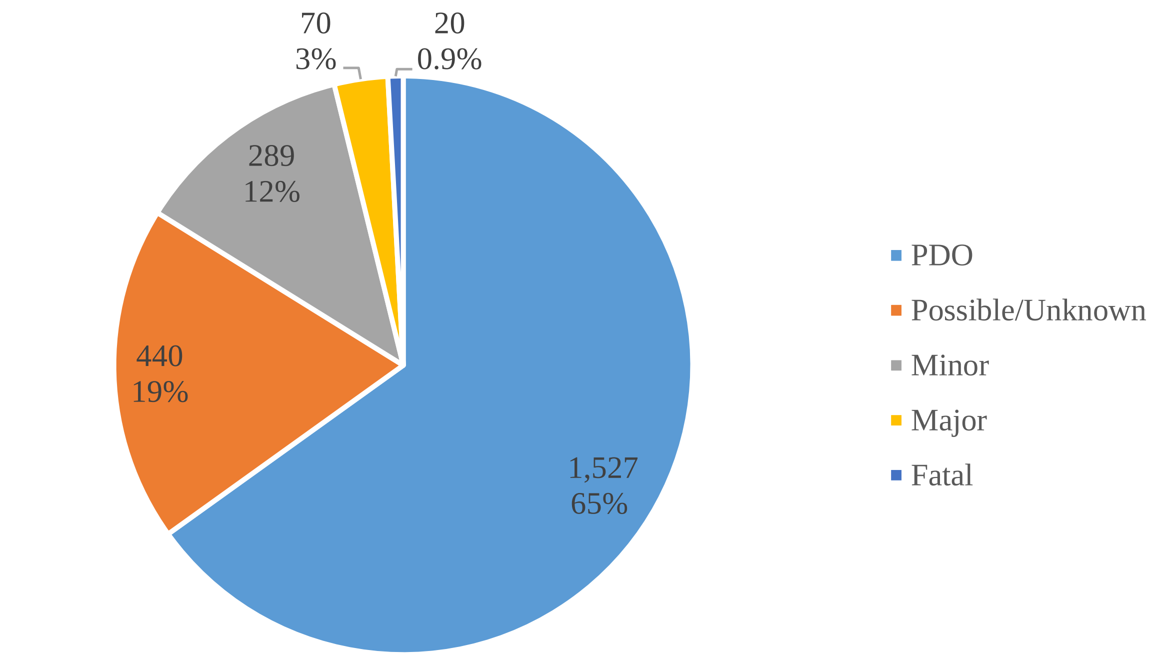


Figure 118. Non-Sloped End Treatment Crashes – Most Severe Injury by Iowa Scale

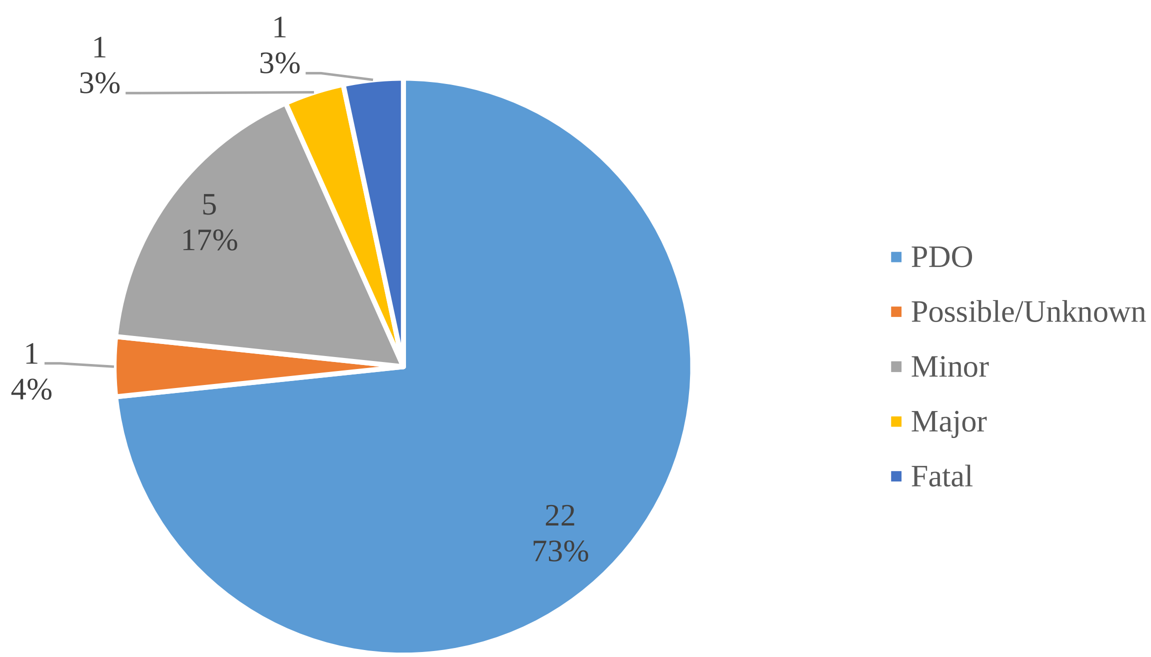


Figure 119. Sloped End Treatment Crashes – Most Severe Injury by Iowa Scale

6.1.3 All Injuries – KABCO Injury Classification Scale

A total of 2,589 injuries resulted from all non-sloped and sloped end treatment crashes, as shown in Table 54. The non-sloped end treatment and sloped end treatment injuries are shown in Figures 120 and 121, respectively.

Table 54. Distribution of Total Injuries (Estimated) by KABCO Injury Classification Scale

Injuries	Number of Injuries	Percent
O	1,610	62%
C	783	30%
B	90	4%
A	82	3%
K	24	0.9%
Total	**2,589**	**100%**

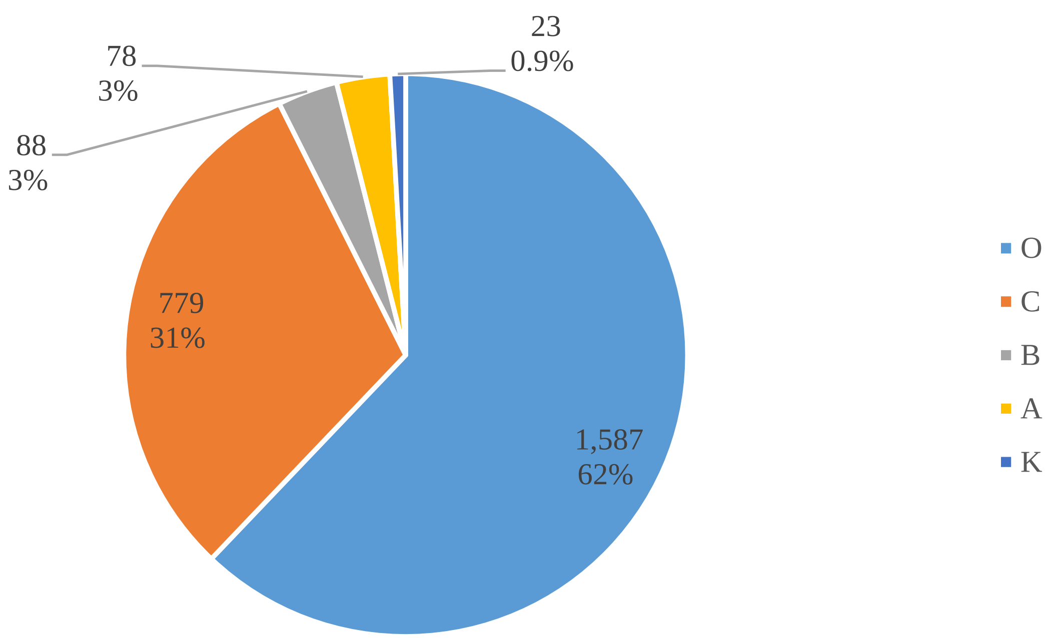


Figure 120. Non-Sloped End Treatment Crashes – All Injuries by KABCO Scale

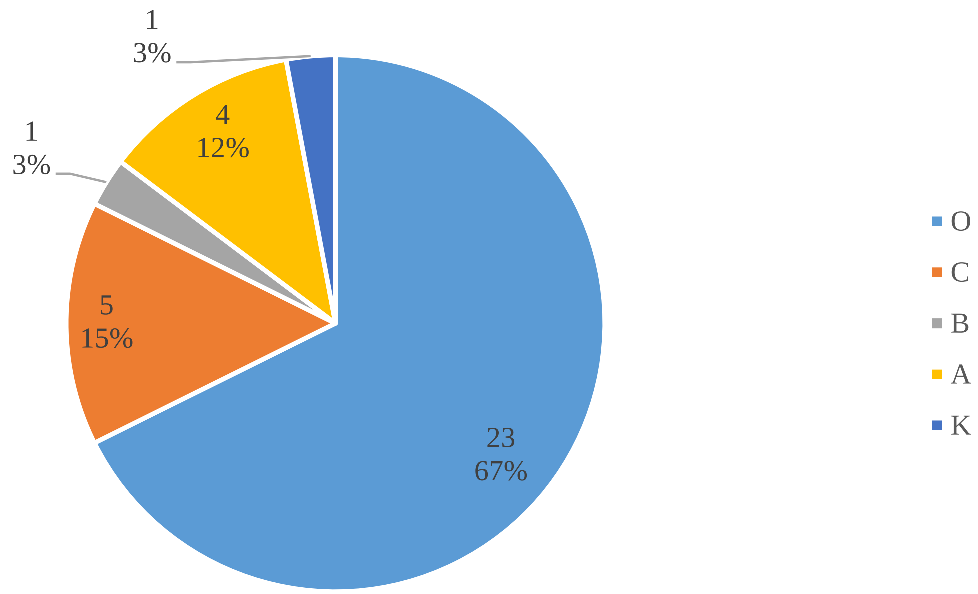


Figure 121. Sloped End Treatment Crashes – All Injuries by KABCO Scale

6.1.4 Most Severe Injury – KABCO Injury Classification Scale

The most severe injury per crash by the KABCO injury classification scale is shown in Table 55. The most severe injury for non-sloped end treatment crashes is shown in Figure 122 and for sloped end treatment crashes is shown in Figure 123. Note that when severe injuries or fatalities occurred, the principal event in the sequence of events which caused the severe outcome was not specifically identified.

Table 55. Number of Most Severe Injuries by KABCO Injury Classification Scale

Injuries	Number of Injuries	Percent
O	1,601	67%
C	610	26%
B	73	3%
A	71	3%
K	21	0.9%
Total	**2,376**	**100%**

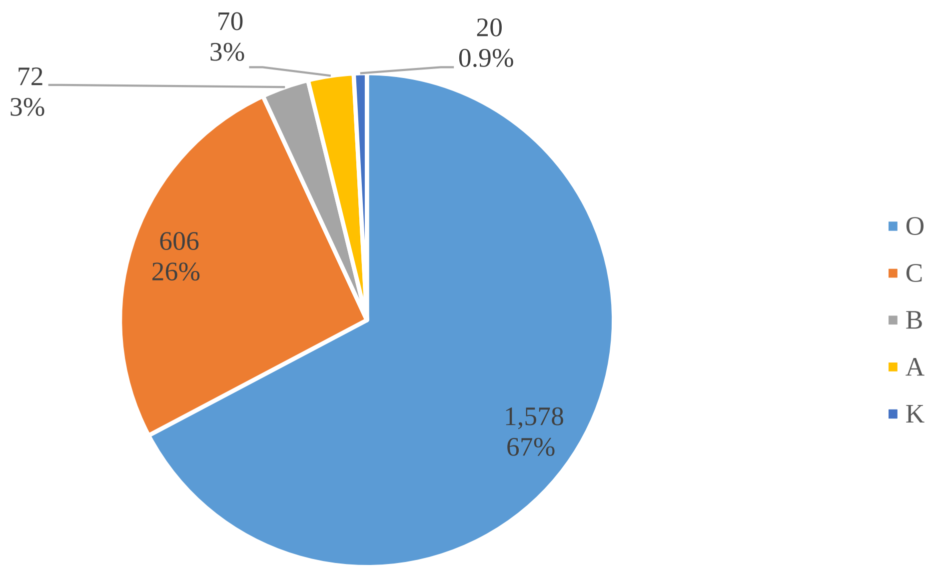


Figure 122. Non-Sloped End Treatment Crashes – Most Severe Injury by KABCO Scale

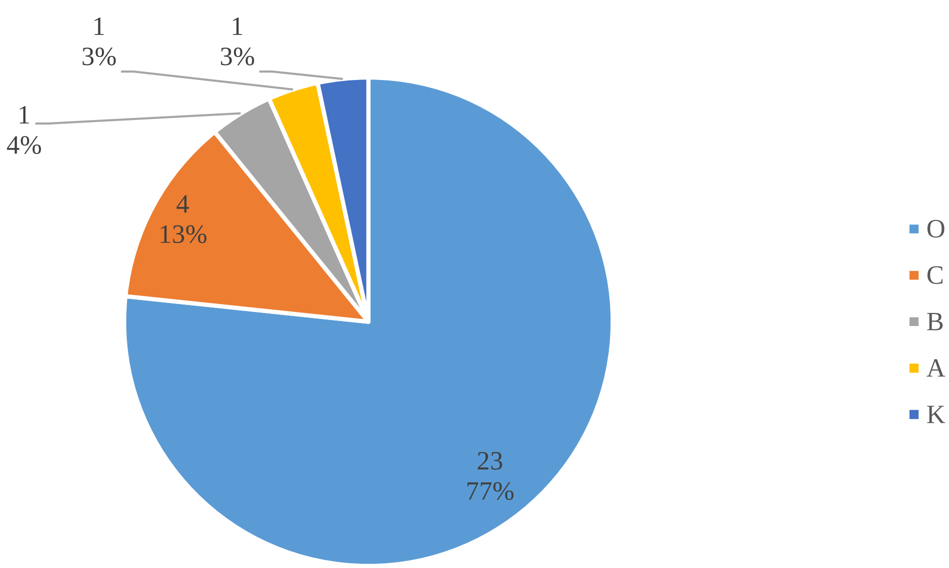


Figure 123. Sloped End Treatment Crashes – Most Severe Injury by KABCO Scale

6.2 Crash Cost

Iowa DOT classified each occupant's injury in a crash as one of: PDO, unknown, possible, minor, major, or fatal. Injury severity estimation can be subjective, as responding officers which file crash reports are rarely trained in medical injury diagnoses. Most injury cost-effectiveness analyses compare a distribution of injuries based on a lumped, relative scale. Most hospitals classify injury severity using a tiered classification system, such as Maximum Abbreviated Injury Scale (MAIS) [74]. Many state DOTs utilized a different subjective injury scale, KABCO: K=killed; A=severe injury; B=moderate injury; C=possible or minor injury; and O=PDO. Due to the infrequency of severe crashes, in general, K-injuries are either recorded as “dead on arrival” (DOA), having expired within the investigation period of a crash (typically 30 days), or an injury which is classified as MAIS=6. Likewise, severe or A-injuries are often associated with any MAIS rating of 3, 4, or 5.

Using injury classifications, average crash costs can be calculated by estimating lifetime tax earnings, average age of crashed victims, cost of emergency response, total medical expenses over duration of recover or burial, and suffering for family and friends of injured people. The FHWA periodically publishes a guide to estimate the Value of a Statistical Life (VSL) [75], which can be linked to the KABCO injury scale using a transportation infrastructure generating economic recovery (TIGER) grant process [76].

Because Iowa does not identify injuries on a KABCO scale, Iowa DOT supplied a version of FHWA’s VSL, which was specific to Iowa’s injury designations. Therefore, crash costs for the most severe injury per crash by the Iowa injury classification scale for non-sloped end and sloped end treatment crashes were calculated using Iowa DOT’s VSL scale, as shown in Table 56.

Over the ten-year evaluation period and using a 0 percent discount rate, the total crash cost of the non-sloped end treatment crashes was $158,234,800, with an average cost of $67,449 per crash. In contrast, the total crash cost of sloped end treatment crashes was $5,347,800, with an average cost of $178,260 per crash.

Table 56. Crash Costs for Non-Sloped End Treatment and Sloped End Treatment Crashes

Crash Category	**Injury**	**VSL**	**Crashes**	**Cost**
Non-Sloped End Treatment Crashes	PDO	$7,400	1,527	$11,299,800
	Possible/Unknown	$35,000	440	$15,400,000
	Minor	$65,000	289	$18,785,000
	Major	$325,000	70	$22,750,000
	Fatal	$4,500,000	20	$90,000,000
	Total	-	2,346	$158,234,800
	Average Cost per Crash			**$67,449**
Sloped End Treatment Crashes	PDO	$7,400	22	$162,800
	Possible/Unknown	$35,000	1	$35,000
	Minor	$65,000	5	$325,000
	Major	$325,000	1	$325,000
	Fatal	$4,500,000	1	$4,500,000
	Total	-	30	$5,347,800
	Average Cost per Crash			**$178,260**

6.3 Discussion

Sloped end treatment crashes showed a higher percentage of PDO injuries, as compared to non-sloped end treatment crashes. However, sloped end treatments had a larger percentage of A+K crashes compared to non-sloped end treatment crashes, 6 percent to 3.9 percent, respectively. As shown in Chapter 5, sloped end treatment crashes occurred frequently on lower speed roads, so speed limit was compared to injuries to determine if there was any correlation.

6.3.1 Indiana Speed Limit vs. Injury

A study was conducted in Indiana in 2008 which evaluated injury levels observed at certain speed limits [77]. Crash data utilized for this study included all crashes that were investigated by the Indiana police in 2004, for a total of 204,382 accidents. It should be noted that 28.6 percent of these crashes were single-vehicle accidents. The remaining crashes involved multiple vehicles, which may or may not involve striking a fixed object. Therefore, the statistics do not perfectly correlate to data presented for this ISPE of concrete sloped end treatments. However, the Indiana speed limit vs. injury data is presented to illustrate the injury levels associated with lower-speed crashes, with no information regarding type of accident.

Statistics for four speed limit ranges were collected: (1) 30 mph or less; (2) 35 to 50 mph; (3) 55 to 60 mph; and (4) 65 mph. Injuries were sorted into three categories: PDO, injury, and fatality. For the year 2004, the percentage of injuries seen at the four speed limit ranges are shown in Table 57. The lowest percentage of fatal crashes occurred on roadways with speed limits of 30 mph or less. The next lowest percentage of fatal crashes occurred on roadways with speed limits between 35 and 50 mph. Crashes occurring on roadways with speed limits of 55 mph or higher resulted in the highest percentages of fatalities.

Furthermore, crashes which occurred in 30 mph or less zones resulted in a lower percentage of injury crashes and a higher percentage of PDO crashes, as compared to those occurring in 35 to 50 mph zones.

Table 57. Indiana Injury Level Percentages vs. Speed Limit [77]

Speed Limit	Injury Level		
	PDO	Injury	Fatality
65 mph	81.7%	17.7%	0.6%
55 to 60 mph	76.7%	22.3%	1.1%
35 to 50 mph	74.5%	25.5%	0.4%
30 mph or less	80.6%	19.2%	0.2%

6.3.2 Iowa Sloped End Treatment Crashes

A higher percentage of sloped end treatment crashes resulted in A+K injuries as compared to non-sloped end treatment crashes. Conversely, a higher percentage of sloped end treatment crashes occurred on lower-speed roadways as compared to non-sloped end treatment crashes. In general, injury severity increases as speed increases, thus the injuries sustained by occupants of vehicles encountering sloped end treatments at low speeds was cause for concern. Therefore, it was concluded that sloped end treatments are associated with greater risk of injury including severe injury than other fixed objects located near sloped end treatments which were struck by vehicles.

7 ANALYSIS OF SLOPED END TREATMENT CRASHES

Sloped end treatments were involved in 30 crashes between 2008 and 2017 across the state of Iowa. Additional analysis was performed on the sloped end treatment crashes, including crash outcome, vehicle action before the crash, sloped end treatment location and geometry, type of road, AADT, traffic controls, and involvement of alcohol. These crash characteristics were examined to further understand the sloped end treatment crashes and determine contributing factors.

7.1 Crash Outcome

Crashes which occurred with sloped end treatments were annotated based on post-crash vehicle behavior: redirection or climbing/overriding the sloped end treatment. Crashes with narratives or scene diagrams, which showed oblique impacts along the side of the sloped end treatments, were labeled as "redirection," whereas trajectory behind or on top of the barrier was noted as "climbed."

Post-crash behavior for sloped end treatment crashes is shown in Figures 124 through 126. A total of eight crashes (27 percent) did not describe the vehicle action or ending position of the vehicle; therefore, these crashes were marked as "unknown." Four of the 30 crashes (13 percent) resulted in vehicle redirection after impacting the sloped end treatment. Redirection was relatively infrequent due to the short longitudinal length of sloped end treatments. Vehicles climbed the sloped end treatment in 18 of the 30 crashes (60 percent).

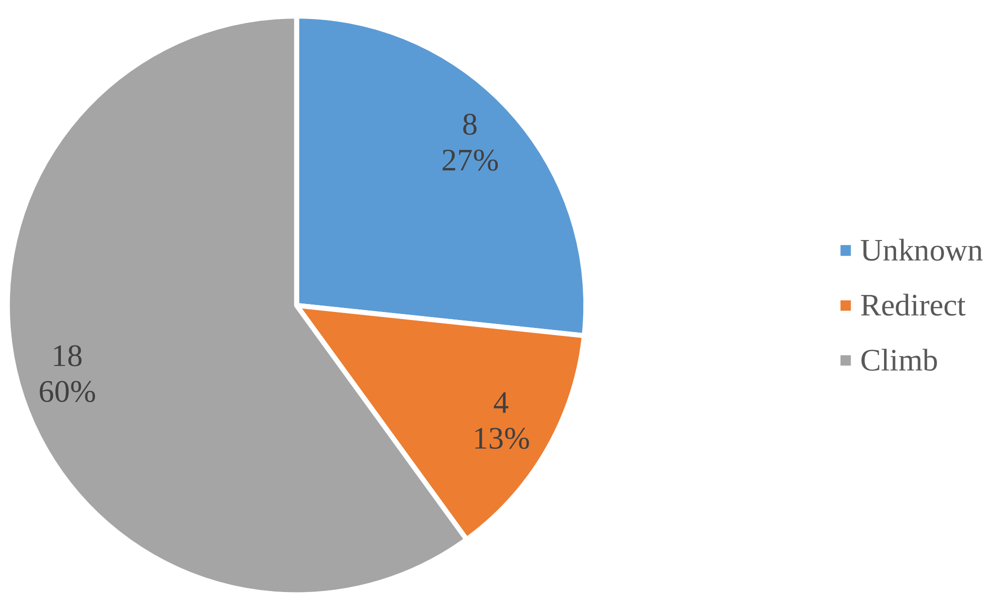


Figure 124. Post-Crash Behavior for Sloped End Treatment Crashes – Unknown, Redirect, or Climb

Additionally, researchers noted whether an impacting vehicle remained upright or rolled over. A rollover was defined as a least a one-quarter turn of the impacting vehicle around its longitudinal axis. When the outcome of the crash could not be determined, the crash was denoted with "unknown" and treated similarly to a "redirection" crash. It is likely that some crashes with an "unknown" outcome experienced either rollover or climbing the sloped end treatment; thus, the outcome analysis may have been skewed in favor of a less severe outcome as the unknown cases were not accounted for.

Vehicle rollover post-crash is shown in Figure 125. The rollover status of eight vehicles (27 percent) was unknown, and nine vehicles (30 percent) did not rollover after impacting a sloped end treatment. Thirteen vehicles were determined to have rolled over (43 percent), four of which resulted from redirection crashes and nine resulted from climbing crashes, as shown in Table 58.

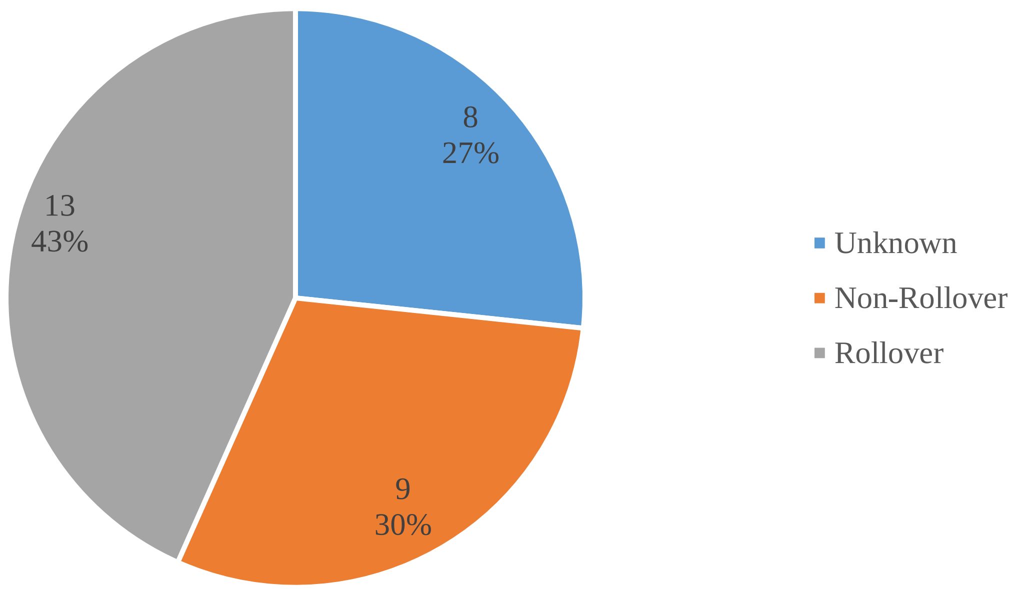


Figure 125. Post-Crash Behavior for Sloped End Treatment Crashes – Unknown, Non-Rollover, or Rollover

Vehicle final resting location relative to the sloped end treatment was also annotated. Options for final rest consisted of "traffic side," "non-traffic side," and "top of barrier." Final rest locations on the non-traffic side of the barrier were strongly influenced by features on the back sides of the bridge rails, such as vertical drop-offs, sidewalks, access ways, or other roads when medians were used to divide road travel directions.

Vehicle final resting location was unknown for 8 of the 30 crashes (27 percent), on the traffic side for 10 crashes (33 percent), on the non-traffic side for 9 crashes (30 percent), and on top of the barrier for 3 crashes (10 percent), as shown in Figure 126.

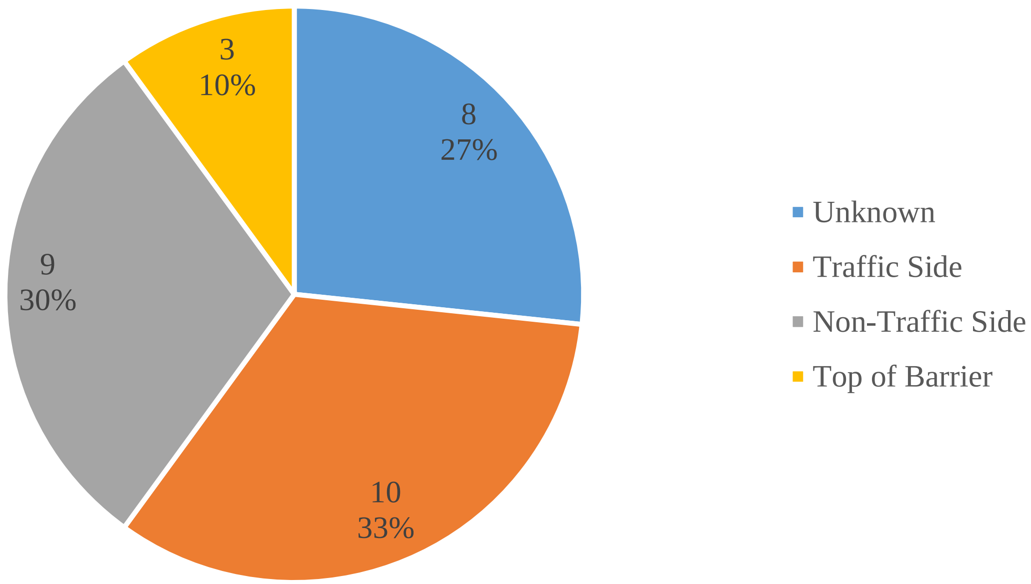


Figure 126. Vehicle Final Resting Location for Sloped End Treatment Crashes

A summary of the crash outcomes compared to the most severe injury sustained during the crash is shown in Table 58. A total of 23 of the 30 sloped end crashes resulted in O injuries (77 percent), as shown in Figure 127. Four of the 30 sloped end treatment crashes resulted in C injuries (13 percent), as shown in Figure 128. The remaining 3 crashes resulted in 1 B injury, 1 A injury, and 1 K injury, as shown in Figures 129, 130, and 131, respectively.

Table 58. Sloped End Treatment Crashes – Most Severe Injury by KABCO Classification vs. Outcome

Outcome			**Injury**					
			O	**C**	**B**	**A**	**K**	**Total**
Unknown			7	1	0	0	0	**8**
Redirect	Non-Rollover	End on Traffic Side	0	0	0	0	0	**0**
		End on Non-Traffic Side	0	0	0	0	0	**0**
		End on Top of Barrier	0	0	0	0	0	**0**
	Rollover	End on Traffic Side	4	0	0	0	0	**4**
		End on Non-Traffic Side	0	0	0	0	0	**0**
		End on Top of Barrier	0	0	0	0	0	**0**
Climb	Non-Rollover	End on Traffic Side	1	0	0	0	0	**1**
		End on Non-Traffic Side	3	1	0	1	0	**5**
		End on Top of Barrier	3	0	0	0	0	**3**
	Rollover	End on Traffic Side	2	2	1	0	0	**5**
		End on Non-Traffic Side	3	0	0	0	1	**4**
		End on Top of Barrier	0	0	0	0	0	**0**
Total			**23**	**4**	**1**	**1**	**1**	**30**

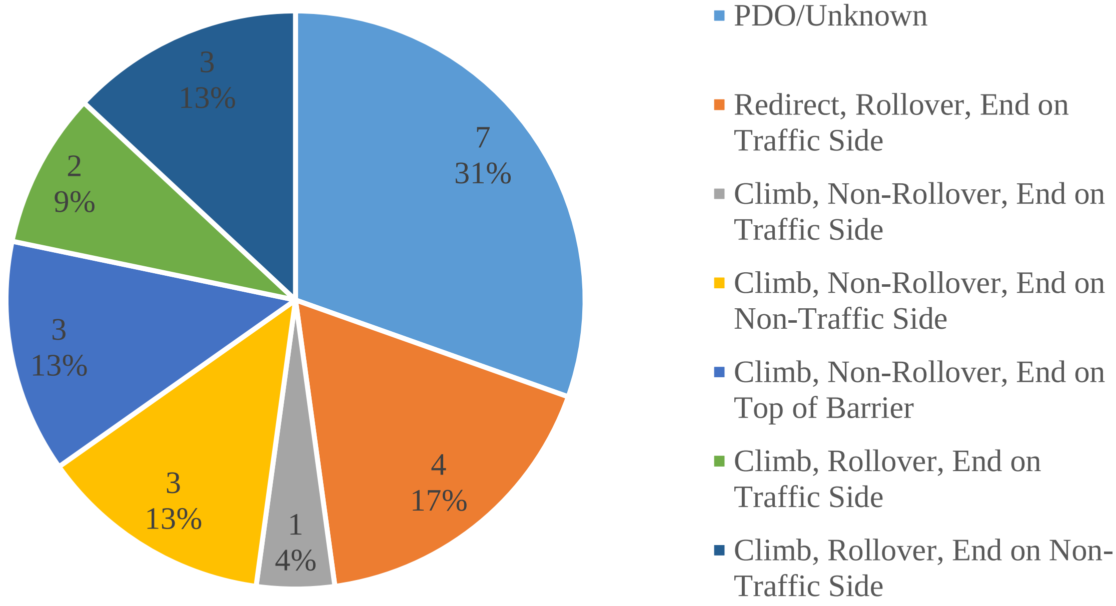


Figure 127. Crash Outcomes for O Injury Crashes

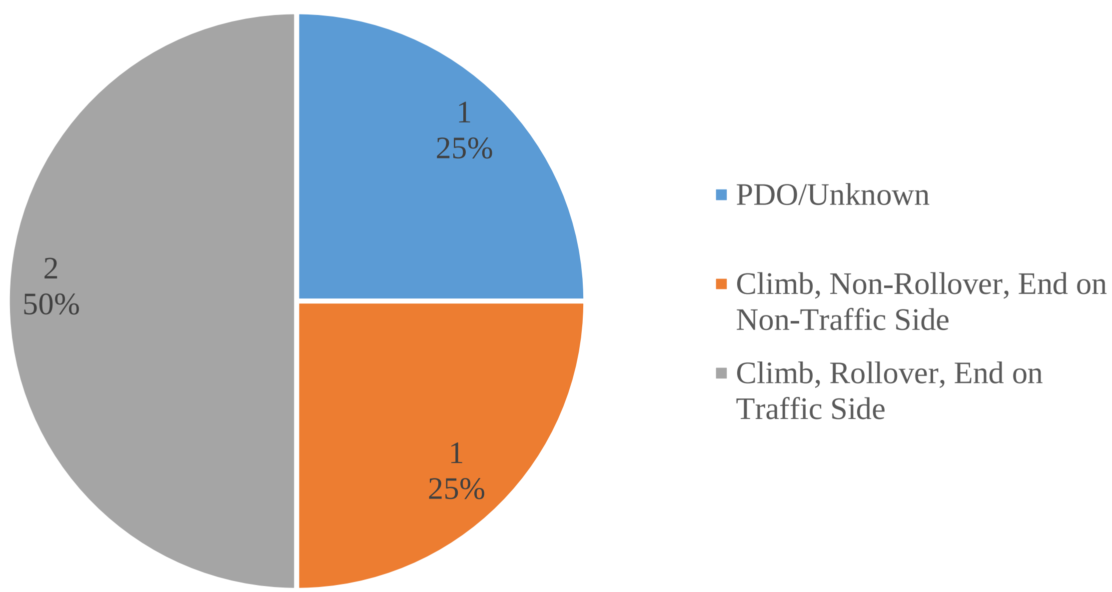


Figure 128. Crash Outcomes for C Injury Crashes

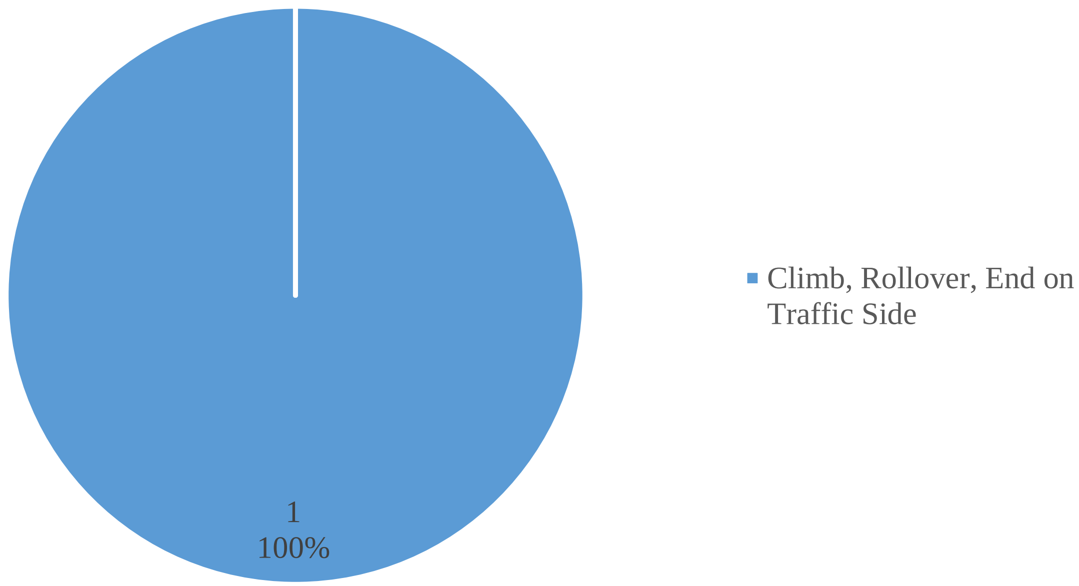


Figure 129. Crash Outcome for B Injury Crash

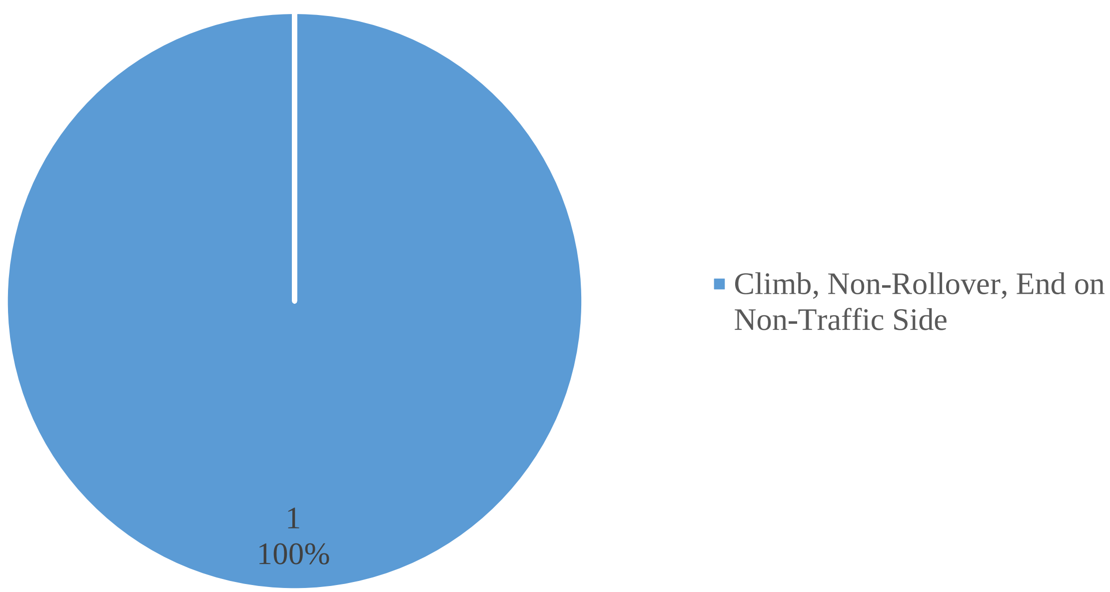


Figure 130. Crash Outcome for A Injury Crash

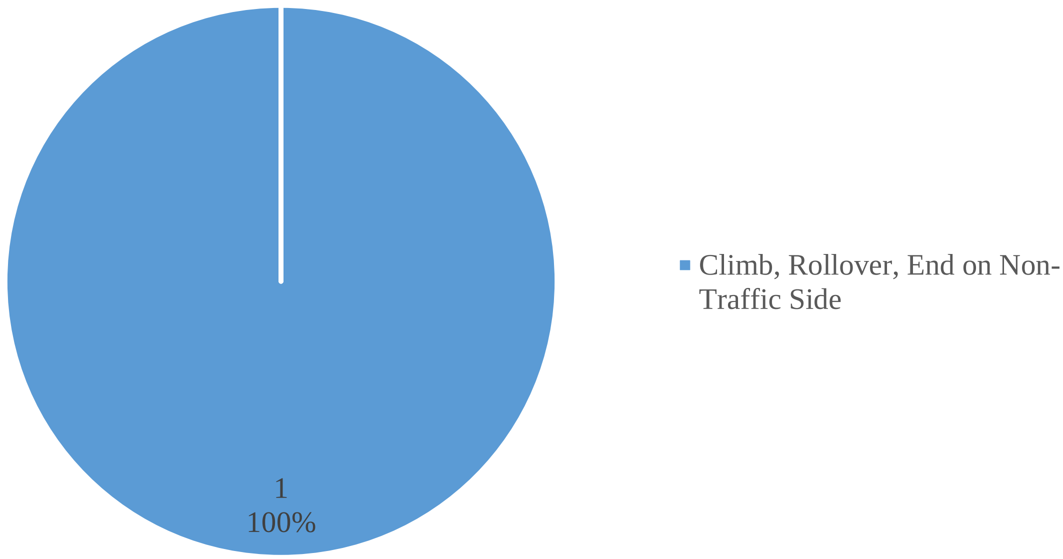


Figure 131. Crash Outcome for K Injury Crash

7.2 Vehicle Action

Vehicle action for the sloped end treatment crashes is shown in Figure 132. Traveling straight was defined as traveling forward on a road, turning vehicles were at intersections or changing roads, and negotiating a curve refers to vehicle action upstream from the bridge rail. A total of 21 crashes (70 percent) involved a vehicle traveling straight, 6 (20 percent) involved a turning vehicle, 1 (3 percent) involved a vehicle negotiating a curve, and vehicle action was unknown for 2 crashes (7 percent).

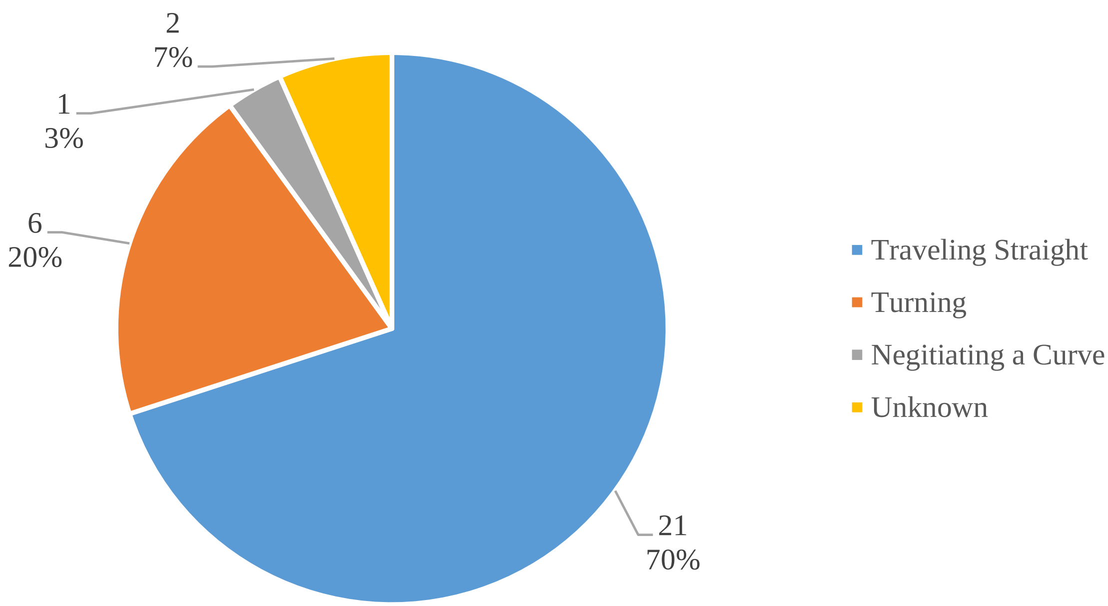


Figure 132. Sloped End Treatment Crashes – Vehicle Action

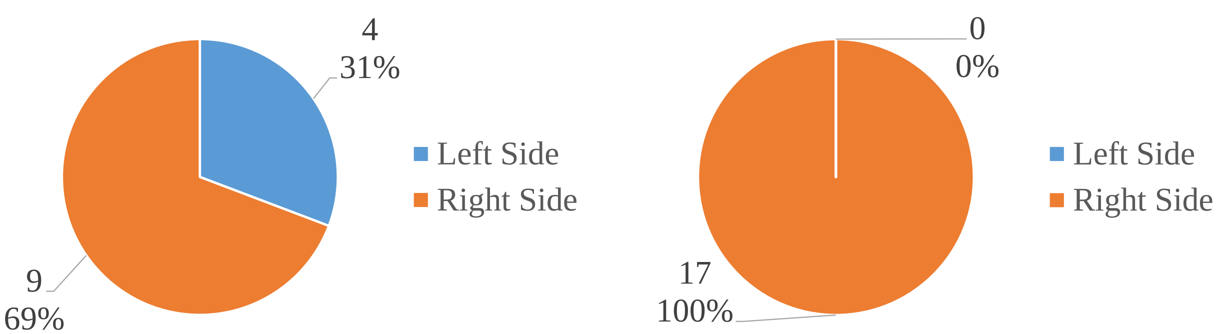
7.3 Location on Roadway

Sloped end treatments are located on the left and right side of both one- and two-way traffic roadways, as shown in Figure 133(a) and (b), respectively. Of the 30 sloped end treatment crashes, 13 crashes (43 percent) occurred on one-way traffic roadways, and 17 (57 percent) occurred on two-way traffic roadways. Entrance and exit ramps were classified as one-way traffic roads.

(a) (b)

Figure 133. Left- and Right-Side Sloped End Treatments for (a) One-Way and (b) Two-Way Traffic

For one-way traffic, 4 crashes (31 percent of one-way, 13 percent of total) involved a left side feature, and 9 crashes (69 percent of one-way, 30 percent of total) involved a right side feature, shown in Figure 134(a). On two-way traffic roads, only right-side features were impacted (100 percent of two-way, 57 percent of total), as shown in Figure 134(b). Left-side features located on two-way traffic roads were not impacted during the ten-year span of crash data.



(a) (b)

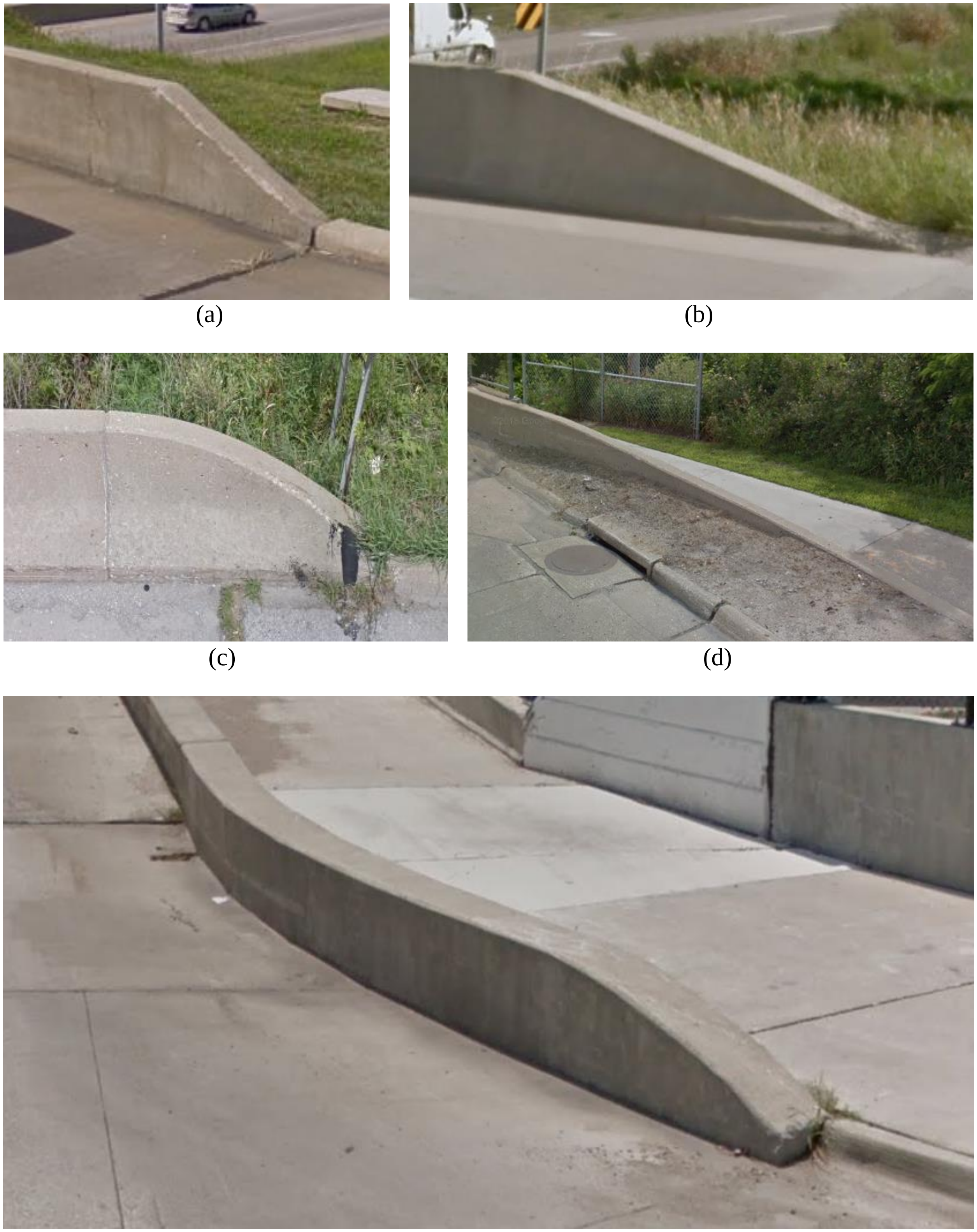
Figure 134. Sloped End Treatment Crashes – Side Feature for (a) One-Way and (b) Two-Way Traffic

7.4 Geometry

The geometry of each impacted sloped end treatment was analyzed using Google Street View [1]. It should be noted that Iowa DOT did not indicate that any of the sloped end treatments involved in crashes in this study were modified or replaced during the 10-year crash data timeframe, and a time-history of the locations with SETs using Google Earth and Street View did not indicate changes or modifications. Five general shapes were identified, including short straight taper, long straight taper, short round taper, long round taper, and low round taper, as shown in Figure 135(a), (b), (c), (d), and (e), respectively. Standard road plans for sloped end treatments were discussed in Section 3.1.3 and are shown in Appendix A.

A total of 19 impacted sloped end treatments (63 percent) had a short straight taper, 2 (7 percent) had a long straight taper, 4 (13 percent) had a short round taper, 3 (10 percent) had a long round taper, and 2 (7 percent) had a low, round taper, as shown in Figure 136. A short straight taper sloped end treatment was involved in the A crash, and a long round taper sloped end treatment was involved in the K crash.

The low round taper, which was involved in two crashes, was not identified as part of the sloped end treatment inventory created for this research and was added to the compendium after discovery. It was located on a bridge in close proximity to an adjacent bridge which had sloped end treatments tabulated. This sloped end treatment was involved in two sloped end treatment crashes, and therefore it was included in the "black spot" analysis, which is discussed in Section 9.1.8.



(a) (b) (c) (d) (e)

Figure 135. Sloped End Treatment Crashes – Geometry, (a) Short Straight Taper, (b) Long Straight Taper, (c) Short Round Taper, (d) Long Round Taper, and (e) Low Round Taper [1]

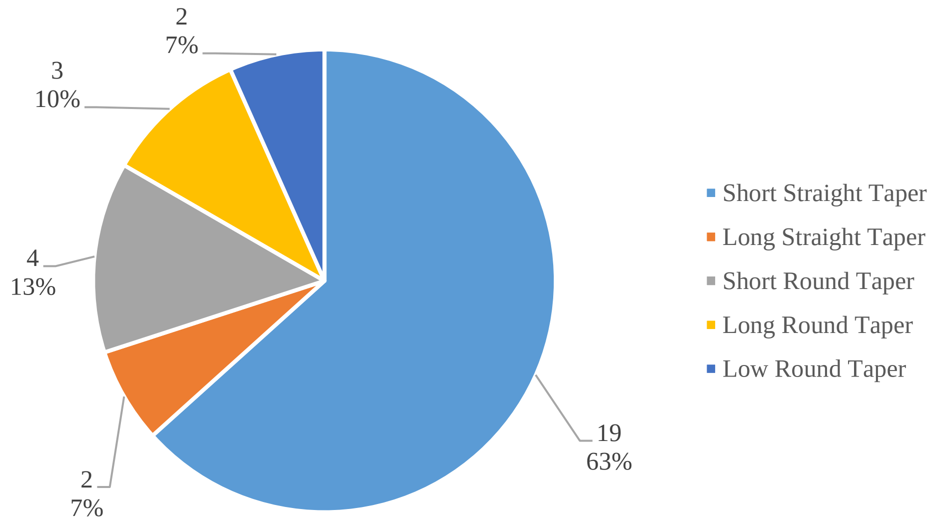


Figure 136. Sloped End Treatment Crashes – Geometry

7.5 Type of Roadway

Sloped end treatments involved in crashes were located on one of three types of roadways: ramps, bridges with ramps, or bridges without ramps. A total of 5 sloped end treatment crashes (17 percent) occurred on ramps, 16 (53 percent) occurred on bridges with ramps, and 9 (30 percent) occurred on bridges without ramps, as shown in Figure 137.

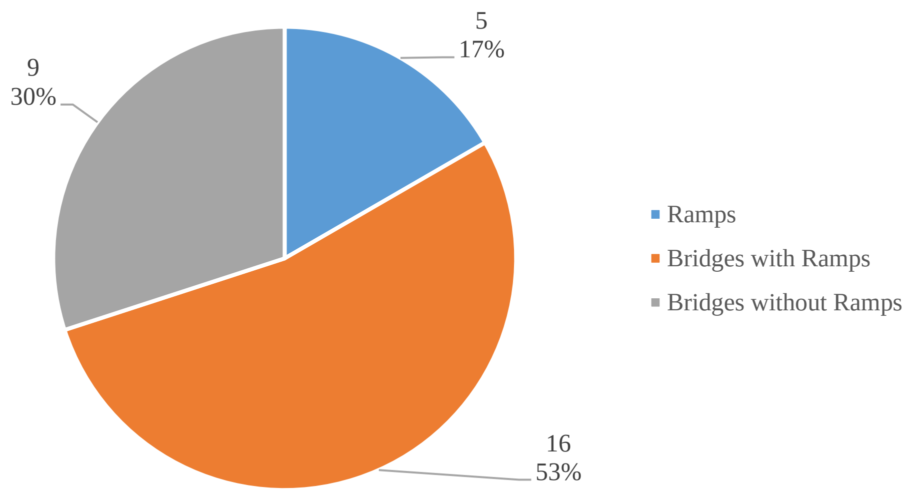


Figure 137. Sloped End Treatment Crashes – Type of Roadway

7.6 AADT

AADT for roadways which featured sloped end treatment crashes ranged from 4,120 to 23,500 vehicles/day, as shown in Table 59. Generally, as the AADT increased, the number of crashes also increased. The median AADT for this data set was 11,350 vehicles per day. The mean traffic volume was 12,973 vehicles per day, and the standard deviation was 6,711.

This data is also shown in Figure 138, where AADT data was fit into “bins” or ranges of AADT. Nearly two-thirds of the sloped end treatment crashes occurred on roadways with an AADT between 5,000 and 14,999 vehicles per day.

Table 59. Sloped End Treatment Crashes – AADT

AADT (Vehicles/Day)	Number of Crashes	Percent
4,120	1	3%
4,170	1	3%
4,210	1	3%
5,700	2	7%
6,100	2	7%
8,600	2	7%
8,800	1	3%
8,900	1	3%
9,500	2	7%
10,300	1	3%
10,500	1	3%
12,200	2	7%
14,700	3	10%
14,900	2	7%
19,000	1	3%
21,300	1	3%
23,100	3	10%
23,500	3	10%
Total	**30**	**100%**

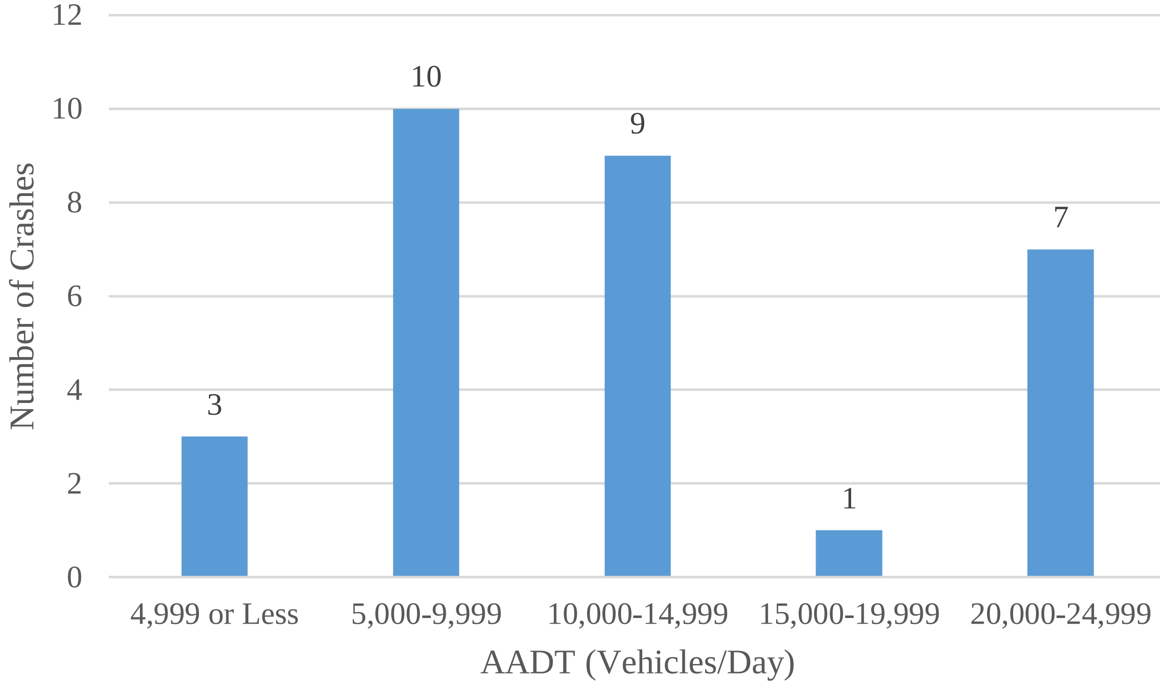


Figure 138. Sloped End Treatment Crashes – AADT

7.7 Traffic Controls

The Iowa DOT accident report form, as shown in Appendix E, records whether or not traffic controls were present at the scene of an accident, which include traffic signals, stop signs, warning signs, or no controls. The form does not specify the location or proximity of traffic controls, only their presence.

Traffic controls were present on roadways in 17 of the 30 sloped end treatment crashes (57 percent). A total of 14 crashes (47 percent) involved traffic signals, 2 (7 percent) involved stop signs, 1 (3 percent) involved warning signs, and 13 (43 percent) involved no traffic controls, as shown in Figure 139.

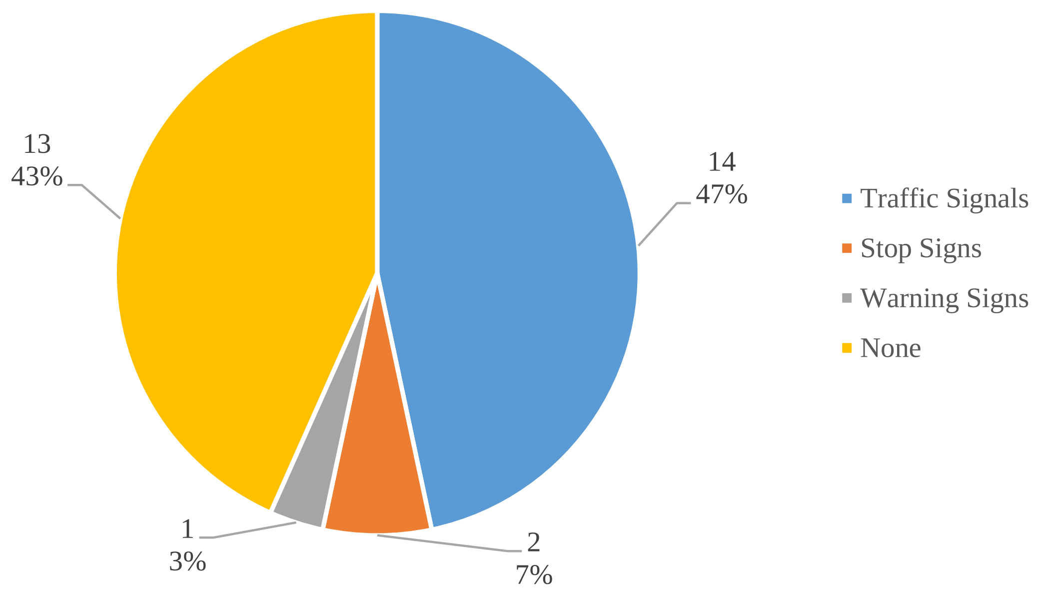


Figure 139. Sloped End Treatment Crashes – Traffic Controls

7.8 Alcohol Related

Of the 30 sloped end treatment crashes, alcohol was not detected in 19 crashes (63 percent), while alcohol was detected in 11 crashes (37 percent), shown in Figure 140.

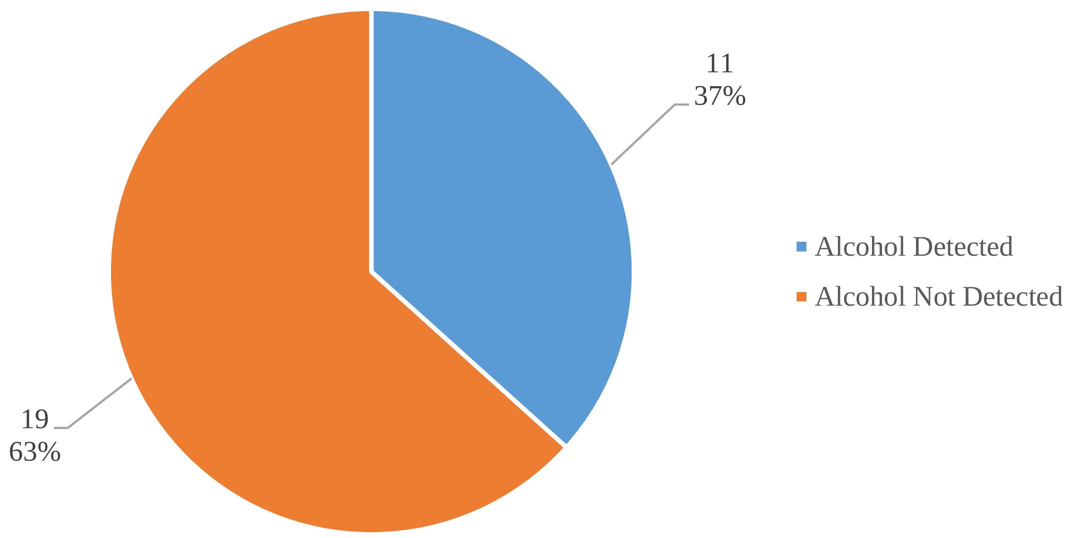


Figure 140. Sloped End Treatment Crashes – Alcohol Related

7.9 Discussion

Sloped end treatments are typically installed in place of blunt concrete ends with the intention of improving safety performance. However, it was found that 43 percent of sloped end treatment crashes resulted in vehicle rollover. According to *An Analysis of Motor Vehicle Rollover Crashes and Injury Outcomes* [79], approximately one third of vehicle fatalities result from rollover crashes, and fatalities are more likely to occur in rollover crashes as compared to non-rollover crashes. When planning construction projects, care should be taken when determining if a sloped end treatment is appropriate based on safety and cost evaluations. Several factors which affected SET impact frequency are discussed below.

All sloped end treatment crashes occurred on roadways with AADTs less than 25,000 vehicles per day. A total of 26 out of the 658 identified sloped end treatments (4 percent) were located on roadways with AADTs greater than 25,000 vehicles per day. Because these are so few and they were never involved in a crash, low priority should be given to the removal of these sloped end treatment installations.

It was also found that during the ten-year span of crash data, no left-side sloped end treatments located on two-way traffic roads were impacted. This finding suggests that, when prioritizing sloped end treatment installations for removal, those located on the left side of two-way traffic roadways would be assigned a low priority.

Sloped end treatments located on a bridge with ramps were typically located on interstate or highway overpasses. Despite accounting for 25 percent of sloped end treatment installations, those sloped end treatments located on bridges with ramps were involved in 53 percent of crashes. Furthermore, sloped end treatments located on ramps accounted for 4 percent of all sloped end treatment installations, but they were involved in 17 percent of crashes. In contrast, sloped end treatments installed in conjunction with bridges without ramps accounted for only 30 percent of the crashes, but were associated with 71 percent of the installations. When prioritizing sloped end treatment removal, those systems located on ramps or bridges with ramps should be assigned higher priority than those systems located on bridges without ramps.

8 BENEFIT-TO-COST ANALYSIS

Benefit cost (B/C) analyses of replacing sloped end treatments with crash cushions were performed. Only crash cushions were considered for replacement, as most SETs impacted in the crash database were located on roads with space constraints and guardrail systems, including short-radius systems, could not be installed at all locations. Crash cushion costs were identified and are discussed. Then, various sloped end treatment removal plans were evaluated and are discussed in the following sections.

8.1 B/C Calculation

Benefit-to-cost analyses, often abbreviated as B/C ratios, were determined using estimated changes in injury severity when substituting crash cushions for SETs. B/C analyses consider the ratio of prospective benefit of a treatment option, using an estimated difference in the "societal cost" of crashes associated with two options (baseline condition and treatments), divided by the difference in investment costs of the two options which includes the one-time installation cost and recurring maintenance, repair, and/or replacement costs. A B/C ratio was calculated for each crash cushion using Equations 2 through 4.

$$\frac{B}{C} = \frac{\Delta_C}{\Delta_{IR}} \qquad \text{Equation 2}$$

$$\Delta_C = \; Crash\ Cost_{Sloped\ End\ Treatment} - \; Crash\ Cost_{Crash\ Cushion} \qquad \text{Equation 3}$$

$$\Delta_{IR} = \left[(Install + Repair\ Cost)_{Crash\ Cushion} + Removal_{Sloped\ End\ Treatment}\right] - (Install + Repair\ Cost)_{Sloped\ End\ Treatment} \qquad \text{Equation 4}$$

8.2 Crash Cushion Installation and Repair Costs

Crash cushions were reviewed and summarized in section 2.4.2 of the literature review. Some, but not all, crash cushions were reviewed in *Guidelines for Crash Cushion Selection* [78], which discussed costs of installing and repairing crash cushions and crash warrants for installing lower-cost, sacrificial crash cushions and higher-cost, non-sacrificial crash cushions. Seven crash cushion systems were reviewed: QuadGuard, QUEST, TRACC, TAU-II, QuadGuard Elite, REACT 350, and Smart Cushion. Installation, repair, and labor costs for each device were estimated and are shown in Table 60. Repair costs for freeways, arterial roadways, and local roadways were estimated. Mobilization cost, or cost of transportation of parts and workers, was not included in the estimates because it will vary greatly depending on the site location. In addition, maintenance costs were not estimated. State DOTs noted that these systems typically only require maintenance when they are struck, which would then be classified as a repair cost.

Table 60. Installation, Repair, and Labor Costs for Crash Cushions (2012) [78]

Crash Cushion	Installation Cost	Repair Cost (Average)			Labor Cost
		Freeway	Arterial	Local	
QuadGuard	$17,769	$2,080	$1,566	$1,235	$263
QUEST	$11,510	$5,153	$3,878	$3,058	$675
TRACC	$11,400	$1,029	$774	$611	$525
TAU-II	$15,433	$1,340	$1,009	$796	$175
QuadGuard Elite	$33,017	$340	$256	$202	$225
REACT 350	$36,067	$35	$27	$21	$225
Smart Cushion	$19,371	$36	$27	$21	$300

The second crash cushion study, *Crash Cushion Selection Criteria* [12], was performed by the Institute of Transportation at ISU in 2017. Nine redirective crash cushions were analyzed: Guardrail Energy Absorbing Terminal (G-R-E-A-T), HEART, hex-foam sandwich system, QuadGuard, QuadTrend, REACT 350, Smart Cushion, TAU-II, and TRACC. Both the GREAT and Hex-Foam Sandwich crash cushions were manufactured by Energy Absorption Systems, Inc. and were evaluated to NCHRP Report No. 230 criteria.

Average installation costs for each redirective system were collected from the Iowa DOT field manager, Kansas DOT contract documents, and Mississippi DOT agency contracts and are shown in Table 61 [12]. In addition, the average repair cost for each crash cushion, which includes materials and labor, was estimated based on information provided by Iowa DOT and crash cushion manufacturers. It is not known if labor costs were included in the installation costs; however, labor is typically less than 10% of the installation or repair cost, and even if labor were not included, the omission is not believed to significantly B/C analysis results.

This report also denotes locations and impact situations where certain types of crash cushions would be advantageous as compared to others. Types of crash cushions include redirective, non-redirective, gating, non-gating, sacrificial, and repairable.

Table 61. Iowa, Kansas, and Mississippi DOT Installation and Repair Costs for Crash Cushions (2017) [12]

Crash Cushion	Installation Cost	Average Repair Cost
GREAT	$10,511	$8,773
HEART	$19,525	$2,025
Hex-Foam Sandwich	$8,030	$3,686
QuadGuard	$20,545	$8,415
QuadTrend	$5,220	$8,410
REACT 350	$32,530	$7,948
Smart Cushion	$22,070	$2,804
TAU-II	$19,500	$6,550
TRACC	$14,430	$9,900

The results shown in Tables 60 and 61 were used to estimate costs for study year 2020 using Equation 5 and a 2 percent inflation rate. The consolidated 2020 cost estimates are shown in Table 62.

$$C_n = C(1+i)^n \qquad \text{Equation 5}$$

Where:

C_n = inflated cost
C = base cost
i = inflation rate
n = difference between selected year and base year

The Smart Cushion, Quad Guard, and QuadGuard Elite are the only crash cushion which have been evaluated under MASH criteria. QuadGuard, Quest, TRACC, TAU-II, QuadGuard Elite, REACT 350, HEART, and QuadTrend have all been evaluated to NCHRP Report No. 350 criteria. Analysis of the costs of repair and installation indicated that using a constant growth rate of 2% did not accurately reflect the real changes in cost for both installation and repair.

Table 62. Estimated 2020 Installation, Repair, and Labor Estimated Costs for Crash Cushions

Crash Cushion	Installation Cost	Repair Cost (Average)			Labor Cost
		Freeway	Arterial	Local	
QuadGuard	$20,819	$2,437	$1,835	$1,447	$308
QUEST	$13,486	$6,038	$4,544	$3,583	$791
TRACC	$13,357	$1,206	$907	$716	$615
TAU-II	$18,082	$1,570	$1,182	$933	$205
QuadGuard Elite	$38,685	$398	$300	$237	$264
REACT 350	$42,258	$41	$32	$25	$264
Smart Cushion	$22,696	$42	$32	$25	$351

8.3 B/C Analysis Overview

8.3.1 Methodology

A total of 23 individual sloped end treatments were involved in the 30 sloped end treatment crashes. Therefore, a maximum of 30 crash outcomes could have generated different injury outcomes had crash cushion treatments been installed instead of sloped end terminations. Installation, repair, and maintenance costs for the sloped end treatments, as well as removal costs, are discussed below:

- For each scenario, it was assumed that the sloped end treatments were already existing. All comparisons were made with respect to the existing sloped end treatments ("Do Nothing" condition). The modeled installation cost for this baseline condition was therefore $0. Note that the actual installation cost for new sloped end treatments was approximately $2,500, but it was not included here.

- According to Iowa DOT input it was assumed that no repairs were performed on the sloped end treatments following the crashes.

- It was assumed that the existing sloped end treatment must be removed for any crash cushion alternative treatment. A removal cost was estimated to be approximately equal to the actual installation cost, or $2,500. The total removal cost for 23 sloped end treatments was $57,500.

The total crash cost for the 30 sloped end treatment crashes was $5,347,800, calculated using Iowa DOT's VSL scale. This crash cost was used as the baseline crash cost in all analyses.

Most crash cushions are designed to pass MASH or prior crash testing standards' safety performance criteria at TL-3 impact conditions. While there are differences in the distribution of injury outcomes by crash cushion type, for the purposes of this report all crash cushions were assumed to perform equally well in service. A report published by ISU, *Crash Cushion Selection Criteria* [12], calculated an injury distribution for crash cushion crashes, as shown in Figure 141. This injury distribution resulted from crashes with crash cushions located on multi-lane divided highways and one-way roadways/ramps. No crash cushion crashes resulted in a fatality ("K" injury).

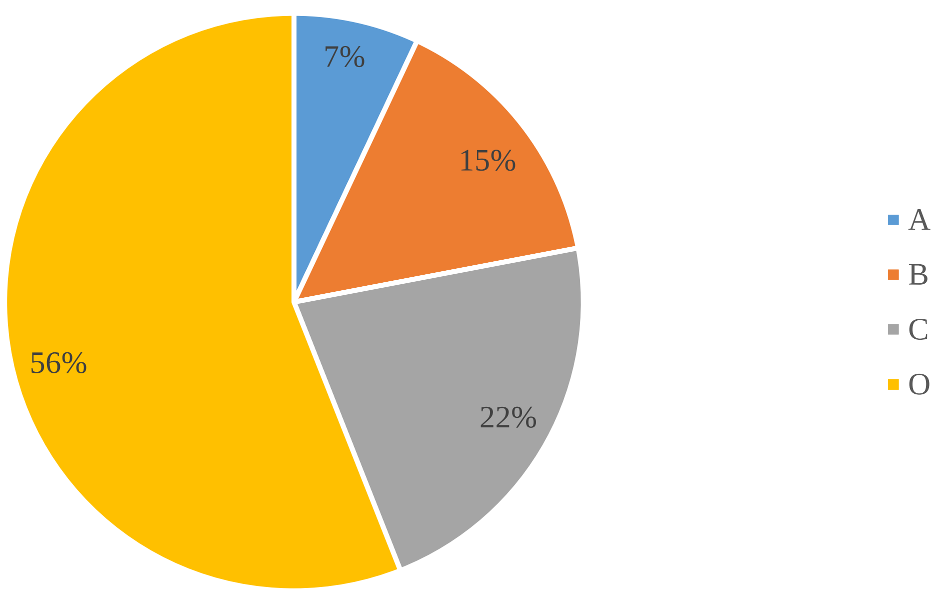


Figure 141. Crash Cushion Injury Distribution [12]

Note that the multi-lane divided highways considered in the ISU report were associated with speed limits greater than the roads with sloped end treatments adjacent to the roadways. It was also assumed that the distribution of speeds in run-off-road crashes is strongly correlated with the speed limit [80]. Thus, the injury distribution for crash cushions was believed to overweight severe and moderate injury crash outcomes.

Benefit-cost analyses were employed which examine the effects that crash cushions *could have had* if the crash cushions had been installed in lieu of SETs. To perform this analysis in an unbiased manner, researchers utilized several assumptions:

- Crash locations would be identical if the treatments were SETs or crash cushions.
- There were no unreported crashes with SETs which would have been identified and reported if crash cushions were used in lieu of SETs.
- The injury probability distribution was independent of the location of the crash (i.e., the likelihood of a given injury outcome was identical at each crash location). Therefore, for each configuration of treatments selected, researchers multiplied the number of crashes with each feature (SET or crash cushion) by the respective average crash cost.

The average SET crash cost was equal to the total crash cost for all SET crashes divided by 30 crashes, and was equal to ($5,347,800 / 30 crashes) = $178,260/crash. To determine average crash cushion crash cost, researchers multiplied the injury probability distribution shown in Figure 141 by 30 crashes and rounded to integer numbers of crashes. For B- and C-injuries, the injury probabilities were between 0.3 and 0.7, leading to some ambiguity for rounding to the nearest integer. Therefore, two crash cushion crash cost distributions were generated: a *conservative* distribution, which was biased toward least-severe injury and therefore was biased toward installing crash cushions in lieu of retaining SETs; and an *economical* distribution, which rounded injuries to the highest severity and therefore maximized the probability that the “Do Nothing” (SET remains in place) option would be chosen. These distributions are shown in Table 63. However, it should be noted that the only difference in datasets based on the rounding was ±1 B or C-level injury outcome, which is the difference between moderate and minor injuries; in general, B or C crash results have a limited influence on recommendations.

Table 63. Number of Injuries for Crash Cushion Crashes

Injury	**Conservative Distribution (Rounding to Lower Severity)**	**Economical Distribution (Rounding to Higher Severity)**
A	2	2
B	4	5
C	7	6
O	17	17
Total	**30**	**30**
Avg Crash Cost	**$42,693**	**$49,693**

For the conservative injury distribution, shown in column no. 2 of Table 63, a minimum crash cost of $1,280,800 was calculated using Iowa DOT's VSL scale. The minimum total cost for each crash cushion is shown in Table 64. For the economical injury distribution, shown in column no. 3 of Table 63, a maximum crash cost of $1,490,800 was calculated using Iowa DOT's VSL scale. For both injury distributions, the reduction in societal crash cost associated with installing crash cushions was substantially higher than the installation and repair costs.

Table 64. B/C Cost for 30 Crashes and 23 Installations

Treatment Option	**Crash Cost (30 Crashes)**	**Install/Remove Cost (23 Locations)**	**Repair Cost (30 Repairs)**
Sloped End Treatment (Baseline)	$5,347,800	$57,500	$0
QuadGuard [78]	Conservative: $1,280,800 Economical: $1,490,800	$478,837	$43,410
QuadGuard [12]		$501,469	$267,900
QUEST [78]		$310,178	$107,490
TRACC [78]		$307,211	$21,480
TRACC [12]		$352,199	$315,180
TAU-II [78]		$415,886	$27,990
TAU-II [12]		$475,962	$208,530
QuadGuard Elite [78]		$889,755	$7,110
REACT 350 [78]		$971,934	$750
REACT 350 [12]		$793,983	$253,020
Smart Cushion [78]		$522,008	$750
Smart Cushion [12]		$538,683	$89,280
GREAT [12]		$256,542	$279,300
HEART [12]		$476,560	$64,470
Hex-Foam Sandwich [12]		$196,006	$117,360
QuadTrend [12]		$127,420	$267,750

Researchers desired to bracket the effectiveness of replacing sloped end treatments with crash cushions. To perform the bracketing analysis, researchers considered two extremes in treatments: either (a) crash cushions would only replace SETs at impact locations, maximizing B/C ratios for the investment cost (maximum possible B/C ratio); and (b) all SETs would be replaced with crash cushions (minimum effectiveness ratio). Results of the bracketing analysis are presented below. Average crash costs are summarized in Table 65.

Table 65. Average Crash Costs

Type of Crash	**Average Crash Cost**
Sloped End Treatment	$178,260
Crash Cushion	$46,193

8.3.2 Maximum B/C Ratio (Replace Only Sloped End Treatments Involved in Crashes)

Crash cushion crash costs were lower on average than SET crash costs, so the maximum possible B/C ratio for replacing SETs with crash cushions would be identified by evaluating a scenario in which SET locations could have been identified before impacts occurred. It was noted that if the maximum possible B/C ratio was less than a cutoff value (assumed to be 2.0), no further analysis would be needed and there would be no recommendation to remove or replace any SETs with crash cushions.

The maximum B/C ratio was found by dividing the difference in total crash costs by the total installation cost of 23 crash cushions. Installation and repair costs from *Guidelines for Crash Cushion Selection* [78] and *Crash Cushion Selection Criteria* [12] were utilized, and the repair cost associated with "local road" classification was used to calculate repair costs for crash cushions found in *Guidelines for Crash Cushion Selection*. Other repair cost options based on road designations such as "freeway" or "arterial" were deemed non-representative of the identified crashes which involved sloped end treatments.

The B/Cs are shown in Table 66, and the three largest B/Cs are highlighted. The minimum B/C was 3.7 for the REACT 350 crash cushion, and the maximum was 11.0 for the Hex-Foam Sandwich crash cushion. The B/C ranged between 3.5 and 10.4 for the REACT 350 and Hex-Foam Sandwich crash cushions, respectively. Every crash cushion option had a B/C ratio higher than the 2.0 cutoff, indicating it was cost-effective to replace impacted SETs with crash cushions.

Table 66. Minimum B/C for 30 Crashes and 23 Installations

Crash Cushion	Δ_C	Δ_{IR}	**Conservative B/C**	**Economical B/C**
QuadGuard [78]	Conservative: $4,067,000 Economical: $3,857,000	$579,747	7.0	6.7
QuadGuard [12]		$826,869	4.9	4.7
QUEST [78]		$475,168	8.6	8.1
TRACC [78]		$386,191	10.5	10.0
TRACC [12]		$724,879	5.6	5.3
TAU-II [78]		$501,376	8.1	7.7
TAU-II [12]		$741,992	5.5	5.2
QuadGuard Elite [78]		$954,365	4.3	4.0
REACT 350 [78]		$1,030,184	3.9	3.7
REACT 350 [12]		$1,104,503	3.7	3.5
Smart Cushion [78]		$580,258	7.0	6.6
Smart Cushion [12]		$685,463	5.9	5.6
GREAT [12]		$593,342	6.9	6.5
HEART [12]		$598,530	6.8	6.4
Hex-Foam Sandwich [12]		$370,866	11.0	10.4
QuadTrend [12]		$452,670	9.0	8.5

8.3.3 All Sloped End Treatments

An alternative extrema for treatment possibilities considered the benefit of replacing every one of the SETs in Iowa with crash cushions. If the B/C ratio for treating all SETs was greater than the cutoff value of 2.0, then researchers would recommend removal of all SETs and replacement with crash cushions, and ban any new SET installations or repairs.

A B/C analysis was performed for replacing all 658 identified sloped end treatments with a crash cushion option, as shown in Table 67. The total cost for sloped end treatments and crash cushions, including installation costs for 658 treatments, repair costs for 30 treatments involved in the identified crashes, and crash costs for the 30 crashes, are shown in Table 67.

All crash cushions were more expensive than sloped end treatments, except the QuadTrend model. The B/C is shown in Table 68, with values ranging between 0.13 and 0.71. None of the crash cushion options had a B/C ratio higher than 1 ("breakeven") and all were much less than the cutoff value of 2.0. Therefore, it would not be cost-effective to replace all SETs with crash cushions in Iowa.

Table 67. Cost for 30 Crashes and Replacing All Installations

Crash Cushion	Crash Cost	Install/Remove Cost	Repair Cost
Sloped End Treatment (658 treatments removed)	$5,347,800	$1,645,000	$0
QuadGuard [78]	Conservative: $1,280,800 Economical: $1,490,800	$13,698,902	$43,410
QuadGuard [12]		$14,346,374	$267,900
QUEST [78]		$8,873,788	$107,490
TRACC [78]		$8,788,906	$21,480
TRACC [12]		$10,075,954	$315,180
TAU-II [78]		$11,897,956	$27,990
TAU-II [12]		$13,616,652	$208,530
QuadGuard Elite [78]		$25,454,730	$7,110
REACT 350 [78]		$27,805,764	$750
REACT 350 [12]		$22,714,818	$253,020
Smart Cushion [78]		$14,933,968	$750
Smart Cushion [12]		$15,411,018	$89,280
GREAT [12]		$7,339,332	$279,300
HEART [12]		$13,633,760	$64,470
Hex-Foam Sandwich [12]		$5,607,476	$117,360
QuadTrend [12]		$3,645,320	$267,750

Table 68. B/C for 30 Crashes and Replacing All Installations

Crash Cushion	Δ_C	Δ_{IR}	Conservative B/C	Economical B/C
QuadGuard [78]	Conservative: $4,067,000 Economical: $3,857,000	$15,387,312	0.25	0.26
QuadGuard [12]		$16,259,274	0.24	0.25
QUEST [78]		$10,626,278	0.36	0.38
TRACC [78]		$10,455,386	0.37	0.39
TRACC [12]		$12,036,134	0.32	0.34
TAU-II [78]		$13,570,946	0.28	0.30
TAU-II [12]		$15,470,182	0.25	0.26
QuadGuard Elite [78]		$27,106,840	0.14	0.15
REACT 350 [78]		$29,451,514	0.13	0.14
REACT 350 [12]		$24,612,838	0.16	0.17
Smart Cushion [78]		$16,579,718	0.23	0.25
Smart Cushion [12]		$17,145,298	0.22	0.24
GREAT [12]		$9,263,632	0.42	0.44
HEART [12]		$15,343,230	0.25	0.27
Hex-Foam Sandwich [12]		$7,369,836	0.52	0.55
QuadTrend [12]		$5,558,070	0.69	0.73

8.4 Optimization of Sloped End Treatment Replacement

Researchers explored treatment option configurations by replacing all SETs with common attributes with crash cushions, and recalculating the resulting B/C ratios. This section describes the methods used for identifying which SET attributes should be prioritized for replacement with crash cushions based on the highest average cost-effectiveness.

As with all B/C analyses conducted for this report, the "Do Nothing" (baseline) condition consisted of no treatment for existing SETs. To ensure that recommendations for replacing SETs with crash cushions would be associated with a minimum B/C ratio of 2.0, the "economical" injury distribution for crash cushions was considered. Thus, the average crash cost reduction for each crash cushion crash compared to SET crash was ($178,260 - $49,693) = $128,567.

8.4.1 Attributes of Sloped End Treatment Crashes

Sloped end treatment crashes were analyzed in Chapter 7. Crashes, which occurred on two-way roads, did not involve any left-side sloped end treatments. One-way bridges featured crashes on both left- and right-side approaches, but no crashes on the departure end of the bridge. It was found that many crashes involved sloped end treatments which were located on bridges with ramps. Furthermore, some crashes involved sloped end treatments located on entrance and exit ramps. B/C analysis for these subgroups of sloped end treatments are discussed in the following sections.

8.4.2 Two-Way Traffic, Right Side Approach

The first subgroup of sloped end treatments which was considered included sloped end treatments located on the right-side approach on two-way traffic roads, such as the example shown with sloped end treatment nos. 1 and 3 in Figure 142. In total, this subgroup included 274 sloped end treatments; 18 of the SET crashes had these attributes. Therefore, if only SETs located on the right side of the road, on the approach side, for two-way roadways had been replaced with crash cushions prior to 2008, then 18 crash cushions and 12 SETs would have been involved in crashes in Iowa.

Removal costs for 274 sloped end treatments were calculated. Crash cushion costs included installation costs for 274 cushions and repair and crash costs for 18 crashes. Costs are shown in Table 69, and B/C is shown in Table 70. The three largest B/Cs are highlighted, and only one was greater than 1. Because none of the B/C ratios were greater than 2.0, this treatment configuration was deemed not cost-effective.

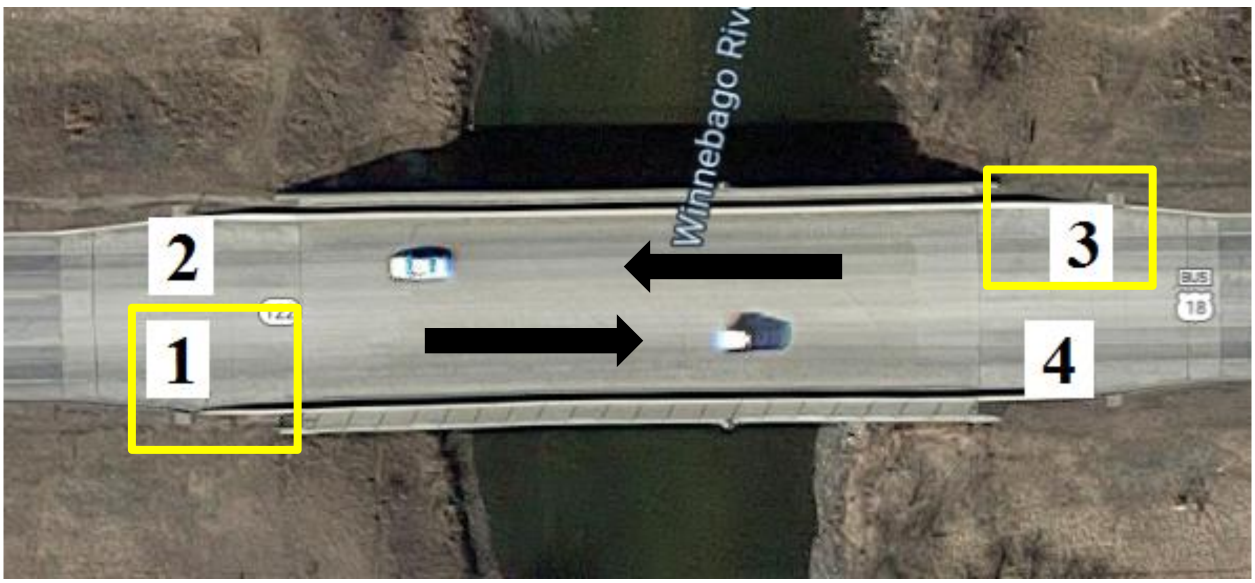


Figure 142. Sloped End Treatments on Two-Way Traffic Road

Table 69. Cost for Right-Side Approaches on Two-Way Traffic Roads

Crash Cushion	Crash Cost	Install/Remove Cost	Repair Cost
Sloped End Treatment (274 treatments removed)	$2,139,120	$685,000	$0
QuadGuard [78]	$831,474	$5,704,406	$26,046
QuadGuard [12]		$5,974,022	$160,740
QUEST [78]		$3,695,164	$64,494
TRACC [78]		$3,659,818	$12,888
TRACC [12]		$4,195,762	$189,108
TAU-II [78]		$4,954,468	$16,794
TAU-II [12]		$5,670,156	$125,118
QuadGuard Elite [78]		$10,599,690	$4,266
REACT 350 [78]		$11,578,692	$450
REACT 350 [12]		$9,458,754	$151,812
Smart Cushion [78]		$6,218,704	$450
Smart Cushion [12]		$6,417,354	$53,568
GREAT [12]		$3,056,196	$167,580
HEART [12]		$5,677,280	$38,682
Hex-Foam Sandwich [12]		$2,335,028	$70,416
QuadTrend [12]		$1,517,960	$160,650

Table 70. B/C for Right-Side Approaches on Two-Way Traffic Roads

Crash Cushion	Δ_C	Δ_{IR}	B/C
QuadGuard [78]	$2,377,206	$6,415,452	0.37
QuadGuard [12]		$6,819,762	0.35
QUEST [78]		$4,444,658	0.53
TRACC [78]		$4,357,706	0.55
TRACC [12]		$5,069,870	0.47
TAU-II [78]		$5,656,262	0.42
TAU-II [12]		$6,480,274	0.37
QuadGuard Elite [78]		$11,288,956	0.21
REACT 350 [78]		$12,264,142	0.19
REACT 350 [12]		$10,295,566	0.23
Smart Cushion [78]		$6,904,154	0.34
Smart Cushion [12]		$7,155,922	0.33
GREAT [12]		$3,908,776	0.61
HEART [12]		$6,400,962	0.37
Hex-Foam Sandwich [12]		$3,090,444	0.77
QuadTrend [12]		$2,363,610	1.01

8.4.3 One-Way Traffic, Both Approaches

The next group of sloped end treatment installations included approaches on one-way traffic roads. For example, sloped end treatment nos. 1 and 2 are shown in Figure 143 may be replaced with crash cushions. A total of 35 SETs had these attributes, and seven crashes occurred for this set of 35 SETs. Therefore, for sloped end treatments, crash costs for 23 crashes and removal costs for 35 treatments were calculated. For crash cushions, installation costs were calculated for 35 crash cushions, and repair and crash costs were calculated for seven crashes. Costs are shown in Table 71, and B/Cs are shown in Table 72. The three largest B/Cs are highlighted. All B/Cs ranged between 0.64 and 2.69.

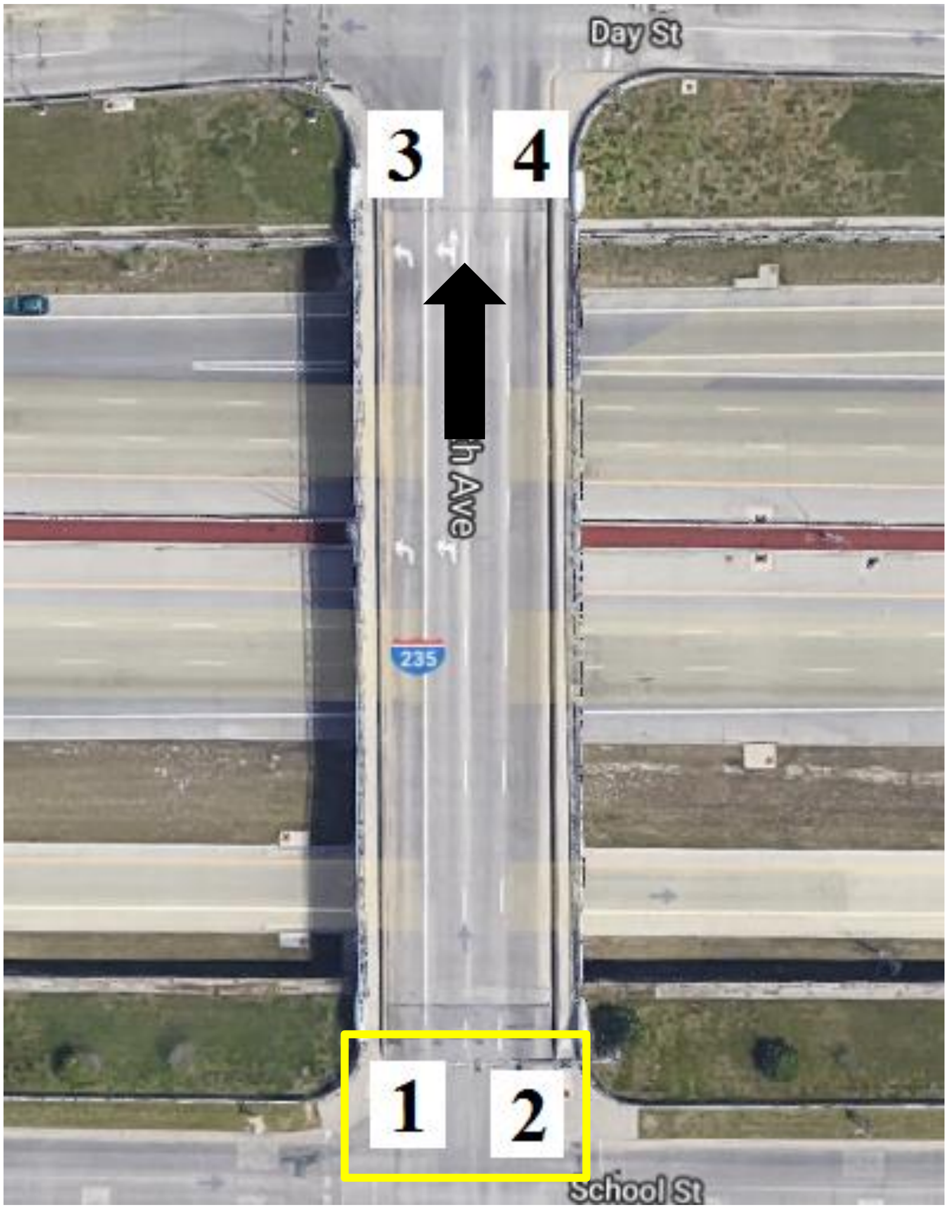


Figure 143. Sloped End Treatments on One-Way Traffic Road

Table 71. Cost for Approaches on One-Way Traffic Roads

Crash Cushion	Crash Cost	Install/Remove Cost	Repair Cost
Sloped End Treatment (35 treatments removed)	$4,099,980	$87,500	$0
QuadGuard [78]	$323,351	$728,665	$10,129
QuadGuard [12]		$763,105	$62,510
QUEST [78]		$472,010	$25,081
TRACC [78]		$467,495	$5,012
TRACC [12]		$535,955	$73,542
TAU-II [78]		$632,870	$6,531
TAU-II [12]		$724,290	$48,657
QuadGuard Elite [78]		$1,353,975	$1,659
REACT 350 [78]		$1,479,030	$175
REACT 350 [12]		$1,208,235	$59,038
Smart Cushion [78]		$794,360	$175
Smart Cushion [12]		$819,735	$20,832
GREAT [12]		$390,390	$65,170
HEART [12]		$725,200	$15,043
Hex-Foam Sandwich [12]		$298,270	$27,384
QuadTrend [12]		$193,900	$62,475

Table 72. B/C for Approaches on One-Way Traffic Roads

Crash Cushion	Δ_C	Δ_{IR}	B/C
QuadGuard [78]	$924,469	$826,294	1.12
QuadGuard [12]		$913,115	1.01
QUEST [78]		$584,591	1.58
TRACC [78]		$560,007	1.65
TRACC [12]		$696,997	1.33
TAU-II [78]		$726,901	1.27
TAU-II [12]		$860,447	1.07
QuadGuard Elite [78]		$1,443,134	0.64
REACT 350 [78]		$1,566,705	0.59
REACT 350 [12]		$1,354,773	0.68
Smart Cushion [78]		$882,035	1.05
Smart Cushion [12]		$928,067	1.00
GREAT [12]		$543,060	1.70
HEART [12]		$827,743	1.12
Hex-Foam Sandwich [12]		$413,154	2.24
QuadTrend [12]		$343,875	2.69

8.4.4 Bridges with Ramps, One- and Two-Way Traffic Approaches

For this group of sloped end treatments, bridges near ramps with one- and two-way traffic were considered and are designated as sloped end treatment nos. 1 and 3 in Figure 144. All approach sloped end treatments on these bridges were included for a total of 110 sloped end treatments and 18 crashes. Therefore, installation, repair, and crash costs for 110 crash cushions and 18 crashes were calculated for crash cushions, and crash costs for 12 crashes were calculated for sloped end treatments. Results are shown in Tables 73 and 74. B/Cs for this subgroup ranged between 0.52 and 2.27. The three highest B/Cs are highlighted, which were found for the GREAT, Hex-Foam Sandwich, and QuadTrend crash cushions.

Figure 144. Sloped End Treatments on Bridge with Ramp

Table 73. Cost for Approaches on Bridges with Ramps with One- and Two-Way Traffic

Crash Cushion	Crash Cost	Install/Remove Cost	Repair Cost
Sloped End Treatment (110 treatments removed)	$2,139,120	$275,000	$0
QuadGuard [78]	$831,474	$2,290,090	$26,046
QuadGuard [12]		$2,398,330	$160,740
QUEST [78]		$1,483,460	$64,494
TRACC [78]		$1,469,270	$12,888
TRACC [12]		$1,684,430	$189,108
TAU-II [78]		$1,989,020	$16,794
TAU-II [12]		$2,276,340	$125,118
QuadGuard Elite [78]		$4,255,350	$4,266
REACT 350 [78]		$4,648,380	$450
REACT 350 [12]		$3,797,310	$151,812
Smart Cushion [78]		$2,496,560	$450
Smart Cushion [12]		$2,576,310	$53,568
GREAT [12]		$1,226,940	$167,580
HEART [12]		$2,279,200	$38,682
Hex-Foam Sandwich [12]		$937,420	$70,416
QuadTrend [12]		$609,400	$160,650

Table 74. B/C for Approaches on Bridges with Ramps with One- and Two-Way Traffic

Crash Cushion	Δ_C	Δ_{IR}	B/C
QuadGuard [78]	$2,377,206	$2,591,136	0.92
QuadGuard [12]		$2,834,070	0.84
QUEST [78]		$1,822,954	1.30
TRACC [78]		$1,757,158	1.35
TRACC [12]		$2,148,538	1.11
TAU-II [78]		$2,280,814	1.04
TAU-II [12]		$2,676,458	0.89
QuadGuard Elite [78]		$4,534,616	0.52
REACT 350 [78]		$4,923,830	0.48
REACT 350 [12]		$4,224,122	0.56
Smart Cushion [78]		$2,772,010	0.86
Smart Cushion [12]		$2,904,878	0.82
GREAT [12]		$1,669,520	1.42
HEART [12]		$2,592,882	0.92
Hex-Foam Sandwich [12]		$1,282,836	1.85
QuadTrend [12]		$1,045,050	2.27

8.4.5 Entrance and Exit Ramps

A total of five crashes involved sloped end treatments located on entrance or exit ramps, see sloped end treatment nos. 3, 4, 7, and 8 in Figure 145, and 23 sloped end treatments were located on ramps. Therefore, calculations for crash cushions were performed with 23 installations and five crashes, and calculations for sloped end treatments were performed with 25 crashes and 23 removals. Results are shown in Tables 75 and 76. B/Cs ranged between 0.64 and 2.88, much higher than any other subgroup of sloped end treatments. The three highest ratios are highlighted, which correspond to the GREAT, Hex-Foam Sandwich, and QuadTrend crash cushions.

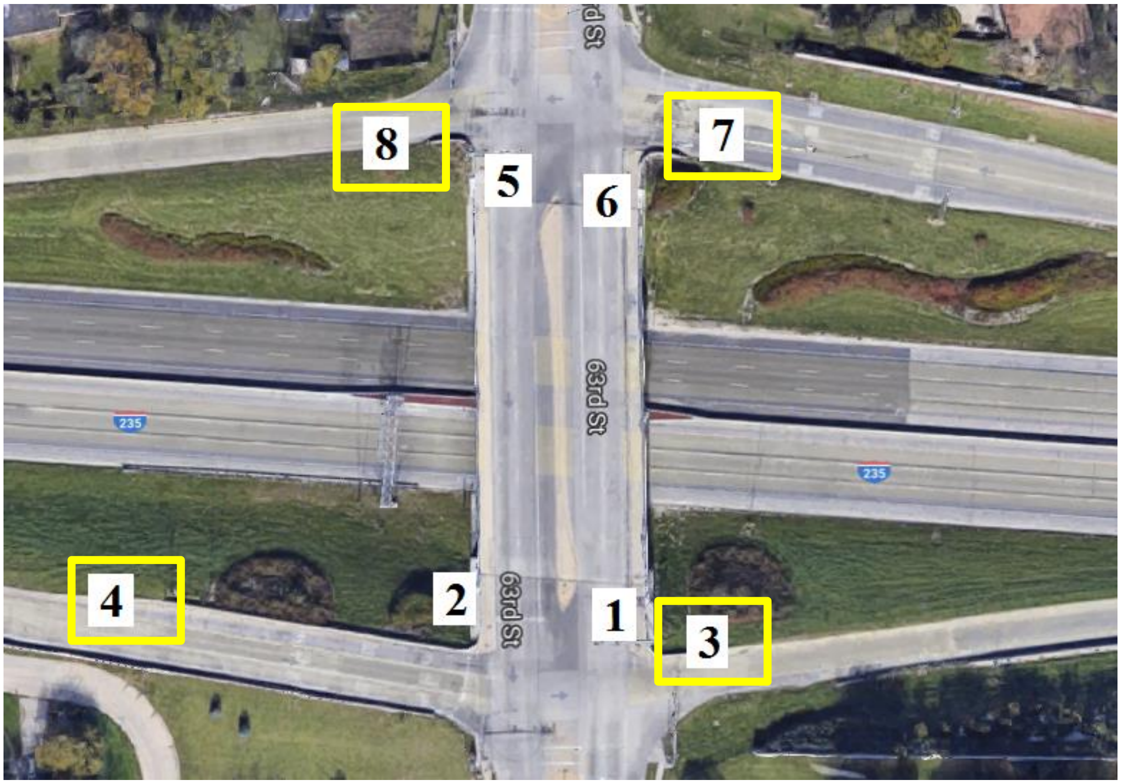


Figure 145. Sloped End Treatments on Entrance and Exit Ramps

Table 75. Cost for Entrance and Exit Ramps

Crash Cushion	Crash Cost	Install/Remove Cost	Repair Cost
Sloped End Treatment (23 treatments removed)	$4,456,500	$57,500	$0
QuadGuard [78]	$230,965	$478,837	$7,235
QuadGuard [12]		$501,469	$44,650
QUEST [78]		$310,178	$17,915
TRACC [78]		$307,211	$3,580
TRACC [12]		$352,199	$52,530
TAU-II [78]		$415,886	$4,665
TAU-II [12]		$475,962	$34,755
QuadGuard Elite [78]		$889,755	$1,185
REACT 350 [78]		$971,934	$125
REACT 350 [12]		$793,983	$42,170
Smart Cushion [78]		$522,008	$125
Smart Cushion [12]		$538,683	$14,880
GREAT [12]		$256,542	$46,550
HEART [12]		$476,560	$10,745
Hex-Foam Sandwich [12]		$196,006	$19,560
QuadTrend [12]		$127,420	$44,625

Table 76. B/C for Ramps

Crash Cushion	Δ_C	Δ_{IR}	B/C
QuadGuard [78]	$660,335	$543,572	1.21
QuadGuard [12]		$603,619	1.09
QUEST [78]		$385,593	1.71
TRACC [78]		$368,291	1.79
TRACC [12]		$462,229	1.43
TAU-II [78]		$478,051	1.38
TAU-II [12]		$568,217	1.16
QuadGuard Elite [78]		$948,440	0.70
REACT 350 [78]		$1,029,559	0.64
REACT 350 [12]		$893,653	0.74
Smart Cushion [78]		$579,633	1.14
Smart Cushion [12]		$611,063	1.08
GREAT [12]		$360,592	1.83
HEART [12]		$544,805	1.21
Hex-Foam Sandwich [12]		$273,066	2.42
QuadTrend [12]		$229,545	2.88

8.4.6 Ramps Plus Bridges with Ramps

For this section of analysis, sloped end treatments and crashes from Sections 8.4.4 and 8.4.5 were combined to evaluate the benefit-cost of replacing approach sloped end treatments on one- and two-way traffic bridges with ramps and replacing sloped end treatments on ramps. Sloped end treatment nos. 1, 2, and 4 are located on ramps and approaches on bridges with ramps, as shown in Figure 146. A total of 133 installations were considered for replacement and 23 crashes involved these installations. Therefore, calculations for the sloped end treatments considered the remaining seven crashes and removal of 133 installations. The calculations for crash cushions considered 133 installations and 23 crashes. Calculations are shown in Table 77, and B/C is shown in Table 78. The three highest B/Cs corresponded to the GREAT, Hex-Foam Sandwich, and QuadTrend crash cushions and are highlighted. The B/Cs ranged between 0.51 and 2.38.

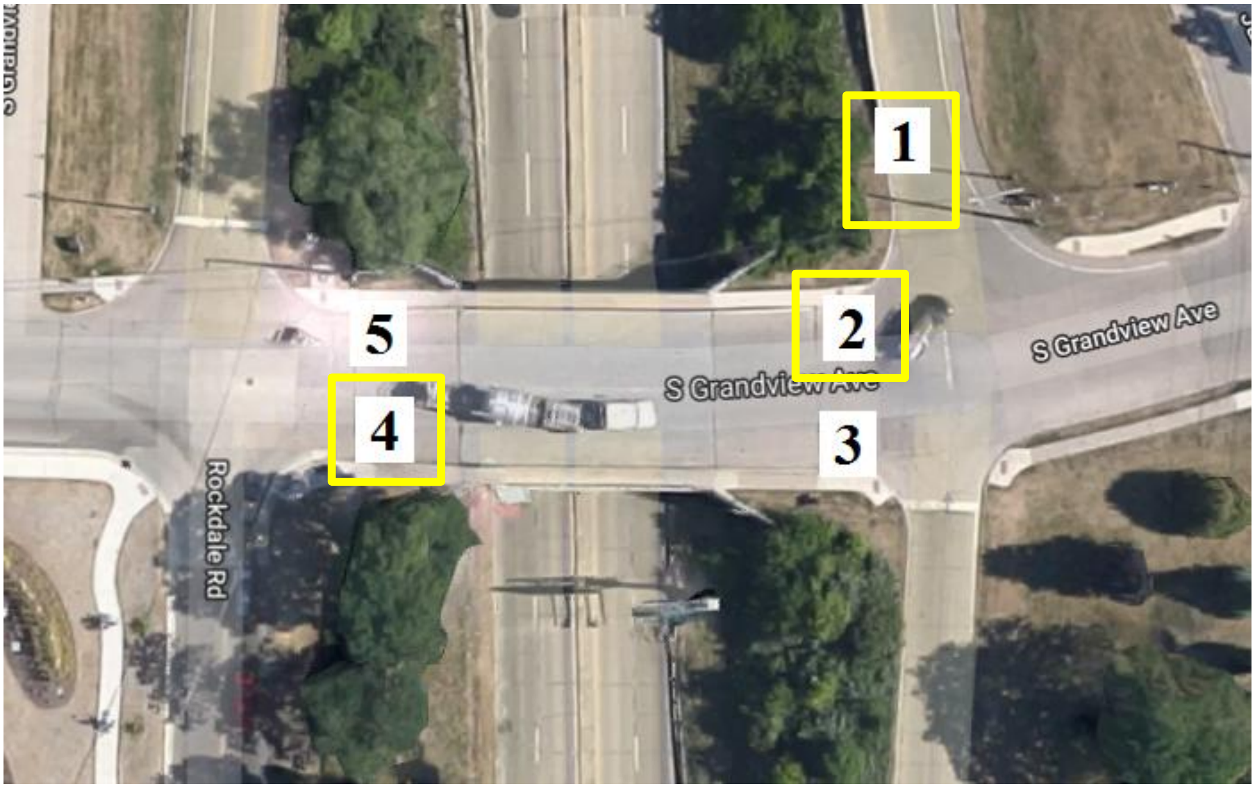


Figure 146. Sloped End Treatments on Ramps and Bridges with Ramps

Table 77. Cost for Ramps and Approaches on Bridges with Ramps

Crash Cushion	Crash Cost	Installation Cost	Repair Cost
Sloped End Treatment (133 treatments removed)	$1,247,820	$332,500	$0
QuadGuard [78]	$1,062,439	$2,768,927	$33,281
QuadGuard [12]		$2,899,799	$205,390
QUEST [78]		$1,793,638	$82,409
TRACC [78]		$1,776,481	$16,468
TRACC [12]		$2,036,629	$241,638
TAU-II [78]		$2,404,906	$21,459
TAU-II [12]		$2,752,302	$159,873
QuadGuard Elite [78]		$5,145,105	$5,451
REACT 350 [78]		$5,620,314	$575
REACT 350 [12]		$4,591,293	$193,982
Smart Cushion [78]		$3,018,568	$575
Smart Cushion [12]		$3,114,993	$68,448
GREAT [12]		$1,483,482	$214,130
HEART [12]		$2,755,760	$49,427
Hex-Foam Sandwich [12]		$1,133,426	$89,976
QuadTrend [12]		$736,820	$205,275

Table 78. B/C for Ramps and Approaches on Bridges with Ramps

Crash Cushion	Δ_C	Δ_{IR}	B/C
QuadGuard [78]	$3,037,54	$3,134,708	0.97
QuadGuard [12]		$3,437,689	0.88
QUEST [78]		$2,208,547	1.38
TRACC [78]		$2,125,449	1.43
TRACC [12]		$2,610,767	1.16
TAU-II [78]		$2,758,865	1.10
TAU-II [12]		$3,244,675	0.94
QuadGuard Elite [78]		$5,483,056	0.55
REACT 350 [78]		$5,953,389	0.51
REACT 350 [12]		$5,117,775	0.59
Smart Cushion [78]		$3,351,643	0.91
Smart Cushion [12]		$3,515,941	0.86
GREAT [12]		$2,030,112	1.50
HEART [12]		$3,137,687	0.97
Hex-Foam Sandwich [12]		$1,555,902	1.95
QuadTrend [12]		$1,274,595	2.38

8.5 Discussion

The cost-effectiveness of replacing sloped end treatments with crash cushions were explored in this research effort. If targeted removal could be completed with only those slope end treatments associated with crashes, the cost-effectiveness, indicated by the benefit-to-cost analysis, is very high, well over 5.0, which indicates an excellent return on investment for safety improvements overall.

However, crashes are quasi-random events and the low number of observed crashes with sloped end treatments make the identification of crash trends difficult. Researchers evaluated possible strategies for replacing sloped end treatments with crash cushions:

- All sloped end treatments;
- All two-way traffic, right-side on the approach (upstream) end;
- All one-way traffic, left- and right-sides on the approach (upstream) end of the bridge;
- All bridges/overpasses with ramps;
- Only at entrance or exit ramps; and
- All ramps plus bridges with ramps.

The benefit-to-cost ratios for each of the scenarios considered were significantly less than the targeted removal. This is because not every sloped end treatment will be involved in a crash, and removing sloped end treatments that are never involved in a crash does not improve public safety. For this reason, most state DOTs require a minimum benefit-to-cost ratio of 2.0 and some states prefer a minimum value of 4.0 to warrant safety improvement funding.

Of the considered scenarios, only the least-expensive crash cushion options were beneficial with a minimum B/C ratio of 2.0, and these crash cushions have not been full-scale crash tested and confirmed to be crashworthy according to MASH. This finding suggests that while sloped end treatments pose a crash risk, safety improvement dollars may be better-prioritized in other areas. Furthermore, only one of the eleven crash cushions have been evaluated to MASH criteria, and it is not recommended to install a system which has not. Researchers recommend a targeted sloped end treatment removal of all sites in which the sloped end treatments were struck because the 30 crashes which occurred were only associated with 19 discrete locations/bridges. This suggests these crash locations may be subjected to additional impacts in the future and therefore have the highest safety prioritization. For the remaining sloped end treatments, bridge reconstruction or rehabilitation projects, local safety improvement projects, or bridge rail replacement projects could be economically viable opportunities to remove existing sloped end treatments and install crashworthy hardware if conditions are warranted. Unfortunately, the crash data set was too limited to make definitive prioritizations based on AADT, speed limit, lane width, or shoulder width, but general characteristics of low- and high-frequency impact locations were identified. The exposure calculations may be a surrogate estimate for likelihood of SET impacts based on AADT.

It should be noted that none of the crashes recorded in the dataset could suggested that downstream ends of bridges with sloped end treatments were unsafe. As a result, sloped end treatments may be viable and low-cost bridge rail termination features in locations where impacts were unlikely: bridges with divided medians or median barriers and treatments on the downstream ends, at the downstream end of ramps, or at the downstream end of one-way bridges. With no increase in crash cost, the cost of installing – much less repairing and replacing – sloped end treatments would result in a negative B/C ratio.

9 SUMMARY OF CRASH EVENTS AND LOCATIONS

All crashes involving sloped end treatments were analyzed and are summarized in this chapter. A total of 635 identified sloped end treatments (97 percent) were not impacted during the ten-year crash data timeframe, and 166 bridges with sloped end treatments (91 percent) had zero observed sloped end treatment crashes. Some bridges featured multiple sloped end treatment crashes, as summarized in Section 9.1. Bridges, which featured only one sloped end treatment crash over the ten-year span of crash data, are summarized in Section 9.2.

9.1 Black Spot Crashes

Researchers analyzed the crash data for instances where multiple crashes occurred on the same bridge. Eight bridges were associated with more than one sloped end crash, combining for 21 of the 30 confirmed sloped end treatment crashes. Both of the severe crashes (A- and K-injury outcome) occurred on bridges each having more than one crash in the Iowa database. Bridges involved more than one crash were analyzed in more detail below.

9.1.1 Bridge No. 7701.3O235

Three crashes occurred on bridge no. 7701.3O235, two at sloped end treatment no. 1 and one at sloped end treatment no. 3. A satellite image of this bridge is shown in Figure 147, with the sloped end treatments labeled 1 through 4.

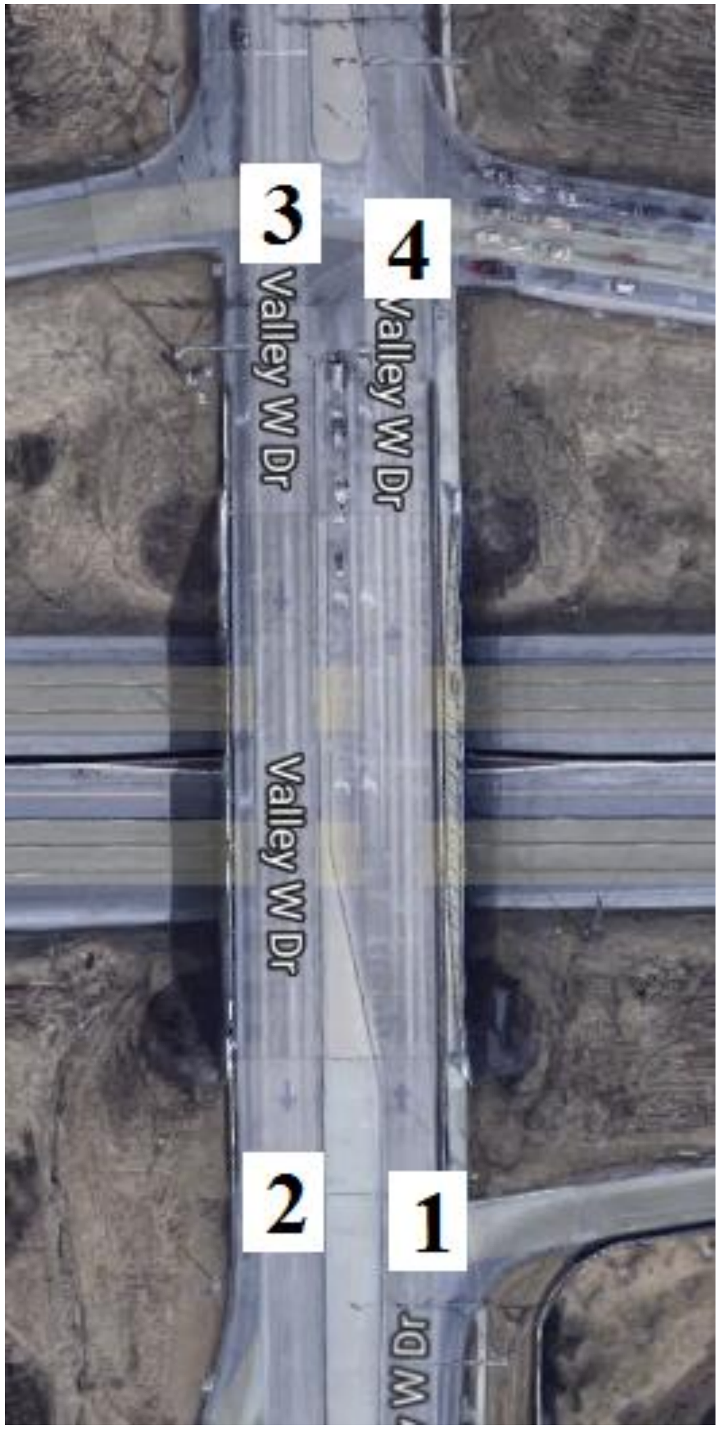


Figure 147. Bridge No. 7701.3O235 with Sloped End Treatments Labeled [1]

Details of the three crashes that occurred on bridge no. 7701.3O235 are summarized in Table 79. Data includes the sloped end treatment that was impacted, speed limit, injury, vehicle, weather, road conditions, and crash outcome.

Sloped end treatment no. 1 was involved in two crashes over the ten-year span of data. Crash no. 1 featured the vehicle overriding the barrier at sloped end treatment no. 1, traveling on the sidewalk behind the concrete barrier and impacting the bridge, resulting in a major injury. Sloped end treatment no. 1 was also involved in crash no. 2, which involved the vehicle ramping up the end of the barrier, forcing the vehicle up on two wheels, and then crossing the center median. Resulting vehicle damage included two flat tires, rim damage, and front bumper damage.

Crash no. 3 involved the vehicle impacting sloped end treatment no. 3 and rolling. This crash resulted in no injuries. Weather may have contributed to this crash, as it was raining and the road was wet.

Table 79. Bridge No. 7701.3O235 Sloped End Treatment Crashes

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	1	35	Major	Car	Cloudy	Dry	23,500	Climb, Non-Rollover, Non-Traffic Side
2	1	35	PDO	SUV	Clear	Dry	23,500	Climb, Non-Rollover, Traffic Side
3	3	35	PDO	SUV	Rain	Wet	23,500	Redirect, Rollover, Traffic Side

9.1.2 Bridge No. 7704.4O235

Five sloped end treatments were located on or near bridge no. 7704.4O235, as shown in Figure 148. Two crashes occurred on this bridge, one at sloped end treatment no. 1 and one at sloped end treatment no. 4. Details of the crashes are shown in Table 80.

Figure 148. Bridge No. 7704.4O235 with Sloped End Treatments Labeled [1]

In crash no. 1, the vehicle impacted sloped end treatment no. 4 and rolled. In crash no. 2, the vehicle impacted sloped end treatment no. 1 and rolled. Neither crash resulted in injuries, only vehicle damage, and both vehicles remained on the bridge after rolling over. Weather may have been a contributing factor in both crashes as it was raining.

Table 80. Bridge No. 7704.4O235 Sloped End Treatment Crashes

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	4	30	PDO	SUV	Rain	Wet	9,500	Redirect, Rollover, Traffic Side
2	1	35	PDO	Car	Rain	Wet	9,500	Climb, Rollover, Traffic Side

9.1.3 Bridge No. 7706.2O235

Four crashes occurred on bridge no. 7706.2O235, as shown in Figure 149. These crashes occurred on sloped end treatment nos. 1, 6, 8, and 9. A total of nine sloped end treatments were identified on or near this bridge.

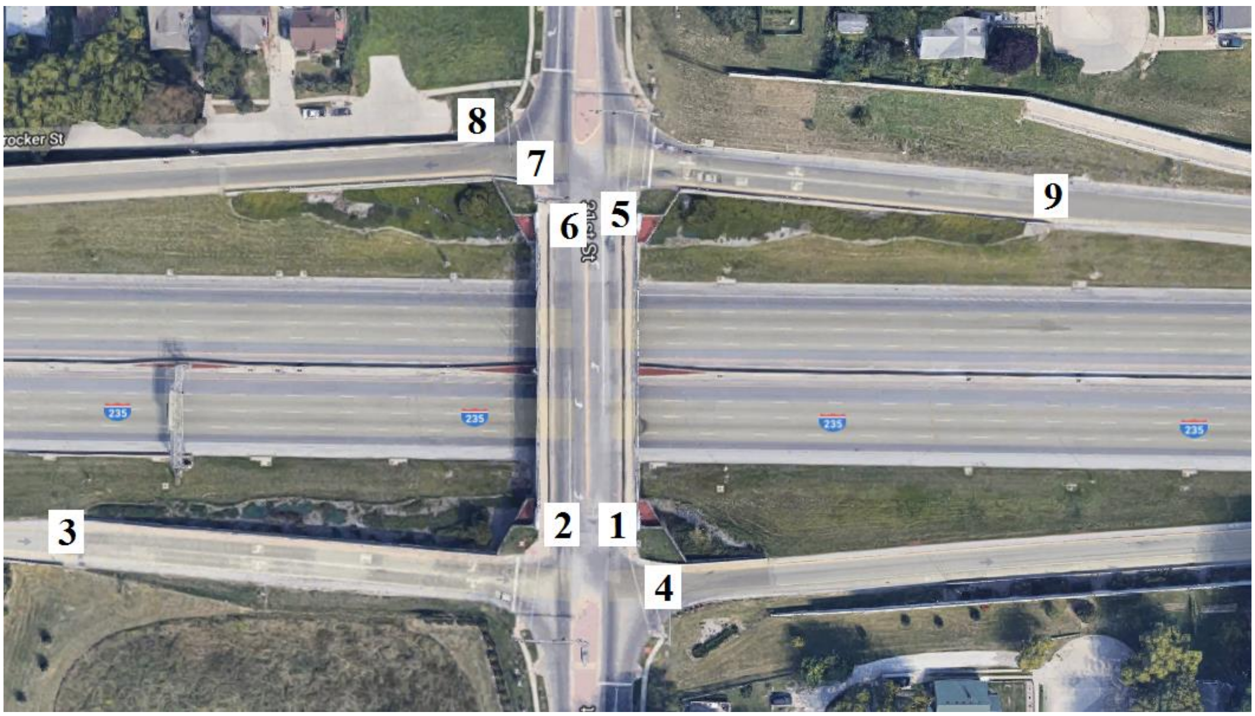


Figure 149. Bridge No. 7706.2O235 with Sloped End Treatments Labeled [1]

Details of the four sloped end treatment crashes are shown in Table 81. All crashes in conjunction with bridge no. 7706.2O235 resulted in PDO. In crash no. 1, the vehicle impacted sloped end treatment no. 6 and rolled onto the traffic side, or roadway. For crash no. 2, the vehicle impacted sloped end treatment no. 1, overrode the barrier, and came to rest upright and on the sidewalk behind the barrier. Weather may have been a contributing factor in crash nos. 1 and 2.

The outcomes of crashes no. 3 and 4 could not be determined based on the crash narratives and scene diagrams. Crash no. 3 involved the vehicle impacting sloped end treatment no. 8. No injuries were reported, only property damage. Sloped end treatment no. 9 was impacted in crash no. 4 and resulted in PDO.

Table 81. Bridge No. 7706.2O235 Sloped End Treatment Crashes

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	6	30	PDO	Car	Rain	Wet	14,900	Redirect, Rollover, Traffic Side
2	1	30	PDO	Car	Rain	Wet	14,900	Climb, Non-Rollover, Non-Traffic Side
3	8	25	PDO	Car	Clear	Dry	5,700	Unknown
4	9	55	PDO	Pickup	Clear	Dry	5,700	Unknown

9.1.4 Bridge No. 7707.1O235

Two crashes involving sloped end treatment nos. 3 and 4 occurred on bridge no. 7707.1O235, as shown in Figure 150. This bridge accommodates one-way traffic southbound and features four sloped end treatments.

Figure 150. Bridge No. 7707.1O235 with Sloped End Treatments Labeled [1]

Sloped end treatment nos. 3 and 4 were involved in one crash each over the ten-year span of data. Both crashes resulted in PDO, as shown in Table 82. In crash no. 1, sloped end treatment no. 3 was impacted by a single unit truck, causing the truck to roll to the traffic side, onto the roadway. Sloped end treatment no. 4 was impacted by the vehicle in crash no. 2, causing the vehicle to launch, become airborne, and land on the sidewalk behind the barrier. The vehicle speed at the time of the accident is unknown, but to become airborne, this vehicle must have been traveling faster than the posted speed limit of 25 mph. As a result of the crash, the vehicle had a flat tire.

Table 82. Bridge No. 7707.1O235 Sloped End Treatment Crashes

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	3	25	PDO	Single Unit Truck	Cloudy	Dry	12,200	Redirect, Rollover, Traffic Side
2	4	25	PDO	SUV	Cloudy	Dry	12,200	Climb, Non-Rollover, Non-Traffic Side

9.1.5 Bridge No. 7708.3O235

Bridge no. 7708.3O235 is shown in Figure 151. Two crashes occurred on this bridge, both at sloped end treatment no. 1. This bridge accommodates one-way traffic northbound. A total of four sloped end treatments were identified on or near this bridge.

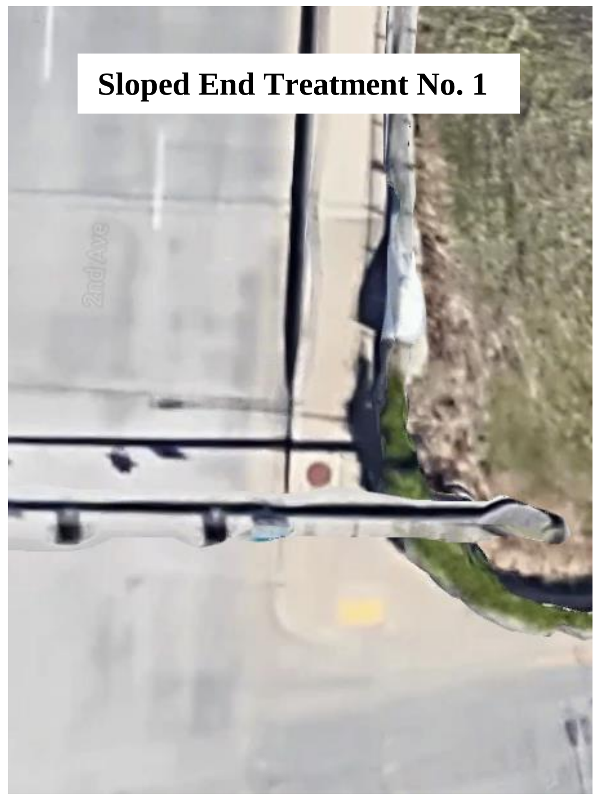


Figure 151. Bridge No. 7708.3O235 with Sloped End Treatments Labeled [1]

Two crashes involving sloped end no. 1 occurred on bridge no. 7708.3O235, as shown in Table 83. During crash no. 1, the vehicle impacted the sloped end treatment and came to rest on the non-traffic side of the bridge rail on the pedestrian sidewalk. During crash no. 2, the vehicle climbed the sloped end treatment and rolled over on the non-traffic side of the bridge rail on the pedestrian sidewalk, resulting in PDO injuries.

Table 83. Bridge No. 7708.3O235 Sloped End Treatment Crashes

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	1	25	PDO	Car	Clear	Dry	8,600	Climb, Non-Rollover, Non-Traffic Side
2	1	35	PDO	SUV	Clear	Dry	8,600	Climb, Rollover, Non-Traffic Side

9.1.6 Bridge No. 7718.3S028

Figure 152 shows the eight sloped end treatments found on or near bridge no. 7718.3S028. A total of three crashes occurred on this bridge in the ten-year span, each of which impacted sloped end treatment no. 5 and resulted in PDO injuries, as shown in Table 84.

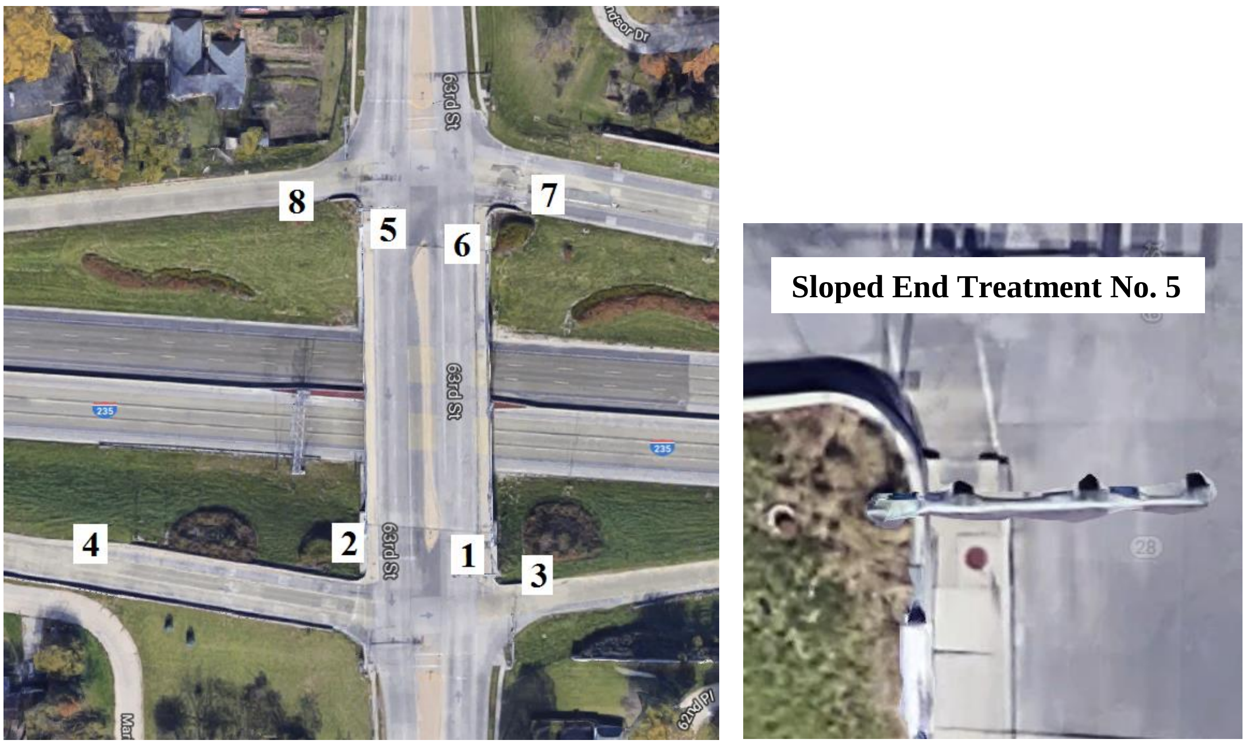


Figure 152. Bridge No. 7718.3S028 with Sloped End Treatments Labeled [1]

During crash no. 1, the vehicle impacted the sloped end treatment and ramped up on the barrier, coming to a stop on top of the barrier. For crash no. 2, the impacting vehicle ramped up the sloped end treatment and became airborne. The vehicle partially rolled while airborne and landed on the sidewalk behind the barrier on the passenger side. In crash no. 3, the vehicle swerved to avoid a collision with another vehicle and impacted the sloped end treatment, disabling the vehicle. It is unknown whether the vehicle was redirected, climbed, or rolled based on the crash narrative and scene diagram, but researchers believe that the vehicle remained upright and came to rest shortly after the point of impact.

Table 84. Bridge No. 7718.3S028 Sloped End Treatment Crashes

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	5	35	PDO	Car	Rain	Wet	23,100	Climb, Non-Rollover, Top
2	5	30	PDO	Car	Cloudy	Dry	23,100	Climb, Rollover, Non-Traffic Side
3	5	35	PDO	SUV	Clear	Dry	23,100	Unknown

9.1.7 Bridge No. 9401.5L926

Bridge no. 9401.5L926 is shown in Figure 153, with the two sloped end treatments labeled. Sloped end treatment no. 1 was involved in one fatal crash and two PDO crashes, as shown in Table 85. Crash no. 1 resulted in one fatality and three major injuries. The vehicle impacted the sloped end treatment, vaulted off the side of the bridge, rolled partially to one side while airborne, and landed on railroad tracks. In crash no. 2, the vehicle lost control due to slushy road conditions and struck the sloped end treatment, disabling the vehicle. It is unknown whether the vehicle was redirected or climbed the barrier. Due to slick travel conditions, researchers believe the vehicle was redirected. The vehicle in crash no. 3 ramped up the sloped end treatment and came to rest on top of the barrier.

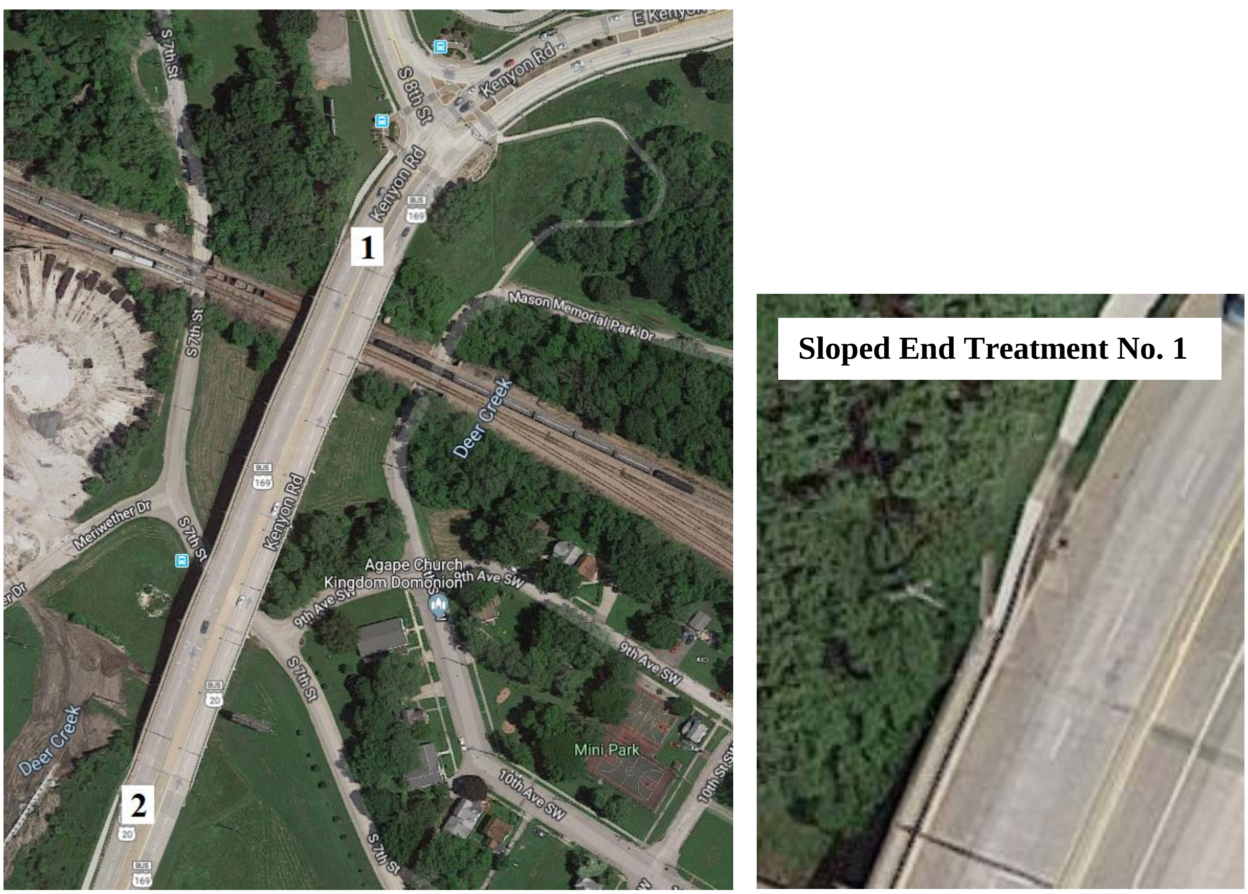


Figure 153. Bridge No. 9401.5L926 with Sloped End Treatments Labeled [1]

Table 85. Bridge No. 9401.5L926 Sloped End Treatment Crashes

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	1	35	Fatal	Pickup	Cloudy	Dry	14,700	Climb, Rollover, Non-Traffic Side
2	1	35	PDO	Pickup	Clear	Slush	14,700	Unknown
3	1	35	PDO	Car	Cloudy	Wet	14,700	Climb, Non-Rollover, Top

9.1.8 Special Case

A sloped end treatment that was not identified in the sloped end treatment inventory created for this research was impacted twice, and is located adjacent to bridge no. 7707.9O235, as shown in Figure 154. The unidentified, impacted sloped end treatment is located at GPS coordinates (41.596257, -93.629453) and is shown in Figure 155. The sloped end treatment has the low round taper shape and is considerably shorter than other sloped end treatment installations in this research.

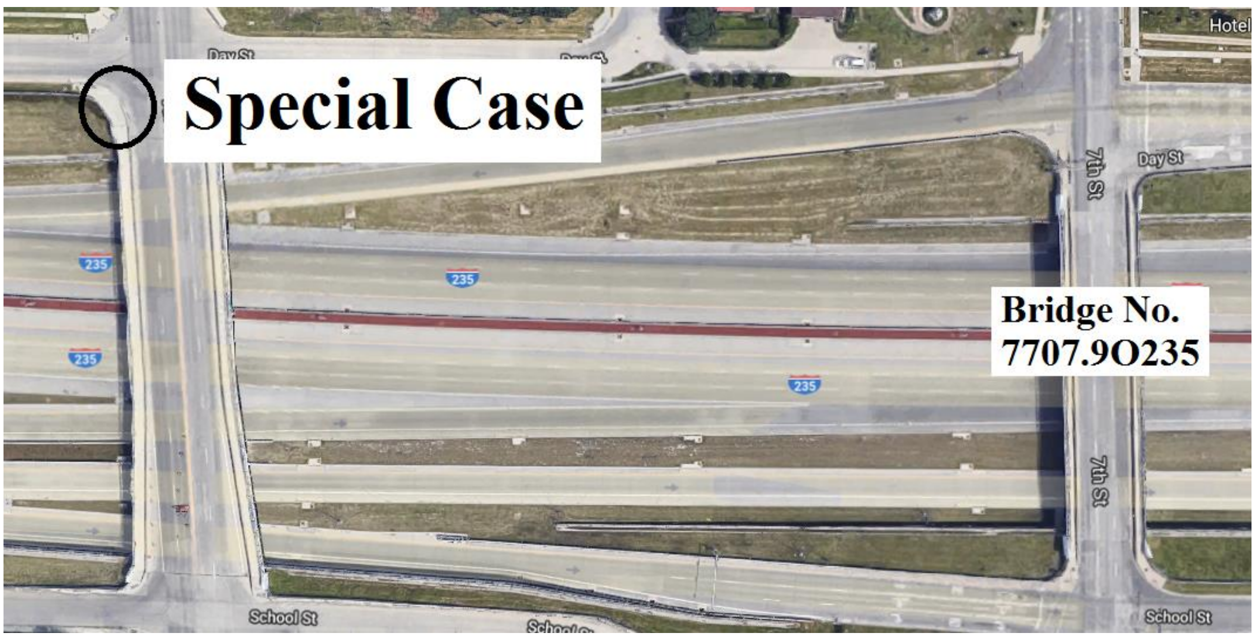


Figure 154. Special Case Bridge with Sloped End Treatment Labeled [1]

Figure 155. Special Case Sloped End Treatment [1]

The special case sloped end treatment was impacted twice between 2008 and 2017, as shown in Table 86. Both crashes resulted in PDO injuries. Note, despite occurring at the same location, the speed limits listed for each crash in the report were not equal, meaning the speed limit was recorded incorrectly for at least one of these crashes.

Crash no. 1 occurred in rain on wet road conditions and consisted of a van impacting the sloped end treatment and coming to rest straddling the barrier. The vehicle remained upright throughout the crash. Crash no. 2 occurred during dry conditions in clear weather with a car. However, crash narrative and scene diagram data were not conclusive to determine what crash outcome occurred.

Table 86. Special Case Sloped End Treatment Crashes

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	Outcome
1	Special Case	25	PDO	Van	Rain	Wet	Climb, Non-Rollover, Top
2	Special Case	35	PDO	Car	Clear	Dry	Unknown

9.2 Single Crashes

Bridges which only featured one sloped end treatment crash over the ten-year span of data are discussed below. A total of nine bridges featured one sloped end treatment crash, which involved one sloped end treatment located on or near each bridge.

9.2.1 Bridge No. 1654.6O080

Bridge no. 1654.6O080, which features four sloped end treatments, is shown in Figure 156. Sloped end treatment no. 1 was involved in one crash during the ten-year span of data, as summarized in Table 87. During this crash, a car impacted sloped end treatment no. 1, climbed the treatment, and ended on the non-traffic side of the barrier resulting in a minor injury.

Figure 156. Bridge No. 1654.6O080 with Sloped End Treatments Labeled [1]

Table 87. Bridge No. 1654.6O080 Sloped End Treatment Crash

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	1	35	Minor	Car	Clear	Dry	4,210	Climb, Non-Rollover, Non-Traffic Side

9.2.2 Bridge No. 5242.1O080

Bridge no. 5242.1O080, as shown in Figure 157, features two sloped end treatments. Sloped end treatment no. 1 was involved in one accident, as shown in Table 88. A PDO injury resulted from a van impacting the sloped end treatment.

Figure 157. Bridge No. 5242.1O080 with Sloped End Treatments Labeled [1]

Table 88. Bridge No. 5242.1O080 Sloped End Treatment Crash

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	1	25	PDO	Van	Cloudy	Dry	10,300	Unknown

9.2.3 Bridge No. 5602.4S136

Figure 158 shows the four sloped end treatments located on bridge no. 5602.4S136, and sloped end treatment no. 1 was involved in one accident, summarized in Table 89. This accident involved a van and resulted in PDO.

Figure 158. Bridge No. 5602.4S136 with Sloped End Treatments Labeled [1]

Table 89. Bridge No. 5602.4S136 Sloped End Treatment Crash

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	1	30	PDO	Van	Clear	Dry	4,120	Unknown

9.2.4 Bridge No. 7705.0O235

Bridge no. 7705.0O235, as shown in Figure 159, featured two sloped end treatments. One accident involved an SUV impacting sloped end treatment no. 1, which resulted in a minor injury, as summarized in Table 90.

Figure 159. Bridge No. 7705.0O235 with Sloped End Treatments Labeled [1]

Table 90. Bridge No. 7705.0O235 Sloped End Treatment Crash

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	1	30	Minor	SUV	Clear	Dry	8,900	Unknown

9.2.5 Bridge No. 7705.4O235

Six sloped end treatments were located on and near bridge no. 7705.4O235, as shown in Figure 160. Sloped end treatment no. 6, located on an exit ramp, was involved in an accident, as summarized in Table 91. During this accident a car impacted sloped end treatment no. 6, climbed the treatment, rolled over, ended on the traffic side of the barrier, resulting in a minor injury.

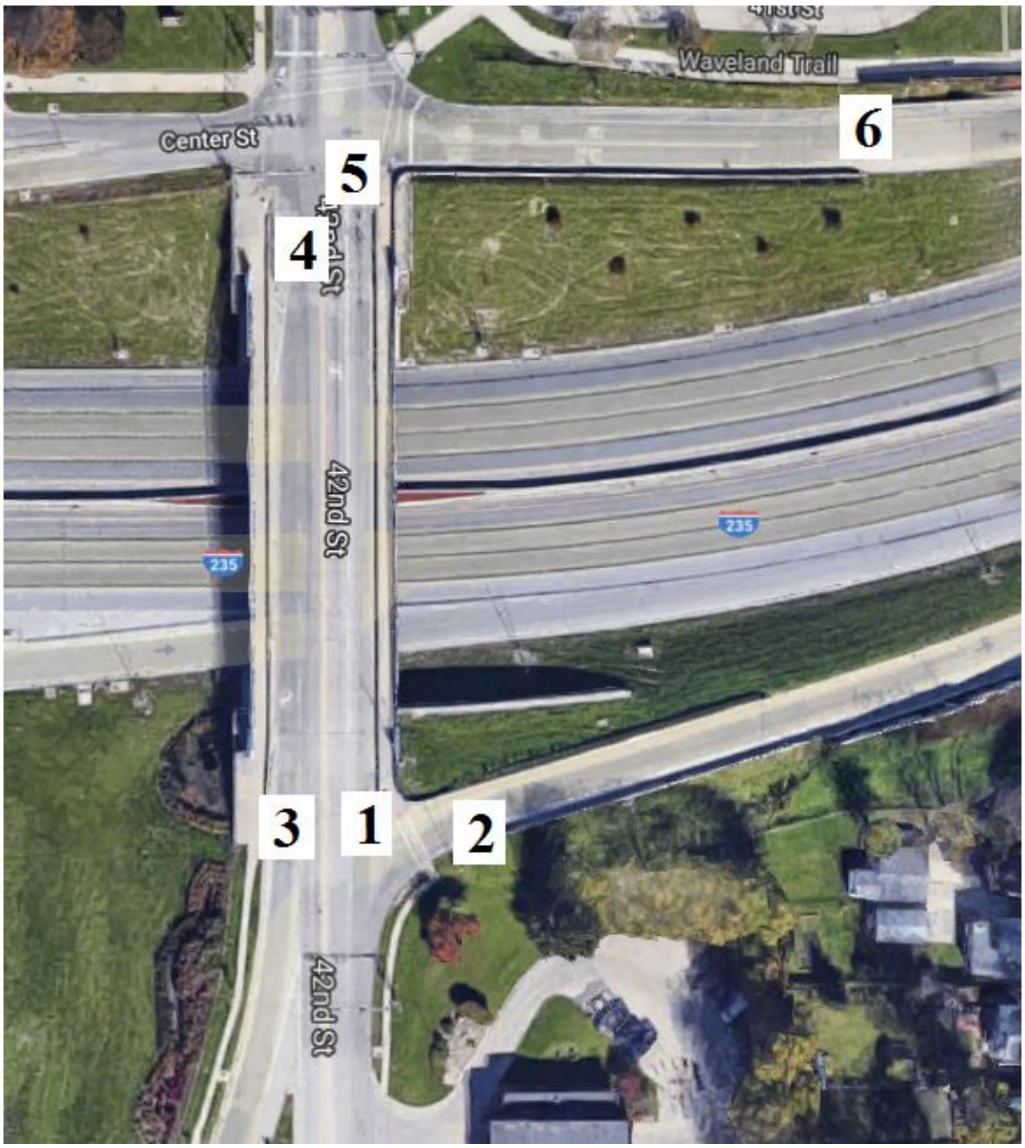


Figure 160. Bridge No. 7705.4O235 with Sloped End Treatments Labeled [1]

Table 91. Bridge No. 7705.4O235 Sloped End Treatment Crash

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	6	55	Minor	Car	Clear	Dry	4,170	Climb, Rollover, Traffic Side

9.2.6 Bridge No. 7710.0A235

Three sloped end treatments were located on the entrance/exit ramp labeled bridge no. 7710.0A235, as shown in Figure 161. One sloped end treatment, no. 1, was involved in one accident, as shown in Table 92. A minor injury resulted from a car impacting the sloped end treatment, climbing the barrier, rolling over, and ending on the traffic side of the barrier.

Figure 161. Bridge No. 7710.0A235 with Sloped End Treatments Labeled [1]

Table 92. Bridge No. 7710.0A235 Sloped End Treatment Crash

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	1	45	Minor	Car	Cloudy	Dry	10,500	Climb, Rollover, Traffic Side

9.2.7 Bridge No. 7785.5S069

Bridge no. 7785.5S069, as shown in Figure 162, featured a total of five sloped end treatments. Sloped end treatment no. 3 was impacted by a car, resulting in PDO, as shown in Table 93. During the crash, the vehicle climbed the treatment, rolled over, and ended on the non-traffic side of the barrier.

Figure 162. Bridge No. 7785.5S069 with Sloped End Treatments Labeled [1]

Table 93. Bridge No. 7785.5S069 Sloped End Treatment Crash

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	3	45	PDO	Car	Clear	Dry	8,800	Climb, Rollover, Non-Traffic Side

9.2.8 Bridge No. 8204.9S006

A total of four sloped end treatments were identified on bridge no. 8204.9S006, as shown in Figure 163. One accident involved sloped end treatment no. 3, as shown in Table 94. Unknown injuries resulted from a pickup truck climbing the sloped end treatment, rolling over, and ending on the traffic side of the barrier.

Figure 163. Bridge No. 8204.9S006 with Sloped End Treatments Labeled [1]

Table 94. Bridge No. 8204.9S006 Sloped End Treatment Crash

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	3	40	Unknown	Pickup	Clear	Dry	19,000	Climb, Rollover, Traffic Side

9.2.9 Bridge No. 8220.1R061

Bridge no. 8220.1R061, as shown in Figure 164, is a one-way northbound traffic bridge which featured two sloped end treatments. Sloped end treatment no. 1 was involved in a crash in which an SUV climbed the barrier, rolled over, and ended on the traffic side of the barrier, as shown in Table 95. This accident resulted in a minor injury.

Figure 164. Bridge No. 8220.1R061 with Sloped End Treatments Labeled [1]

Table 95. Bridge No. 8220.1R061 Sloped End Treatment Crash

Crash No.	Sloped End No.	Speed Limit (mph)	Injury	Vehicle	Weather	Road Conditions	AADT (Vehicles/Day)	Outcome
1	1	35	Minor	SUV	Clear	Dry	21,300	Climb, Rollover, Traffic Side

9.3 Discussion

It was found that all 30 sloped end treatment crashes occurred on a total of 17 out of the total 183 bridges (9 percent). Furthermore, the crashes involved 23 unique sloped end treatments out of the total 658 (3 percent).

A total of 21 crashes occurred at black spots, which were defined to be bridges with more than one crash in the ten-year data span. These crashes occurred on a total of 8 bridges, 7 of which were bridges with ramps. AADT for the bridges involved in the black spot crashes ranged between 5,700 and 23,500 vehicles per day. This AADT range is similar to that for non-black spot crashes and for non-impacted sloped end treatments.

Furthermore, no black spot or single crashes occurred on roadways with AADTs greater than 23,500 vehicles per day. A total of 26 sloped end treatments were located on roadways with AADTs greater than 25,000 vehicles per day which were not involved in any crashes.

For "black spot" bridges, 14 unique sloped end treatments were involved in the 21 crashes. If these treatments were removed and the same crash pattern continued, 70 percent of sloped end crashes would not occur. It is assumed that the SET impacts are quasi-random events and could occur anywhere in Iowa, but the prevalence of crashes at the "black spot" bridges suggests that the highest priority for treating SETs are locations with crash histories.

The remaining 9 crashes occurred at 9 unique bridge locations, three of which were associated with ramps and six of which were bridges without ramps. AADTs for these bridges ranged between 4,120 and 21,300 vehicles per day.

A summary of the attributes of sloped end treatments and SET crashes is shown in Table 96. Twenty percent of sloped end treatments which were installed on ramps were involved in a crash during the ten-year span of data, 7 percent of SETs installed at bridges with ramps were involved in a crash, and 1.5 percent of SETs installed at bridges without ramps were involved in a crash. Overall, 3.5 percent of the identified SETs were involved in crashes between 2008 and 2017.

Table 96. Type of Roadway for Black Spot, Single, and Total Sloped End Treatment Crashes

Type of Roadway	Sloped End Treatments	Impacted Sloped End Treatments		
		Black Spot	Single	Total
Ramps	25	2 (8%)	3 (12%)	5 (20%)
Bridges with Ramps	162	11 (7%)	0 (0%)	11 (7%)
Bridges without Ramps	471	1 (0.2%)	6 (1.3%)	7 (1.5%)
Total	**658**	**14 (2%)**	**9 (1.4%)**	**23 (3.5%)**

Black spot crashes occurred overwhelmingly on bridges with ramps, which are typically interstate and highway overpasses. These bridges have AADTs similar to AADTs for the entire sloped end treatment inventory. However, bridges which feature ramps allow for more turning opportunities as compared to bridges without ramps, which may have led to the increased number of crashes occurring at these locations. Further research may be needed to determine the validity of this assumption.

Researchers did not have crash records or impact observations for SETs which were inadvertently struck by large trucks (e.g., tractor-trailers) or passenger vehicles during a turn which resulted in minimal vehicle damage and were not tabulated in crash reports. As such, replacing some SETs with crash cushions at ramp locations or instances where lateral clearance, turn radius, and road widths were narrow could result in impacts which were not previously observed, or additional maintenance which is not currently considered in the calculations. However, it was also observed that the crash cost estimation for these crashes was very high relative to what would be expected based on the posted speed limit (PSL). Moreover, researchers did not have severity, installation, or maintenance costs for low-speed crash cushions, including the “Raptor” by GSI [81] or the TrafFix Devices, Inc. SLED [36]. Additionally, ultra-short length inertial energy absorbers such as sand barrel arrays (e.g., “Energite” by Trinity Highway Products [82], “CrashGard” by PSS Innovations [83], or “Big Sandy” by TrafFix Devices, Inc [84]) may be a robust and low-cost method of treating parapet blunt ends by reducing an impacting vehicle’s speed at the point of contact with the vertical blunt end. Although it is believed that sand barrel arrays have higher crash costs overall than crash cushions for the same impact conditions, the significantly-reduced installation and maintenance costs associated with sand barrel arrays may allow for more cost-effective and safe treatments of SETs within the same space limitations. As well, travel speeds near locations with SETs in Iowa were much lower than for most high-speed applications for which sand barrels are designed, and if ROR speeds follow a similar distribution to speed limits, the crash costs and injury risks for sand barrels may be minimal. It is recommended that if site conditions warrant the use of inertial or low-cost crash cushions, that these be strongly considered due to low frequency of impacts and repairs.

If no other safety treatments are cost-effective, researchers recommend low-cost safety treatments related to increasing driver attentiveness, such as warning signs or channelizers, or rumble strips located adjacent to or in the roadway. Calculation of the economic benefits of implementing these devices was beyond the scope of this research study, but it is anticipated that the benefits of driver alertness improvements may be significant in preventing future crashes with existing and untreated SETs. Research studies have suggested the safety benefits of reflective materials to avoid some types of crashes, although the benefit of those treatments applied to sloped end treatments is unclear.

10 SUMMARY, DISCUSSION, AND CONCLUSIONS

10.1 Summary and Discussion

Iowa DOT funded the first ISPE study of concrete sloped end treatments on Iowa roads and bridges. Researchers were asked to determine if additional action was needed to treat sloped end treatments, and if so, how to prioritize those safety treatments.

First, a literature search was conducted. An ISPE manual and published ISPE studies were reviewed for procedures and instructions. Full-scale crash tests performed on four types of concrete sloped end treatments were reviewed to evaluate performance under NCHRP Report No. 230, NCHRP Report No. 350, and MASH testing conditions. Alternative barrier terminating ends, such as short radius guardrail and crash cushions, were also reviewed as potential alternatives for concrete sloped end treatments. Due to space limitations which were common with SETs, particularly at "black spot" locations, guardrail and short-radius configurations were not considered in benefit-to-cost analyses.

Next, because no concrete sloped end treatment inventory was available, one was created utilizing Iowa DOT's bridge inventory and Google Earth. After sloped end treatments were located, exposure was calculated for each installation. Crash data for years 2008 through 2017 in Iowa was provided, which included all fixed object crashes for the ten-year span. The program ArcGIS was utilized to collect all fixed object crashes which occurred within 1,000 ft of sloped end treatments in the inventory. Crash narratives and scene diagrams were reviewed to determine if a concrete sloped end treatment was involved in the crash. These "proximity" crashes, a total of 2,376 crashes, were then split into two groups: sloped end treatment crashes (30) and non-sloped end treatment, fixed-object impact crashes (2,346).

Crash characteristics from both datasets were reviewed to determine if they were comparable. The non-sloped end treatment crash set was not intended to evaluate other end treatment options and performance, but instead be a comparison of crashes with similar conditions located near sloped end treatments. It was found that 25 of the 30 sloped end treatment crashes (83 percent) occurred on roads with speed limits less than or equal to 35 mph. In contrast, 52 percent of non-sloped end treatment crashes occurred on roads with speed limits of 40 mph or higher. Non-sloped end and sloped end treatment crashes had similar attributes overall, although non-sloped end treatment crashes occurred more frequently on higher-speed limit roads and were therefore assumed to have higher average speeds. Therefore, injuries and crash costs for sloped end and non-sloped end treatment crashes were collected, calculated, and compared.

An injury analysis was conducted comparing results of the sloped end treatment crashes to the non-sloped end treatment fixed object crashes. Because the non-sloped end treatment crashes occurred more often on higher-speed limit roads, it was anticipated that injury severity would be higher as compared to the sloped end treatment crashes. More severe injuries result in higher crash costs, so it was also anticipated that non-sloped end treatment crashes would have higher costs as compared to sloped end treatment crashes. Sloped end treatment crashes showed a higher percentage of major injuries and fatalities (6 percent) as compared to the non-sloped end treatment crashes (3.9 percent). The estimated crash cost for sloped end treatments was approximately $178,260 per crash as compared to $67,449 per crash for non-sloped end treatment fixed objects on similar roadways.

Significant vehicle instability was observed both in full-scale crash testing [4-8] and in real-world crash data. Crash outcome and vehicle action were reviewed, and it was found that 13 of the 30 (43 percent) sloped end treatment crashes resulted in vehicle rollover. Furthermore, based on observation of full-scale crash tests [4-8] and real-world crashes, sloped end treatments can induce vehicle climb and launch over the barrier. Moreover, slope end treatments which contribute to rollover or vaulting may expose the impacting vehicle and occupants to additional risk. Some crashes resulted in the vehicle ending on top of the barrier, which suggests these crashes occurred at low speeds because they did not result in the vehicle launching over the barrier.

Blunt ends of concrete barriers are rigid, fixed objects, typically located in close proximity to the side of the road, and may pose a significant hazard to impacting vehicles if not treated with a crashworthy safety treatment. However, safety treatments may contribute to injuries and fatalities as well, as described in previous ISPE studies [85-88], and often increase the total number of observed crashes by adding to the total number of roadside fixed objects.

Short-radius guardrail systems were specifically designed to minimize the guardrail length required upstream from a concrete barrier. However, the minimum length of these systems adjacent to the concrete parapet is 18 ft (TL-2 Yuma County system) [28]. For many locations where the sloped end treatments were used in Iowa, less than 18 ft of usable space exists. Likewise, installing the angled leg of the short-radius system is not always possible, such as at intersections with on- and off-ramp locations near overpasses due to roadway and turn lane interference, land grading, and angles formed between intersecting roads. As only two MASH-approved short radius system configurations exist and no modifications of those systems have been evaluated or found to be crashworthy, there are few locations in Iowa which could utilize these short-radius systems in lieu of the sloped end treatments. Furthermore, crash cushions range vastly in size: between 8 ft – 6 in. and 37 ft – 6 in. in length; between 22 in. and 150 in. in width; and 27.75 in. and 53 in. in height. Because the identified sloped end treatments also vary in size, each installation would need to be reviewed to determine if a viable crash cushion option is viable.

Sloped end treatment geometry and location were also reviewed and it was found that on two-way traffic roadways, left-side sloped end treatments were never involved in a crash. Furthermore, no departure sloped end treatment was impacted on one-way traffic roadways. Roadway type (ramp, bridge with ramps, and bridge without ramps) was reviewed for each sloped end treatment crash, and it was found that 70 percent of crashes occurred on ramps or bridges with ramps. A review of all sloped end treatments was conducted, and it was found that 28 percent were located on ramps and bridges with ramps. Therefore, priority for replacement would be given to sloped end treatments located on approaches on bridges with ramps.

A B/C analysis was performed to evaluate cost-effectiveness of replacing sloped end treatments with crash cushions. Analysis only considered crash cushions for which installation and repair costs were available, only one of which has been evaluated to MASH criteria. Various configurations of replacement were considered, including replacing only sloped end treatments which were involved in crashes, all sloped end treatments in Iowa, and sloped end treatments located on certain types of roadways.

Finally, the 30 sloped end treatment crashes were located and the specific sloped end treatment involved was analyzed. Researchers analyzed the crash data for instances where crashes occurred on the same bridge. Eight bridges were associated with more than one sloped end crash, combining for 21 of the 30 confirmed sloped end treatment crashes. Both of the severe crashes (A- and K-injury outcomes) occurred on bridges which had more than one crash in the Iowa database. Seven of these 8 bridges were bridges with ramps. The remaining 9 crashes occurred at 9 separate locations. Three of these were ramps and 6 were bridges without ramps. In total, 20 percent of sloped end treatments located on ramps were involved in crashes, 7 percent of treatments located on bridges with ramps were impacted, and 1.5 percent of treatments located on bridges without ramps were impacted.

10.2 Conclusions

With an average of only three sloped end treatment crashes per year at a total of 23 unique locations, which resulted in one severe injury crash and one fatal crash, replacing sloped end treatments may have a reduced priority as compared to other safety treatment options. However, sloped end treatments can pose a safety risk for impacting vehicles relative to alternative treatment options.

Sloped end treatments in Iowa were on lower service-level or lower-speed roads. If other state DOTs seek to use results of this study, it is important to consider whether the attributes of SET installation locations are applicable, or if the SETs are installed in higher-speed or higher-ADT roadways which may increase the benefit-to-cost ratio of treating these features. When used in combination with higher speed limits or larger ADTs, more severe crash outcomes may occur.

Guardrail and crash cushion alternatives that could be used in place of sloped end treatments were reviewed in Sections 2.3 and 2.4. Estimated costs associated with some crash cushions were discussed in Section 8.2. Total removal of all sloped end treatments in Iowa may not be feasible or necessary, considering only 3.5 percent of sloped end treatments were involved in crashes between 2008 and 2017, crash rates are low, and exposure is low. However, the crash cost associated with sloped end treatment crashes was higher than that for non-sloped end treatment crashes. Replacing the sloped end treatments involved in the 30 crashes with a crash cushion would have reduced the total sloped end treatment crash cost by approximately $4,124,500, from the calculated current cost of $5,405,300 with only SETs to an estimated $1,280,800 with crash cushions.

Recommendations for installing new sloped end treatments and removing or replacing current sloped end treatments are discussed in the next chapter.

11 RECOMMENDATIONS AND PRIORITIZATION

11.1 Iowa Recommendations and Prioritization

Based on this ISPE, crashes with SETs were expected to be more hazardous on average than crashes into other approved safety treatments, including crash cushions, but the expected difference in total cost (maintenance, installation, materials, labor, and crash cost) may not be sufficient to justify widespread removal or replacement of the SETs. Crashes involving sloped end treatments were rare, 30 out of 534,246 crashes during the ten-year span (0.006 percent). Nevertheless, 43 percent of sloped end treatment crashes resulted in vehicle rollover and 6 percent of sloped end treatment crashes had an injury level of A or K. Figure 165 shows a flow diagram of items which should be considered before a sloped end treatment is installed.

Most roads which utilized SETs were associated with low posted speed limits and traffic volumes. Crash cushions designed for low speeds (TL-1 or TL-2) may offer sufficient protection for most impacts encountered, even if some expected impact conditions exceed the design specifications of the devices. However, a sloped end treatment may be installed rather than terminating the barrier with a blunt end if no other option is available or if the crash risk is deemed sufficiently low such that the estimated benefit does not exceed the actual cost. SETs are preferred treatments compared to some other low-cost treatments such as blunt ends.

Sloped end treatments with drop offs located behind the barrier should be given priority for removal or replacement. A total of 18 sloped end treatment crashes (60 percent) involved the vehicle climbing the barrier and a total of 9 sloped end treatment crashes (30 percent) resulted in the vehicle's final resting place being on the non-traffic side of the barrier.

With regard to removing and/or replacing concrete sloped end treatments with an alternate end treatment, prioritization should be given to certain sloped end treatments. A B/C ratio greater than 2 was found for replacing (1) sloped end treatments located on ramps, and (2) sloped end treatments located on bridges with ramps. Due to the limited dataset, it was shown that had crash cushions been installed initially, significant cost savings could have occurred; however, it is not reasonable to assume that the locations of crashes can be known *a priori* such that only the crash cushions involved in crashes would be replaced. Further B/C analysis should be performed on crash cushions or other end treatment options if cost information becomes available for a treatment Iowa wants to pursue. As well, it is recommended that Iowa consider the benefit of installing lower-service crash cushions.

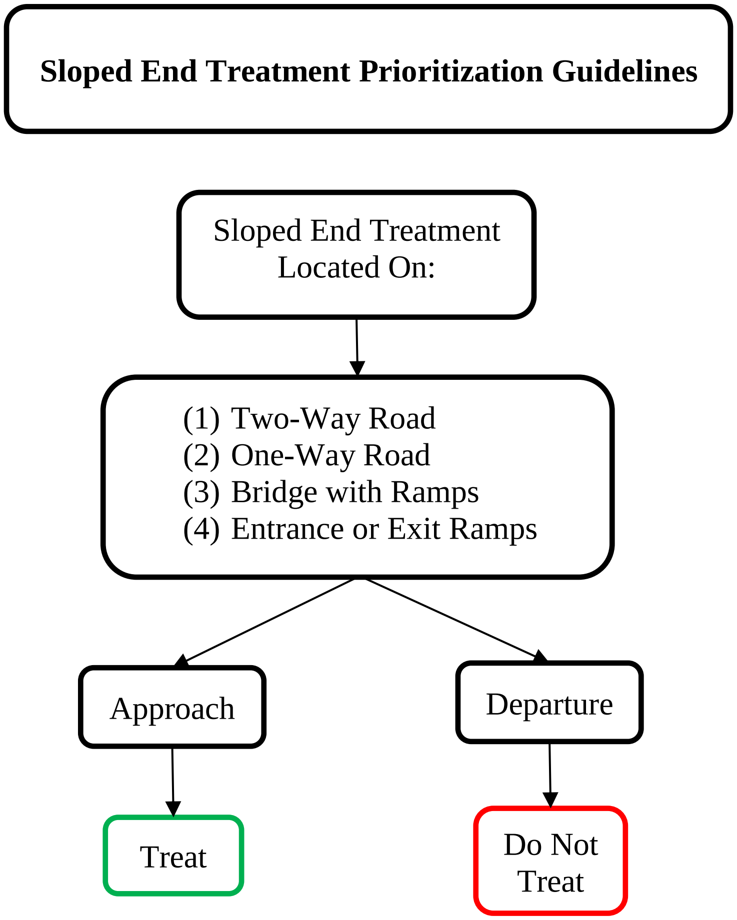


Figure 165. Sloped End Treatment Prioritization Flowchart

It was found that 21 of the 30 sloped end treatment crashes (70 percent) involved sloped end treatments located on ramps (interstate entrance or exit ramps) or bridges with ramps (highway or interstate overpasses). Unlike bridges without ramps, drivers may approach the sloped end treatments from multiple directions and require active vehicle maneuvering, which may explain the increased number of crashes.

Sloped end treatments located on the left-side approach of two-way traffic roads were not impacted during the ten-year span of crash data. Therefore, sloped end treatments located on the left-side approach of two-way traffic roadways should be given lowest priority for removal or replacement. Furthermore, the exposure calculations utilized an estimated risk distribution with 50% of roadside departures to the right side and 50% to the left side of undivided two-way roads. Although exposure would not be significantly different by adjusting to a different distribution, such as 60% right / 40% left, which is closer to expectations, the benefit-cost analysis presented in this report would not be affected because it used actual crash outcome substitution and average crash cost comparison, not statistical modeling. However, when determining warrants related to other states, increasing the expected run-off-road crash risk for right-side departures may be appropriate.

For future work with regard to this ISPE study, it is recommended that sloped end treatments, speed limits, and traffic volumes be mapped to determine if specific attributes of the impact and non-impact locations are useful for predicting future impact locations, in addition to what was investigated in this study. Speed limits for sloped end treatments involved in crashes were known from the crash reports, but speed limits for non-impacted sloped end treatments were not known or collected. Because 83 percent of sloped end treatment crashes occurred on roadways with speed limits less than or equal to 35 mph, it would be useful to see this compared to the exposure of sloped end treatments located on roadways with similar and dissimilar speeds. Subsequent analysis is recommended to generate the actual distribution of speed limits at all installations to better characterize crash risk by speed limit and ADT.

11.2 National Recommendations and Prioritization

Researchers recommend that Iowa ISPE data be supplemented by sloped end treatment data in other states to determine the best national prioritization for the modification or retrofit of these features, or to determine the need for short-length, crashworthy crash cushions or end terminals which could be substituted for sloped end treatments.

Further research is recommended to identify criteria for determining when sloped end treatments should be prioritized. Research is also recommended to determine the best practices when end treatments are in conjunction with limited right-of-way or longitudinal space needed for a MASH-approved end treatment, as well as slopes, curbs, or adjacent intersecting roadways. Although installation of MASH-approved hardware is desirable, the low-crash frequency, low-speed, and low-risk nature of the impacts identified in this study may warrant the use of the least-expensive safety treatments to maximize benefit-cost. It is believed that crash cushions approved according to NCHRP Report No. 350, but not MASH, would be safer during an impact than either a blunt end or a sloped end treatment.

11.3 ISPE Procedure Recommendations

Researchers spent significant time identifying where SETs were located in Iowa and correlating crash data with those SETs. It is recommended that objects struck in impacts be correlated with an asset management database or spatial mapping technique to accelerate similar ISPEs and facilitate excellent correlation of crash data to struck object impact performance. To ensure these features as well as other roadside features are identified correctly, some type of officer training would need to be implemented. If crashes could have been sorted by type of fixed object struck, such as concrete sloped end treatments for this study, the time required to review crash report narratives and diagrams would have been significantly reduced.

12 REFERENCES

1. Google Maps, Google, Available <https://maps.google.com>, August 16, 2019.

2. Ross, H.E., Sicking, D.L., and Zimmer, R.A., *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program (NCHRP) Report No. 350, National Cooperative Highway Research Program, Washington, D.C., 1993.

3. *Manual for Assessing Safety Hardware (MASH), Second Edition*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2016.

4. Beason, W.L., *Development of an End Treatment for a Low-Profile Concrete Barrier*, Report No. TX-92-1949-2, Texas Transportation Institute (TTI), Texas A&M University, College Station, Texas, November, 1992.

5. Bronstad, M.E., Calcote, L.R., and Kimball Jr., C.E., *Concrete Median Barrier Research Volume 2 – Research Report*, Report No. FHWA-RD-77-4, Southwest Research Institute (SwRI), San Antonio, Texas, March, 1976.

6. Ross, H.E., Krammes, R.A., Sicking D.L., Tyer, K.D., and Perera, H.S., *Recommended Practices for Use of Traffic Barrier and Control Treatments for Restricted Work Zones*, National Cooperative Highway Research Program (NCHRP) Report No. 358, National Cooperative Highway Research Program, Washington, D.C., 1994.

7. Beason, W.L., Menges, W.L., and Ivey, D.L., *Compliance Testing of an End Treatment for the Low-Profile Concrete Barrier*, Report No. TX-98-1303-S, Texas Transportation Institute (TTI), Texas A&M University, College Station, Texas, April 1998.

8. Beason, W.L., Brackin, M.S., Bligh, R.P., and Menges, W.L., *Development and Testing of a Non-Pinned Low-Profile End Treatment*, Report No. TX-13-9-1002-12-7, Texas Transportation Institute (TTI), Texas A&M University, College Station, Texas, October, 2013.

9. Albuquerque, F.D.B., and Sicking, D.L., "In-Service Safety Performance Evaluation of Roadside Concrete Barriers," *Journal of Transportation Safety and Security*, No. 5 Issue 2, May 2013. DOI: 10.1080/19439962.2012.715618.

10. Ray, M.H., and Weir, J., "Unreported Collisions with Post-and-Beam Guardrails in Connecticut, Iowa, and North Carolina," *Journal of the Transportation Research Board*, No. 1743, Dec 2000, pp 111-119. DOI: 10.3141/1743-15.

11. Stolle, C.S., and Sicking, D.L., *Cable Median Barrier Failure Analysis and Prevention*, Report No. TRP-03-275-12, Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln, Lincoln, Nebraska, December, 2012.

12. Savolainen, P.T., Barnwal, A., and Kirsch, T.J., *Crash Cushion Selection Criteria*, Final Report to the Iowa Department of Transportation, Iowa State University Center for Transportation Research and Education, Ames, Iowa, September 2017.

13. Ray, M.H., Weir, J., and Hopp, J., *In-Service Performance of Traffic Barriers*, National Cooperative Highway Research Program (NCHRP) Report No. 490, National Cooperative Highway Research Program, Washington, D.C., 2003.

14. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, R.W., Reid, J.D., and Coon, B.A., *Performance Evaluation of the Guardrail to Concrete Barrier Transition – Update to NCHRP 350 Test No. 3-21 with 28" C.G. Height (2214T-1)*, Report No. TRP-03-175-06, Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln, Lincoln, Nebraska, October, 2006.

15. Rosenbaugh, S.K., Lechtenberg, K.A., Faller, R.K., Sicking, D.L., Bielenberg, R.W., and Reid, J.D., *Development of the MGS Approach Guardrail Transition Using Standardized Steel Posts*, Report No. TRP-03-210-10, Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln, Lincoln, Nebraska, December 21, 2010.

16. MFGF Guardrail Turndown San Marcos, Tx, Flickr, Available <https://www.flickr.com/photos/40971431@N04/albums/72157634850129510/>, October 23, 2019.

17. Gattis, J.L., Varghese, J.P., and Toothaker, L.E., *Analysis of Guardrail-End Accidents in Oklahoma*, Transportation Research Record 1419, Transportation Research Board, Washington, D.C., 1993, pages 52-62.

18. Buth, C.E., and Hirsch, T.J., *Improved End Treatment for Metal Beam Guardrail*, Report No. TTI-2-10-76-189-1F, Texas Transportation Institute, Texas A&M University, College Station, Texas, May, 1977.

19. Hirsch, T.J., Dolf, T.J., and Arnold, A., *Maryland Turned-Down Guardrail Terminal*, Texas Transportation Institute, Texas A&M University, College Station, Texas, August, 1982.

20. Pfeifer, B.G., Magdaleno, J.A., Faller, R.K., and Post, E.R., *Static Tests on Collapsing Guardrail Designs*, Report No. TRP-03-018-89, Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln, Lincoln, Nebraska, July, 1989.

21. Faller, R.K., Holloway, J.C., Rosson, B.T., Pfeifer, B.G., and Luedke, J.K., *Safety Performance Evaluation on the Nebraska Turned-Down Approach Terminal Section*, Report No. TRP-03-032-92, Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln, Lincoln, Nebraska, October, 1992.

22. Paulsen, G.W., Reid, J.D., Faller, R.K., and Sicking, D.L., *Concept Design and Analysis of Nebraska Turned-Down Approach Terminal Sections*, Report No. TRP-03-045-95, Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln, Lincoln, Nebraska, January, 1995.

23. Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program (NCHRP) Report No. 230, National Cooperative Highway Research Program, Washington, D.C., March 1981.

24. Fortuniewicz, J.S., Bryden, J.E., Hahn, K.C., and Phillips, R.G., *Evaluation of an End Treatment for Heavy-Post Median Barriers*, Report No. FHWA/NY/RR-83/103, Engineering Research and Development Bureau, New York State Department of Transportation, Albany, New York, 1983.

25. Ivey, D.L., Bronstad, M.E., and Griffin III, L.I., *Guardrail End Treatments in the 1990s*, Transportation Research Record 1367, Transportation Research Board, Washington, D.C., 1992, pages 63-75.

26. Stolle, C.S., Polivka, K.A., Bielenberg, R.W., Reid, J.D., Faller, R.K., Rohde, J.R., and Sicking, D.L., *Phase IV Development of a Short-Radius Guardrail for Intersecting Roadways,* Report No. TRP-03-199-08, Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln, Lincoln, Nebraska, February 29, 2008.

27. *Guide Specifications for Bridge Railings*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 1989.

28. Abu-Odeh, A.Y., Kim, K., and Alberson, D., *Evaluation of Existing T-Intersection Guardrail Systems for Equivalency with NCHRP Report 350 TL-2 Test Conditions*, Report No. 405160-10, Texas Transportation Institute (TTI), Texas A&M University, College Station, Texas, August 2010.

29. Abu-Odeh, A.Y., McCaskey, K., Bligh, R.P., Menges, W.L., and Kuhn, D.L., *Crash Test and MASH TL-3 Evaluation of the TxDOT Short Radius Guardrail*, Report No. FHWA/TX-15/0-6711-1, Texas Transportation Institute (TTI), Texas A&M University, College Station, Texas, March 2015.

30. Barrier Terminals & Crash Cushions, U.S. Department of Transportation Federal Highway Administration (USDOT FHWA), Available <https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/listing.cfm?code=cushions>, August 15, 2019.

31. Barrier Terminals & Crash Cushions – NCHRP 350, U.S. Department of Transportation Federal Highway Administration (USDOT FHWA) , Available <https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/listingarchived.cfm?code=cushions>, August 15, 2019.

32. Crash Cushions, U.S. Department of Administration Federal Highway Administration (USDOT FHWA), Available <https://safety.fhwa.dot.gov/roadway_dept/countermeasures/docs/CrashCushions_Nov2013Safelogo.pdf>, August 16, 2019.

33. QuadGuard M10, Trinity Highway, Available <https://trinityhighway.com/product/quadguard-m10/>, August 16, 2019.

34. ABSORB-M MASH, Water-Filled Crash Cushion, Barrier Systems, Available <http://www.barriersystemsinc.com/absorb-m-mash-water-filled-crash-cushion>, August 16, 2019.

35. Universal TAU-M MASH Crash Cushion, Barrier Systems, Available <http://www.barriersystemsinc.com/tau-m-crash-cushion>, August 16, 2019.

36. SLED Sentry Longitudinal Energy Dissipater, TrafFix Devices, Available <https://www.traffixdevices.com/products/attenuators/sled-us>, August 16, 2019.

37. SLED Mini, TrafFix Devices, Available <https://www.traffixdevices.com/products/attenuators/sled-mini>, August 16, 2019.

38. SMA Hercules, Safety Modular Absorber, Available <https://www.smaroadsafety.com/en/gamma/view/28/hercules>, August 16, 2019.

39. Smart Cushion, Hill & Smith, Available <https://hillandsmith.com/products/smart-cushion/>, August 16, 2019.

40. QuadGuard, Trinity Highway, Available <https://trinityhighway.com/product/quadguard/>, August 16, 2019.

41. QuadGuard Elite, Trinity Highway, Available <https://trinityhighway.com/product/quadguard-elite/>, August 16, 2019.

42. QuadGuard High Speed (HS), Trinity Highway, Available <https://trinityhighway.com/product/quadguard-hs/>, August 16, 2019.

43. QuadGuard II, Trinity Highway, Available <https://trinityhighway.com/product/quadguard-ii/>, August 16, 2019.

44. REACT 350, Trinity Highway, Available <https://trinityhighway.com/product/react-350/>, August 16, 2019.

45. REACT 350 II, Trinity Highway, Available <https://trinityhighway.com/product/react-350-ii/>, August 16, 2019.

46. REACT 350 Wide, Trinity Highway, Available <https://trinityhighway.com/product/react-350-wide/>, August 16, 2019.

47. TRACC, Trinity Highway, Available <https://trinityhighway.com/product/tracc-crash-cushion/>, August 16, 2019.

48. FasTRACC, Trinity Highway, Available <https://trinityhighway.com/product/fastracc/>, August 16, 2019.

49. ShorTRACC, Trinity Highway, Available <https://trinityhighway.com/product/shortracc/>, August 16, 2019.

50. WideTRACC, Trinity Highway, Available <https://trinityhighway.com/product/widetracc/>, August 16, 2019.

51. QUEST System, Trinity Highway, Available <https://trinityhighway.com/product/quest/>, August 16, 2019.

52. N-E-A-T, Trinity Highway, Available <https://trinityhighway.com/product/n-e-a-t/>, August 16, 2019.

53. ACZ-350, Trinity Highway, Available <https://trinityhighway.com/product/acz-350/>, August 16, 2019.

54. ADIEM, Trinity Highway, Available <https://trinityhighway.com/product/adiem/>, August 16, 2019.

55. CAT 350, Trinity Highway, Available <https://trinityhighway.com/product/cat/>, August 16, 2019.

56. HEART, Trinity Highway, Available <https://trinityhighway.com/product/heart/>, August 16, 2019.

57. ABSORB 350 Anchorless Crash Cushion, Barrier Systems, Available <http://www.barriersystemsinc.com/absorb-350-crash-cushion>, August 16, 2019.

58. Universal TAU-II Family of Crash Cushions, Barrier Systems, Available <http://www.barriersystemsinc.com/tau-ii-crash-cushion>, August 16, 2019.

59. Universal TAU-II-R Family of Reusable Crash Cushions, Barrier Systems, Available <http://www.barriersystemsinc.com/tau-ii-r-crash-cushion>, August 16, 2019.

60. X-TENuator Crash Cushion, Barrier Systems, Available <http://www.barriersystemsinc.com/xtenuator-impact-attenuator>, August 16, 2019.

61. X-Tension Median Attenuator, Barrier Systems, Available <http://www.barriersystemsinc.com/xmas-impact-attenuator>, August 16, 2019.

62. Compressor, TrafFix Devices, Available <https://www.traffixdevices.com/products/attenuators/compressor>, August 16, 2019.

63. SMA 110P/TL 3, Safety Modular Absorber, Available <https://www.smaroadsafety.com/en/gamma/view/13/110ptl-3>, August 16, 2019.

64. BEAT-SSCC, Road Systems, Inc., Available <http://www.roadsystems.com/beat-sscc/>, August 16, 2019.

65. Connecticut Impact Attenuation System – A Crash Cushion, Connecticut Department of Transportation, Available <https://portal.ct.gov/DOT/Division-of-Research/Connecticut-Impact-Attenuation-System---A-Crash-Cushion>, August 16, 2019.

66. Bligh, R.P., Sheikh, N.M., Menges, W.L., and Haug, R.R., *Portable Concrete Traffic Barrier for Maintenance Operations*, Report No. FHWA/TX-05/0-4692-1, Texas Transportation Institute (TTI), Texas A&M University, College Station, Texas, May 2005.

67. QuadTrend 350, John Thomas Inc., Available <https://www.jtitraffic.com/our-products/end-treatments/quadtrend-350/>, August 16, 2019.

68. Iowa Department of Transportation (DOT), Design – Standard Road Plans, Available <https://iowadot.gov/design/standard-road-plans> October 7, 2019.

69. U.S. Department of Transportation: Federal Highway Administration (USDOT FHWA), Policy and Governmental Affairs: Office of Highway Policy Information, Available: <https://www.fhwa.dot.gov/policyinformation/statistics/2017/> June 19, 2019.

70. Iowa Traffic Counts, ArcGIS, Available <https://www.arcgis.com/home/item.html?id=8304ce251dac4c5cbde64c04a4a46c4b> August 6, 2019.

71. *Model Minimum Uniform Crash Criteria (MMUCC) Guideline*, National Highway Traffic Safety Administration (NHTSA), Washington, D.C., 2017.

72. Iowa Department of Transportation (DOT), Iowa Crash Analysis Tool (ICAT), Available: <https://icat.iowadot.gov/#> May 22, 2019.

73. Skszek, S.L., *Actual Speeds on the Roads Compared to the Posted Limits*, Report No. FHWA-AZ-04-551, Arizona Department of Transportation, Phoenix, Arizona, October 2004.

74. *TIGER Benefit-Cost Analysis (BCA) Resource Guide*, U.S. Department of Transportation, Washington, D.C., March 2015, Available <https://www.transportation.gov/sites/dot.gov/files/docs/Tiger_Benefit-Cost_Analysis_%28BCA%29_Resource_Guide_1.pdf>.

75. *Revised Departmental Guidance 2016: Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses*, U.S. Department of Transportation, Washington, D.C., August 2016, Available <https://www.transportation.gov/sites/dot.gov/files/docs/2016%20Revised%20Value%20of%20a%20Statistical%20Life%20Guidance.pdf>.

76. Stolle, C.S., Yim, A., Faller, R.K., Urbank, E.L., Ammon, T.J., Vargas, C.M., and Lechtenberg, K.A., *Data-Driven Development of a Roadside Safety Marketing Campaign for Tree Removal – Phase 1*, Report No. TRP-03-375-18, Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln, Lincoln, Nebraska, July, 2018.

77. Malyshkina, N.V., and Mannering, F., *Effect of Increases in Speed Limits on Severities of Injuries in Accidents*, Transportation Research Record 2083, Transportation Research Board, Washington, D.C., 2008, pages 122-127.

78. Schrum, K.D., Albuquerque, F.B.D., Sicking, D.L., Lechtenberg, K.A., and Reid, J.D., *Guidelines for Crash Cushion Selection*, Report No. TRP-03-252-12 (revised), Midwest Roadside Safety Facility (MwRSF), University of Nebraska-Lincoln, Lincoln, Nebraska, June 19, 2013.

79. Strashny, A., *An Analysis of Motor Vehicle Rollover Crashes and Injury Outcomes*, Report No. DOT HS 810 741, National Center for Statistics and Analysis (NCSA), National Highway Traffic Safety Administration (NHTSA), Washington, D.C., March 2007.

80. *Roadside Design Guide*, 4th Edition, American Association of State and Highway Transportation Officials (AASHTO), Washington D.C., 2011.

81. Raptor, GSI Highway Products, Available <https://www.gsihighway.com/raptor>, April 22, 2020.

82. Energite III, Trinity Highway, Available <https://trinityhighway.com/product/energite-iii/>, April 22, 2020.

83. CrashGard Sand Barrel System, PSS, Available <https://www.pss-innovations.com/safety-products/crash-cushions-channelizers-drums/crashgard-sand-barrel-system>, April 22, 2020.

84. Big Sandy, TrafFix Devices, Available <https://www.traffixdevices.com/products/attenuators/big-sandy>, April 22, 2020.

85. Fortuniewicz, J., Bryden, J.E., Hahn, K.C., and Phillips, R.G., *Evaluation of an End Treatment for Heavy-Post Median Barriers*, Research Report 103, Engineering Research and Development Bureau, New York State Department of Transportation, Albany, New York, April 1983.

86. Snyder, R.R., *In-Service Evaluation of the Brakemaster and C-A-T Crash Cushions*, Report No. FHWA-PA-94-001+90-058, Pennsylvania Department of Transportation, Harrisburg, Pennsylvania, June 30, 1993.

87. Ray, M.H., *Safety Effectiveness of Upgrading Guardrail Terminals to NCHRP Report 350 Standards*, Transportation Research Record 1720, Transportation Research Board, Washington, D.C., 2000, pages 52-58.

88. Wang, Y.G., Chen, K.M., Ci, Y.S., and Hu, L.W., *Safety Performance Audit for Roadside and Median Barriers using Freeway Crash Records: Case Study in Jiangxi, China*, Scientia Iranica, Sharif University of Technology, Tehran, Iran.

13 APPENDICES

Appendix A. Iowa DOT Standard Road Plans

The standard road plans for bridge approach sections in Iowa are shown in Appendix A [68]. The standard plan for two-lane abutting with PCC pavement (BR-102) is shown in Figure A-1, two-lane bridge reconstruction with PCC pavement (BR-103) in Figure A-2, existing bridges with PCC pavement (BR-104) in Figure A-3, two-lane with HMA pavement (BR-105) in Figure A-4, two-lane bridge reconstruction with HMA pavement (BR-106) in Figure A-5, existing bridges with HMA pavement (BR-107) in Figure A-6, and bridge deck overlays (BR-112) in Figure A-7.

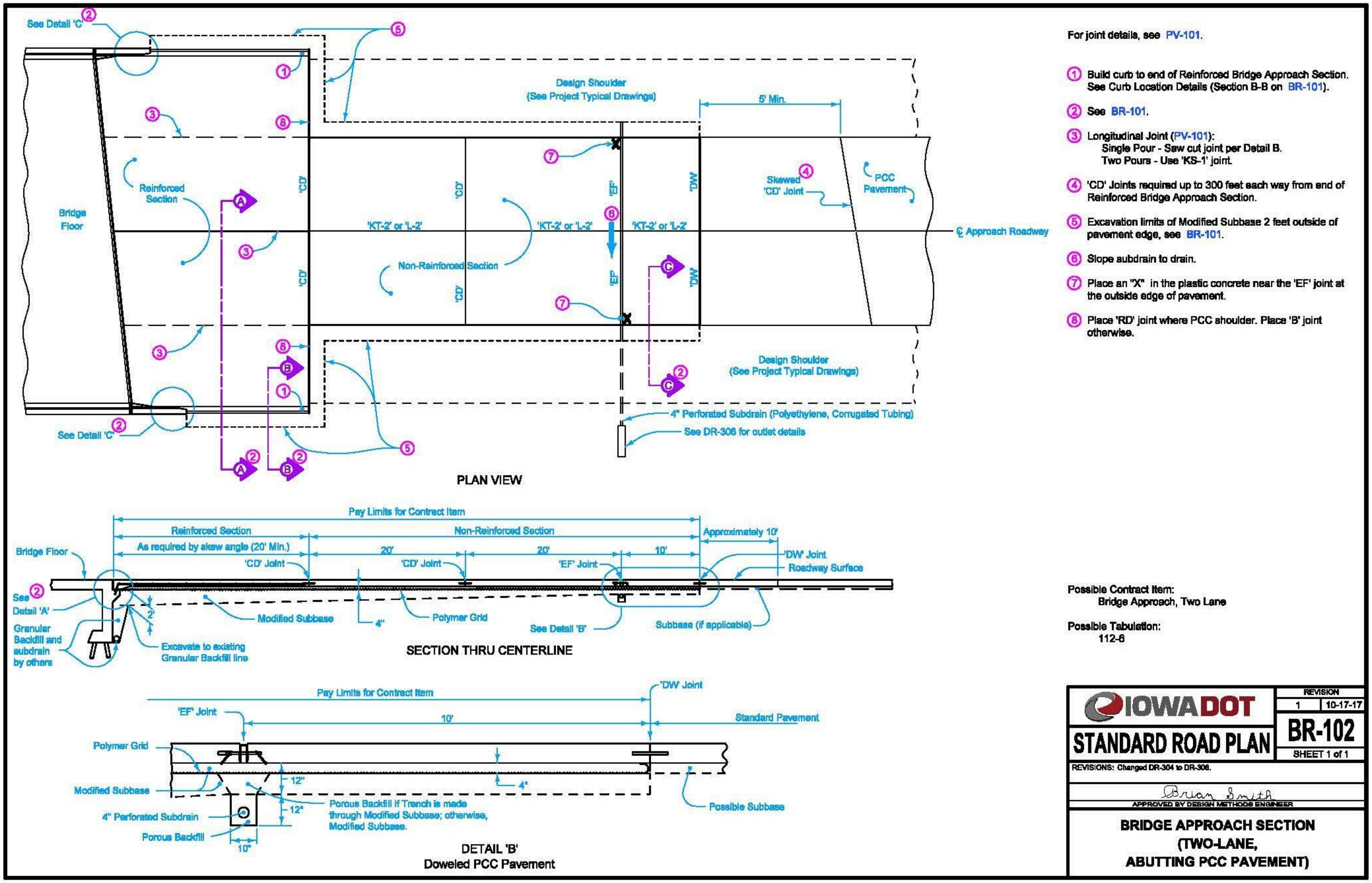


Figure A-1. Iowa DOT Standard Road Plan BR-102 – Bridge Approach Section (Two-Lane, Abutting PCC Pavement) [68]

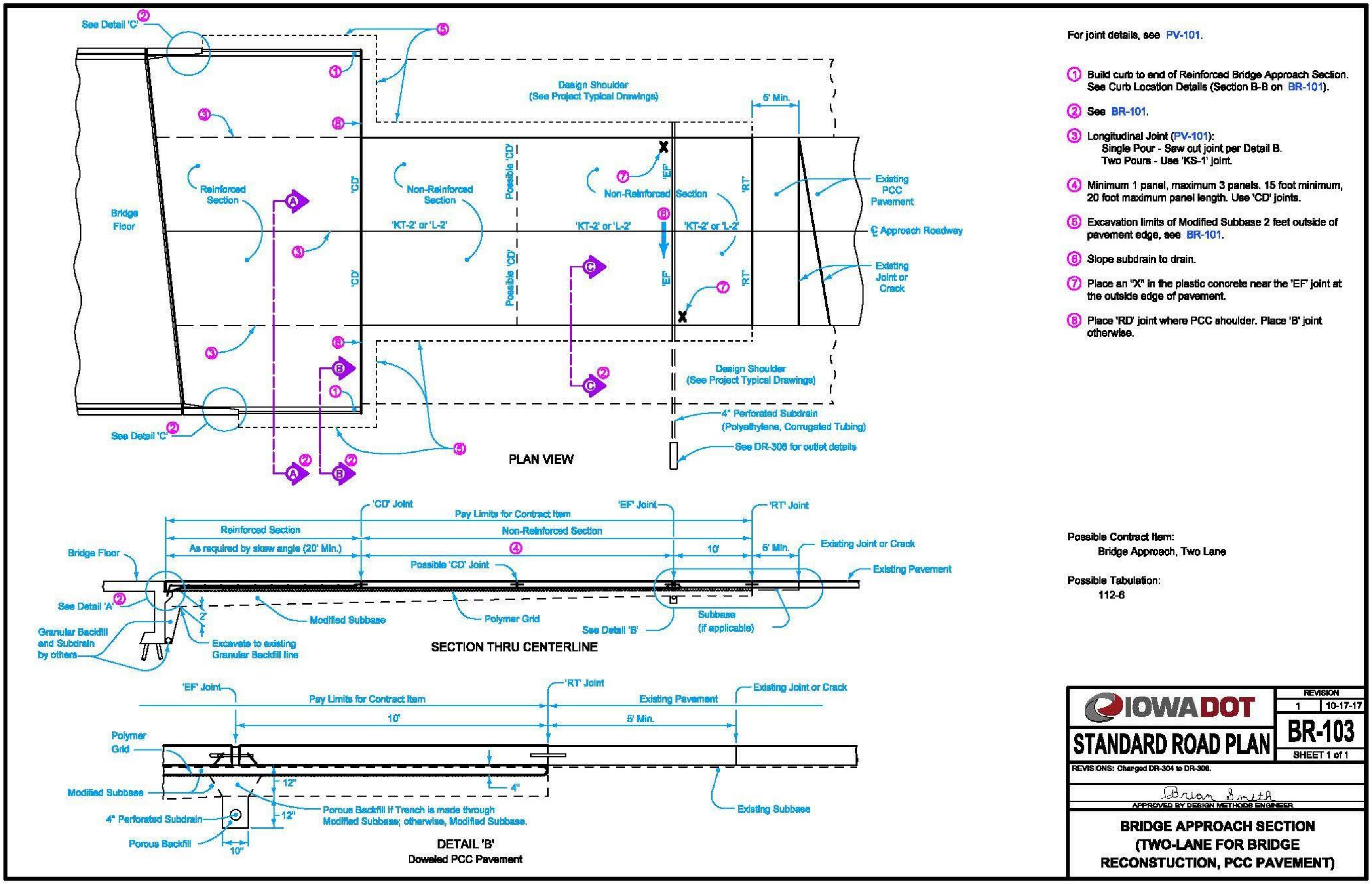


Figure A-2. Iowa DOT Standard Road Plan BR-103 – Bridge Approach Section (Two-Lane for Bridge Reconstruction, PCC Pavement) [68]

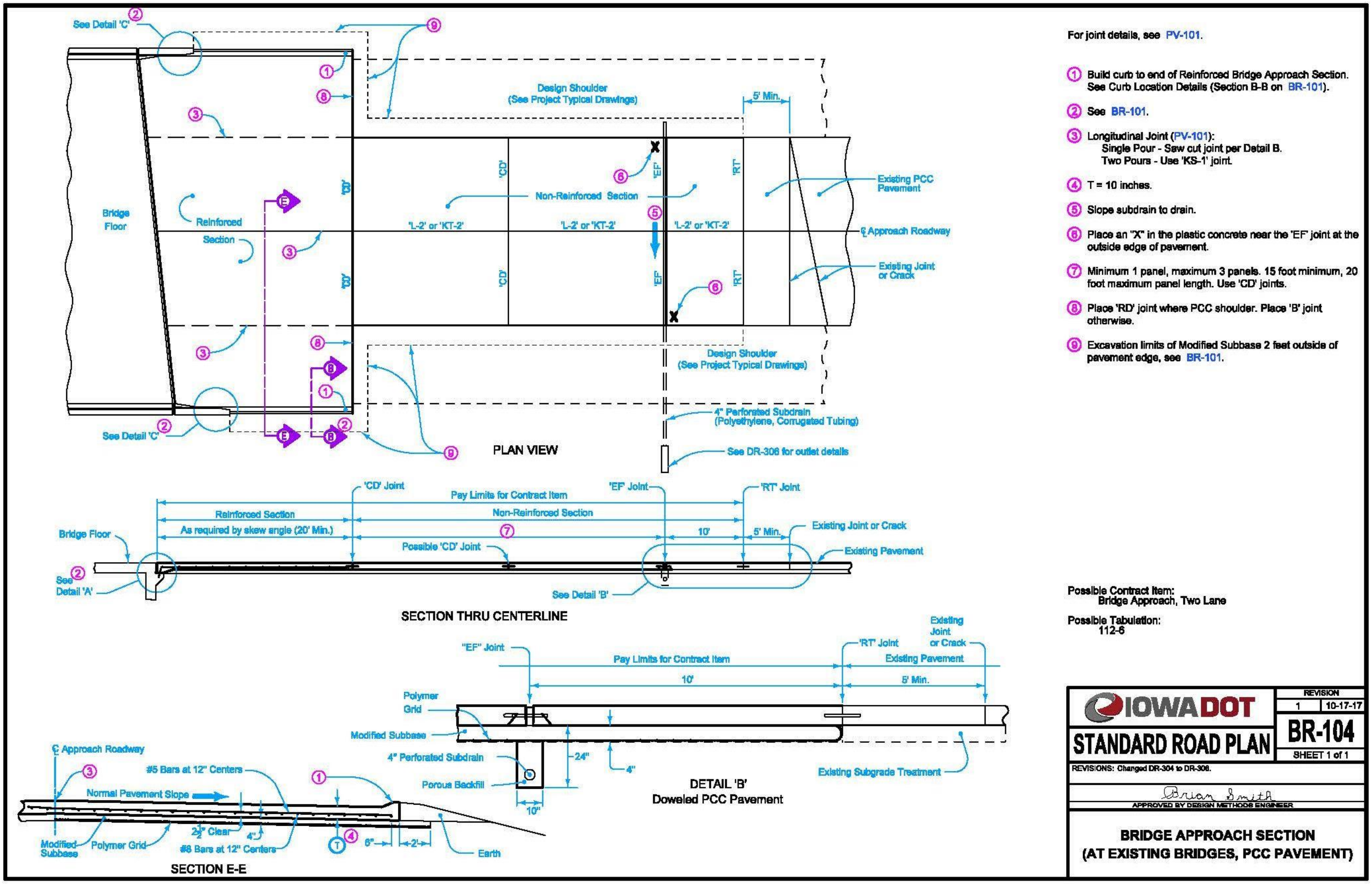


Figure A-3. Iowa DOT Standard Road Plan BR-104 – Bridge Approach Section (at Existing Bridges, PCC Pavement) [68]

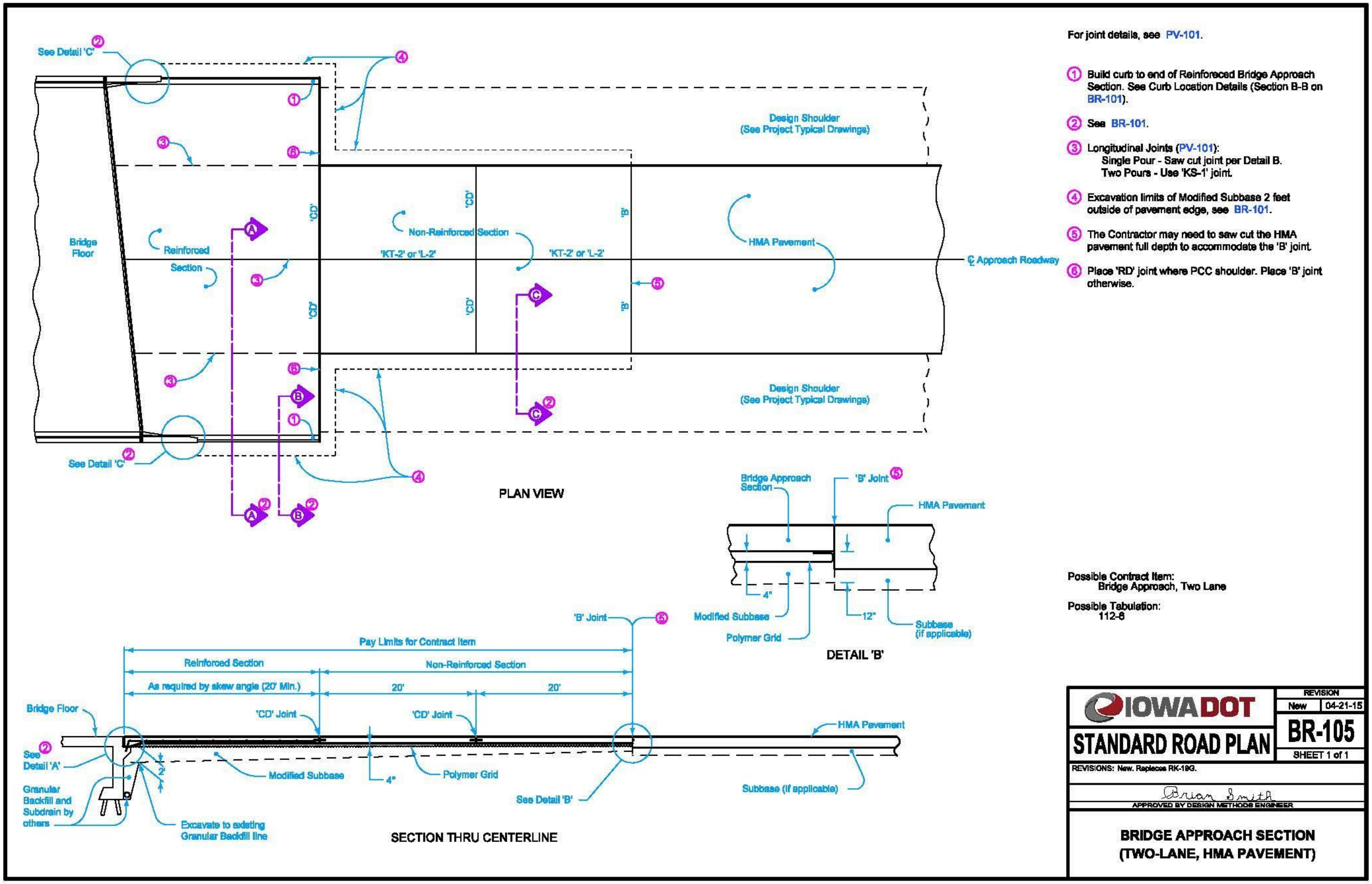


Figure A-4. Iowa DOT Standard Road Plan BR-105 – Bridge Approach Section (Two-Lane, HMA Pavement) [68]

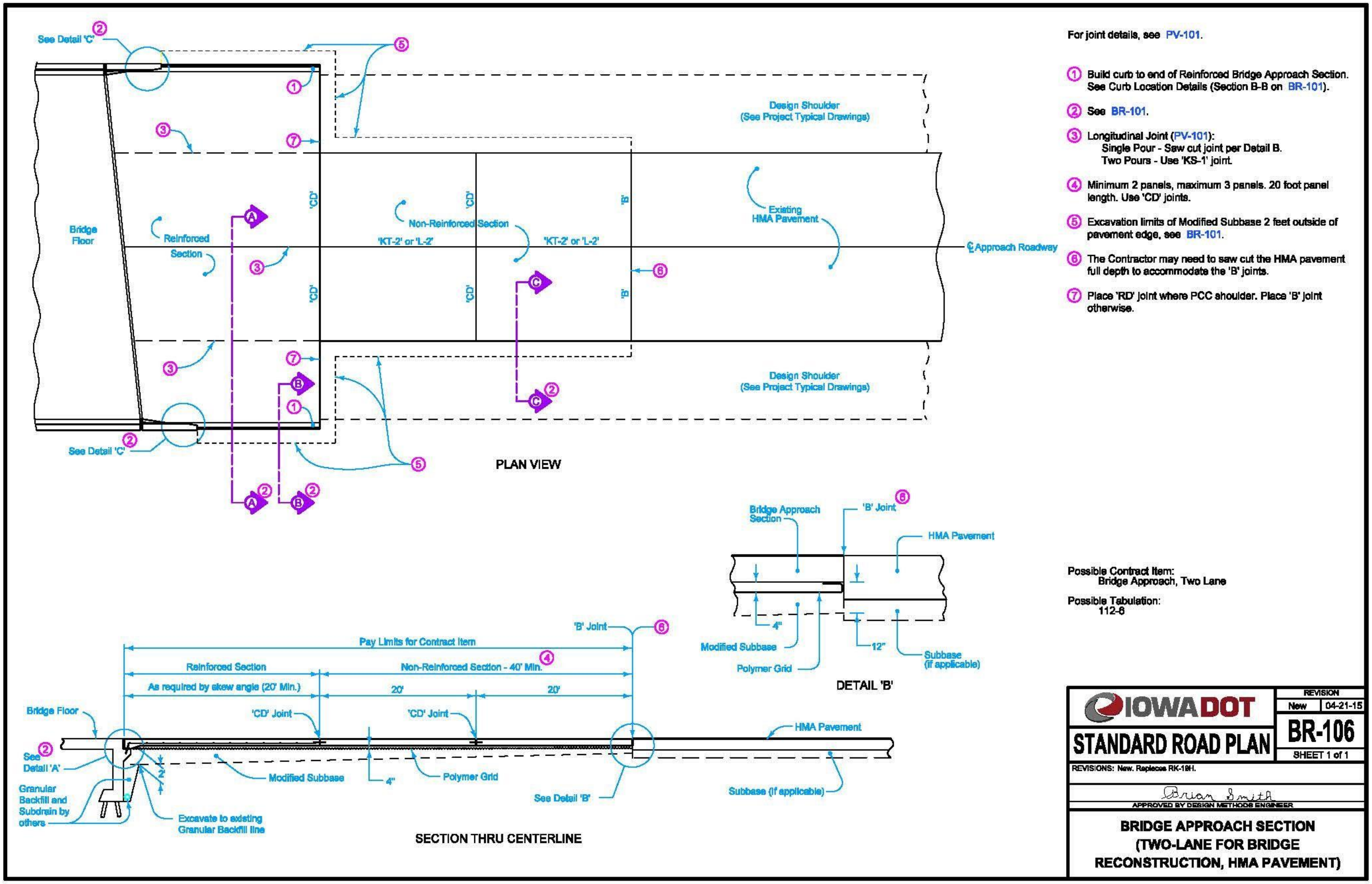


Figure A-5. Iowa DOT Standard Road Plan BR-106 – Bridge Approach Section (Two-Lane for Bridge Reconstruction, HMA Pavement) [68]

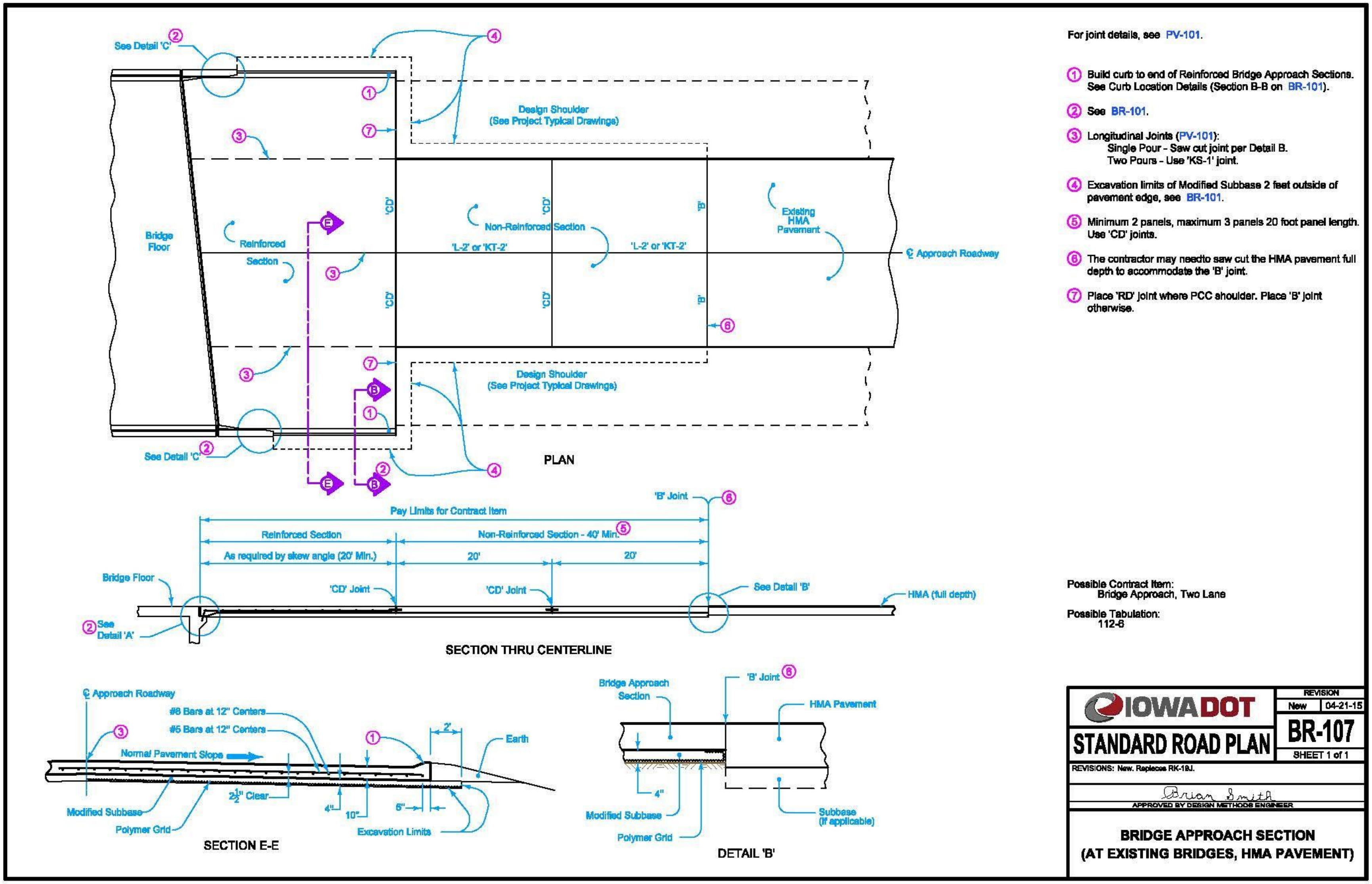


Figure A-6. Iowa DOT Standard Road Plan BR-107 – Bridge Approach Section (at Existing Bridges, HMA Pavement) [68]

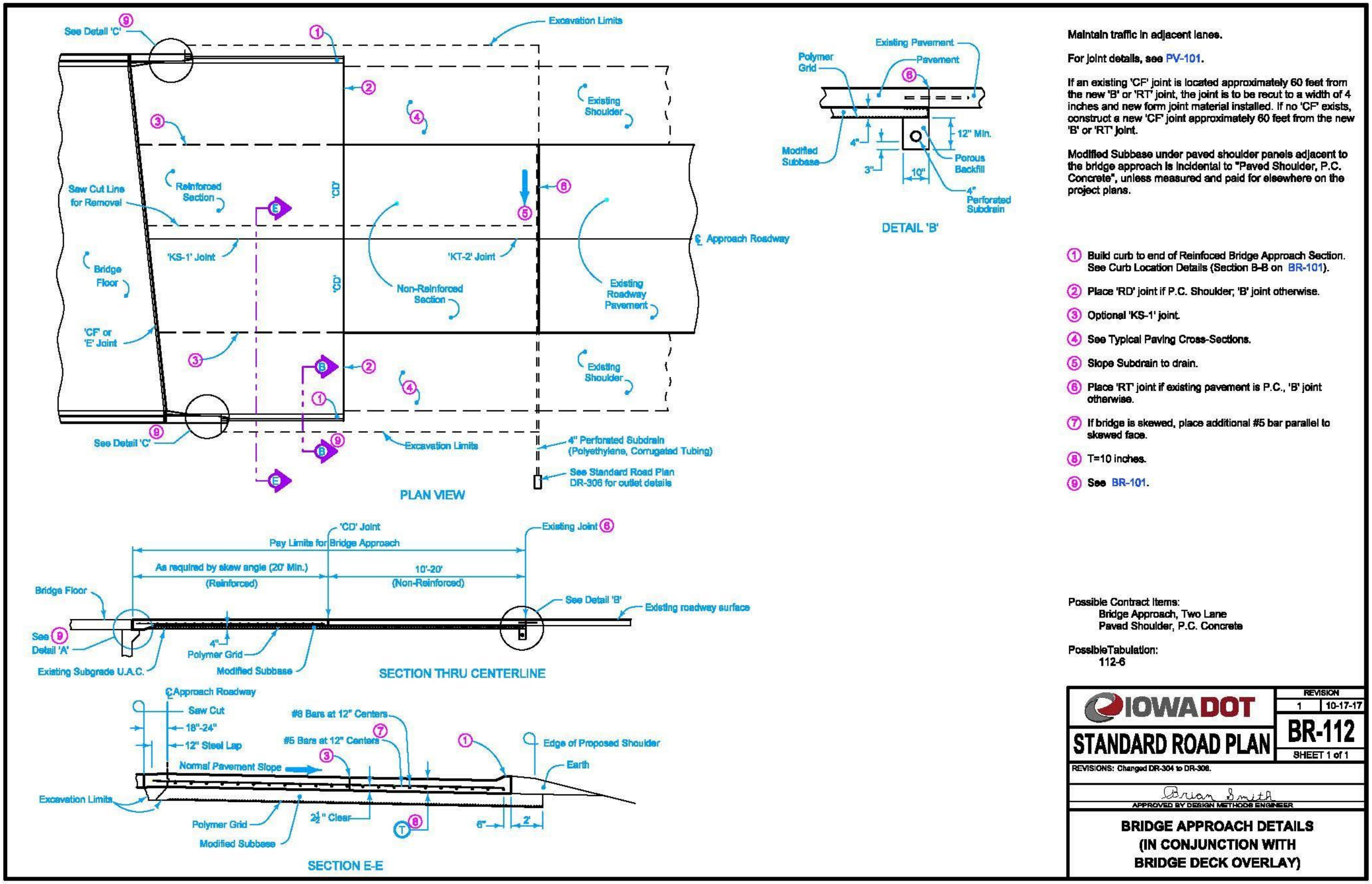


Figure A-7. Iowa DOT Standard Road Plan BR-112 – Bridge Approach Details (in Conjunction with Bridge Deck Overlay) [68]

Appendix B. Bridges with Sloped End Treatments

A total of 183 bridges featuring sloped end treatments were identified across the state of Iowa. The bridge no., latitude, and longitude are shown in Table B-1, sorted by sloped end treatment configuration.

Google Earth images of each bridge are shown in Figures B-6 through B-183, with each sloped end treatment numbered. This identifying number corresponds to the sloped end treatment no. found in the exposure calculations in Appendix C.

Table B-1. Bridge Locations, Sorted by Sloped End Treatment Configuration

Sloped End Treatment Configuration	Bridge No.	Latitude	Longitude
Four Treatments, Two-Way Traffic	0728.0O020	42.45523	-92.395833
	0729.0O020	42.453203	-92.376193
	0730.0O020	42.452872	-92.356535
	0731.0O020	42.452395	-92.336871
	0995.4O218	42.649327	-92.452622
	1023.9S281	42.639243	-92.052766
	1246.8S014	42.580615	-92.790537
	1477.0S141	41.9066	-95.070591
	1542.6S048	41.231596	-95.137138
	1654.6O080	41.66353	-91.346659
	1710.2S122	43.14805	-93.162803
	1858.8S059	42.742411	-95.551498
	1859.0S059	42.744302	-95.551417
	2181.0S018	43.137584	-95.144543
	2204.5S076	43.041314	-91.177822
	2318.8S136	41.960347	-90.470571
	2521.4O080	41.59119	-93.808841
	2841.6S013	42.483855	-91.465279
	2942.2L061	40.829405	-91.141543
	2962.0O034	40.817182	-91.126281
	2963.0O034	40.814871	-91.107133
	2963.2O034	40.814864	-91.103576
	2963.3O034	40.813934	-91.102503
	3026.6S071	43.424113	-95.093713
	3118.4O020	42.490784	-90.688572
	3118.5O020	42.491427	-90.685938
	3119.0O020	42.489443	-90.677755
	3146.6O052	42.496747	-90.664756
	3150.7A052	42.543136	-90.695128
	3182.0S136	42.398089	-91.120133
	3288.1S009	43.401868	-94.845108
	3364.6S150	42.773814	-91.87657
	3372.6S018	42.997468	-91.658302
	3412.7S018	43.063544	-92.676253
	3568.3S065	42.74535	-93.202395
	3712.2S025	42.019526	-94.551566
	3723.0S004	42.020575	-94.377351
	4055.6S175	42.306832	-93.636818

Table B-2. Bridge Locations, Sorted by Sloped End Treatment Configuration (Cont.)

Sloped End Treatment Configuration	Bridge No.	Latitude	Longitude
Four Treatments, Two-Way Traffic	4249.6S065	42.517747	-93.26297
	4800.2S151	41.687264	-91.910926
	5007.7S117	41.680875	-93.246506
	5243.0O080	41.685333	-91.564633
	5245.1O080	41.68702	-91.524334
	5249.3S006	41.670734	-91.571649
	5286.5S001	41.657759	-91.52902
	5287.2R001	41.661606	-91.522766
	5314.8S064	42.058853	-91.008156
	5342.8S038	41.995453	-91.141517
	5363.6S038	42.233169	-91.181208
	5598.7S169	43.078502	-94.235536
	5602.4S136	40.391561	-91.395056
	5718.4O380	41.955956	-91.671334
	5724.4O380	42.034652	-91.676505
	5724.7O380	42.038712	-91.677696
	5851.3S092	41.278909	-91.361478
	6020.4S009	43.431759	-96.164957
	6200.9S622	41.28513	-92.538881
	6276.0S063	41.469659	-92.64804
	6616.8S009	43.36377	-92.562417
	6834.5S005	41.019337	-92.807717
	7078.0A006	41.566258	-91.08226
	7403.2A018	43.12668	-94.718312
	7509.3S140	42.585352	-95.96728
	7606.6S015	42.818902	-94.527854
	7607.2S003	42.732538	-94.661588
	7700.8O235	41.591809	-93.76143
	7701.3O235	41.591766	-93.751689
	7701.8O235	41.591907	-93.742095
	7706.9O235	41.595641	-93.648624
	7709.0O235	41.594383	-93.606388
	7709.1O235	41.594851	-93.602741
	7722.4O080	41.591697	-93.790477
	7723.8O080	41.5953	-93.778788
	7724.1O080	41.600348	-93.77761
	7727.1O080	41.643917	-93.777668
	7735.4S006	41.627607	-93.646137
	7738.9S006	41.62765	-93.575933

Table B-3. Bridge Locations, Sorted by Sloped End Treatment Configuration (Cont.)

Sloped End Treatment Configuration	Bridge No.	Latitude	Longitude
Four Treatments, Two-Way Traffic	7740.2S006	41.627659	-93.549809
	7772.2O035	41.584395	-93.77816
	7801.7O080	41.231801	-95.879118
	7815.0S083	41.476309	-95.330667
	8203.8O074	41.536599	-90.517305
	8204.9S006	41.560085	-90.613569
	8206.5S067	41.532265	-90.475385
	8403.4S010	43.002025	-96.487912
	8514.8S069	42.013156	-93.610179
	8516.1O069	42.025	-93.620534
	8600.5S008	42.191601	-92.455793
	8603.0O030	41.981976	-92.578396
	8840.0S169	41.030175	-94.197539
	8903.8S001	40.727677	-91.959544
	9001.4O149	41.032591	-92.414273
	9091.2O034	41.008403	-92.388854
	9235.4S022	41.485804	-91.711207
	9505.0S069	43.268403	-93.632345
	9700.1S031	42.230836	-95.93061
	9708.1S012	42.493566	-96.467448
	9741.2O029	42.400482	-96.367229
Three Treatments, Two-Way Traffic	0713.9S281	42.572755	-92.160679
	0783.2O218	42.508255	-92.37571
	3192.7S136	42.546206	-91.11414
	4287.7S175	42.36065	-93.083667
	4922.8S052	42.250927	-90.419321
	5752.3O030	41.92663	-91.67626
	7726.1O080	41.629337	-93.777637
	9621.3S024	43.141566	-91.932906
One Bridge End, Two-Way Traffic	0767.1S218	42.316727	-92.191605
	1412.0S071	42.067884	-94.878509
	2515.1S006	41.614353	-94.012834
	2589.1S169	41.623094	-94.01746
	2711.3S069	40.640162	-93.808103
	4208.0S057	42.556696	-93.048248
	4319.5S030	41.642965	-95.78484
	4864.8S149	41.666236	-92.007297
	4958.3O061	42.061353	-90.683208
	5286.9L001	41.660762	-91.52585

Table B-4. Bridge Locations, Sorted by Sloped End Treatment Configuration (Cont.)

Sloped End Treatment Configuration	Bridge No.	Latitude	Longitude
Treatments Adjacent to One Lane, Two-Way Traffic	0230.3S148	40.983836	-94.731977
	0230.5S148	40.987139	-94.731897
	1562.9S148	41.442952	-94.763217
	2959.6O034	40.816811	-91.170001
	2962.9O034	40.815486	-91.110148
	4309.8S030	41.556421	-95.902555
	4922.0S064	42.073326	-90.881368
	5242.1O080	41.68958	-91.581916
	5718.0O380	41.951488	-91.670466
	5752.9O030	41.927464	-91.666606
	7700.3O235	41.591637	-93.771289
	7717.8S028	41.586802	-93.703319
	8336.8S037	41.776574	-95.411358
	8557.9O030	42.005459	-93.444461
	8558.4O030	42.008434	-93.435041
	9401.3L926	42.495449	-94.188499
	9703.4O020	42.459562	-96.326919
One Treatment, Two-Way Traffic	0601.5S150	42.169891	-92.023986
	5753.4O030	41.927307	-91.656929
	8208.0R006	41.556692	-90.55287
	9701.8O020	42.444219	-96.347241
	9704.6S012	42.489707	-96.395845
Special Cases, Two-Way Traffic	0743.1S057	42.537729	-92.444045
	1797.9S065	43.172332	-93.200971
	1900.5S346	42.95452	-92.535618
	3021.8S071	43.37727	-95.127876
	3145.1O052	42.478168	-90.667744
	5285.9L001	41.658158	-91.540309
	5722.7O380	42.011742	-91.667185
	7702.4S160	41.702788	-93.576746
	7704.4O235	41.592132	-93.693651
	7705.4O235	41.590853	-93.674266
	7706.2O235	41.592797	-93.659275
	7718.3S028	41.592684	-93.703385

Table B-5. Bridge Locations, Sorted by Sloped End Treatment Configuration (Cont.)

Sloped End Treatment Configuration	Bridge No.	Latitude	Longitude
Four Treatments, One-Way Traffic	5720.8O380	41.983899	-91.663913
	7707.1O235	41.59547	-93.644218
	7707.9O235	41.596078	-93.626957
	7708.0O235	41.595341	-93.625767
	7708.8O235	41.595661	-93.610065
	7708.9O235	41.594564	-93.608296
One Bridge End, One-Way Traffic	0763.1L063	42.501147	-92.342006
	0763.1R063	42.498873	-92.342732
	5720.6O380	41.983933	-91.665299
	8220.1L061	41.554843	-90.576982
	8220.1R061	41.55364	-90.569138
Special Cases, One-Way Traffic	2963.7A034	40.812588	-91.099829
	5723.8O380	42.027735	-91.673185
	7707.2O235	41.595505	-93.642472
	7708.1A235	41.595274	-93.624265
	7708.2O235	41.596753	-93.621284
	7708.3O235	41.59532	-93.619693
	7710.0A235	41.600858	-93.5867
	7785.5S069	41.596441	-93.599156
Split Bridge Numbers	5244.3O080	41.687319	-91.540499
	5244.4O080	41.685979	-91.539223
	6401.9S014	42.040526	-92.907831
	6402.0S014	42.041542	-92.907841
	7705.0O235	41.592214	-93.681742
	7705.1O235	41.59132	-93.681493
	8544.7O030	42.00894	-93.678823
	8544.8O030	42.00795	-93.678676
	8619.1L063	41.982831	-92.58182
	8619.1R063	41.98188	-92.581555
	9401.5L926	42.49922	-94.186477
	9401.5R926	42.497133	-94.187261
	9700.2S077	42.49122	-96.412919
	9700.3S077	42.492001	-96.412474

Table B-6. Bridge Locations, Sorted by Sloped End Treatment Configuration (Cont.)

Sloped End Treatment Configuration	Bridge No.	Latitude	Longitude
No AADT Data	0700.4S820	42.507388	-92.456491
	2801.1S603	42.621699	-91.556957
	2803.7S603	42.598864	-91.537751
	2803.8S603	42.599805	-91.538347
	6100.1S637	41.297396	-94.072226
	8100.3S607	42.299282	-95.043776
	9200.4S612	41.178478	-91.880647

Figure B-1. Bridge No. 0230.3S148 [1]

Figure B-2. Bridge No. 0230.5S148 [1]

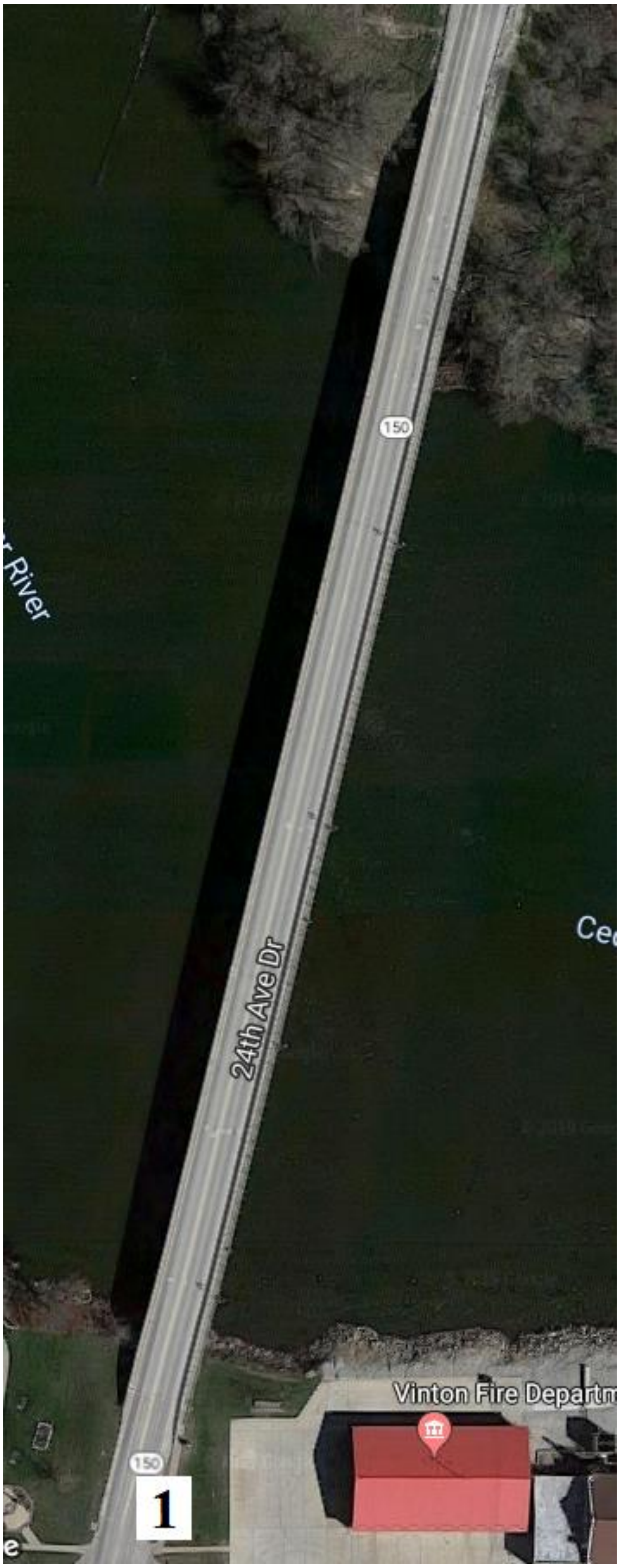


Figure B-3. Bridge No. 0601.5S150 [1]

Figure B-4. Bridge No. 0700.4S820 [1]

Figure B-5. Bridge No. 0713.9S281 [1]

Figure B-6. Bridge No. 0728.0O020 [1]

Figure B-7. Bridge No. 0729.0O020 [1]

Figure B-8. Bridge No. 0730.0O020 [1]

Figure B-9. Bridge No. 0731.0O020 [1]

Figure B-10. Bridge No. 0743.1S057 [1]

Figure B-11. Bridge No. 0763.1L063 [1]

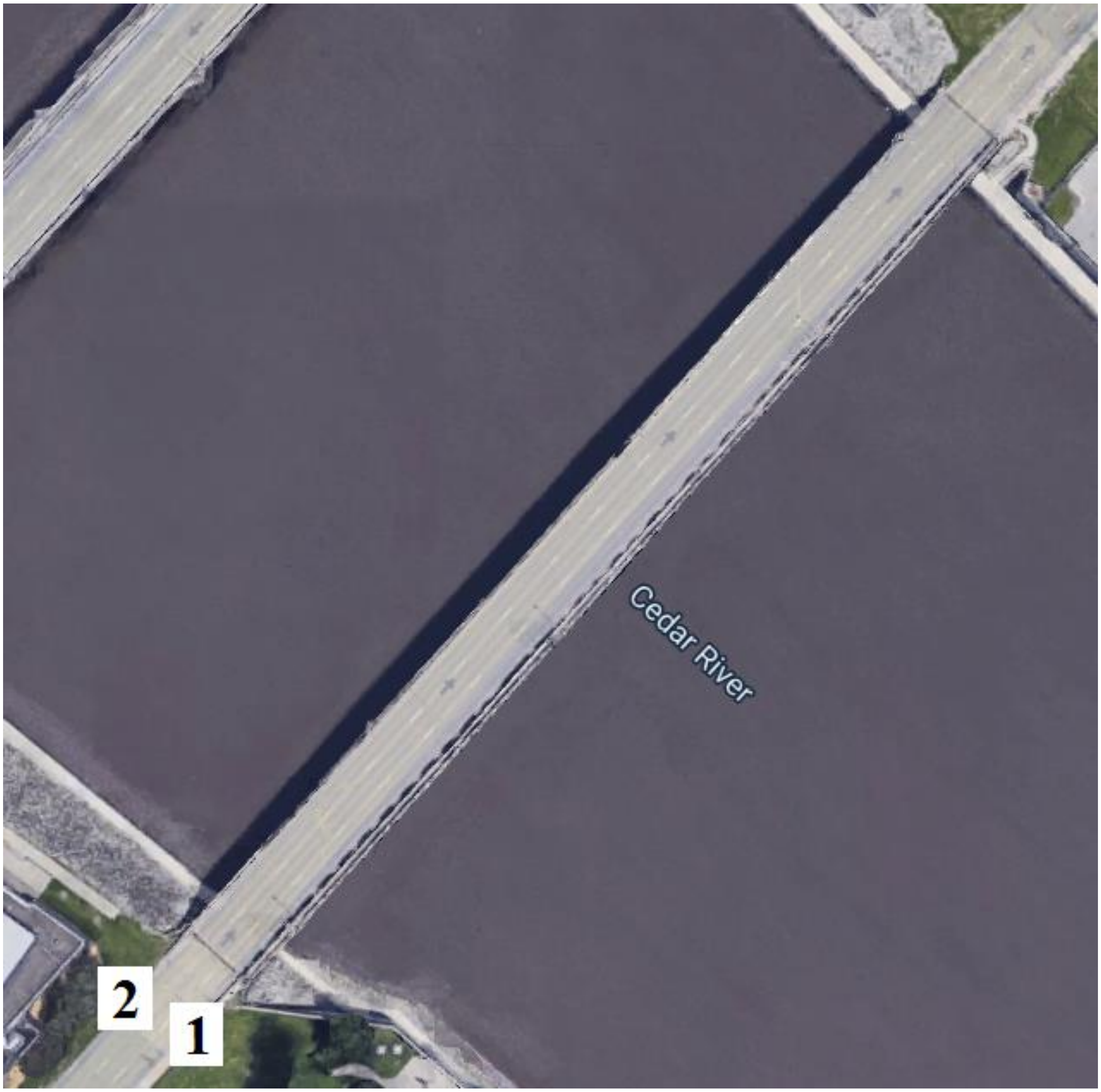


Figure B-12. Bridge No. 0763.1R063 [1]

Figure B-13. Bridge No. 0767.1S218 [1]

Figure B-14. Bridge No. 0783.2O218 [1]

Figure B-15. Bridge No. 0995.4O218 [1]

Figure B-16. Bridge No. 1023.9S281 [1]

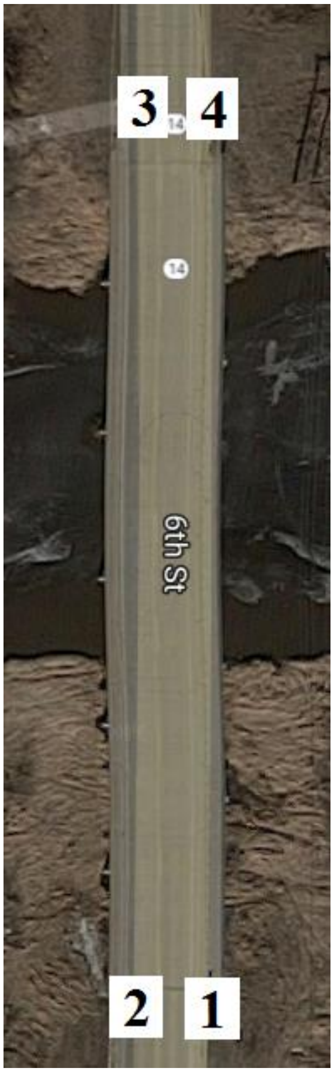


Figure B-17. Bridge No. 1246.8S014 [1]

Figure B-18. Bridge No. 1412.0S071 [1]

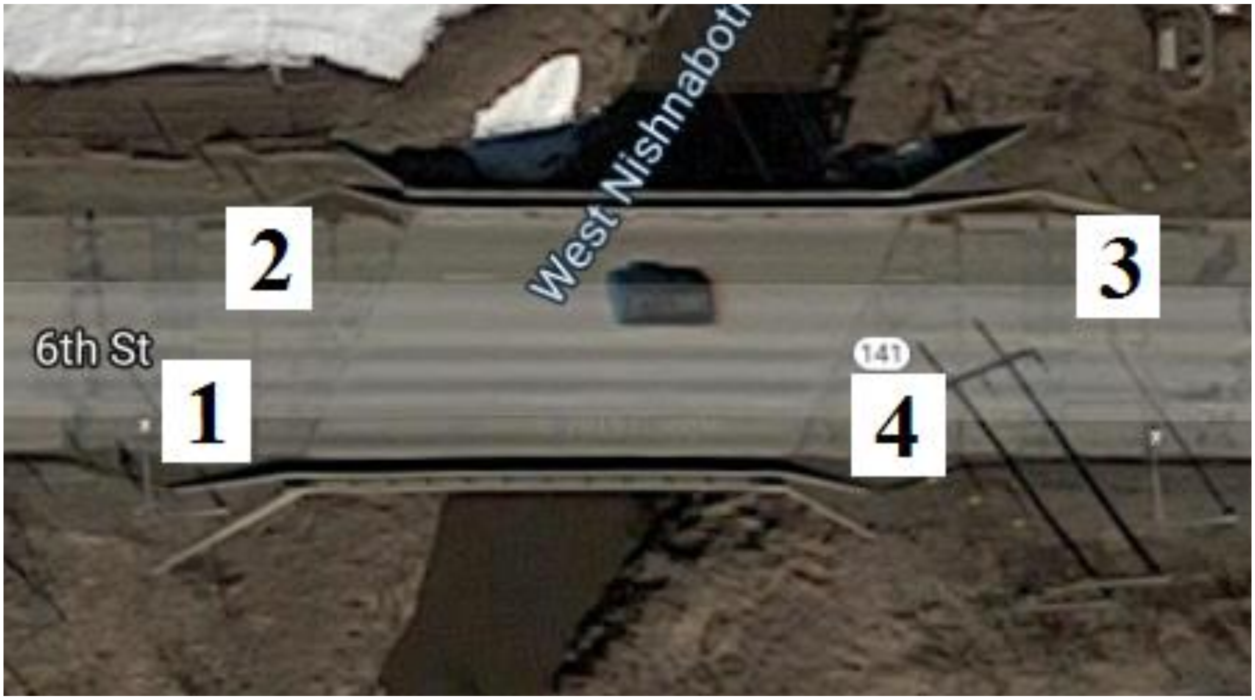


Figure B-19. Bridge No. 1477.0S141 [1]

Figure B-20. Bridge No. 1542.6S048 [1]

Figure B-21. Bridge No. 1562.9S148 [1]

Figure B-22. Bridge No. 1654.6O080 [1]

Figure B-23. Bridge No. 1710.2S122 [1]

Figure B-24. Bridge No. 1797.9S065 [1]

Figure B-25. Bridge No. 1858.8S059 [1]

Figure B-26. Bridge No. 1859.0S059 [1]

Figure B-27. Bridge No. 1900.5S346 [1]

Figure B-28. Bridge No. 2181.0S018 [1]

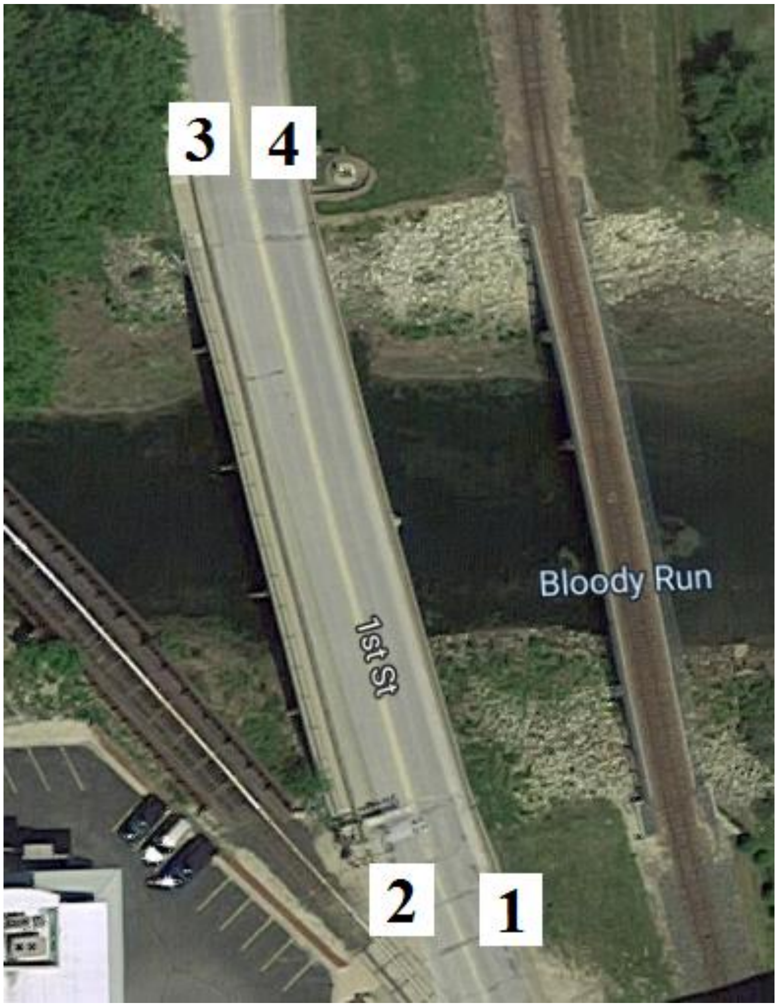


Figure B-29. Bridge No. 2204.5S076 [1]

Figure B-30. Bridge No. 2318.8S136 [1]

Figure B-31. Bridge No. 2515.1S006 [1]

Figure B-32. Bridge No. 2521.4O080 [1]

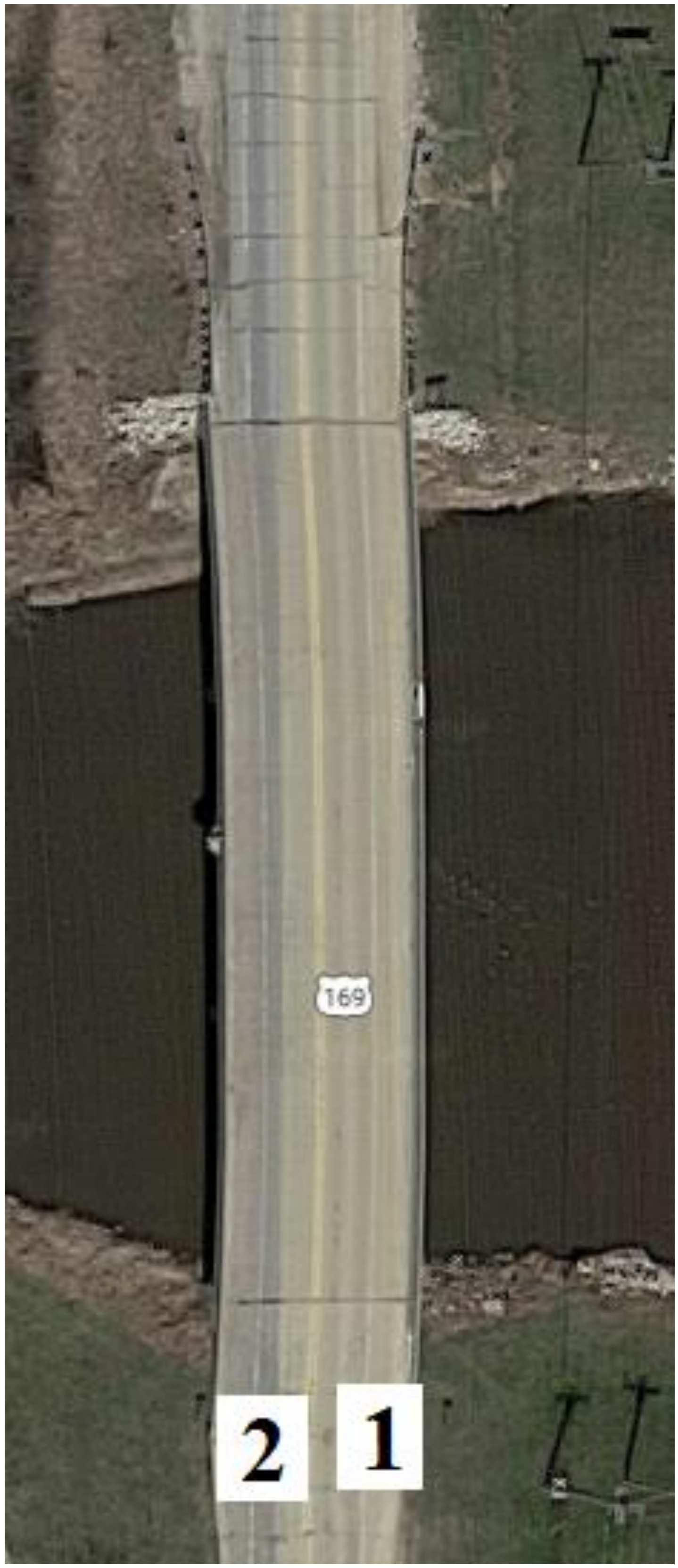


Figure B-33. Bridge No. 2589.1S169 [1]

Figure B-34. Bridge No. 2711.3S069 [1]

Figure B-35. Bridge No. 2801.1S603 [1]

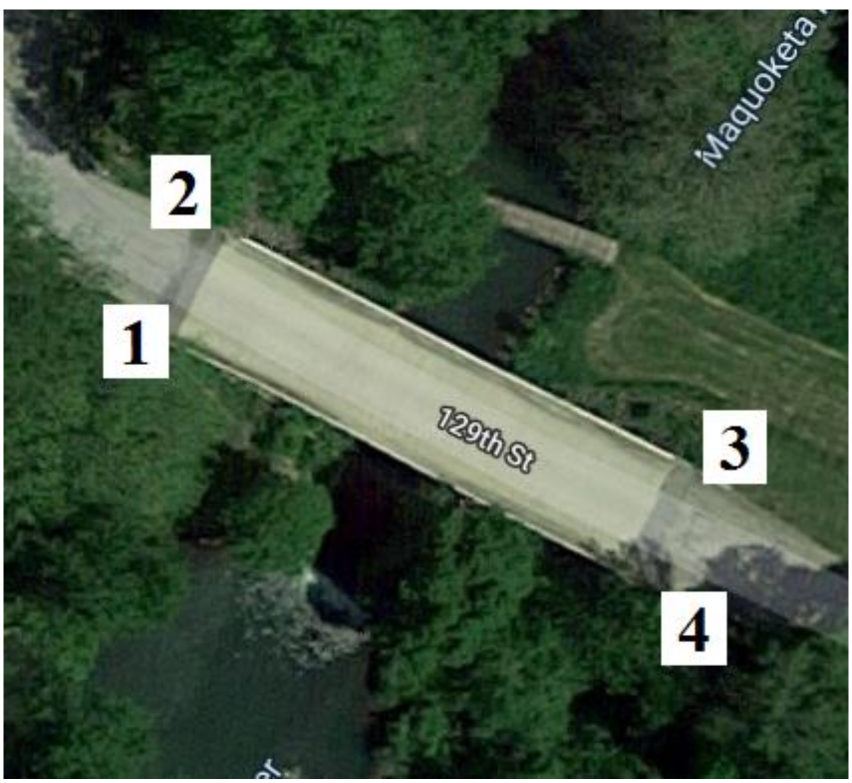


Figure B-36. Bridge No. 2803.7S603 [1]

Figure B-37. Bridge No. 2803.8S603 [1]

Figure B-38. Bridge No. 2841.6S013 [1]

Figure B-39. Bridge No. 2942.2L061 [1]

Figure B-40. Bridge No. 2959.6O034 [1]

Figure B-41. Bridge No. 2962.0O034 [1]

Figure B-42. Bridge No. 2962.9O034 [1]

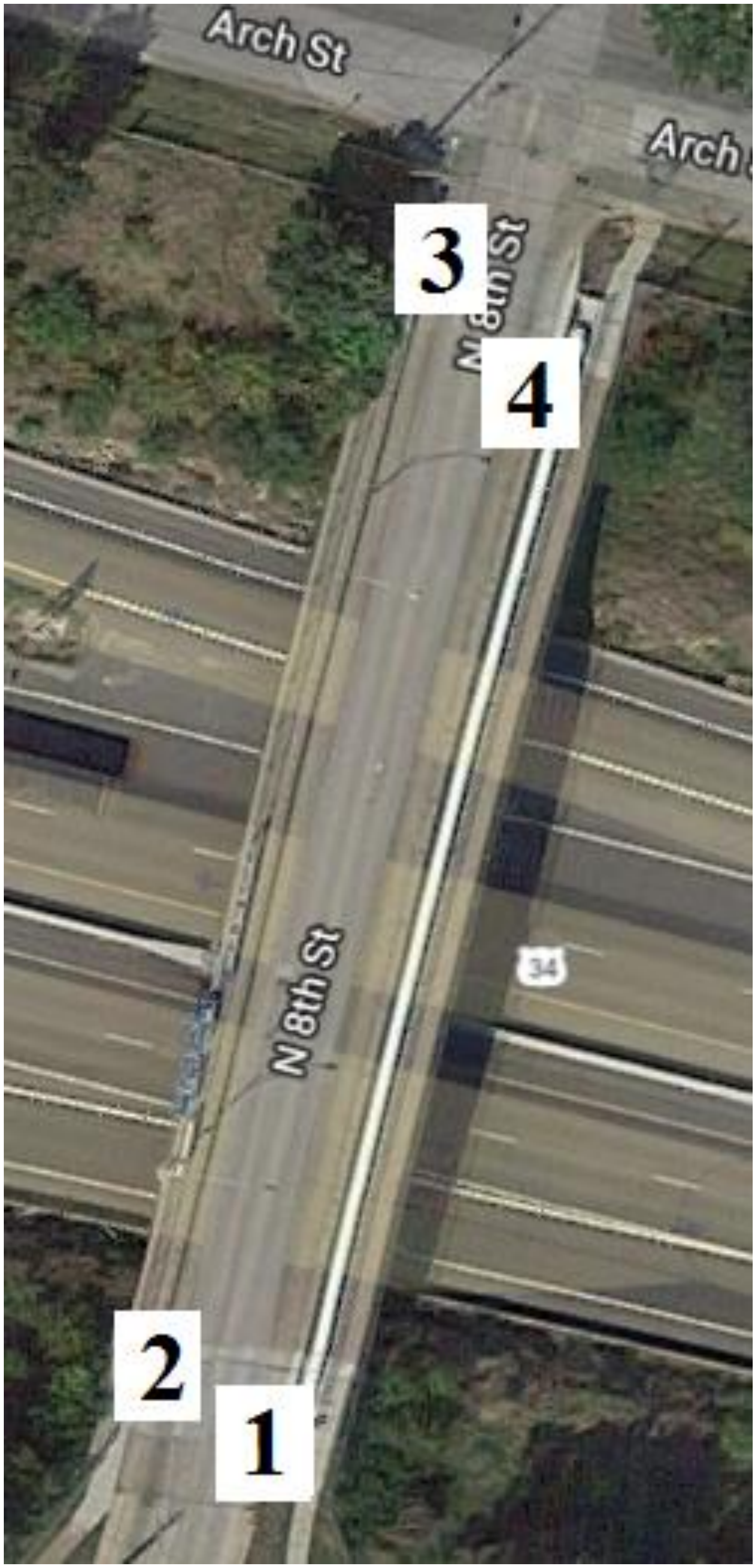


Figure B-43. Bridge No. 2963.0O034 [1]

Figure B-44. Bridge No. 2963.2O034 [1]

Figure B-45. Bridge No. 2963.3O034 [1]

Figure B-46. Bridge No. 2963.7A034 [1]

Figure B-47. Bridge No. 3021.8S071 [1]

Figure B-48. Bridge No. 3026.6S071 [1]

Figure B-49. Bridge No. 3118.4O020 [1]

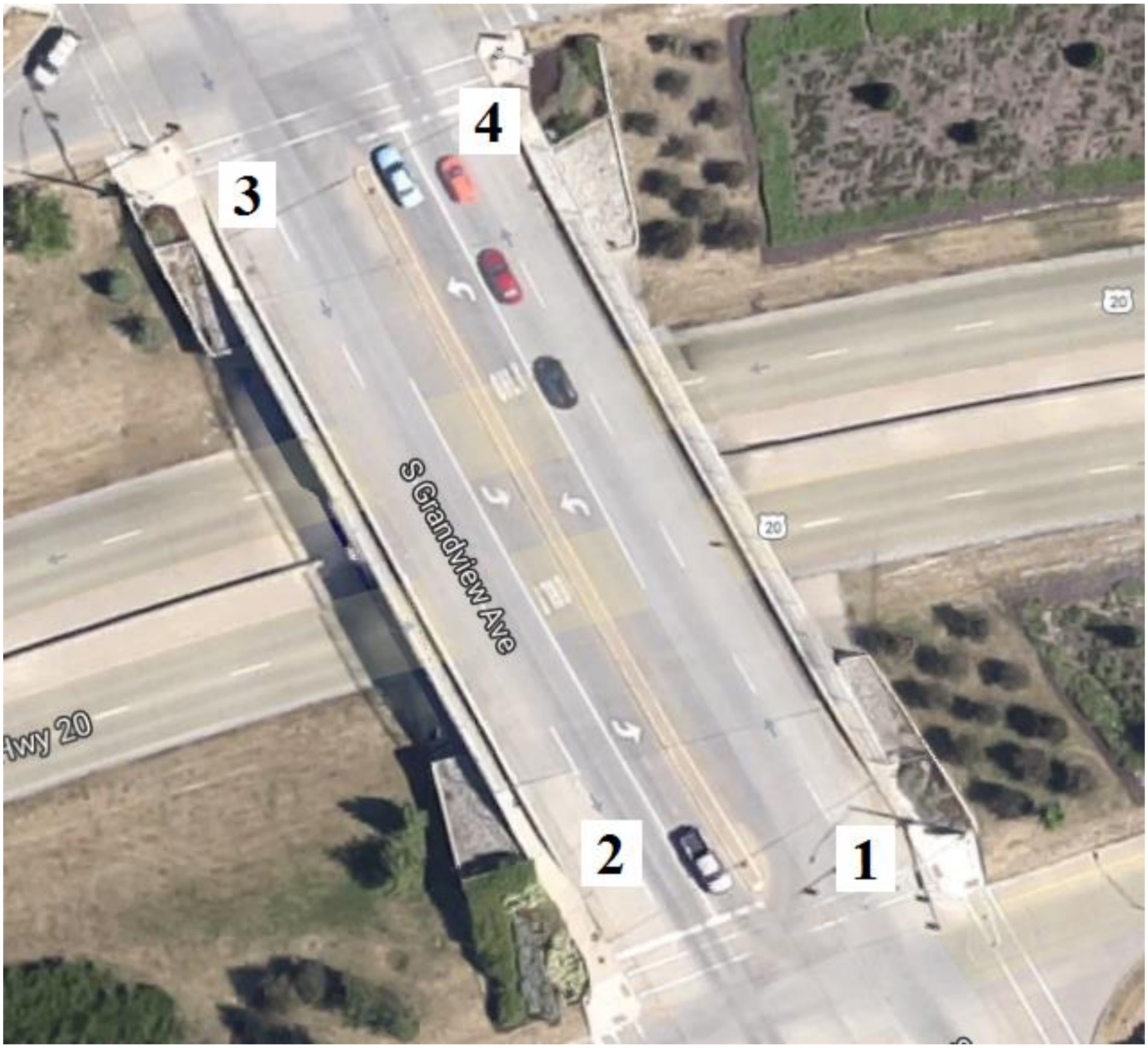


Figure B-50. Bridge No. 3118.5O020 [1]

Figure B-51. Bridge No. 3119.0O020 [1]

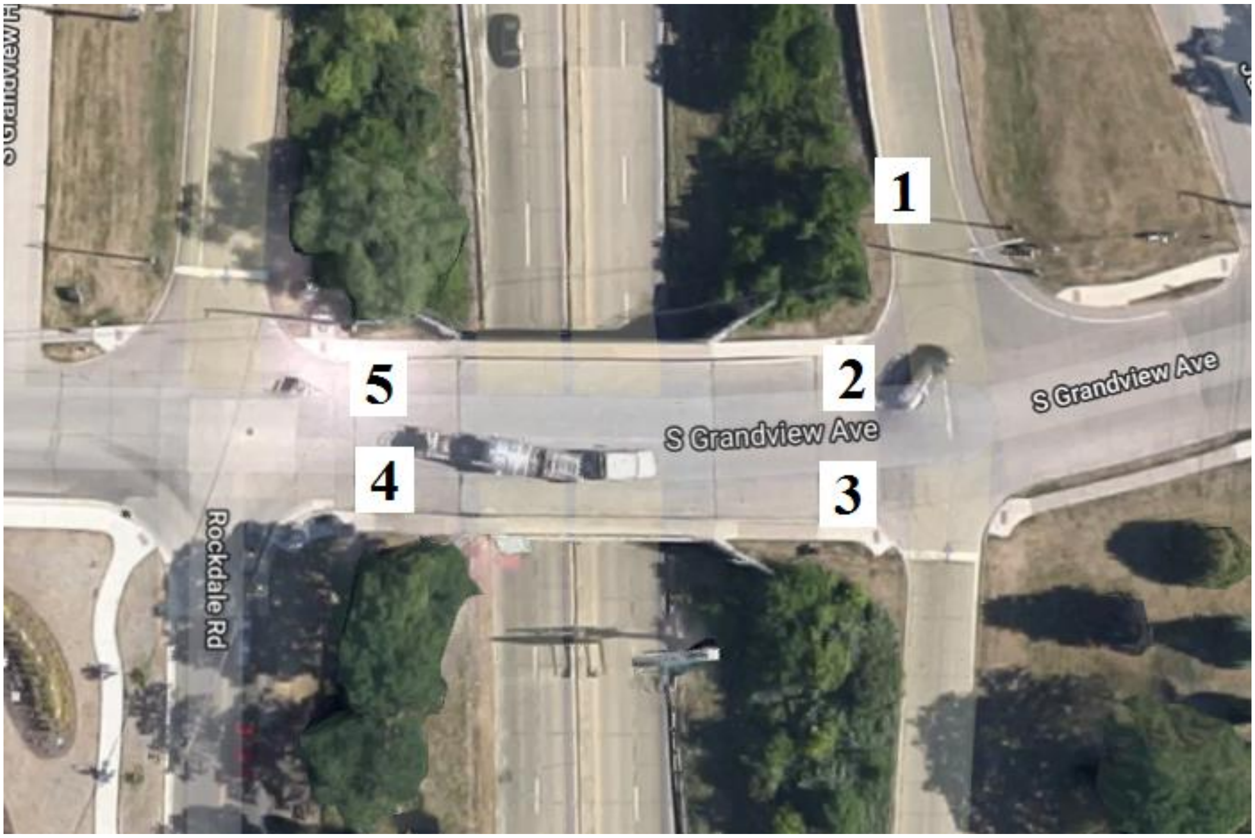


Figure B-52. Bridge No. 3145.1O052 [1]

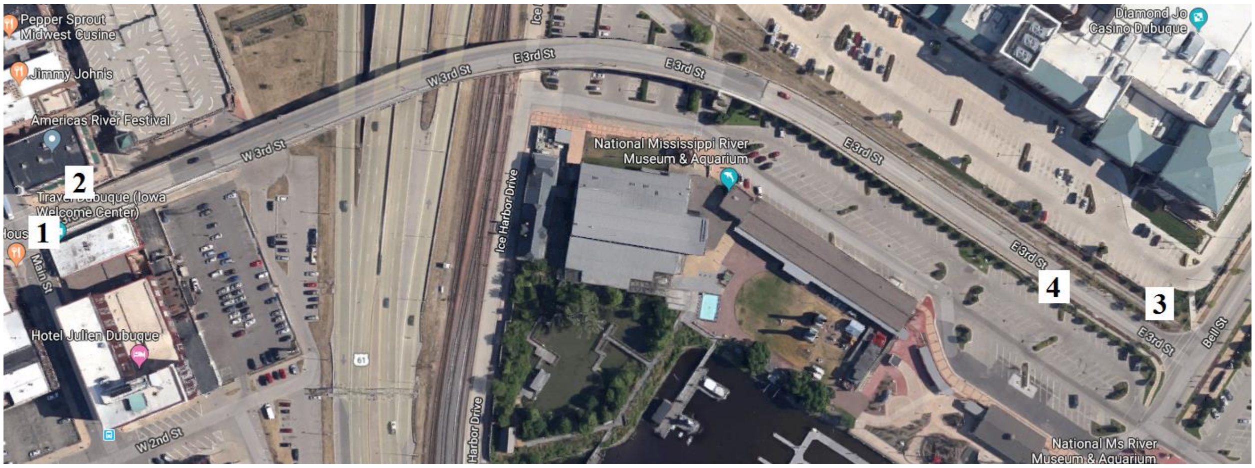


Figure B-53. Bridge No. 3146.6O052 [1]

Figure B-54. Bridge No. 3150.7A052 [1]

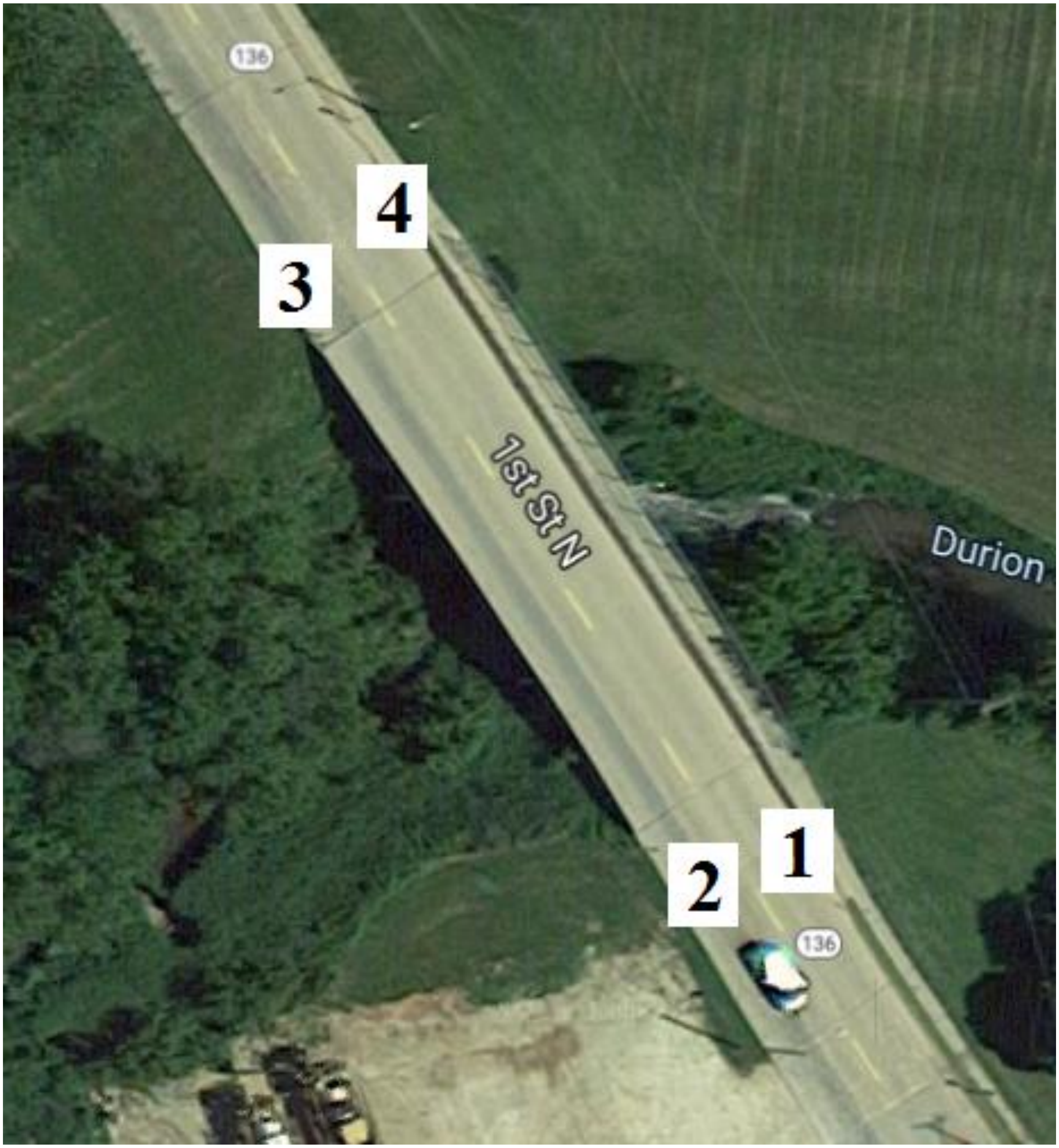


Figure B-55. Bridge No. 3182.0S136 [1]

Figure B-56. Bridge No. 3192.7S136 [1]

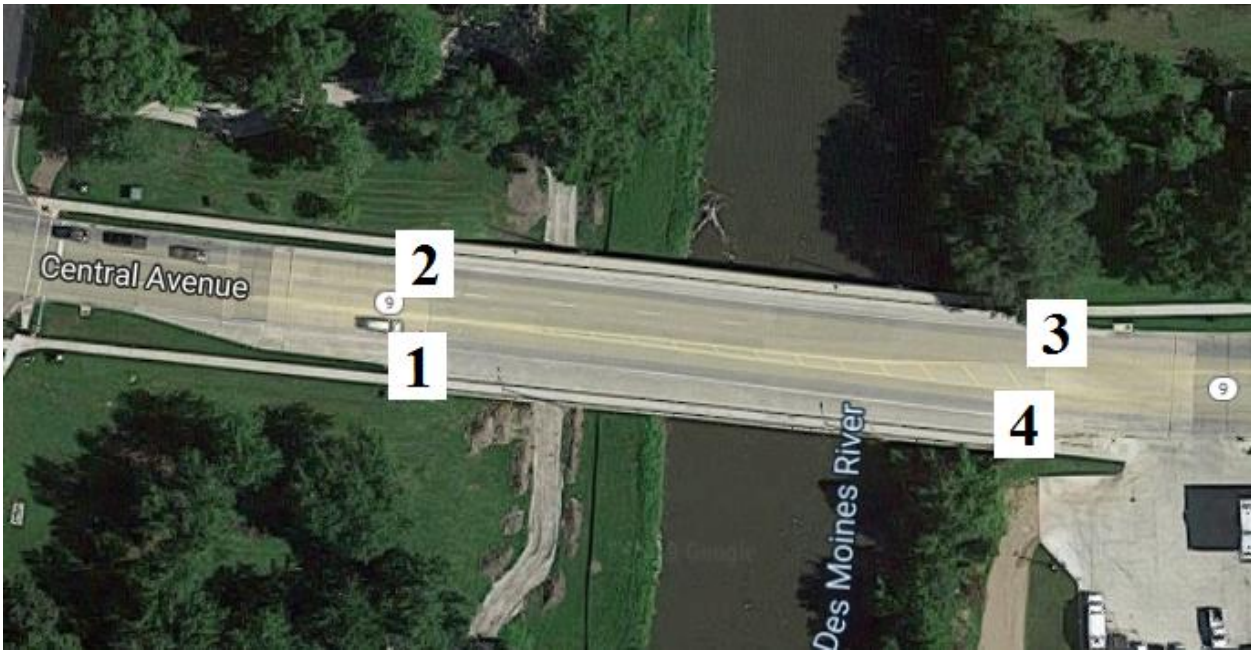


Figure B-57. Bridge No. 3288.1S009 [1]

Figure B-58. Bridge No. 3364.6S150 [1]

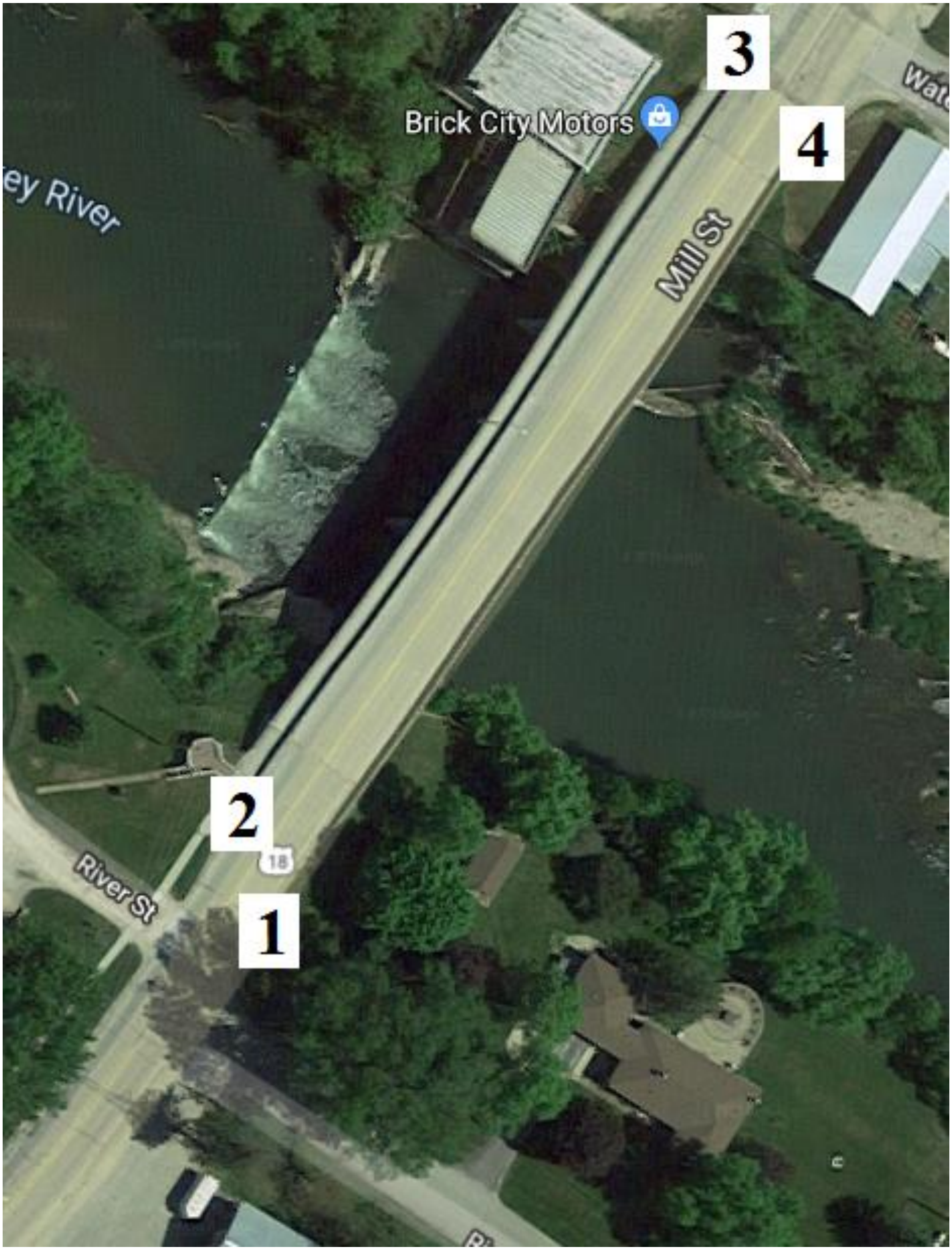


Figure B-59. Bridge No. 3372.6S018 [1]

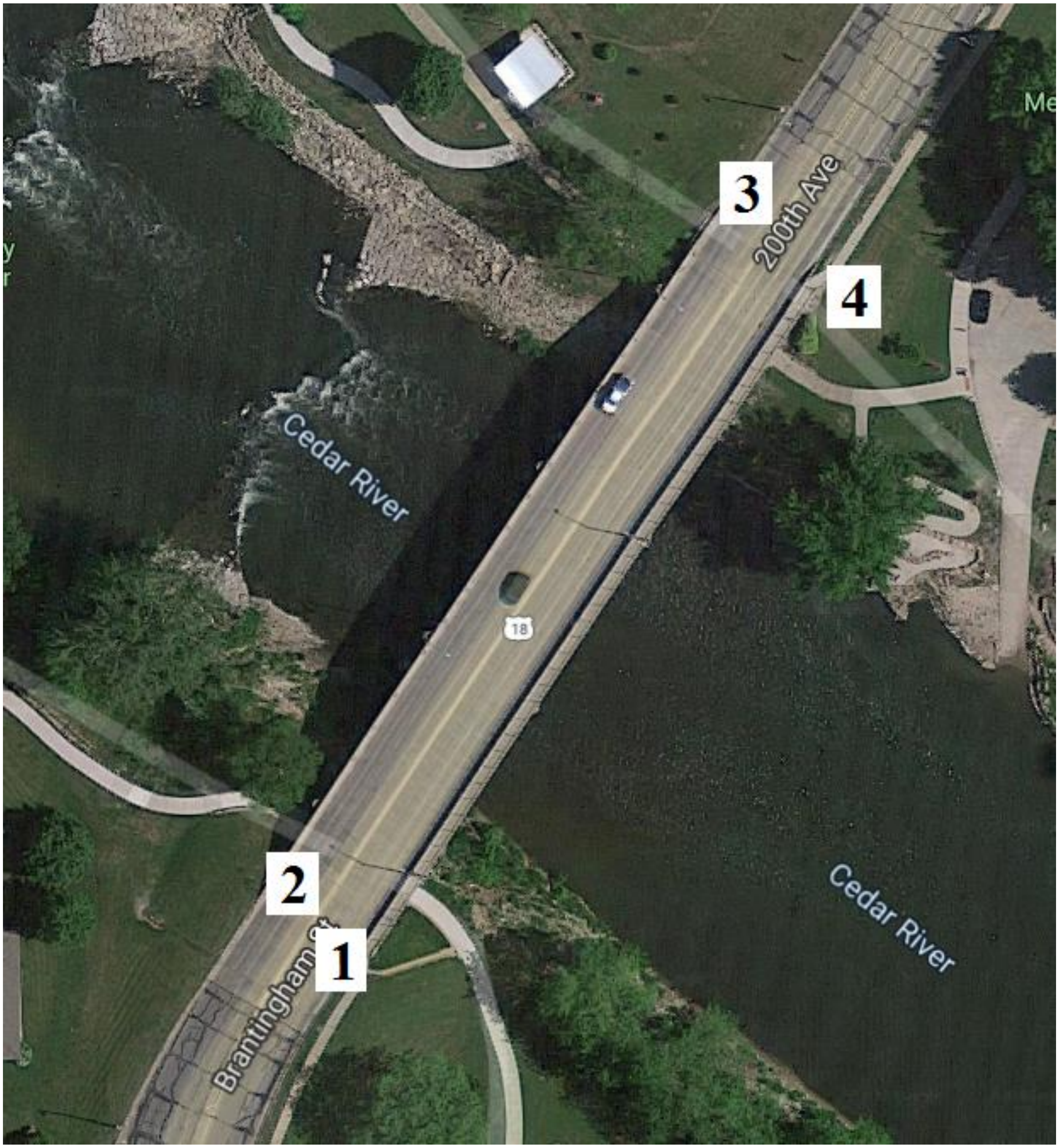


Figure B-60. Bridge No. 3412.7S018 [1]

Figure B-61. Bridge No. 3568.3S065 [1]

Figure B-62. Bridge No. 3712.2S025 [1]

Figure B-63. Bridge No. 3723.0S004 [1]

Figure B-64. Bridge No. 4055.6S175 [1]

Figure B-65. Bridge No. 4208.0S057 [1]

Figure B-66. Bridge No. 4309.8S030 [1]

Figure B-67. Bridge No. 4249.6S065 [1]

Figure B-68. Bridge No. 4287.7S175 [1]

Figure B-69. Bridge No. 4319.5S030 [1]

Figure B-70. Bridge No. 4800.2S151 [1]

Figure B-71. Bridge No. 4864.8S149 [1]

Figure B-72. Bridge No. 4922.0S064 [1]

Figure B-73. Bridge No. 4922.8S052 [1]

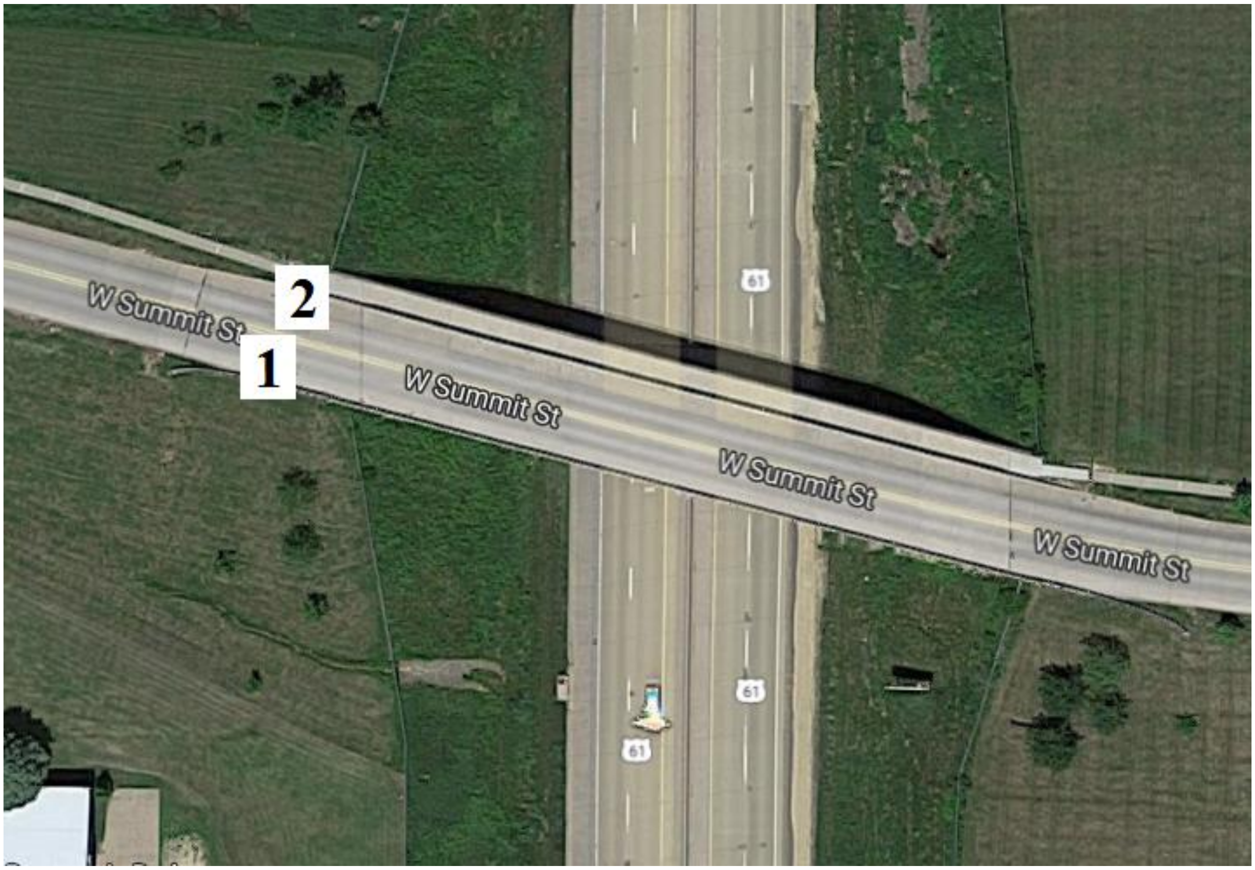


Figure B-74. Bridge No. 4958.3O061 [1]

Figure B-75. Bridge No. 5007.7S117 [1]

Figure B-76. Bridge No. 5242.1O080 [1]

Figure B-77. Bridge No. 5243.0O080 [1]

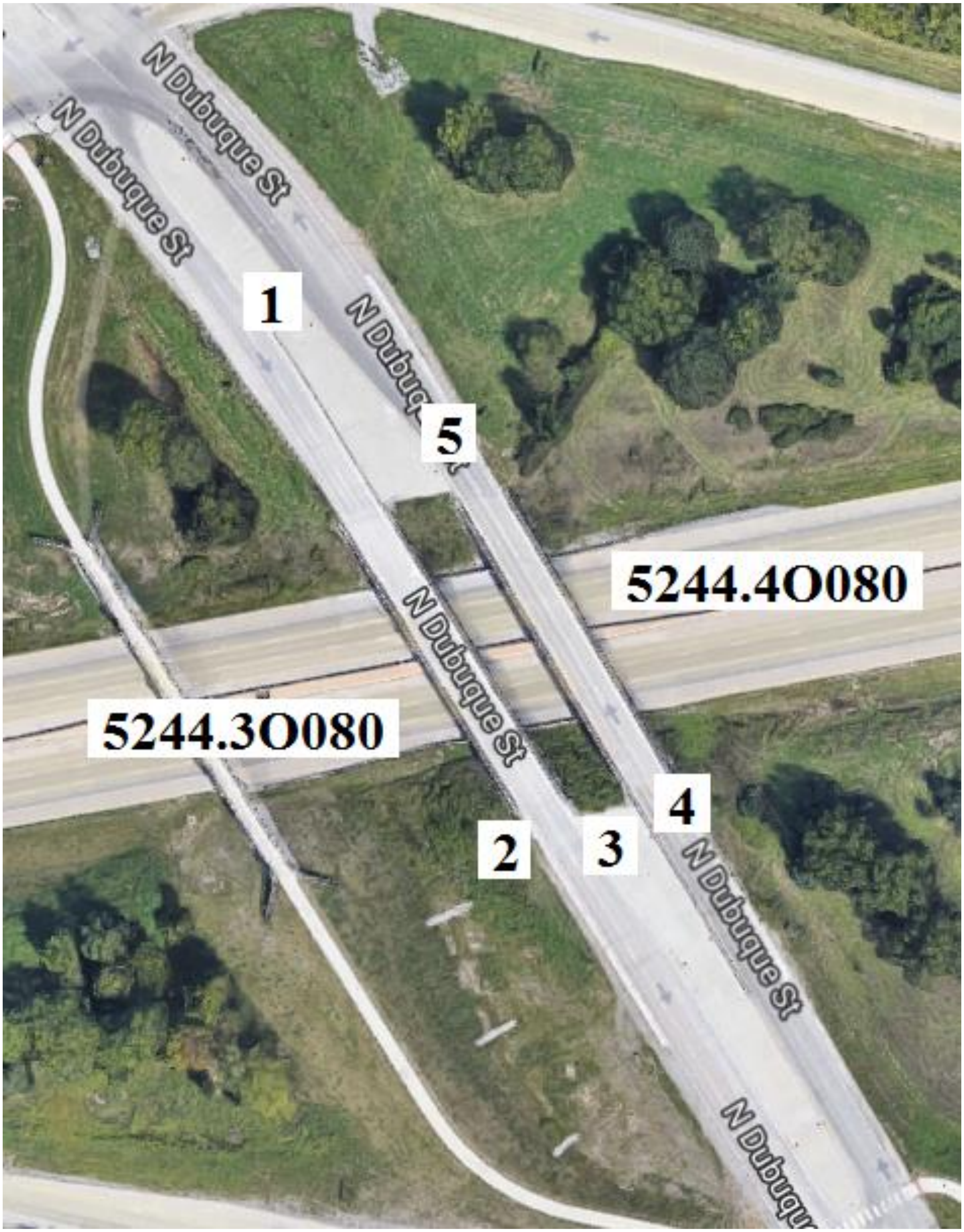


Figure B-78. Bridge Nos. 5244.3O080 and 5244.4O080 [1]

Figure B-79. Bridge No. 5245.1O080 [1]

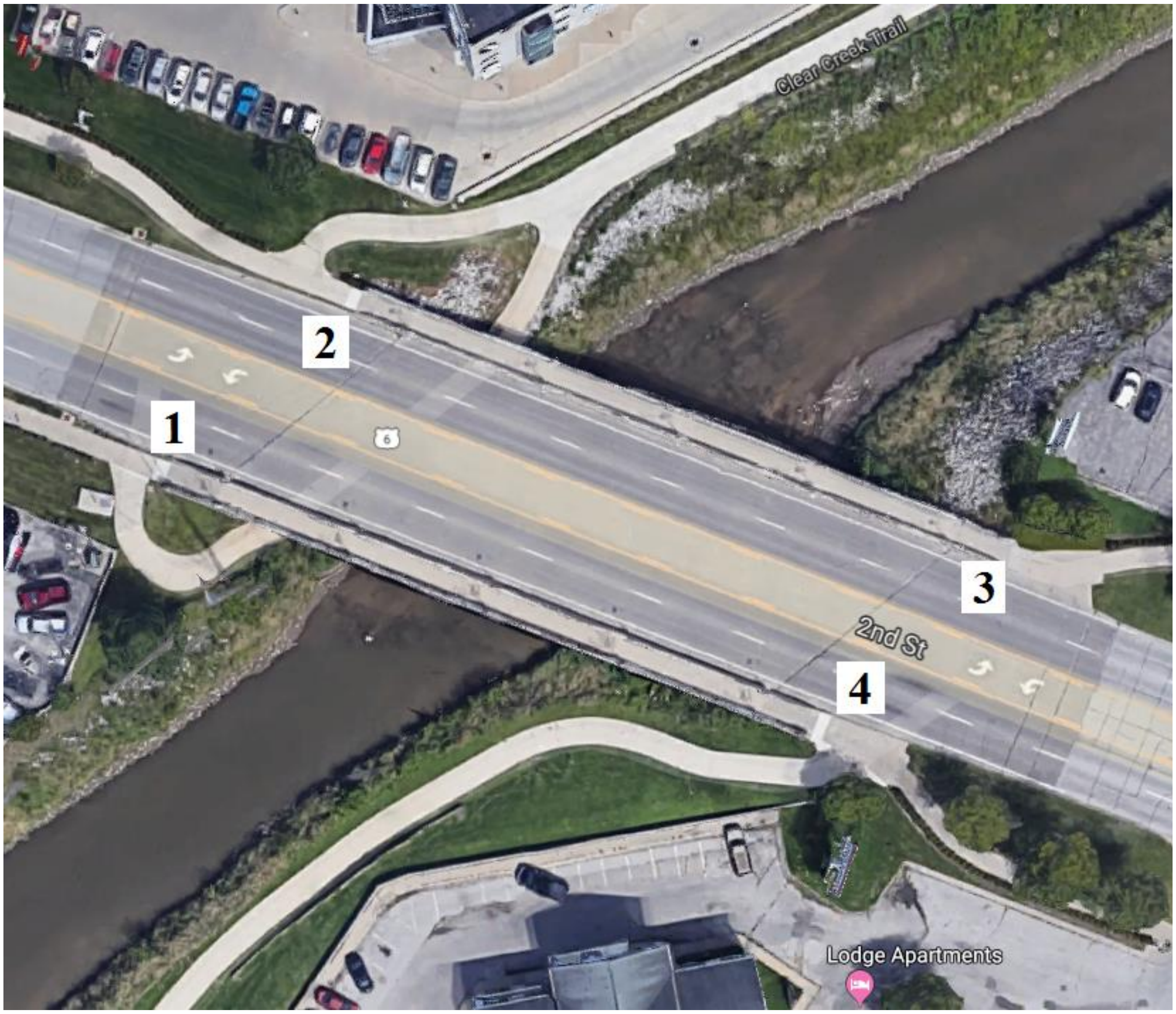


Figure B-80. Bridge No. 5249.3S006 [1]

Figure B-81. Bridge No. 5285.9L001 [1]

Figure B-82. Bridge No. 5286.5S001 [1]

Figure B-83. Bridge No. 5286.9L001 [1]

Figure B-84. Bridge No. 5287.2R001 [1]

Figure B-85. Bridge No. 5314.8S064 [1]

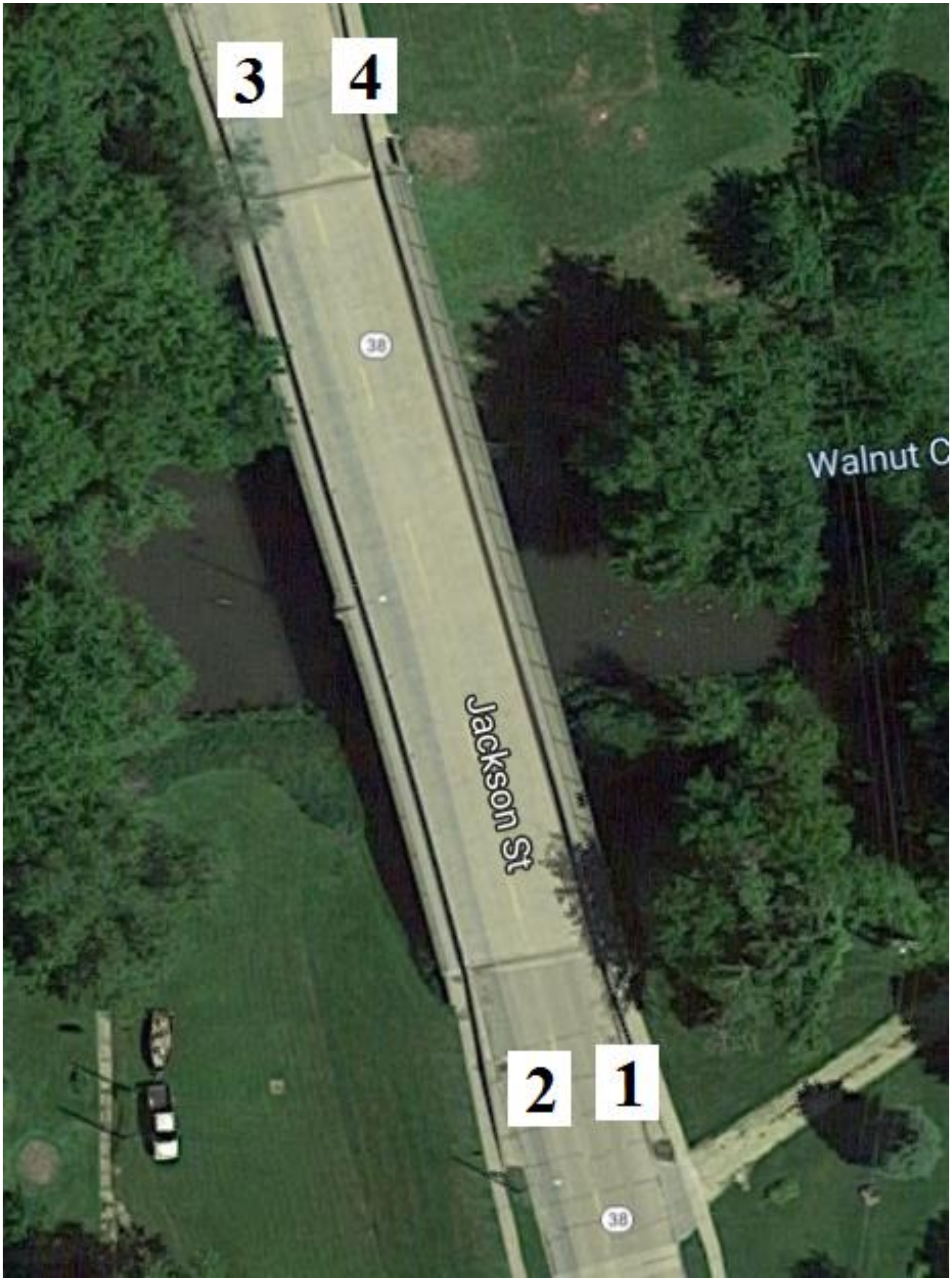


Figure B-86. Bridge No. 5342.8S038 [1]

Figure B-87. Bridge No. 5363.6S038 [1]

Figure B-88. Bridge No. 5598.7S169 [1]

Figure B-89. Bridge No. 5602.4S136 [1]

Figure B-90. Bridge No. 5718.0O380 [1]

Figure B-91. Bridge No. 5718.4O380 [1]

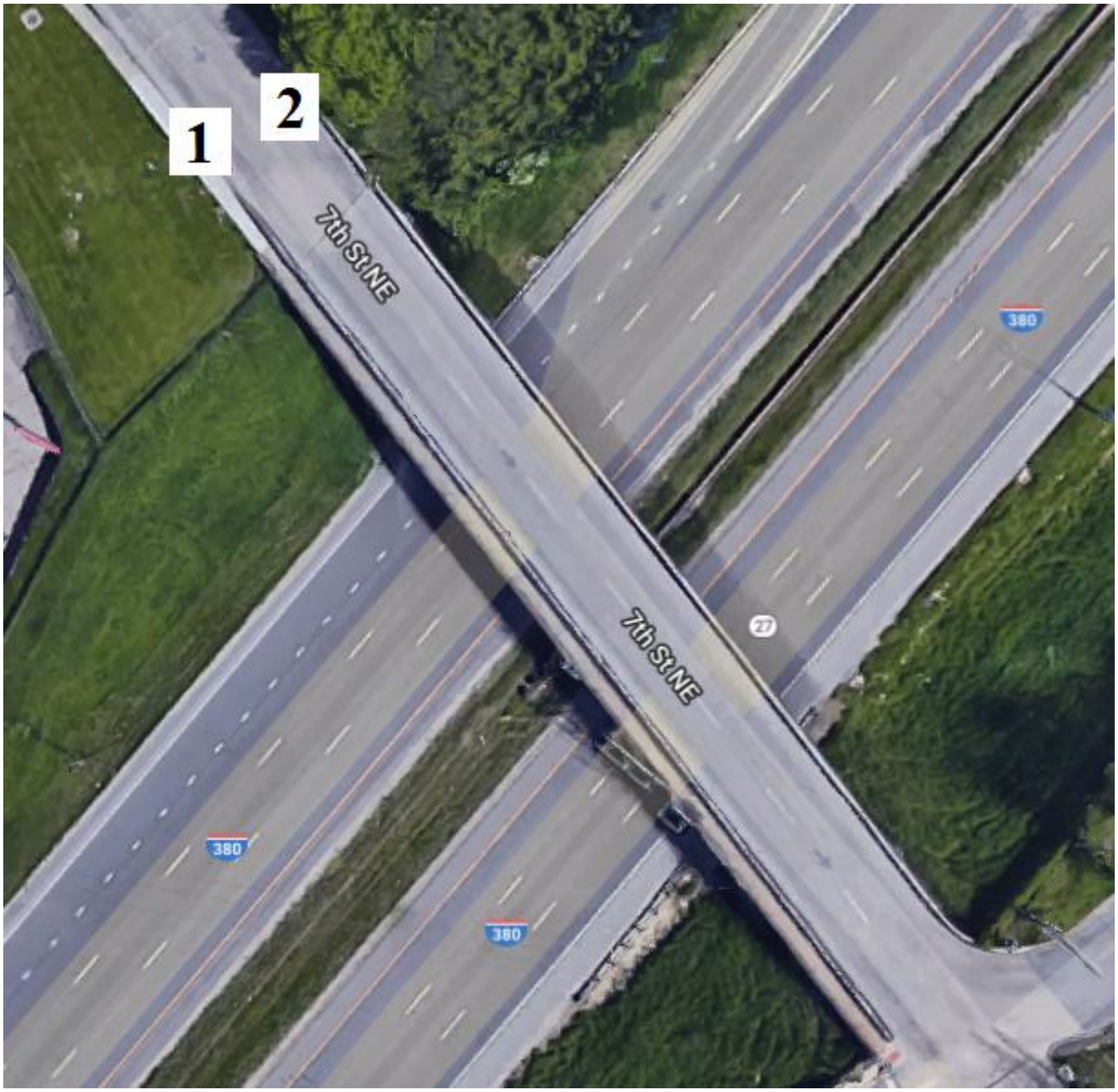


Figure B-92. Bridge No. 5720.6O380 [1]

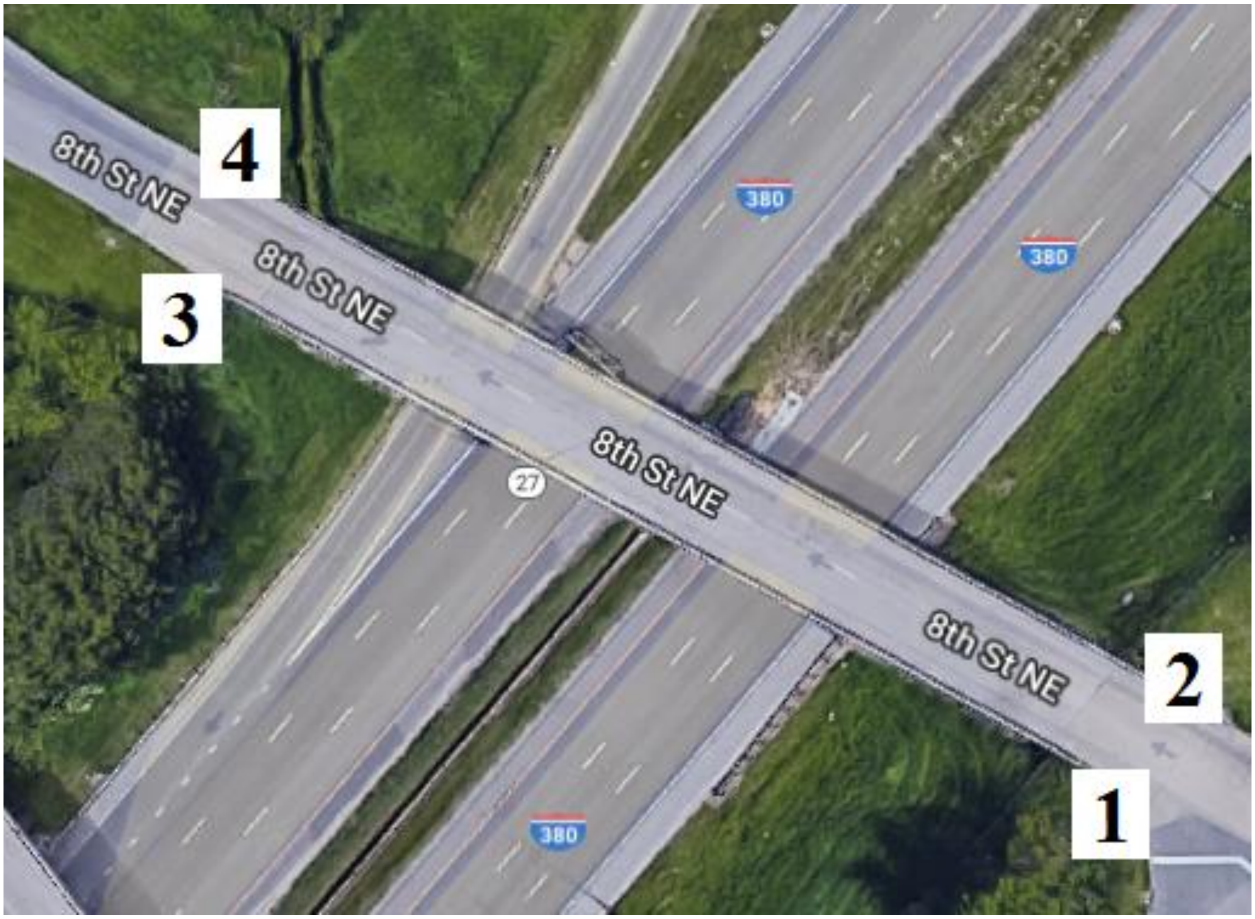


Figure B-93. Bridge No. 5720.8O380 [1]

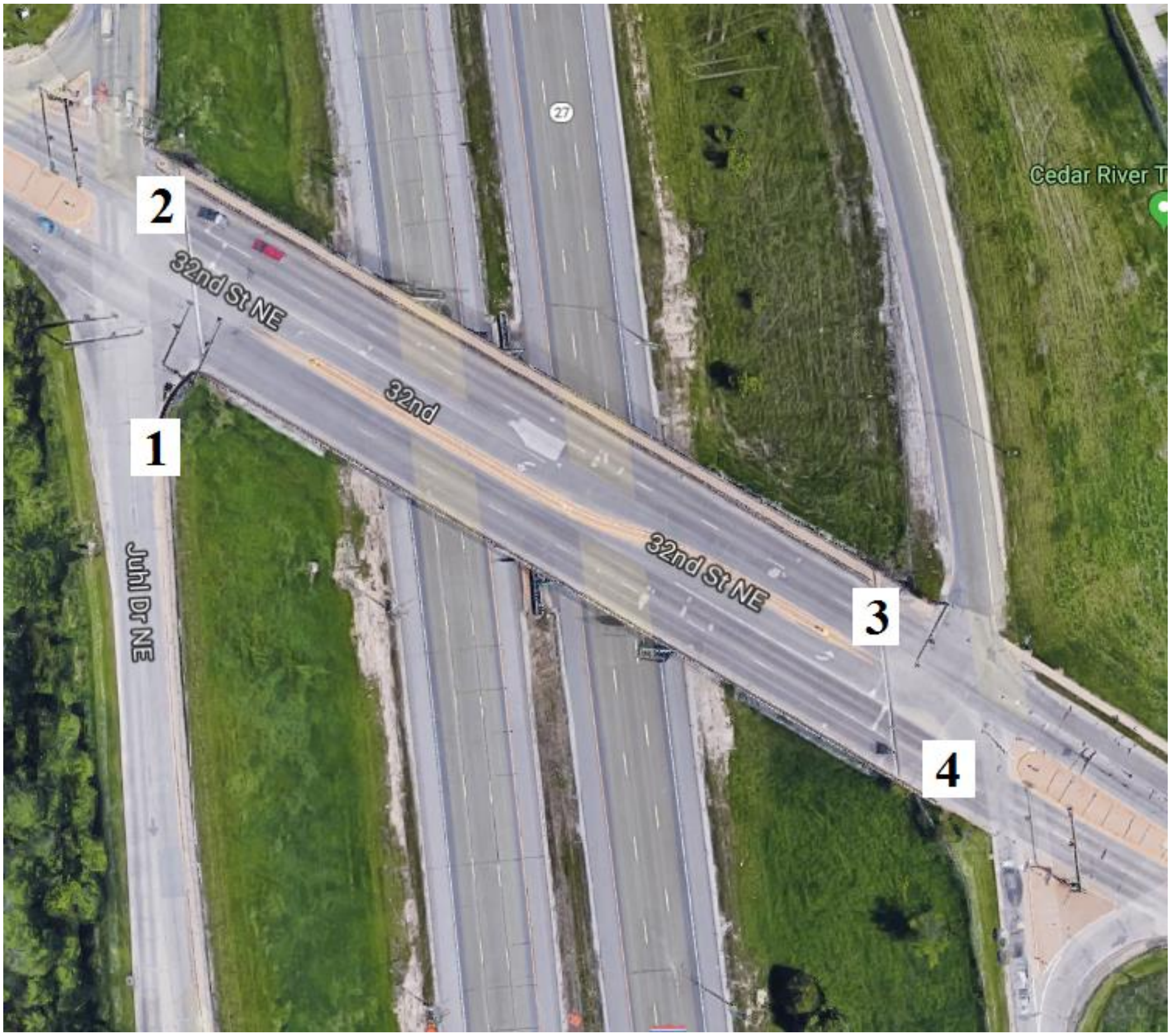


Figure B-94. Bridge No. 5722.7O380 [1]

Figure B-95. Bridge No. 5723.8O380 [1]

Figure B-96. Bridge No. 5724.4O380 [1]

Figure B-97. Bridge No. 5724.7O380 [1]

Figure B-98. Bridge No. 5752.3O030 [1]

Figure B-99. Bridge No. 5752.9O030 [1]

Figure B-100. Bridge No. 5753.4O030 [1]

Figure B-101. Bridge No. 5851.3S092 [1]

Figure B-102. Bridge No. 6020.4S009 [1]

Figure B-103. Bridge No. 6100.1S637 [1]

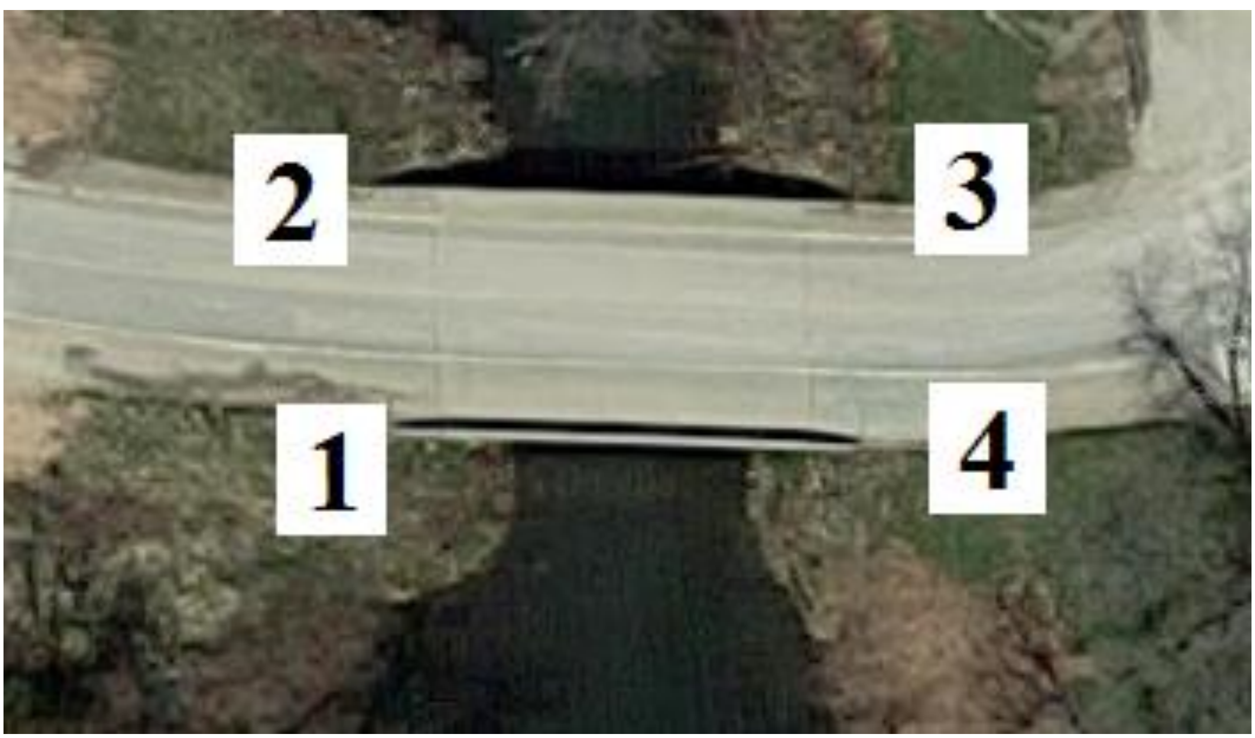


Figure B-104. Bridge No. 6200.9S622 [1]

Figure B-105. Bridge No. 6276.0S063 [1]

Figure B-106. Bridge Nos. 6401.9S014 and 6401.0S014 [1]

Figure B-107. Bridge No. 6616.8S009 [1]

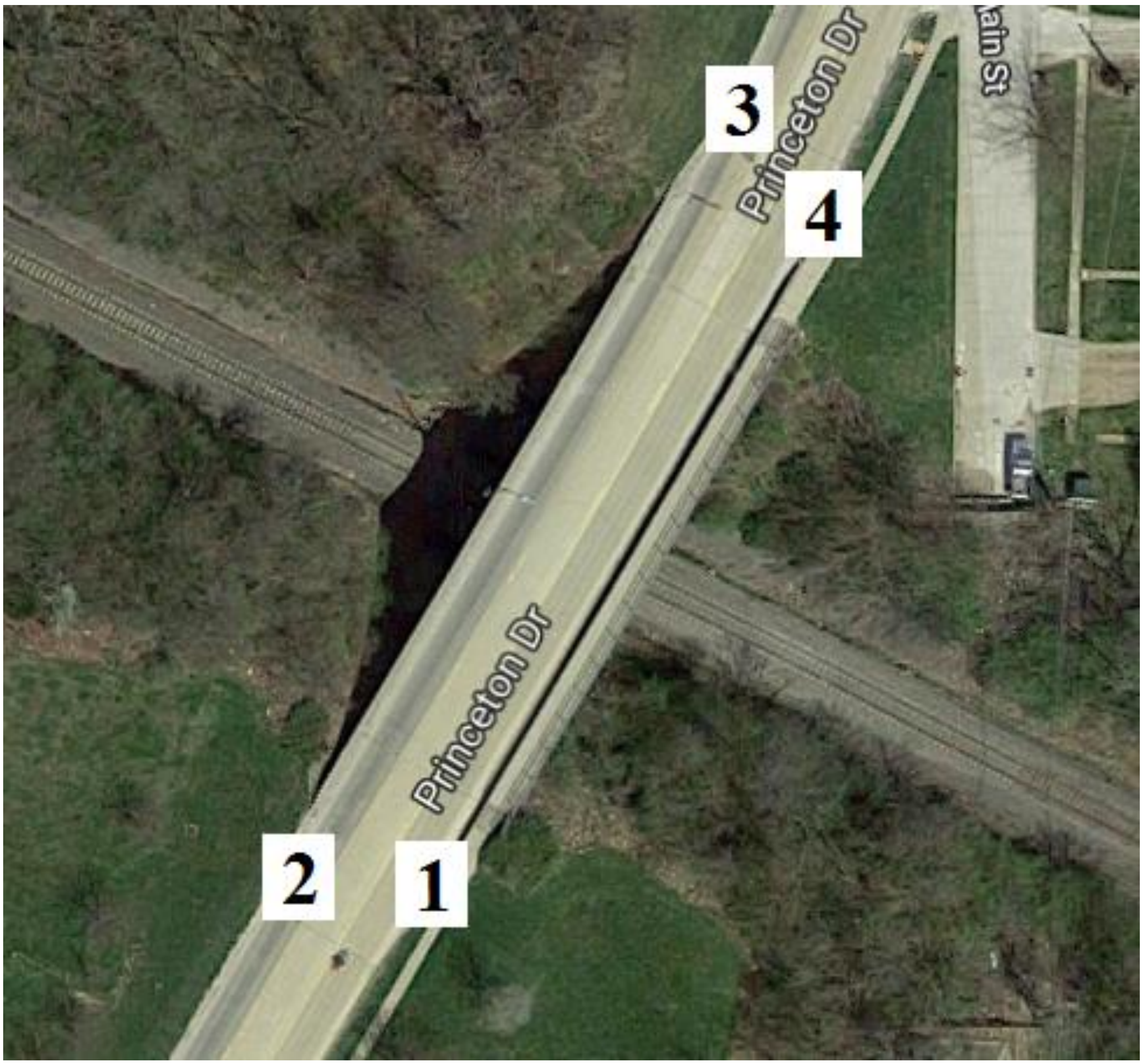


Figure B-108. Bridge No. 6834.5S005 [1]

Figure B-109. Bridge No. 7078.0A006 [1]

Figure B-110. Bridge No. 7403.2A018 [1]

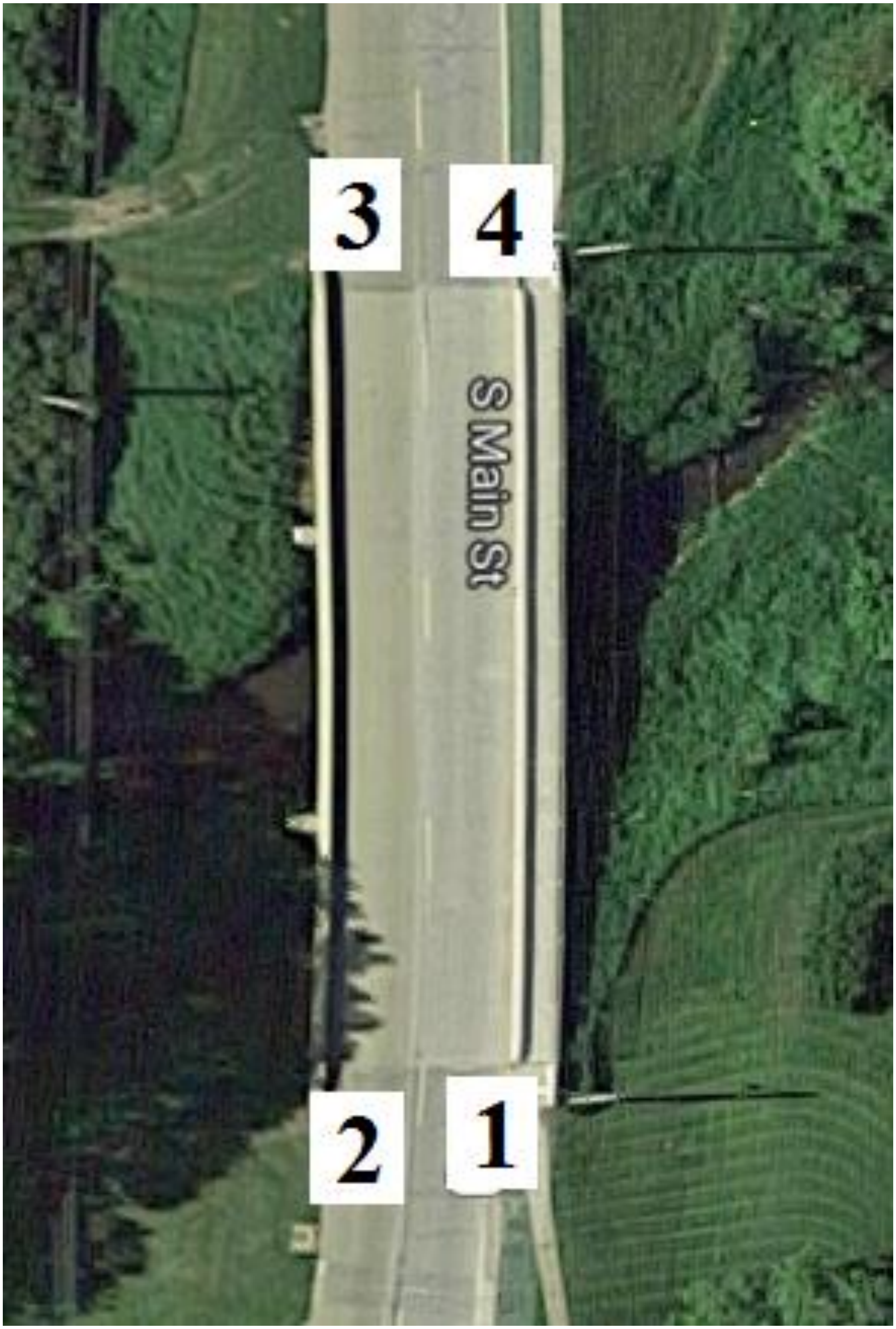


Figure B-111. Bridge No. 7509.3S140 [1]

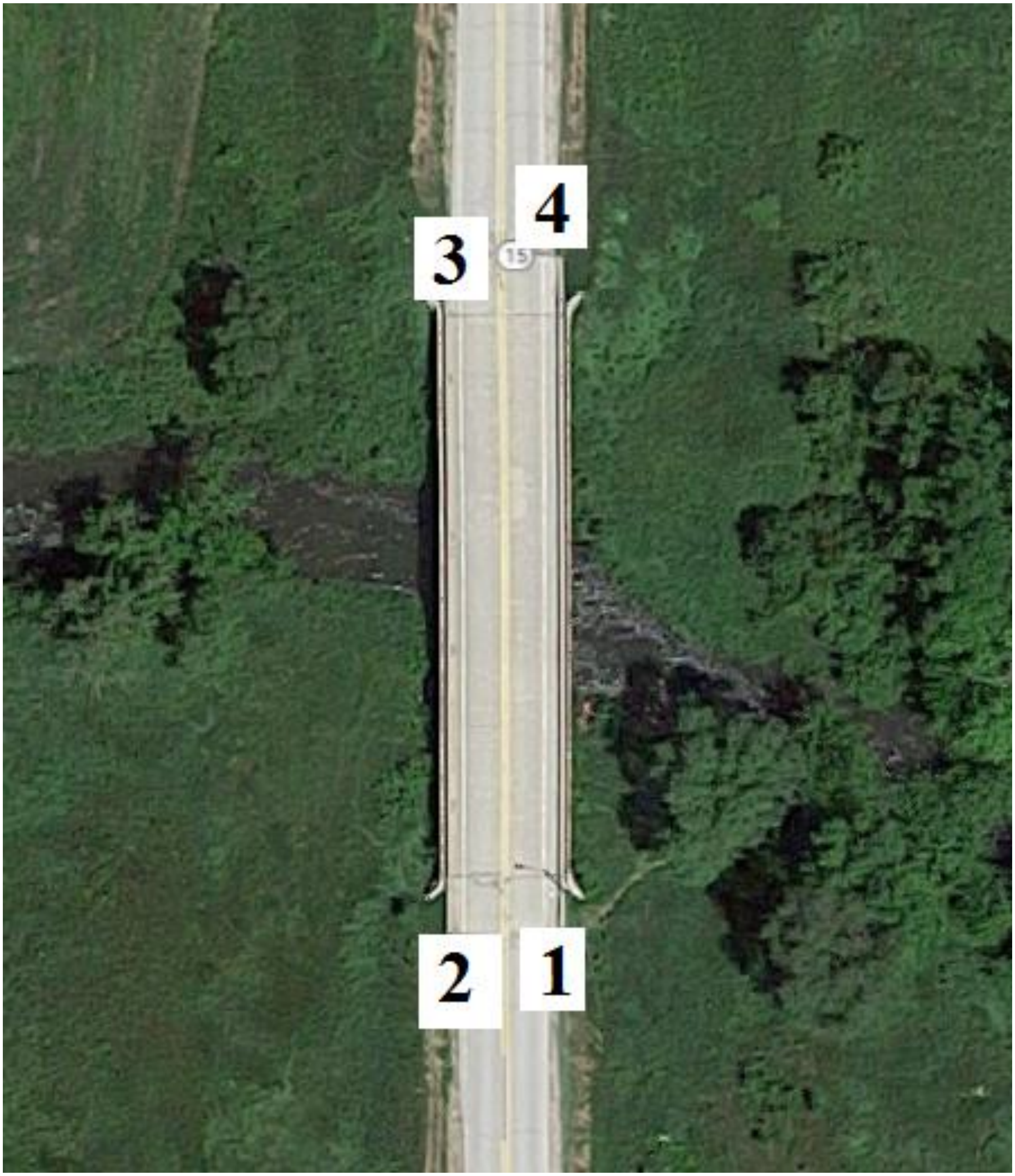


Figure B-112. Bridge No. 7606.6S015 [1]

Figure B-113. Bridge No. 7607.2S003 [1]

Figure B-114. Bridge No. 7700.3O235 [1]

Figure B-115. Bridge No. 7700.8O235 [1]

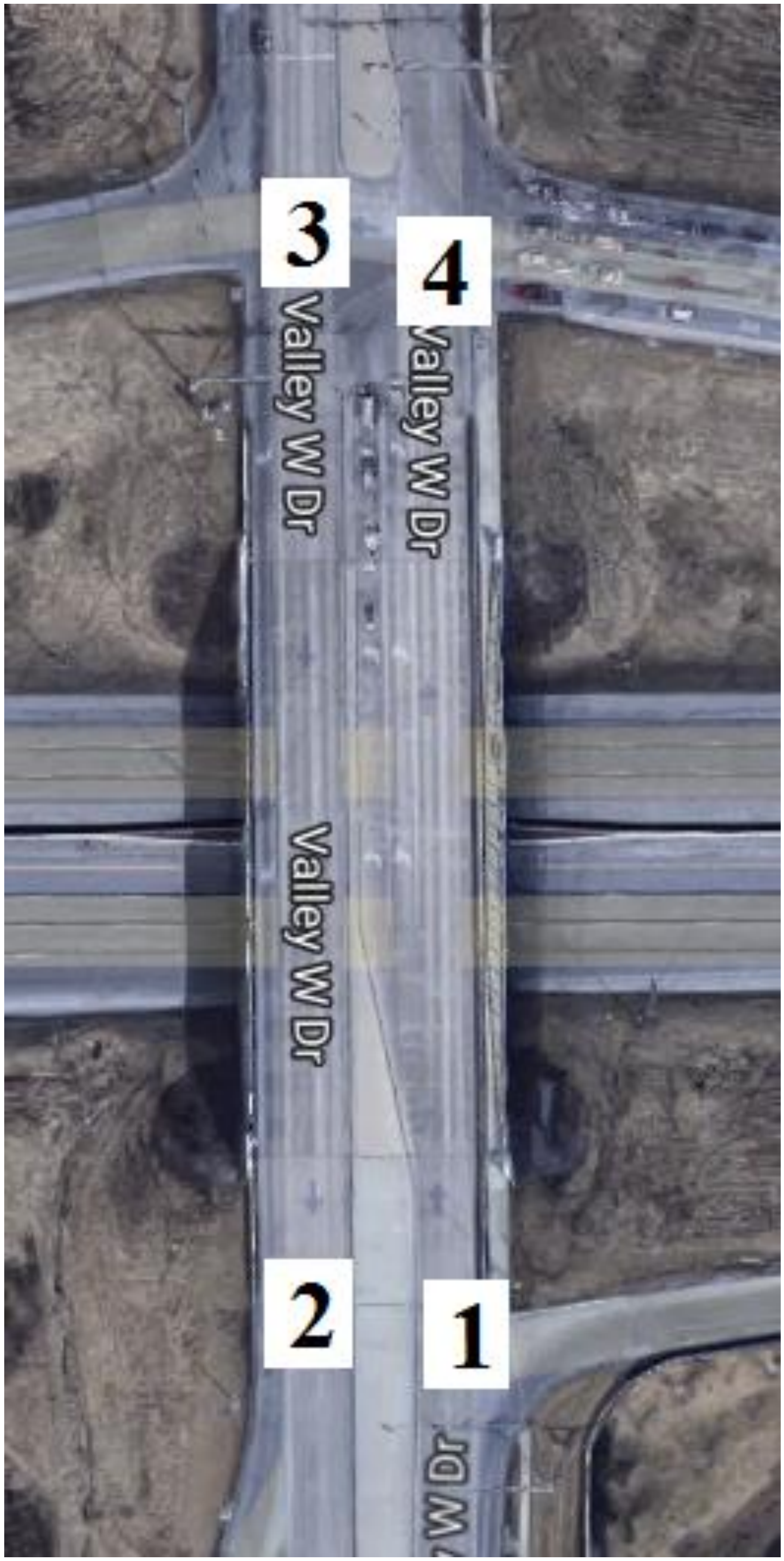


Figure B-116. Bridge No. 7701.3O235 [1]

Figure B-117. Bridge No. 7701.8O235 [1]

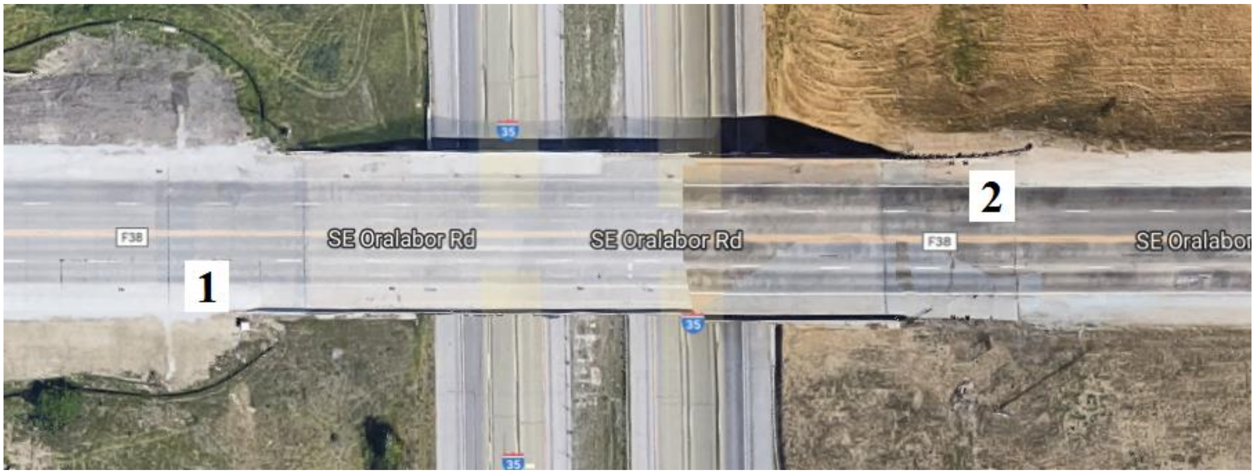


Figure B-118. Bridge No. 7702.4S160 [1]

Figure B-119. Bridge No. 7704.4O235 [1]

Figure B-120. Bridge Nos. 7705.0O235 and 7705.1O235 [1]

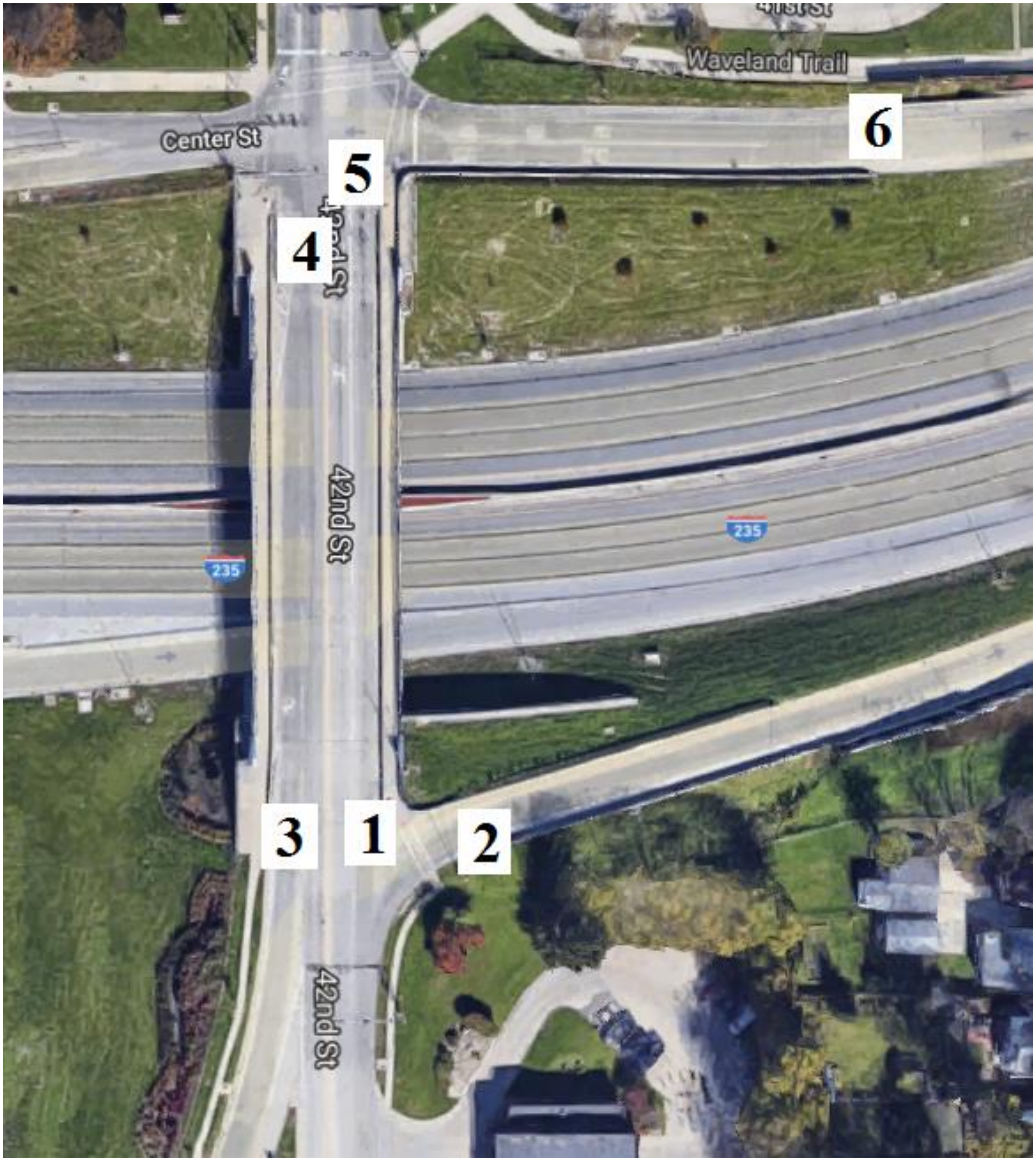


Figure B-121. Bridge No. 7705.4O235 [1]

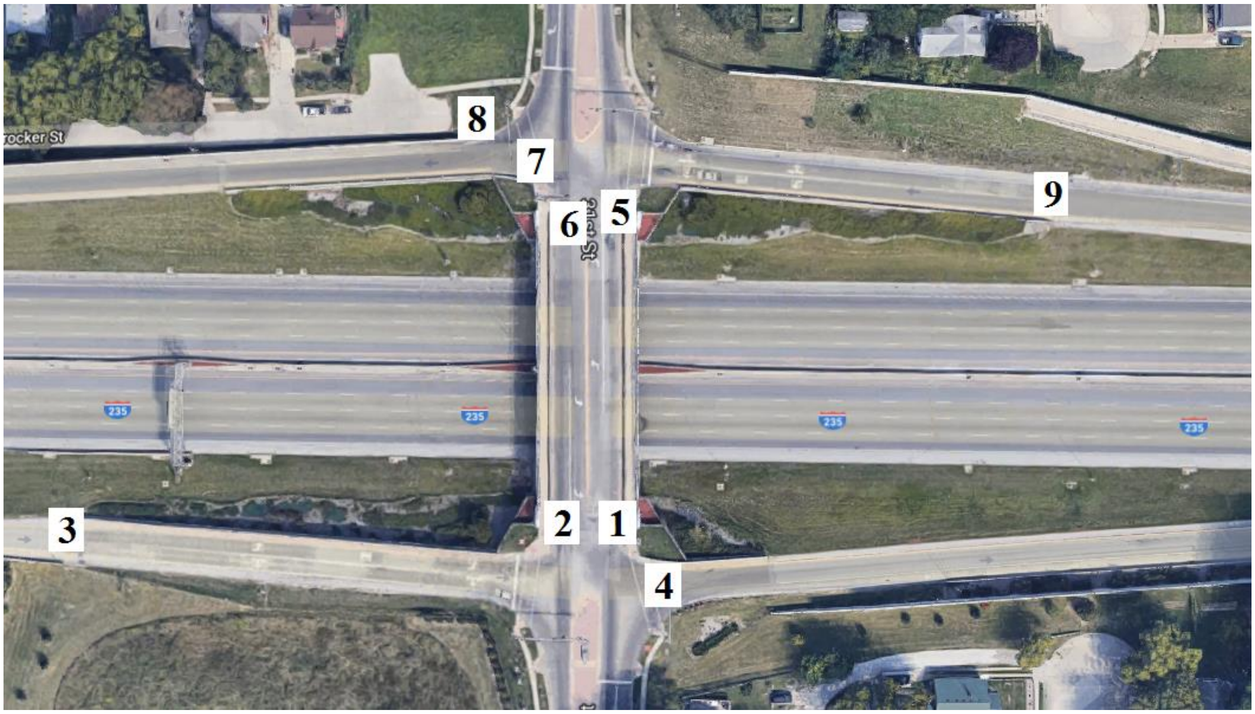


Figure B-122. Bridge No. 7706.2O235 [1]

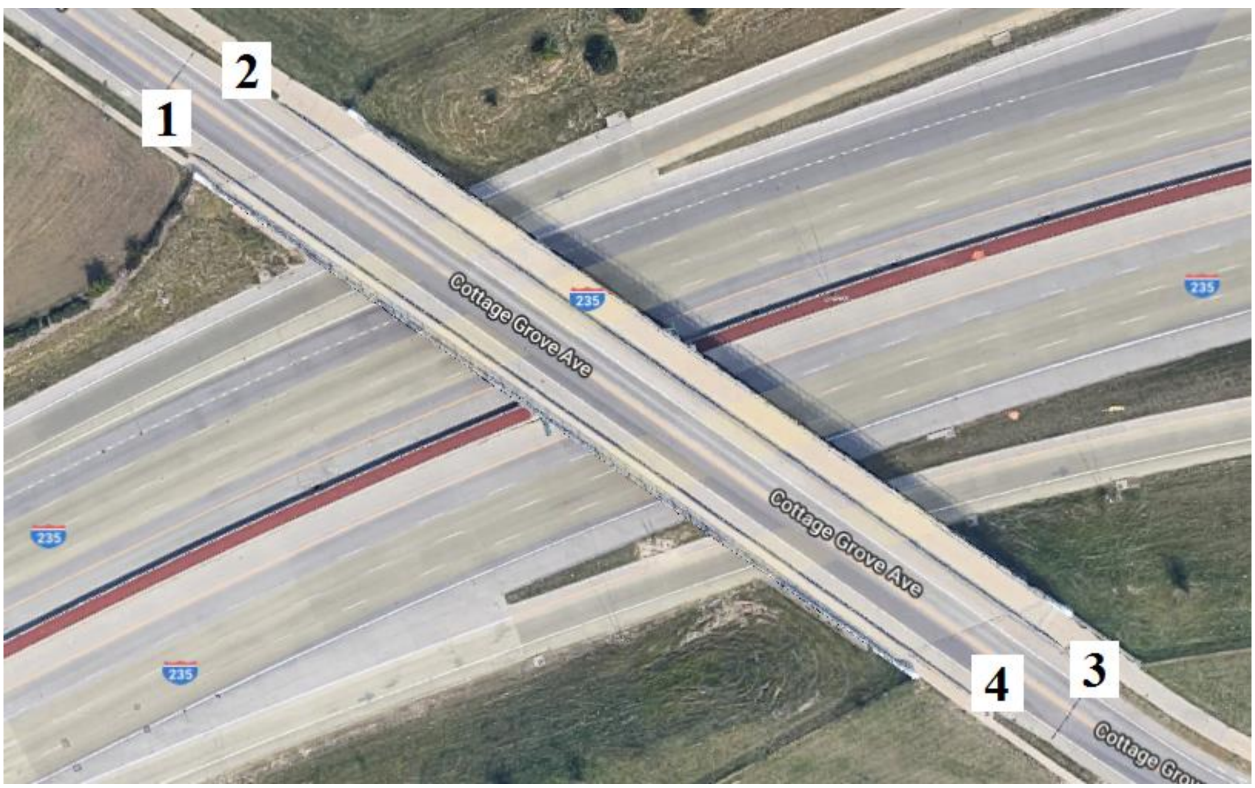


Figure B-123. Bridge No. 7706.9O235 [1]

Figure B-124. Bridge No. 7707.1O235 [1]

Figure B-125. Bridge No. 7707.2O235 [1]

Figure B-126. Bridge No. 7707.9O235 [1]

Figure B-127. Bridge No. 7708.0O235 [1]

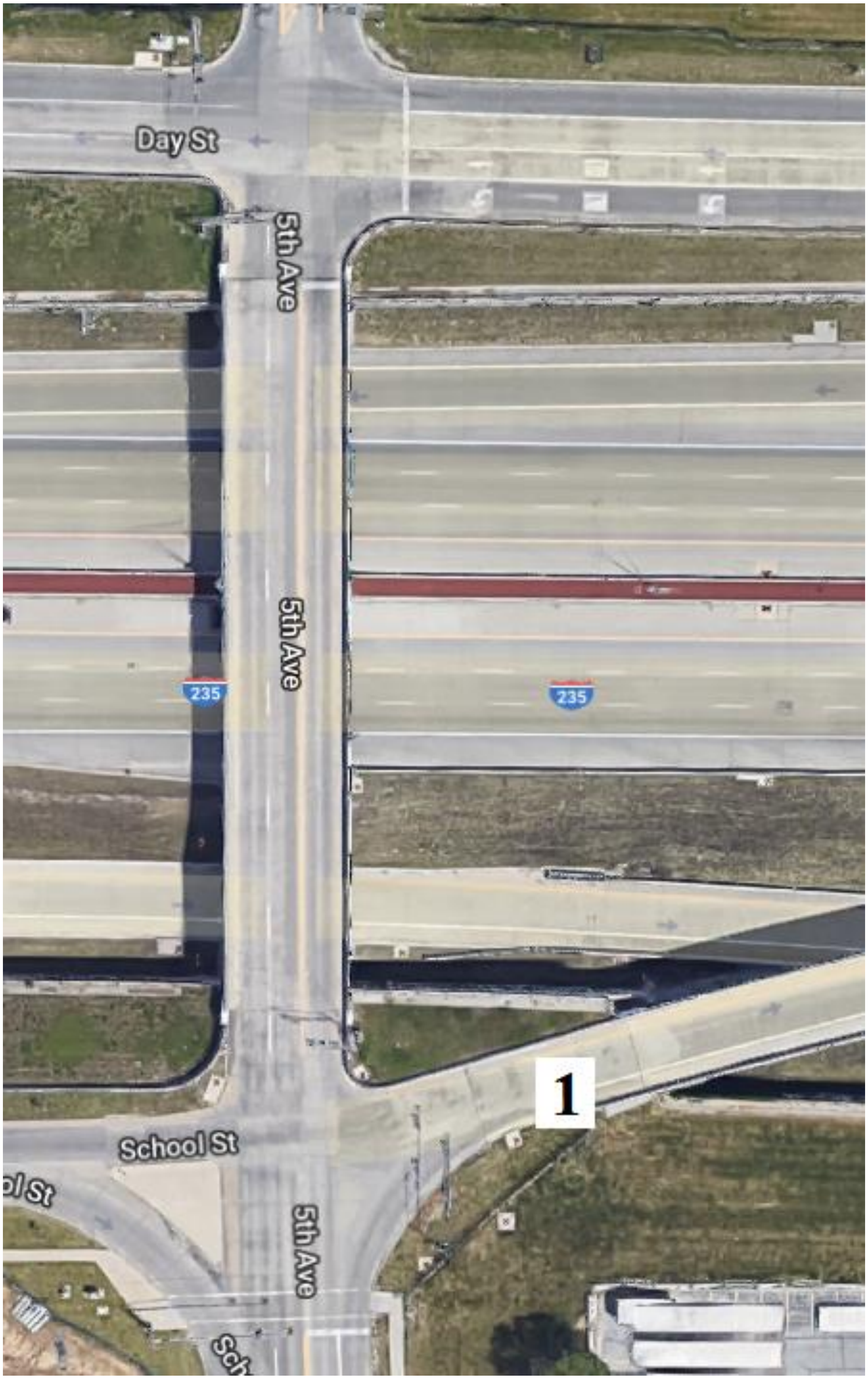


Figure B-128. Bridge No. 7708.1A235 [1]

Figure B-129. Bridge No. 7708.2O235 [1]

Figure B-130. Bridge No. 7708.3O235 [1]

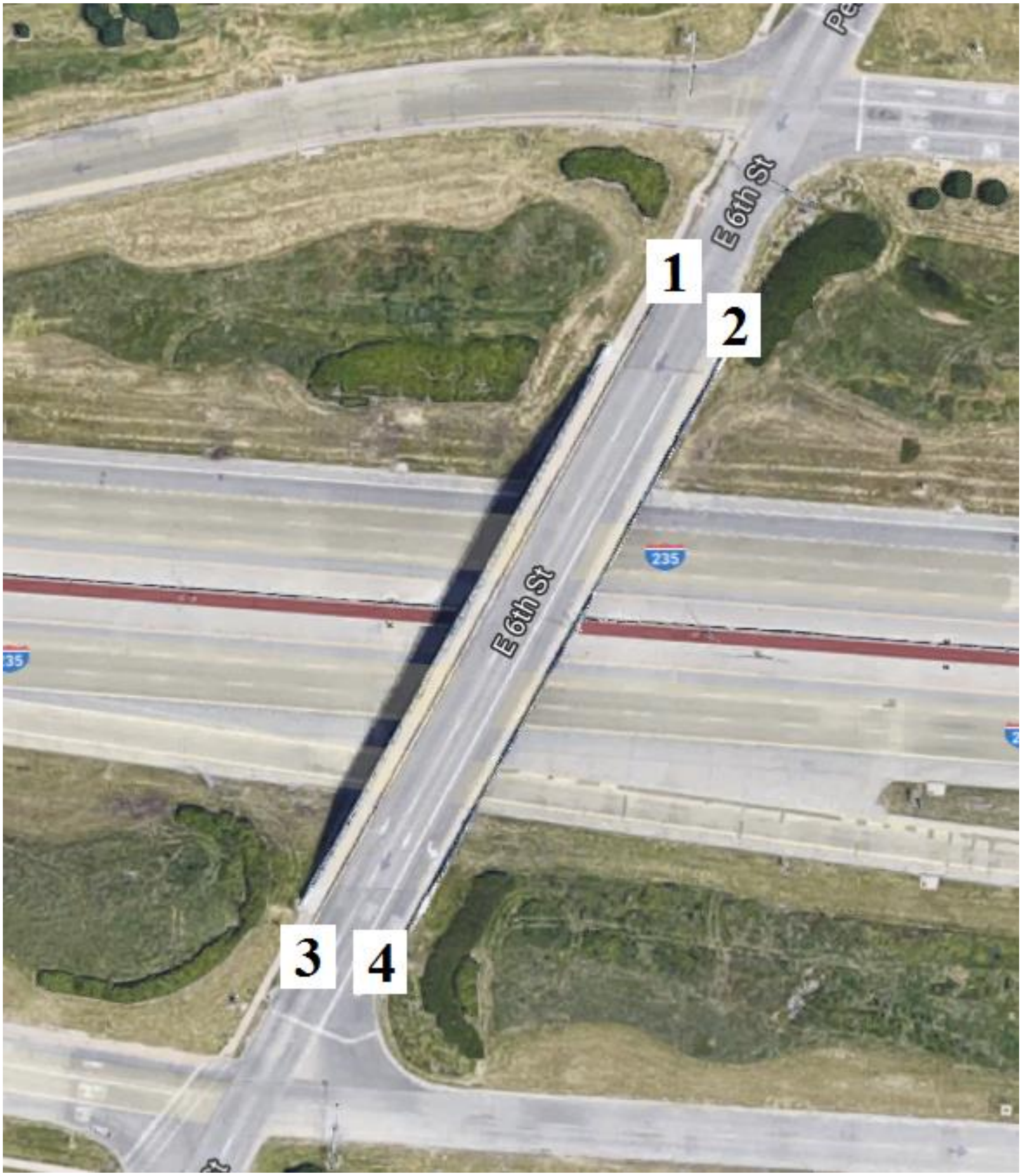


Figure B-131. Bridge No. 7708.8O235 [1]

Figure B-132. Bridge No. 7708.9O235 [1]

Figure B-133. Bridge No. 7709.0O235 [1]

Figure B-134. Bridge No. 7709.1O235 [1]

Figure B-135. Bridge No. 7710.0A235 [1]

Figure B-136. Bridge No. 7717.8S028 [1]

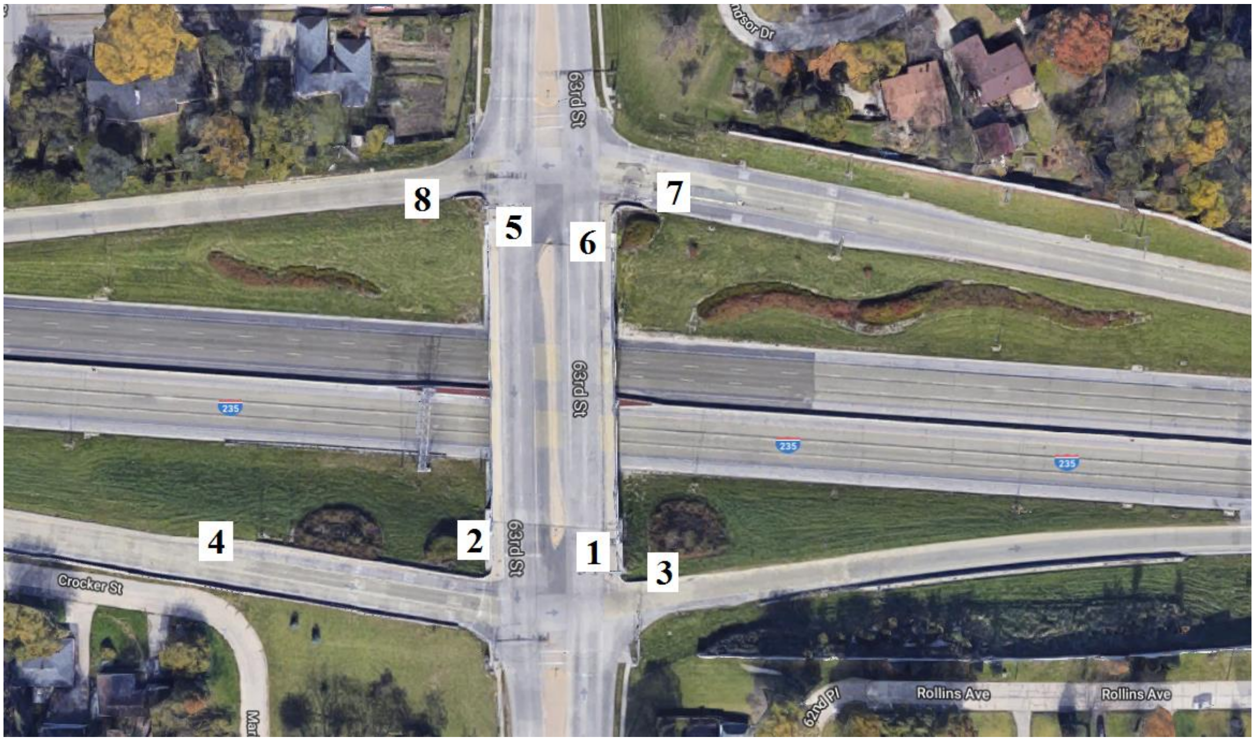


Figure B-137. Bridge No. 7718.3S028 [1]

Figure B-138. Bridge No. 7722.4O080 [1]

Figure B-139. Bridge No. 7723.8O080 [1]

Figure B-140. Bridge No. 7724.1O080 [1]

Figure B-141. Bridge No. 7726.1O080 [1]

Figure B-142. Bridge No. 7727.1O080 [1]

Figure B-143. Bridge No. 7735.4S006 [1]

Figure B-144. Bridge No. 7738.9S006 [1]

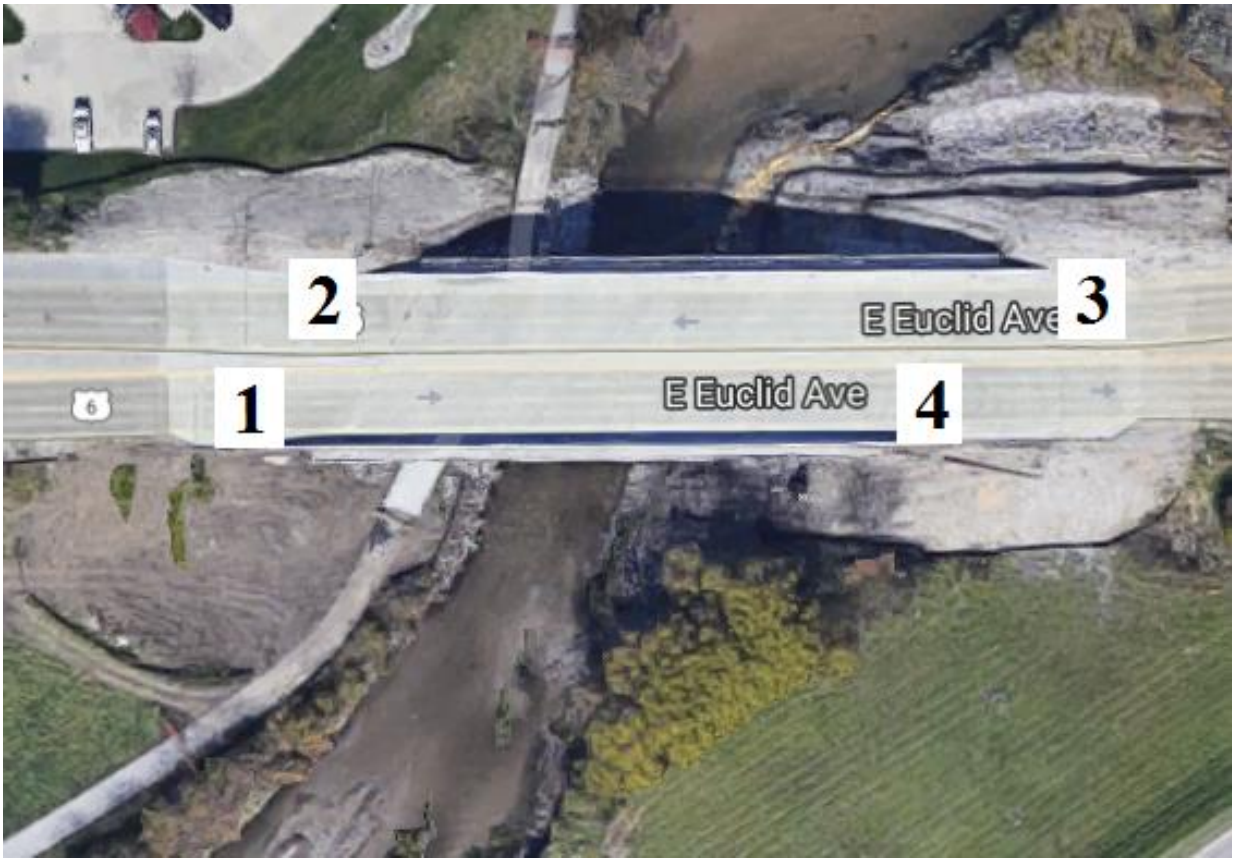


Figure B-145. Bridge No. 7740.2S006 [1]

Figure B-146. Bridge No. 7772.2O035 [1]

Figure B-147. Bridge No. 7785.5S069 [1]

Figure B-148. Bridge No. 7801.7O080 [1]

Figure B-149. Bridge No. 7815.0S083 [1]

Figure B-150. Bridge No. 8100.3S607 [1]

Figure B-151. Bridge No. 8203.8O074 [1]

Figure B-152. Bridge No. 8204.9S006 [1]

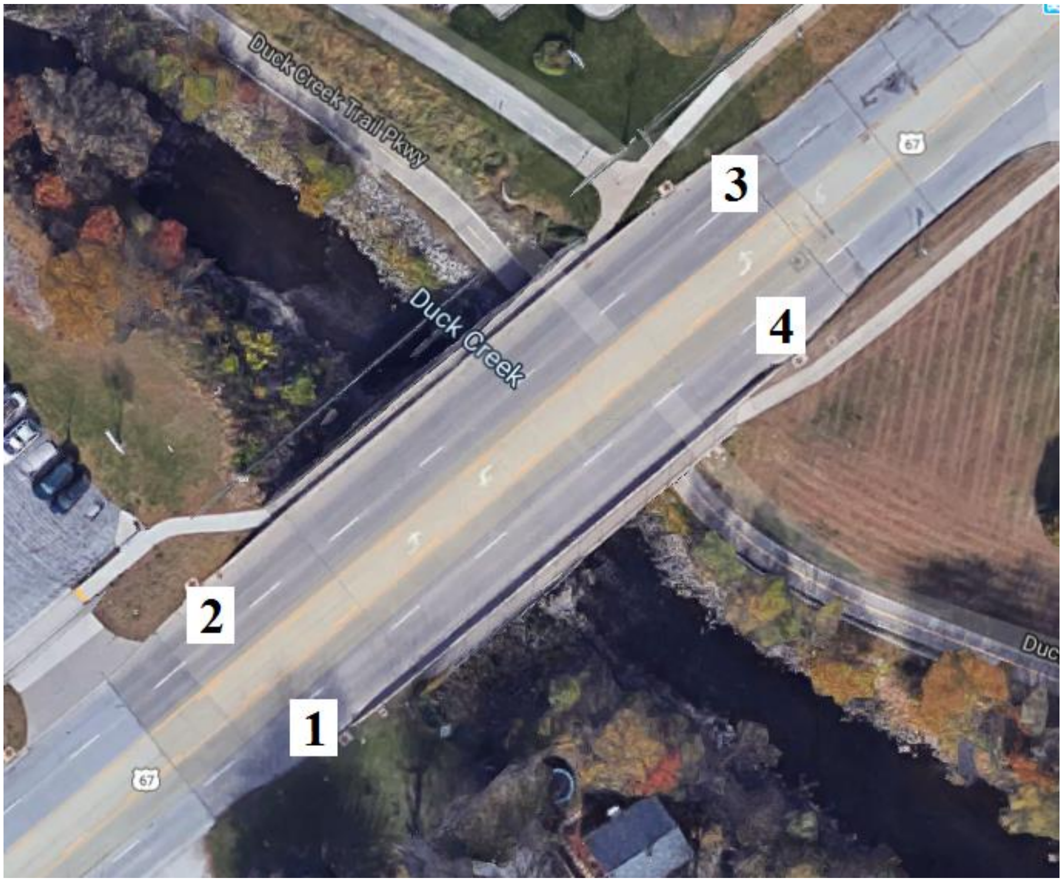


Figure B-153. Bridge No. 8206.5S067 [1]

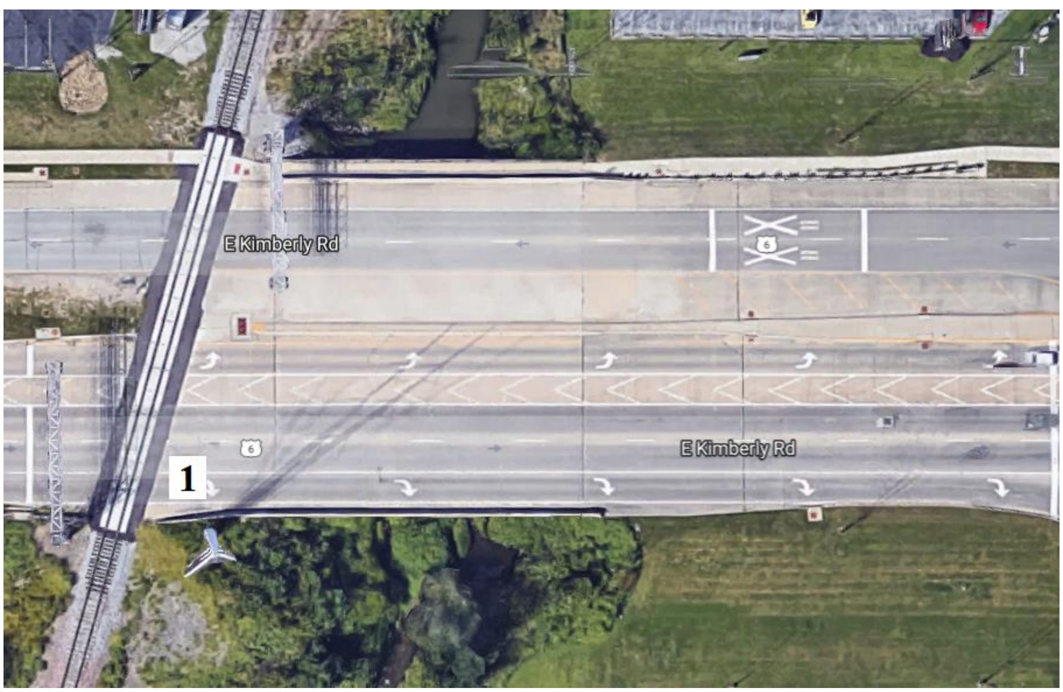


Figure B-154. Bridge No. 8208.0R006 [1]

Figure B-155. Bridge No. 8220.1L061 [1]

Figure B-156. Bridge No. 8220.1R061 [1]

Figure B-157. Bridge No. 8336.8S037 [1]

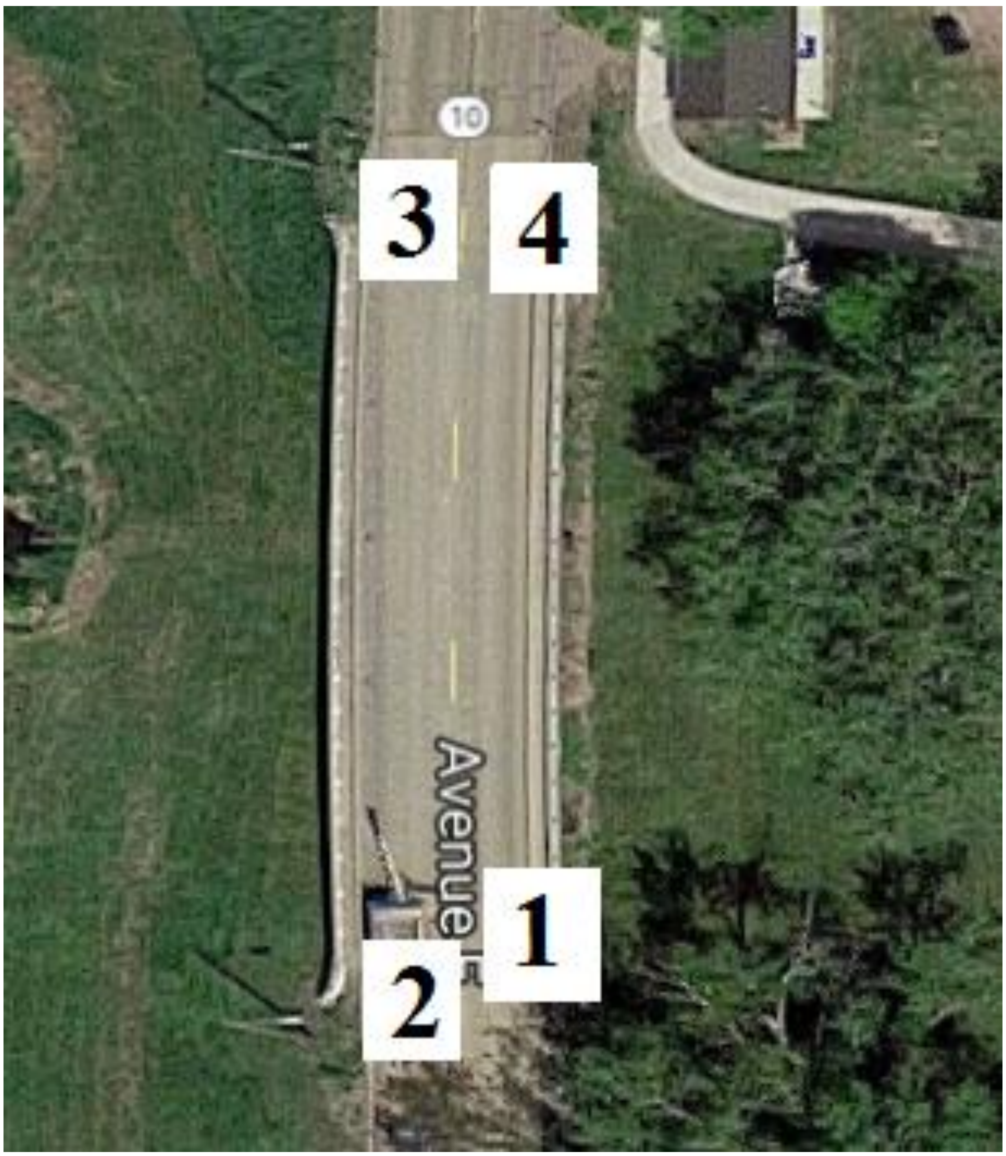


Figure B-158. Bridge No. 8403.4S010 [1]

Figure B-159. Bridge No. 8514.8S069 [1]

Figure B-160. Bridge No. 8516.1O069 [1]

Figure B-161. Bridge Nos. 8544.7O030 and 8544.8O030 [1]

Figure B-162. Bridge No. 8557.9O030 [1]

Figure B-163. Bridge No. 8558.4O030 [1]

Figure B-164. Bridge No. 8600.5S008 [1]

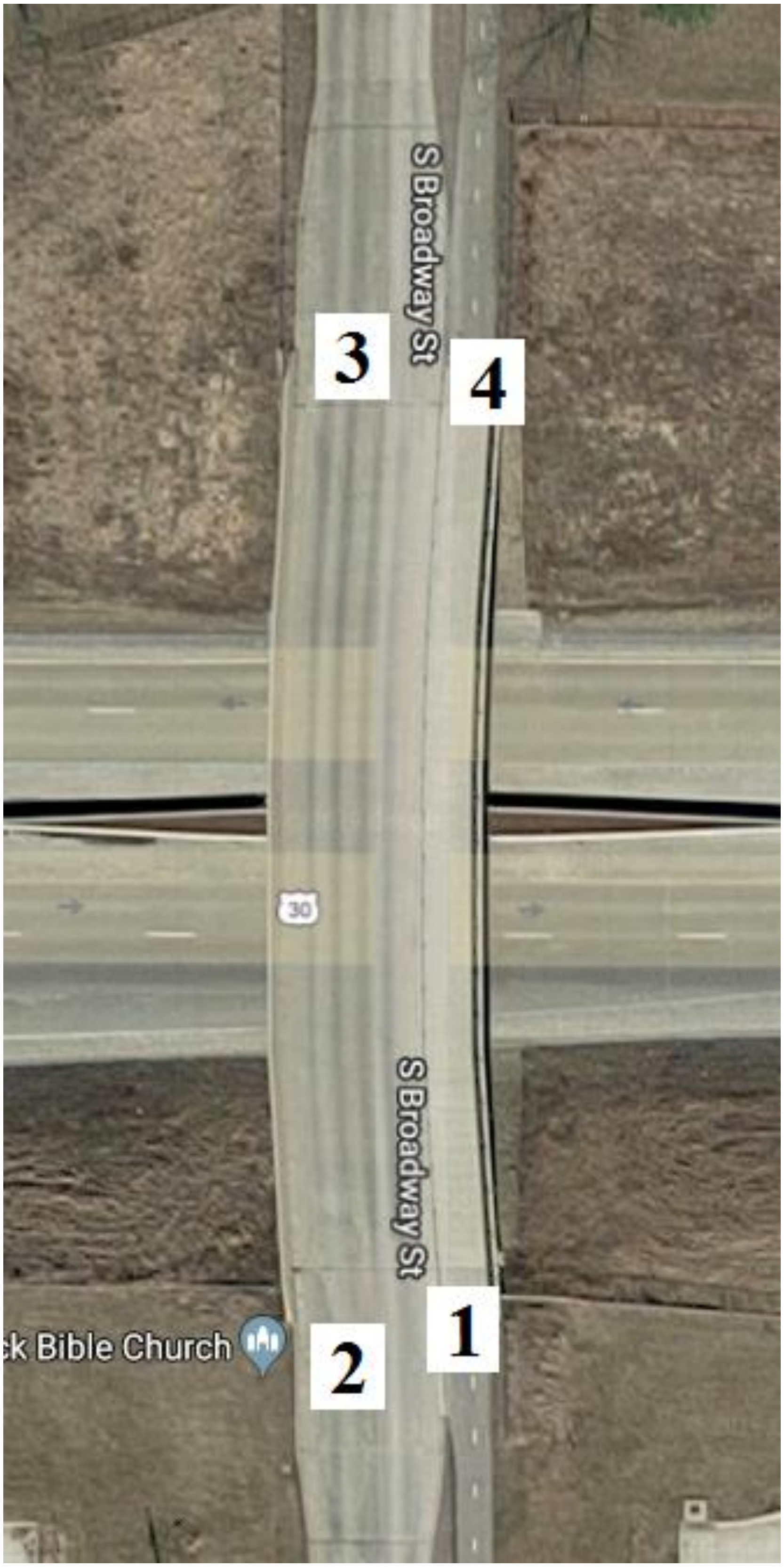


Figure B-165. Bridge No. 8603.0O030 [1]

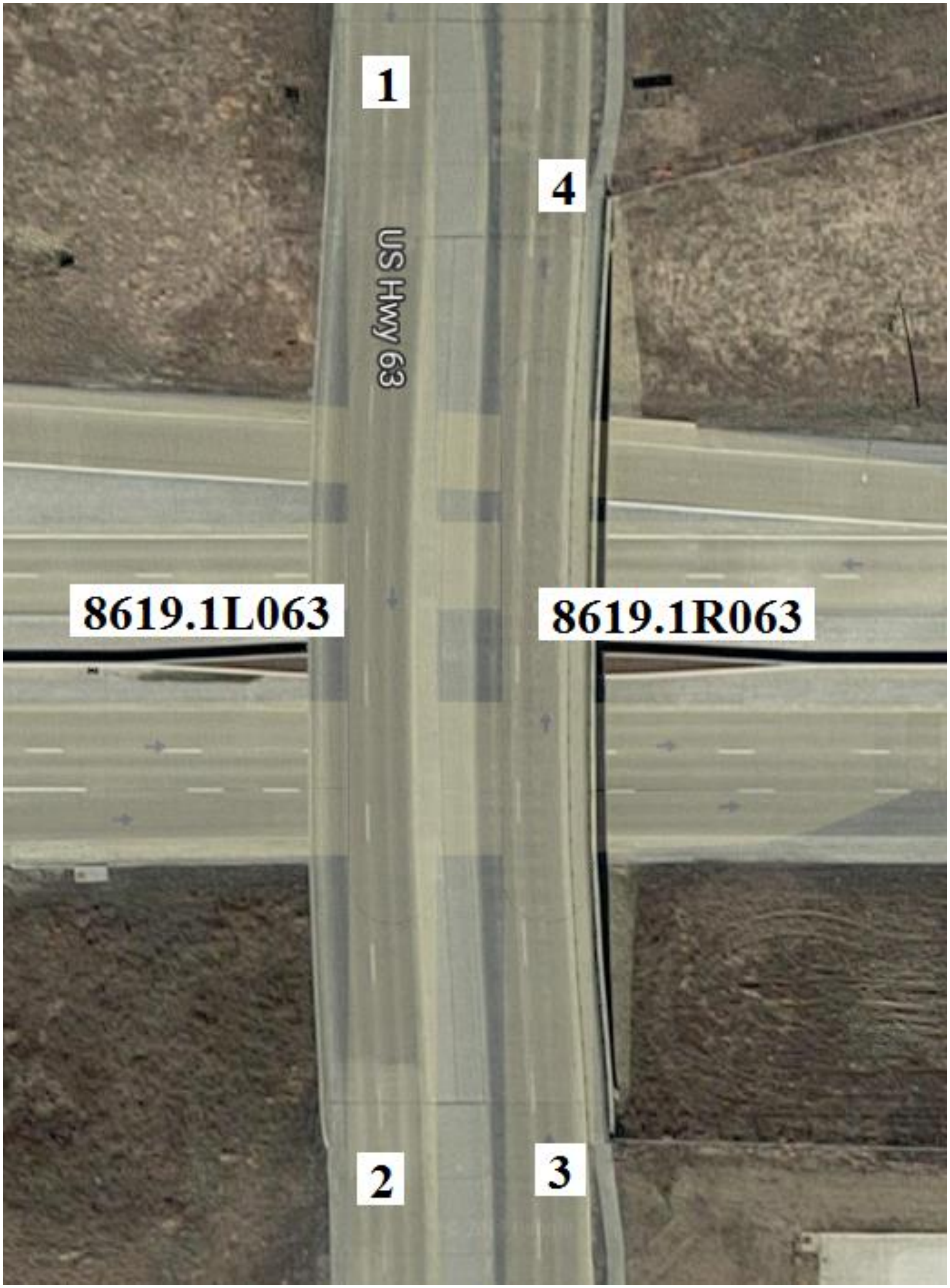


Figure B-166. Bridge Nos. 8619.1L063 and 8619.1R063 [1]

Figure B-167. Bridge No. 8840.0S169 [1]

Figure B-168. Bridge No. 8903.8S001 [1]

Figure B-169. Bridge No. 9001.4O149 [1]

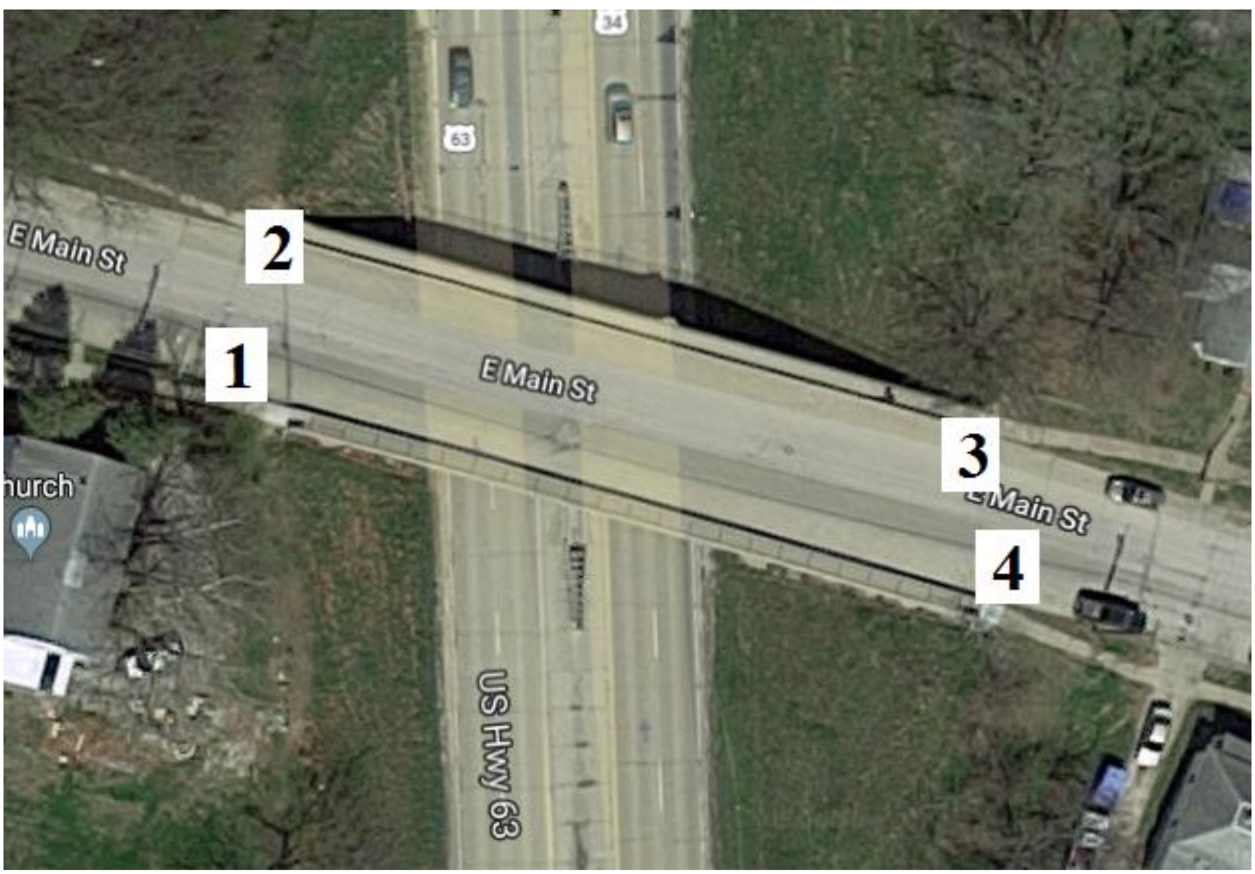


Figure B-170. Bridge No. 9091.2O034 [1]

Figure B-171. Bridge No. 9200.4S612 [1]

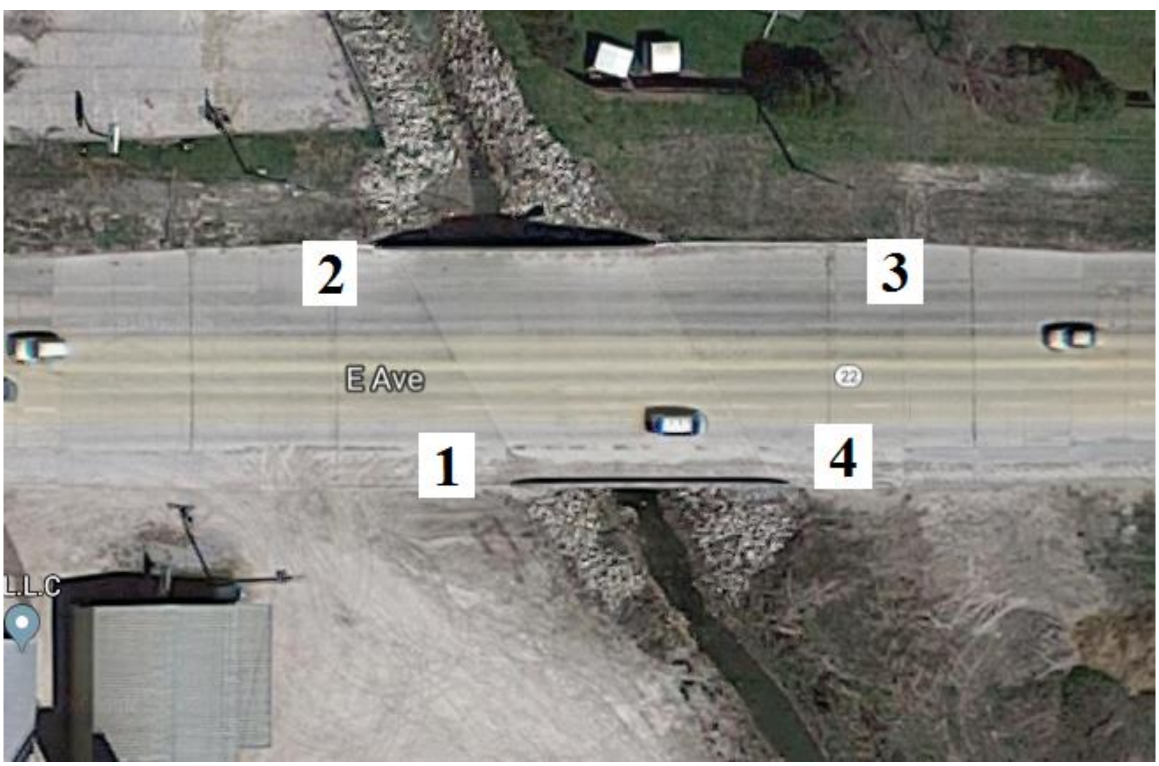


Figure B-172. Bridge No. 9235.4S022 [1]

Figure B-173. Bridge No. 9401.3L926 [1]

Figure B-174. Bridge Nos. 9401.5L926 and 9401.5R926 [1]

Figure B-175. Bridge No. 9505.0S069 [1]

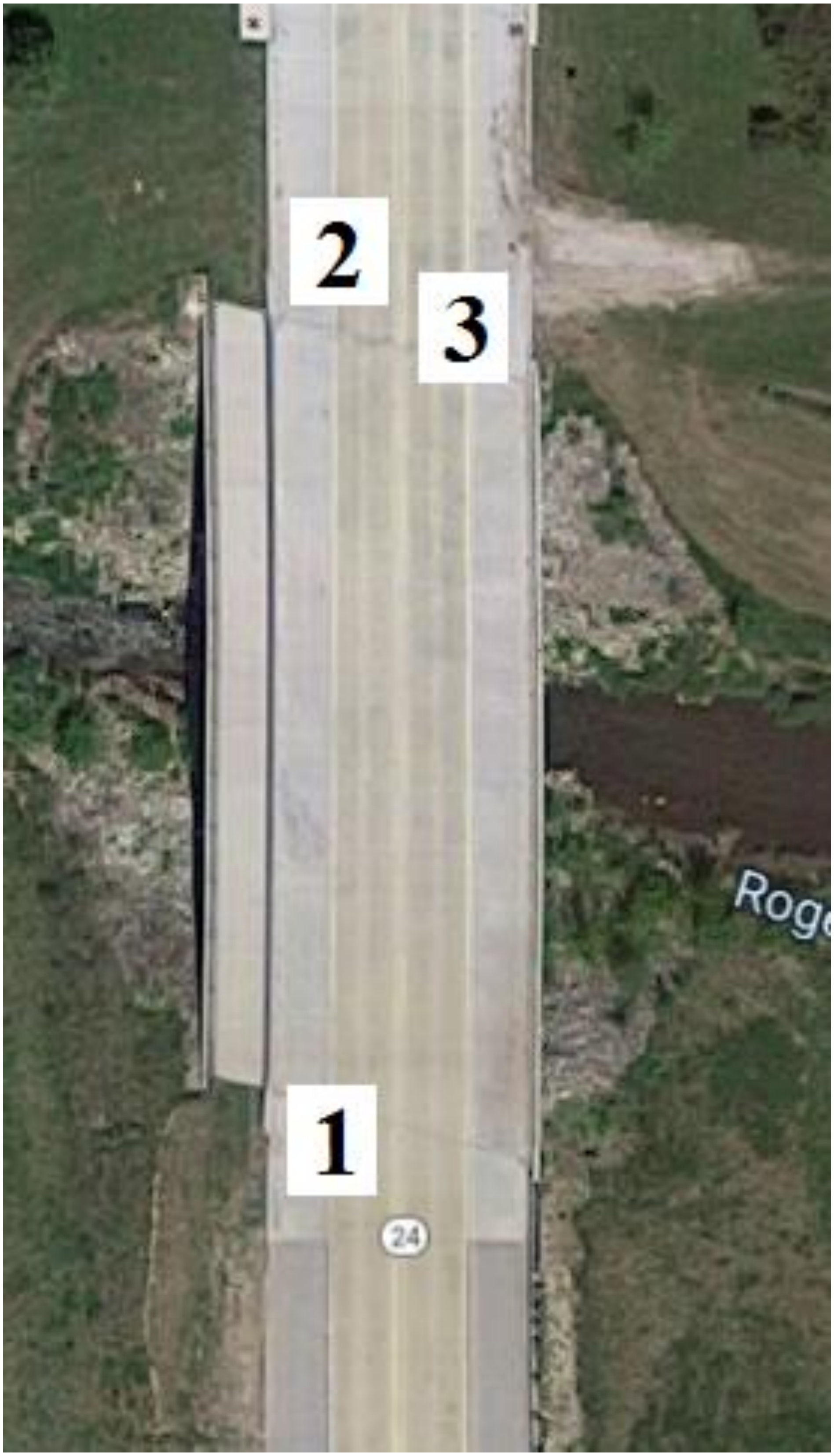


Figure B-176. Bridge No. 9621.3S024 [1]

Figure B-177. Bridge No. 9700.1S031 [1]

Figure B-178. Bridge Nos. 9700.2S077 and 9700.3S077[1]

Figure B-179. Bridge No. 9701.8O020 [1]

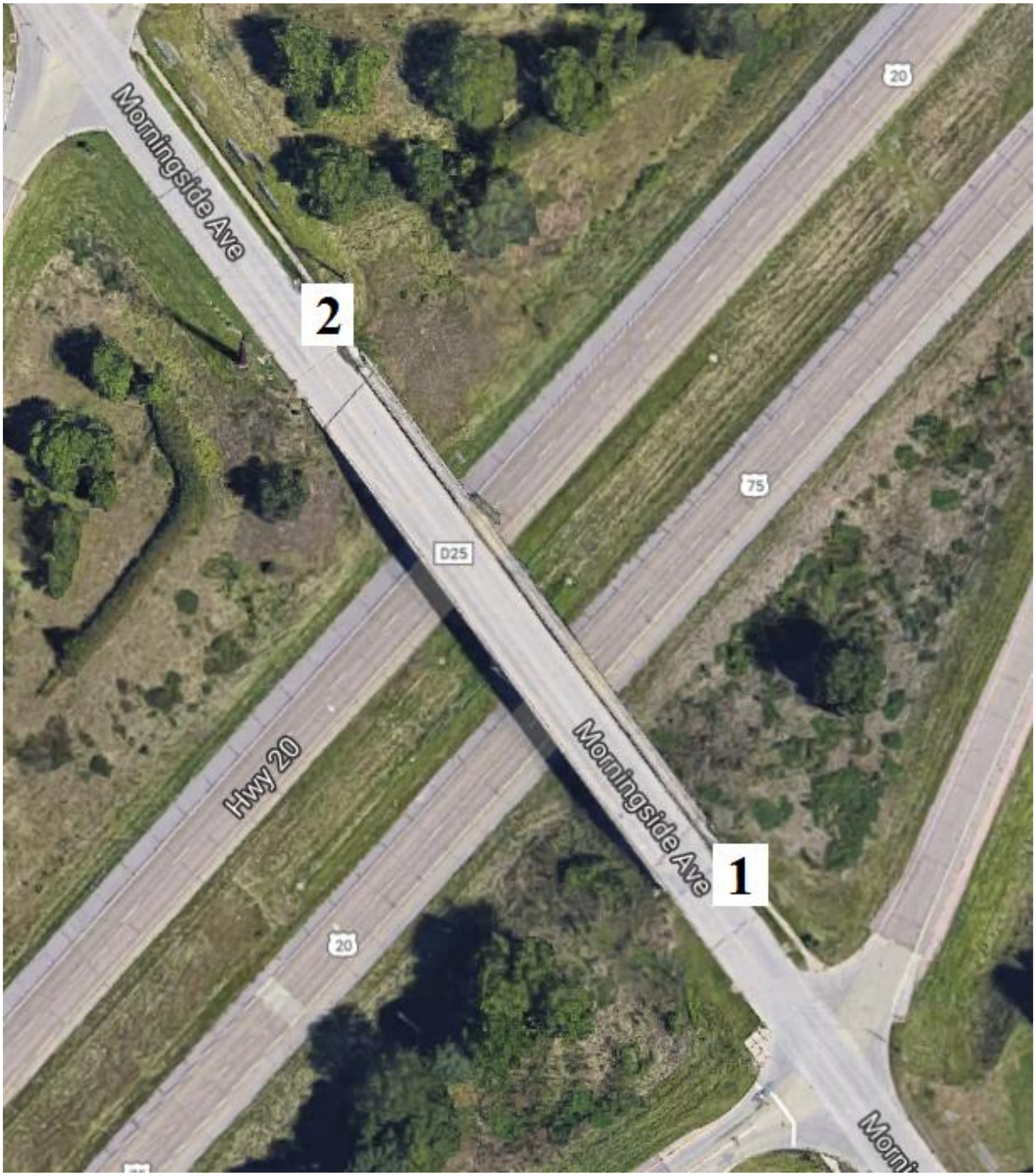


Figure B-180. Bridge No. 9703.4O020 [1]

Figure B-181. Bridge No. 9704.6S012 [1]

Figure B-182. Bridge No. 9708.1S012 [1]

Figure B-183. Bridge No. 9741.2O029 [1]

Appendix C. Exposure Calculations

Exposure calculations are shown in Tables E-1 through E-27 for the 183 identified bridges which feature sloped end treatments. The total exposure for each sloped end treatment configuration and the overall total exposure is shown in Table C-28.

Table C-1. Exposure Calculations – Four Treatments, Two-Way Traffic

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
0728.0O020	1	3,640	0.5	0.5	3,653	3,324,230
	2	3,640	0.5	0.5	3,653	3,324,230
	3	3,640	0.5	0.5	3,653	3,324,230
	4	3,640	0.5	0.5	3,653	3,324,230
	Total					13,296,920
0729.0O020	1	5,600	0.5	0.5	3,653	5,114,200
	2	5,600	0.5	0.5	3,653	5,114,200
	3	5,600	0.5	0.5	3,653	5,114,200
	4	5,600	0.5	0.5	3,653	5,114,200
	Total					20,456,800
0730.0O020	1	7,100	0.5	0.5	3,653	6,484,075
	2	7,100	0.5	0.5	3,653	6,484,075
	3	7,100	0.5	0.5	3,653	6,484,075
	4	7,100	0.5	0.5	3,653	6,484,075
	Total					25,936,300
0731.0O020	1	3,990	0.5	0.5	3,653	3,643,868
	2	3,990	0.5	0.5	3,653	3,643,868
	3	3,990	0.5	0.5	3,653	3,643,868
	4	3,990	0.5	0.5	3,653	3,643,868
	Total					14,575,470
0995.4O218	1	2,220	0.5	0.5	3,653	2,027,415
	2	2,220	0.5	0.5	3,653	2,027,415
	3	2,220	0.5	0.5	3,653	2,027,415
	4	2,220	0.5	0.5	3,653	2,027,415
	Total					8,109,660
1023.9S281	1	3,490	0.5	0.5	3,653	3,187,243
	2	3,490	0.5	0.5	3,653	3,187,243
	3	3,490	0.5	0.5	3,653	3,187,243
	4	3,490	0.5	0.5	3,653	3,187,243
	Total					12,748,970
1246.8S014	1	1,360	0.5	0.5	3,653	1,242,020
	2	1,360	0.5	0.5	3,653	1,242,020
	3	1,360	0.5	0.5	3,653	1,242,020
	4	1,360	0.5	0.5	3,653	1,242,020
	Total					4,968,080

Table C-2. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
1477.0S141	1	2,840	0.5	0.5	3,653	2,593,630
	2	2,840	0.5	0.5	3,653	2,593,630
	3	2,840	0.5	0.5	3,653	2,593,630
	4	2,840	0.5	0.5	3,653	2,593,630
	Total					10,374,520
1542.6S048	1	1,440	0.5	0.5	3,653	1,315,080
	2	1,440	0.5	0.5	3,653	1,315,080
	3	1,440	0.5	0.5	3,653	1,315,080
	4	1,440	0.5	0.5	3,653	1,315,080
	Total					5,260,320
1654.6O080	1	4,210	0.5	0.5	3,653	3,844,783
	2	4,210	0.5	0.5	3,653	3,844,783
	3	4,210	0.5	0.5	3,653	3,844,783
	4	4,210	0.5	0.5	3,653	3,844,783
	Total					15,379,130
1710.2S122	1	6,800	0.5	0.5	3,653	6,210,100
	2	6,800	0.5	0.5	3,653	6,210,100
	3	6,800	0.5	0.5	3,653	6,210,100
	4	6,800	0.5	0.5	3,653	6,210,100
	Total					24,840,400
1858.8S059	1	5,300	0.5	0.5	3,653	4,840,225
	2	5,300	0.5	0.5	3,653	4,840,225
	3	5,300	0.5	0.5	3,653	4,840,225
	4	5,300	0.5	0.5	3,653	4,840,225
	Total					19,360,900
1859.0S059	1	5,300	0.5	0.5	3,653	4,840,225
	2	5,300	0.5	0.5	3,653	4,840,225
	3	5,300	0.5	0.5	3,653	4,840,225
	4	5,300	0.5	0.5	3,653	4,840,225
	Total					19,360,900
2181.0S018	1	15,500	0.5	0.5	3,653	14,155,375
	2	15,500	0.5	0.5	3,653	14,155,375
	3	15,500	0.5	0.5	3,653	14,155,375
	4	15,500	0.5	0.5	3,653	14,155,375
	Total					56,621,500

Table C-3. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
2204.5S076	1	4,160	0.5	0.5	3,653	3,799,120
	2	4,160	0.5	0.5	3,653	3,799,120
	3	4,160	0.5	0.5	3,653	3,799,120
	4	4,160	0.5	0.5	3,653	3,799,120
	Total					15,196,480
2318.8S136	1	1,130	0.5	0.5	3,653	1,031,973
	2	1,130	0.5	0.5	3,653	1,031,973
	3	1,130	0.5	0.5	3,653	1,031,973
	4	1,130	0.5	0.5	3,653	1,031,973
	Total					4,127,890
2521.4O080	1	37,300	0.5	0.5	3,653	34,064,225
	2	37,300	0.5	0.5	3,653	34,064,225
	3	37,300	0.5	0.5	3,653	34,064,225
	4	37,300	0.5	0.5	3,653	34,064,225
	Total					136,256,900
2841.6S013	1	10,300	0.5	0.5	3,653	9,406,475
	2	10,300	0.5	0.5	3,653	9,406,475
	3	10,300	0.5	0.5	3,653	9,406,475
	4	10,300	0.5	0.5	3,653	9,406,475
	Total					37,625,900
2942.2L061	1	13,100	0.5	0.5	3,653	11,963,575
	2	13,100	0.5	0.5	3,653	11,963,575
	3	13,100	0.5	0.5	3,653	11,963,575
	4	13,100	0.5	0.5	3,653	11,963,575
	Total					47,854,300
2962.0O034	1	6,600	0.5	0.5	3,653	6,027,450
	2	6,600	0.5	0.5	3,653	6,027,450
	3	6,600	0.5	0.5	3,653	6,027,450
	4	6,600	0.5	0.5	3,653	6,027,450
	Total					24,109,800
2963.0O034	1	1,960	0.5	0.5	3,653	1,789,970
	2	1,960	0.5	0.5	3,653	1,789,970
	3	1,960	0.5	0.5	3,653	1,789,970
	4	1,960	0.5	0.5	3,653	1,789,970
	Total					7,159,880

Table C-4. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
2963.2O034	1	930	0.5	0.5	3,653	849,323
	2	930	0.5	0.5	3,653	849,323
	3	930	0.5	0.5	3,653	849,323
	4	930	0.5	0.5	3,653	849,323
	Total					3,397,290
2963.3O034	1	1,510	0.5	0.5	3,653	1,379,008
	2	1,510	0.5	0.5	3,653	1,379,008
	3	1,510	0.5	0.5	3,653	1,379,008
	4	1,510	0.5	0.5	3,653	1,379,008
	Total					5,516,030
3026.6S071	1	7,900	0.5	0.5	3,653	7,214,675
	2	7,900	0.5	0.5	3,653	7,214,675
	3	7,900	0.5	0.5	3,653	7,214,675
	4	7,900	0.5	0.5	3,653	7,214,675
	Total					28,858,700
3118.4O020	1	4,340	0.5	0.5	3,653	3,963,505
	2	4,340	0.5	0.5	3,653	3,963,505
	3	4,340	0.5	0.5	3,653	3,963,505
	4	4,340	0.5	0.5	3,653	3,963,505
	Total					15,854,020
3118.5O020	1	11,000	0.5	0.5	3,653	10,045,750
	2	11,000	0.5	0.5	3,653	10,045,750
	3	11,000	0.5	0.5	3,653	10,045,750
	4	11,000	0.5	0.5	3,653	10,045,750
	Total					40,183,000
3119.0O020	1	7,000	0.5	0.5	3,653	6,392,750
	2	7,000	0.5	0.5	3,653	6,392,750
	3	7,000	0.5	0.5	3,653	6,392,750
	4	7,000	0.5	0.5	3,653	6,392,750
	Total					25,571,000
3146.6O052	1	4,250	0.5	0.5	3,653	3,881,313
	2	4,250	0.5	0.5	3,653	3,881,313
	3	4,250	0.5	0.5	3,653	3,881,313
	4	4,250	0.5	0.5	3,653	3,881,313
	Total					15,525,250

Table C-5. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
3150.7A052	1	50	0.5	0.5	3,653	45,663
	2	50	0.5	0.5	3,653	45,663
	3	50	0.5	0.5	3,653	45,663
	4	50	0.5	0.5	3,653	45,663
	Total					182,650
3182.0S136	1	2,480	0.5	0.5	3,653	2,264,860
	2	2,480	0.5	0.5	3,653	2,264,860
	3	2,480	0.5	0.5	3,653	2,264,860
	4	2,480	0.5	0.5	3,653	2,264,860
	Total					9,059,440
3288.1S009	1	8,500	0.5	0.5	3,653	7,762,625
	2	8,500	0.5	0.5	3,653	7,762,625
	3	8,500	0.5	0.5	3,653	7,762,625
	4	8,500	0.5	0.5	3,653	7,762,625
	Total					31,050,500
3364.6S150	1	1,600	0.5	0.5	3,653	1,461,200
	2	1,600	0.5	0.5	3,653	1,461,200
	3	1,600	0.5	0.5	3,653	1,461,200
	4	1,600	0.5	0.5	3,653	1,461,200
	Total					5,844,800
3372.6S018	1	2,700	0.5	0.5	3,653	2,465,775
	2	2,700	0.5	0.5	3,653	2,465,775
	3	2,700	0.5	0.5	3,653	2,465,775
	4	2,700	0.5	0.5	3,653	2,465,775
	Total					9,863,100
3412.7S018	1	11,700	0.5	0.5	3,653	10,685,025
	2	11,700	0.5	0.5	3,653	10,685,025
	3	11,700	0.5	0.5	3,653	10,685,025
	4	11,700	0.5	0.5	3,653	10,685,025
	Total					42,740,100
3568.3S065	1	5,500	0.5	0.5	3,653	5,022,875
	2	5,500	0.5	0.5	3,653	5,022,875
	3	5,500	0.5	0.5	3,653	5,022,875
	4	5,500	0.5	0.5	3,653	5,022,875
	Total					20,091,500

Table C-6. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
3712.2S025	1	1,130	0.5	0.5	3,653	1,031,973
	2	1,130	0.5	0.5	3,653	1,031,973
	3	1,130	0.5	0.5	3,653	1,031,973
	4	1,130	0.5	0.5	3,653	1,031,973
	Total					4,127,890
3723.0S004	1	6,800	0.5	0.5	3,653	6,210,100
	2	6,800	0.5	0.5	3,653	6,210,100
	3	6,800	0.5	0.5	3,653	6,210,100
	4	6,800	0.5	0.5	3,653	6,210,100
	Total					24,840,400
4055.6S175	1	1,800	0.5	0.5	3,653	1,643,850
	2	1,800	0.5	0.5	3,653	1,643,850
	3	1,800	0.5	0.5	3,653	1,643,850
	4	1,800	0.5	0.5	3,653	1,643,850
	Total					6,575,400
4249.6S065	1	9,400	0.5	0.5	3,653	8,584,550
	2	9,400	0.5	0.5	3,653	8,584,550
	3	9,400	0.5	0.5	3,653	8,584,550
	4	9,400	0.5	0.5	3,653	8,584,550
	Total					34,338,200
4800.2S151	1	2,240	0.5	0.5	3,653	2,045,680
	2	2,240	0.5	0.5	3,653	2,045,680
	3	2,240	0.5	0.5	3,653	2,045,680
	4	2,240	0.5	0.5	3,653	2,045,680
	Total					8,182,720
5007.7S117	1	6,600	0.5	0.5	3,653	6,027,450
	2	6,600	0.5	0.5	3,653	6,027,450
	3	6,600	0.5	0.5	3,653	6,027,450
	4	6,600	0.5	0.5	3,653	6,027,450
	Total					24,109,800
5243.0O080	1	19,000	0.5	0.5	3,653	17,351,750
	2	19,000	0.5	0.5	3,653	17,351,750
	3	19,000	0.5	0.5	3,653	17,351,750
	4	19,000	0.5	0.5	3,653	17,351,750
	Total					69,407,000

Table C-7. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
5245.1O080	1	2,420	0.5	0.5	3,653	2,210,065
	2	2,420	0.5	0.5	3,653	2,210,065
	3	2,420	0.5	0.5	3,653	2,210,065
	4	2,420	0.5	0.5	3,653	2,210,065
	Total					8,840,260
5249.3S006	1	27,200	0.5	0.5	3,653	24,840,400
	2	27,200	0.5	0.5	3,653	24,840,400
	3	27,200	0.5	0.5	3,653	24,840,400
	4	27,200	0.5	0.5	3,653	24,840,400
	Total					99,361,600
5286.5S001	1	14,800	0.5	0.5	3,653	13,516,100
	2	14,800	0.5	0.5	3,653	13,516,100
	3	14,800	0.5	0.5	3,653	13,516,100
	4	14,800	0.5	0.5	3,653	13,516,100
	Total					54,064,400
5287.2R001	1	6,100	0.5	0.5	3,653	5,570,825
	2	6,100	0.5	0.5	3,653	5,570,825
	3	6,100	0.5	0.5	3,653	5,570,825
	4	6,100	0.5	0.5	3,653	5,570,825
	Total					22,283,300
5314.8S064	1	2,340	0.5	0.5	3,653	2,137,005
	2	2,340	0.5	0.5	3,653	2,137,005
	3	2,340	0.5	0.5	3,653	2,137,005
	4	2,340	0.5	0.5	3,653	2,137,005
	Total					8,548,020
5342.8S038	1	1,650	0.5	0.5	3,653	1,506,863
	2	1,650	0.5	0.5	3,653	1,506,863
	3	1,650	0.5	0.5	3,653	1,506,863
	4	1,650	0.5	0.5	3,653	1,506,863
	Total					6,027,450
5363.6S038	1	3,240	0.5	0.5	3,653	2,958,930
	2	3,240	0.5	0.5	3,653	2,958,930
	3	3,240	0.5	0.5	3,653	2,958,930
	4	3,240	0.5	0.5	3,653	2,958,930
	Total					11,835,720

Table C-8. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
5598.7S169	1	8,700	0.5	0.5	3,653	7,945,275
	2	8,700	0.5	0.5	3,653	7,945,275
	3	8,700	0.5	0.5	3,653	7,945,275
	4	8,700	0.5	0.5	3,653	7,945,275
	Total					31,781,100
5602.4S136	1	4,120	0.5	0.5	3,653	3,762,590
	2	4,120	0.5	0.5	3,653	3,762,590
	3	4,120	0.5	0.5	3,653	3,762,590
	4	4,120	0.5	0.5	3,653	3,762,590
	Total					15,050,360
5718.4O380	1	15,000	0.5	0.5	3,653	13,698,750
	2	15,000	0.5	0.5	3,653	13,698,750
	3	15,000	0.5	0.5	3,653	13,698,750
	4	15,000	0.5	0.5	3,653	13,698,750
	Total					54,795,000
5724.4O380	1	28,200	0.5	0.5	3,653	25,753,650
	2	28,200	0.5	0.5	3,653	25,753,650
	3	28,200	0.5	0.5	3,653	25,753,650
	4	28,200	0.5	0.5	3,653	25,753,650
	Total					103,014,600
5724.7O380	1	4,190	0.5	0.5	3,653	3,826,518
	2	4,190	0.5	0.5	3,653	3,826,518
	3	4,190	0.5	0.5	3,653	3,826,518
	4	4,190	0.5	0.5	3,653	3,826,518
	Total					15,306,070
5851.3S092	1	3,000	0.5	0.5	3,653	2,739,750
	2	3,000	0.5	0.5	3,653	2,739,750
	3	3,000	0.5	0.5	3,653	2,739,750
	4	3,000	0.5	0.5	3,653	2,739,750
	Total					10,959,000
6020.4S009	1	4,750	0.5	0.5	3,653	4,337,938
	2	4,750	0.5	0.5	3,653	4,337,938
	3	4,750	0.5	0.5	3,653	4,337,938
	4	4,750	0.5	0.5	3,653	4,337,938
	Total					17,351,750

Table C-9. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
6200.9S622	1	230	0.5	0.5	3,653	210,048
	2	230	0.5	0.5	3,653	210,048
	3	230	0.5	0.5	3,653	210,048
	4	230	0.5	0.5	3,653	210,048
	Total					840,190
6276.0S063	1	2,200	0.5	0.5	3,653	2,009,150
	2	2,200	0.5	0.5	3,653	2,009,150
	3	2,200	0.5	0.5	3,653	2,009,150
	4	2,200	0.5	0.5	3,653	2,009,150
	Total					8,036,600
6616.8S009	1	1,770	0.5	0.5	3,653	1,616,453
	2	1,770	0.5	0.5	3,653	1,616,453
	3	1,770	0.5	0.5	3,653	1,616,453
	4	1,770	0.5	0.5	3,653	1,616,453
	Total					6,465,810
6834.5S005	1	7,800	0.5	0.5	3,653	7,123,350
	2	7,800	0.5	0.5	3,653	7,123,350
	3	7,800	0.5	0.5	3,653	7,123,350
	4	7,800	0.5	0.5	3,653	7,123,350
	Total					28,493,400
7078.0A006	1	1,250	0.5	0.5	3,653	1,141,563
	2	1,250	0.5	0.5	3,653	1,141,563
	3	1,250	0.5	0.5	3,653	1,141,563
	4	1,250	0.5	0.5	3,653	1,141,563
	Total					4,566,250
7403.2A018	1	90	0.5	0.5	3,653	82,193
	2	90	0.5	0.5	3,653	82,193
	3	90	0.5	0.5	3,653	82,193
	4	90	0.5	0.5	3,653	82,193
	Total					328,770
7509.3S140	1	1,950	0.5	0.5	3,653	1,780,838
	2	1,950	0.5	0.5	3,653	1,780,838
	3	1,950	0.5	0.5	3,653	1,780,838
	4	1,950	0.5	0.5	3,653	1,780,838
	Total					7,123,350

Table C-10. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
7606.6S015	1	600	0.5	0.5	3,653	547,950
	2	600	0.5	0.5	3,653	547,950
	3	600	0.5	0.5	3,653	547,950
	4	600	0.5	0.5	3,653	547,950
	Total					2,191,800
7607.2S003	1	2,970	0.5	0.5	3,653	2,712,353
	2	2,970	0.5	0.5	3,653	2,712,353
	3	2,970	0.5	0.5	3,653	2,712,353
	4	2,970	0.5	0.5	3,653	2,712,353
	Total					10,849,410
7700.8O235	1	3,719	0.5	0.5	3,653	3,396,377
	2	3,719	0.5	0.5	3,653	3,396,377
	3	3,719	0.5	0.5	3,653	3,396,377
	4	3,719	0.5	0.5	3,653	3,396,377
	Total					13,585,507
7701.3O235	1	23,500	0.5	0.5	3,653	21,461,375
	2	23,500	0.5	0.5	3,653	21,461,375
	3	23,500	0.5	0.5	3,653	21,461,375
	4	23,500	0.5	0.5	3,653	21,461,375
	Total					85,845,500
7701.8O235	1	5,300	0.5	0.5	3,653	4,840,225
	2	5,300	0.5	0.5	3,653	4,840,225
	3	5,300	0.5	0.5	3,653	4,840,225
	4	5,300	0.5	0.5	3,653	4,840,225
	Total					19,360,900
7706.9O235	1	4,000	0.5	0.5	3,653	3,653,000
	2	4,000	0.5	0.5	3,653	3,653,000
	3	4,000	0.5	0.5	3,653	3,653,000
	4	4,000	0.5	0.5	3,653	3,653,000
	Total					14,612,000
7709.0O235	1	1,900	0.5	0.5	3,653	1,735,175
	2	1,900	0.5	0.5	3,653	1,735,175
	3	1,900	0.5	0.5	3,653	1,735,175
	4	1,900	0.5	0.5	3,653	1,735,175
	Total					6,940,700

Table C-11. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
7709.1O235	1	3,237	0.5	0.5	3,653	2,956,190
	2	3,237	0.5	0.5	3,653	2,956,190
	3	3,237	0.5	0.5	3,653	2,956,190
	4	3,237	0.5	0.5	3,653	2,956,190
	Total					11,824,761
7722.4O080	1	17,100	0.5	0.5	3,653	15,616,575
	2	17,100	0.5	0.5	3,653	15,616,575
	3	17,100	0.5	0.5	3,653	15,616,575
	4	17,100	0.5	0.5	3,653	15,616,575
	Total					62,466,300
7723.8O080	1	11,900	0.5	0.5	3,653	10,867,675
	2	11,900	0.5	0.5	3,653	10,867,675
	3	11,900	0.5	0.5	3,653	10,867,675
	4	11,900	0.5	0.5	3,653	10,867,675
	Total					43,470,700
7724.1O080	1	33,500	0.5	0.5	3,653	30,593,875
	2	33,500	0.5	0.5	3,653	30,593,875
	3	33,500	0.5	0.5	3,653	30,593,875
	4	33,500	0.5	0.5	3,653	30,593,875
	Total					122,375,500
7727.1O080	1	9,300	0.5	0.5	3,653	8,493,225
	2	9,300	0.5	0.5	3,653	8,493,225
	3	9,300	0.5	0.5	3,653	8,493,225
	4	9,300	0.5	0.5	3,653	8,493,225
	Total					33,972,900
7735.4S006	1	18,700	0.5	0.5	3,653	17,077,775
	2	18,700	0.5	0.5	3,653	17,077,775
	3	18,700	0.5	0.5	3,653	17,077,775
	4	18,700	0.5	0.5	3,653	17,077,775
	Total					68,311,100
7738.9S006	1	21,900	0.5	0.5	3,653	20,000,175
	2	21,900	0.5	0.5	3,653	20,000,175
	3	21,900	0.5	0.5	3,653	20,000,175
	4	21,900	0.5	0.5	3,653	20,000,175
	Total					80,000,700

Table C-12. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
7740.2S006	1	14,100	0.5	0.5	3,653	12,876,825
	2	14,100	0.5	0.5	3,653	12,876,825
	3	14,100	0.5	0.5	3,653	12,876,825
	4	14,100	0.5	0.5	3,653	12,876,825
	Total					51,507,300
7772.2O035	1	13,400	0.5	0.5	3,653	12,237,550
	2	13,400	0.5	0.5	3,653	12,237,550
	3	13,400	0.5	0.5	3,653	12,237,550
	4	13,400	0.5	0.5	3,653	12,237,550
	Total					48,950,200
7801.7O080	1	14,100	0.5	0.5	3,653	12,876,825
	2	14,100	0.5	0.5	3,653	12,876,825
	3	14,100	0.5	0.5	3,653	12,876,825
	4	14,100	0.5	0.5	3,653	12,876,825
	Total					51,507,300
7815.0S083	1	1,040	0.5	0.5	3,653	949,780
	2	1,040	0.5	0.5	3,653	949,780
	3	1,040	0.5	0.5	3,653	949,780
	4	1,040	0.5	0.5	3,653	949,780
	Total					3,799,120
8203.8O074	1	2,860	0.5	0.5	3,653	2,611,895
	2	2,860	0.5	0.5	3,653	2,611,895
	3	2,860	0.5	0.5	3,653	2,611,895
	4	2,860	0.5	0.5	3,653	2,611,895
	Total					10,447,580
8204.9S006	1	19,000	0.5	0.5	3,653	17,351,750
	2	19,000	0.5	0.5	3,653	17,351,750
	3	19,000	0.5	0.5	3,653	17,351,750
	4	19,000	0.5	0.5	3,653	17,351,750
	Total					69,407,000
8206.5S067	1	17,000	0.5	0.5	3,653	15,525,250
	2	17,000	0.5	0.5	3,653	15,525,250
	3	17,000	0.5	0.5	3,653	15,525,250
	4	17,000	0.5	0.5	3,653	15,525,250
	Total					62,101,000

Table C-13. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
8403.4S010	1	2,630	0.5	0.5	3,653	2,401,848
	2	2,630	0.5	0.5	3,653	2,401,848
	3	2,630	0.5	0.5	3,653	2,401,848
	4	2,630	0.5	0.5	3,653	2,401,848
	Total					9,607,390
8514.8S069	1	24,400	0.5	0.5	3,653	22,283,300
	2	24,400	0.5	0.5	3,653	22,283,300
	3	24,400	0.5	0.5	3,653	22,283,300
	4	24,400	0.5	0.5	3,653	22,283,300
	Total					89,133,200
8516.1O069	1	3,170	0.5	0.5	3,653	2,895,003
	2	3,170	0.5	0.5	3,653	2,895,003
	3	3,170	0.5	0.5	3,653	2,895,003
	4	3,170	0.5	0.5	3,653	2,895,003
	Total					11,580,010
8600.5S008	1	2,110	0.5	0.5	3,653	1,926,958
	2	2,110	0.5	0.5	3,653	1,926,958
	3	2,110	0.5	0.5	3,653	1,926,958
	4	2,110	0.5	0.5	3,653	1,926,958
	Total					7,707,830
8603.0O030	1	1,730	0.5	0.5	3,653	1,579,923
	2	1,730	0.5	0.5	3,653	1,579,923
	3	1,730	0.5	0.5	3,653	1,579,923
	4	1,730	0.5	0.5	3,653	1,579,923
	Total					6,319,690
8840.0S169	1	2,990	0.5	0.5	3,653	2,730,618
	2	2,990	0.5	0.5	3,653	2,730,618
	3	2,990	0.5	0.5	3,653	2,730,618
	4	2,990	0.5	0.5	3,653	2,730,618
	Total					10,922,470
8903.8S001	1	2,800	0.5	0.5	3,653	2,557,100
	2	2,800	0.5	0.5	3,653	2,557,100
	3	2,800	0.5	0.5	3,653	2,557,100
	4	2,800	0.5	0.5	3,653	2,557,100
	Total					10,228,400

Table C-14. Exposure Calculations – Four Treatments, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
9001.4O149	1	590	0.5	0.5	3,653	538,818
	2	590	0.5	0.5	3,653	538,818
	3	590	0.5	0.5	3,653	538,818
	4	590	0.5	0.5	3,653	538,818
	Total					2,155,270
9091.2O034	1	1,480	0.5	0.5	3,653	1,351,610
	2	1,480	0.5	0.5	3,653	1,351,610
	3	1,480	0.5	0.5	3,653	1,351,610
	4	1,480	0.5	0.5	3,653	1,351,610
	Total					5,406,440
9235.4S022	1	6,500	0.5	0.5	3,653	5,936,125
	2	6,500	0.5	0.5	3,653	5,936,125
	3	6,500	0.5	0.5	3,653	5,936,125
	4	6,500	0.5	0.5	3,653	5,936,125
	Total					23,744,500
9505.0S069	1	6,100	0.5	0.5	3,653	5,570,825
	2	6,100	0.5	0.5	3,653	5,570,825
	3	6,100	0.5	0.5	3,653	5,570,825
	4	6,100	0.5	0.5	3,653	5,570,825
	Total					22,283,300
9700.1S031	1	770	0.5	0.5	3,653	703,203
	2	770	0.5	0.5	3,653	703,203
	3	770	0.5	0.5	3,653	703,203
	4	770	0.5	0.5	3,653	703,203
	Total					2,812,810
9708.1S012	1	8,200	0.5	0.5	3,653	7,488,650
	2	8,200	0.5	0.5	3,653	7,488,650
	3	8,200	0.5	0.5	3,653	7,488,650
	4	8,200	0.5	0.5	3,653	7,488,650
	Total					29,954,600
9741.2O029	1	6,500	0.5	0.5	3,653	5,936,125
	2	6,500	0.5	0.5	3,653	5,936,125
	3	6,500	0.5	0.5	3,653	5,936,125
	4	6,500	0.5	0.5	3,653	5,936,125
	Total					23,744,500
Total						**2,593,140,498**

Table C-15. Exposure Calculations – Three Treatments, Two-Way Traffic

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
0713.9S281	1	2,450	0.5	0.5	3,653	2,237,463
	2	2,450	0.5	0.5	3,653	2,237,463
	3	2,450	0.5	0.5	3,653	2,237,463
	Total					6,712,388
0783.2O218	1	8,600	0.5	0.5	3,653	7,853,950
	2	8,600	0.5	0.5	3,653	7,853,950
	3	8,600	0.5	0.5	3,653	7,853,950
	Total					23,561,850
3192.7S136	1	3,720	0.5	0.5	3,653	3,397,290
	2	3,720	0.5	0.5	3,653	3,397,290
	3	3,720	0.5	0.5	3,653	3,397,290
	Total					10,191,870
4287.7S175	1	3,740	0.5	0.5	3,653	3,415,555
	2	3,740	0.5	0.5	3,653	3,415,555
	3	3,740	0.5	0.5	3,653	3,415,555
	Total					10,246,665
4922.8S052	1	3,230	0.5	0.5	3,653	2,949,798
	2	3,230	0.5	0.5	3,653	2,949,798
	3	3,230	0.5	0.5	3,653	2,949,798
	Total					8,849,393
5752.3O030	1	12,600	0.5	0.5	3,653	11,506,950
	2	12,600	0.5	0.5	3,653	11,506,950
	3	12,600	0.5	0.5	3,653	11,506,950
	Total					34,520,850
7726.1O080	1	22,600	0.5	0.5	3,653	20,639,450
	2	22,600	0.5	0.5	3,653	20,639,450
	3	22,600	0.5	0.5	3,653	20,639,450
	Total					61,918,350
9621.3S024	1	2,870	0.5	0.5	3,653	2,621,028
	2	2,870	0.5	0.5	3,653	2,621,028
	3	2,870	0.5	0.5	3,653	2,621,028
	Total					7,863,083
Total						**163,864,448**

Table C-16. Exposure Calculations – One Bridge End, Two-Way Traffic

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
0767.1S218	1	1,710	0.5	0.5	3,653	1,561,658
	2	1,710	0.5	0.5	3,653	1,561,658
	Total					3,123,315
1412.0S071	1	5,600	0.5	0.5	3,653	5,114,200
	2	5,600	0.5	0.5	3,653	5,114,200
	Total					10,228,400
2515.1S006	1	8,300	0.5	0.5	3,653	7,579,975
	2	8,300	0.5	0.5	3,653	7,579,975
	Total					15,159,950
2589.1S169	1	4,480	0.5	0.5	3,653	4,091,360
	2	4,480	0.5	0.5	3,653	4,091,360
	Total					8,182,720
2711.3S069	1	780	0.5	0.5	3,653	712,335
	2	780	0.5	0.5	3,653	712,335
	Total					1,424,670
4208.0S057	1	1,630	0.5	0.5	3,653	1,488,598
	2	1,630	0.5	0.5	3,653	1,488,598
	Total					2,977,195
4319.5S030	1	6,000	0.5	0.5	3,653	5,479,500
	2	6,000	0.5	0.5	3,653	5,479,500
	Total					10,959,000
4864.8S149	1	6,300	0.5	0.5	3,653	5,753,475
	2	6,300	0.5	0.5	3,653	5,753,475
	Total					11,506,950
4958.3O061	1	2,360	0.5	0.5	3,653	2,155,270
	2	2,360	0.5	0.5	3,653	2,155,270
	Total					4,310,540
5286.9L001	1	7,700	0.5	0.5	3,653	7,032,025
	2	7,700	0.5	0.5	3,653	7,032,025
	Total					14,064,050
Total						**81,936,790**

Table C-17. Exposure Calculations – Treatments Adjacent to One Lane, Two-Way Traffic

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
0230.3S148	1	4,520	0.5	0.5	3,653	4,127,890
	2	4,520	0.5	0.5	3,653	4,127,890
	Total					8,255,780
0230.5S148	1	4,520	0.5	0.5	3,653	4,127,890
	2	4,520	0.5	0.5	3,653	4,127,890
	Total					8,255,780
1562.9S148	1	1,770	0.5	0.5	3,653	1,616,453
	2	1,770	0.5	0.5	3,653	1,616,453
	Total					3,232,905
2959.6O034	1	11,900	0.5	0.5	3,653	10,867,675
	2	11,900	0.5	0.5	3,653	10,867,675
	Total					21,735,350
2962.9O034	1	5,400	0.5	0.5	3,653	4,931,550
	2	5,400	0.5	0.5	3,653	4,931,550
	Total					9,863,100
4309.8S030	1	9,400	0.5	0.5	3,653	8,584,550
	2	9,400	0.5	0.5	3,653	8,584,550
	Total					17,169,100
4922.0S064	1	1,330	0.5	0.5	3,653	1,214,623
	2	1,330	0.5	0.5	3,653	1,214,623
	Total					2,429,245
5242.1O080	1	10,300	0.5	0.5	3,653	9,406,475
	2	10,300	0.5	0.5	3,653	9,406,475
	Total					18,812,950
5718.0O380	1	1,220	0.5	0.5	3,653	1,114,165
	2	1,220	0.5	0.5	3,653	1,114,165
	Total					2,228,330
5752.9O030	1	4,240	0.5	0.5	3,653	3,872,180
	2	4,240	0.5	0.5	3,653	3,872,180
	Total					7,744,360
7700.3O235	1	20,700	0.5	0.5	3,653	18,904,275
	2	20,700	0.5	0.5	3,653	18,904,275
	Total					37,808,550
7717.8S028	1	25,200	0.5	0.5	3,653	23,013,900
	2	25,200	0.5	0.5	3,653	23,013,900
	Total					46,027,800

Table C-18. Exposure Calculations – Treatments Adjacent to One Lane, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
8336.8S037	1	1,150	0.5	0.5	3,653	1,050,238
	2	1,150	0.5	0.5	3,653	1,050,238
	Total					2,100,475
8557.9O030	1	2,120	0.5	0.5	3,653	1,936,090
	2	2,120	0.5	0.5	3,653	1,936,090
	Total					3,872,180
8558.4O030	1	4,240	0.5	0.5	3,653	3,872,180
	2	4,240	0.5	0.5	3,653	3,872,180
	Total					7,744,360
9401.3L926	1	14,700	0.5	0.5	3,653	13,424,775
	2	14,700	0.5	0.5	3,653	13,424,775
	Total					26,849,550
9703.4O020	1	6,400	0.5	0.5	3,653	5,844,800
	2	6,400	0.5	0.5	3,653	5,844,800
	Total					11,689,600
Total						**235,819,415**

Table C-19. Exposure Calculations – One Treatment, Two-Way Traffic

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
0601.5S150	1	4,300	0.5	0.5	3,653	3,926,975
5753.4O030	1	11,900	0.5	0.5	3,653	10,867,675
8208.0R006	1	32,400	0.5	0.5	3,653	29,589,300
9701.8O020	1	17,600	0.5	0.5	3,653	16,073,200
9704.6S012	1	22,500	0.5	0.5	3,653	20,548,125
Total						**81,005,275**

Table C-20. Exposure Calculations – Special Cases, Two-Way Traffic

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
0743.1S057	1	15,200	0.5	0.5	3,653	13,881,400
	2	15,200	0.5	0.5	3,653	13,881,400
	3	15,200	0.5	0.0	3,653	0
	Total					27,762,800
1797.9S065	1	6,400	0.5	0.5	3,653	5,844,800
	2	6,400	0.5	0.5	3,653	5,844,800
	Total					11,689,600
1900.5S346	1	3,750	0.5	0.5	3,653	3,424,688
	2	3,750	0.5	0.5	3,653	3,424,688
	3	3,750	0.5	0.5	3,653	3,424,688
	4	3,750	0.5	0.5	3,653	3,424,688
	5	3,750	0.5	0.5	3,653	3,424,688
	Total					17,123,438
3021.8S071	1	15,500	0.5	0.5	3,653	14,155,375
	2	15,500	0.5	0.50	3,653	14,155,375
	3	15,500	0.5	0.5	3,653	14,155,375
	4	15,500	0.5	0.50	3,653	14,155,375
	5	15,500	0.5	0.50	3,653	14,155,375
	6	15,500	0.5	0.5	3,653	14,155,375
	Total					84,932,250
3145.1O052	1	1,450	1.0	0.5	3,653	2,648,425
	2	5,800	0.5	0.5	3,653	5,296,850
	3	5,800	0.5	0.5	3,653	5,296,850
	4	5,800	0.5	0.5	3,653	5,296,850
	5	5,800	0.5	0.5	3,653	5,296,850
	Total					23,835,825
5285.9L001	1	26,100	0.5	0.5	3,653	23,835,825
	2	26,100	0.5	0.5	3,653	23,835,825
	3	26,100	0.5	0.5	3,653	23,835,825
	4	26,100	0.5	0.0	3,653	0
	5	26,100	0.5	0.5	3,653	23,835,825
	6	26,100	0.5	0.5	3,653	23,835,825
	Total					119,179,125
5722.7O380	1	12,100	1.0	0.5	3,653	22,100,650
	2	12,100	0.5	0.5	3,653	11,050,325
	3	12,100	0.5	0.5	3,653	11,050,325
	4	12,100	0.5	0.5	3,653	11,050,325
	Total					55,251,625

Table C-21. Exposure Calculations – Special Cases, Two-Way Traffic (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
7702.4S160	1	23,500	0.5	0.5	3,653	21,461,375
	2	23,500	0.5	0.5	3,653	21,461,375
	Total					42,922,750
7704.4O235	1	9,500	0.5	0.5	3,653	8,675,875
	2	3,880	1.0	0.5	3,653	7,086,820
	3	9,500	0.5	0.5	3,653	8,675,875
	4	9,500	0.5	0.5	3,653	8,675,875
	5	9,500	0.5	0.5	3,653	8,675,875
	Total					41,790,320
7705.4O235	1	13,300	0.5	0.5	3,653	12,146,225
	2	1,090	1.0	0.5	3,653	1,990,885
	3	13,300	0.5	0.5	3,653	12,146,225
	4	13,300	0.5	0.5	3,653	12,146,225
	5	13,300	0.5	0.5	3,653	12,146,225
	6	4,170	1.0	0.5	3,653	7,616,505
	Total					58,192,290
7706.2O235	1	14,900	0.5	0.5	3,653	13,607,425
	2	14,900	0.5	0.5	3,653	13,607,425
	3	5,500	1.0	0.5	3,653	10,045,750
	4	5,200	1.0	0.5	3,653	9,497,800
	5	14,900	0.5	0.5	3,653	13,607,425
	6	14,900	0.5	0.5	3,653	13,607,425
	7	5,700	1.0	0.5	3,653	10,411,050
	8	5,700	1.0	0.5	3,653	10,411,050
	9	5,700	1.0	0.5	3,653	10,411,050
	Total					105,206,400
7718.3S028	1	23,100	0.5	0.5	3,653	21,096,075
	2	23,100	0.5	0.5	3,653	21,096,075
	3	9,500	1.0	0.5	3,653	17,351,750
	4	6,800	1.0	0.5	3,653	12,420,200
	5	23,100	0.5	0.5	3,653	21,096,075
	6	23,100	0.5	0.5	3,653	21,096,075
	7	9,000	1.0	0.5	3,653	16,438,500
	8	6,800	1.0	0.0	3,653	0
	Total					130,594,750
Total						**911,633,548**

Table C-22. Exposure Calculations – Four Treatments, One-Way Traffic

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
5720.8O380	1	4,160	1.0	0.5	3,653	7,598,240
	2	4,160	1.0	0.5	3,653	7,598,240
	3	4,160	1.0	0	3,653	0
	4	4,160	1.0	0	3,653	0
	Total					15,196,480
7707.1O235	1	12,200	1.0	0	3,653	0
	2	12,200	1.0	0	3,653	0
	3	12,200	1.0	0.5	3,653	22,283,300
	4	12,200	1.0	0.5	3,653	22,283,300
	Total					44,566,600
7707.9O235	1	7,600	1.0	0.5	3,653	13,881,400
	2	7,600	1.0	0.5	3,653	13,881,400
	3	7,600	1.0	0	3,653	0
	4	7,600	1.0	0	3,653	0
	Total					27,762,800
7708.0O235	1	10,200	1.0	0.5	3,653	18,630,300
	2	10,200	1.0	0.5	3,653	18,630,300
	3	10,200	1.0	0	3,653	0
	4	10,200	1.0	0	3,653	0
	Total					37,260,600
7708.8O235	1	5,800	1.0	0.5	3,653	10,593,700
	2	5,800	1.0	0.5	3,653	10,593,700
	3	5,800	1.0	0	3,653	0
	4	5,800	1.0	0	3,653	0
	Total					21,187,400
7708.9O235	1	8,100	1.0	0.5	3,653	14,794,650
	2	8,100	1.0	0.5	3,653	14,794,650
	3	8,100	1.0	0	3,653	0
	4	8,100	1.0	0	3,653	0
	Total					29,589,300
Total						**175,563,180**

Table C-23. Exposure Calculations – One Bridge End, One-Way Traffic

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
0763.1L063	1	10,200	1.0	0.5	3,653	18,630,300
	2	10,200	1.0	0.5	3,653	18,630,300
	Total					37,260,600
0763.1R063	1	7,800	1.0	0.5	3,653	14,246,700
	2	7,800	1.0	0.5	3,653	14,246,700
	Total					28,493,400
5720.6O380	1	6,900	1.0	0.5	3,653	12,602,850
	2	6,900	1.0	0.5	3,653	12,602,850
	Total					25,205,700
8220.1L061	1	17,100	1.0	0.5	3,653	31,233,150
	2	17,100	1.0	0.5	3,653	31,233,150
	Total					62,466,300
8220.1R061	1	21,300	1.0	0.5	3,653	38,904,450
	2	21,300	1.0	0.5	3,653	38,904,450
	Total					77,808,900
Total						**231,234,900**

Table C-24. Exposure Calculations – Special Cases, One-Way Traffic

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
2963.7A034	1	1,040	1.0	0.5	3,653	1,899,560
	2	1,040	1.0	0.5	3,653	1,899,560
	Total					3,799,120
5723.8O380	1	2,390	1.0	0.5	3,653	4,365,335
	2	2,390	1.0	0	3,653	0
	Total					4,365,335
7707.2O235	1	19,600	1.0	0.5	3,653	35,799,400
	2	9,300	1.0	0	3,653	0
	3	5,800	1.0	0.5	3,653	10,593,700
	4	7,400	1.0	0.5	3,653	13,516,100
	Total					59,909,200
7708.1A235	1	7,300	1.0	0.5	3,653	13,333,450
7708.2O235	1	11,900	1.0	0.5	3,653	21,735,350
	2	2,840	1.0	0.5	3,653	5,187,260
	3	11,900	1.0	0	3,653	0
	Total					26,922,610
7708.3O235	1	8,600	1.0	0.5	3,653	15,707,900
	2	5,600	1.0	0.5	3,653	10,228,400
	3	8,600	1.0	0	3,653	0
	4	8,600	1.0	0	3,653	0
	Total					25,936,300
7710.0A235	1	10,500	1.0	0.5	3,653	19,178,250
	2	10,500	1.0	0.5	3,653	19,178,250
	3	10,500	1.0	0	3,653	0
	Total					38,356,500
7785.5S069	1	13,700	1.0	0.5	3,653	25,023,050
	2	13,700	1.0	0.5	3,653	25,023,050
	3	8,800	1.0	0.5	3,653	16,073,200
	4	13,700	1.0	0	3,653	0
	5	13,700	1.0	0	3,653	0
	Total					66,119,300
Total						**238,741,815**

Table C-25. Exposure Calculations – Split Bridge Numbers

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
5244.3O080	1	17,800	0.5	0.5	3,653	16,255,850
	2	17,800	0.5	0	3,653	0
	3	17,800	0.5	0.5	3,653	16,255,850
	Subtotal					32,511,700
5244.4O080	4	17,800	0.5	0.5	3,653	16,255,850
	5	17,800	0.5	0	3,653	0
	Subtotal					16,255,850
Total						48,767,550
6401.9S014	1	13,900	0.5	0.5	3,653	12,694,175
	2	13,900	0.5	0.5	3,653	12,694,175
	3	13,900	0.5	0.5	3,653	12,694,175
	Subtotal					38,082,525
6402.0S014	4	13,900	0.5	0.5	3,653	12,694,175
	5	13,900	0.5	0.5	3,653	12,694,175
	6	13,900	0.5	0.5	3,653	12,694,175
	Subtotal					38,082,525
Total						76,165,050
7705.0O235	1	8,900	0.5	0.5	3,653	8,127,925
	2	8,900	0.5	0	3,653	0
	Subtotal					8,127,925
7705.1O235	3	8,900	0.5	0.5	3,653	8,127,925
	4	8,900	0.5	0	3,653	0
	Subtotal					8,127,925
Total						16,255,850
8544.7O030	1	9,900	0.5	0.5	3,653	9,041,175
	2	9,900	0.5	0.5	3,653	9,041,175
	3	9,900	0.5	0	3,653	0
	4	9,900	0.5	0.5	3,653	9,041,175
	Subtotal					27,123,525
8544.8O030	5	9,900	0.5	0.5	3,653	9,041,175
	6	9,900	0.5	0	3,653	0
	Subtotal					9,041,175
Total						36,164,700
8619.1L063	1	7,600	0.5	0.6	3,653	8,328,840
	2	7,600	0.5	0.4	3,653	5,552,560
	Subtotal					13,881,400

Table C-26. Exposure Calculations – Split Bridge Numbers (Cont.)

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
8619.1R063	3	7,600	0.5	0.6	3,653	8,328,840
	4	7,600	0.5	0.4	3,653	5,552,560
	Subtotal					13,881,400
Total						27,762,800
9401.5L926	1	14,700	0.5	0.6	3,653	16,109,730
	2	14,700	0.5	0.4	3,653	10,739,820
	Subtotal					26,849,550
9401.5R926	3	14,700	0.5	0.6	3,653	16,109,730
	4	14,700	0.5	0.4	3,653	10,739,820
	Subtotal					26,849,550
Total						53,699,100
9700.2S077	1	20,200	0.5	0.5	3,653	18,447,650
	2	4,030	1.0	0.5	3,653	7,360,795
	3	20,200	0.5	0.5	3,653	18,447,650
	4	20,200	0.5	0.5	3,653	18,447,650
	Subtotal					62,703,745
9700.3S077	5	20,200	0.5	0.5	3,653	18,447,650
	6	20,200	0.5	0.0	3,653	0
	7	20,200	0.5	0.5	3,653	18,447,650
	8	20,200	0.5	0.5	3,653	18,447,650
	9	20,200	0.5	0.5	3,653	18,447,650
	Subtotal					73,790,600
Total						136,494,345
Total						**395,309,395**

Table C-27. Exposure Calculations – No AADT Data

Bridge No.	Sloped End No.	AADT	Traffic Factor	Side Factor	Time	Exposure
0700.4S820	1	Not Available	0.5	0.5	3,653	-
	2	Not Available	0.5	0.5	3,653	-
	3	Not Available	0.5	0.5	3,653	-
2801.1S603	1	Not Available	0.5	0.5	3,653	-
	2	Not Available	0.5	0.5	3,653	-
	3	Not Available	0.5	0.5	3,653	-
	4	Not Available	0.5	0.5	3,653	-
2803.7S603	1	Not Available	0.5	0.5	3,653	-
	2	Not Available	0.5	0.5	3,653	-
	3	Not Available	0.5	0.5	3,653	-
	4	Not Available	0.5	0.5	3,653	-
2803.8S603	1	Not Available	0.5	0.5	3,653	-
	2	Not Available	0.5	0.5	3,653	-
	3	Not Available	0.5	0.5	3,653	-
	4	Not Available	0.5	0.5	3,653	-
6100.1S637	1	Not Available	0.5	0.5	3,653	-
	2	Not Available	0.5	0.5	3,653	-
	3	Not Available	0.5	0.5	3,653	-
8100.3S607	1	Not Available	0.5	0.5	3,653	-
	2	Not Available	0.5	0.5	3,653	-
	3	Not Available	0.5	0.5	3,653	-
	4	Not Available	0.5	0.5	3,653	-
9200.4S612	1	Not Available	0.5	0.5	3,653	-
	2	Not Available	0.5	0.5	3,653	-
	3	Not Available	0.5	0.5	3,653	-
	4	Not Available	0.5	0.5	3,653	-

Table C-28. Total Exposure for Sloped End Treatments

Sloped End Treatment Configuration	Table No.	Exposure
Four Treatments, Two-Way Traffic	Table C-1	2,593,140,498
Three Treatments, Two-Way Traffic	Table C-15	163,864,448
One Bridge End, Two-Way Traffic	Table C-16	81,936,790
Treatments Adjacent to One Lane, Two-Way Traffic	Table C-17	235,819,415
One Treatment, Two-Way Traffic	Table C-19	81,005,275
Special Cases, Two-Way Traffic	Table C-20	718,481,173
Four Treatments, One-Way Traffic	Table C-22	175,563,180
One Bridge End, One-Way Traffic	Table C-23	231,234,900
Special Cases, One-Way Traffic	Table C-24	238,741,815
Split Bridge Numbers	Table C-25	395,309,395
No AADT Data	Table C-27	0
Total Exposure		**4,915,096,889**

Appendix D. Iowa DOT Crash Database

The crash database provided by Iowa DOT contained 103 data elements for each crash. The elements, sorted by category, are listed in Table D-1, with their description and data type.

Table D-1. Data Elements from Iowa DOT Crash Database

Data Category	Element Name	Description	Data Type
Identification	CASENUMBER	Iowa DOT Case Number	Number
	LECASENUMBER	Law Enforcement Case Number	Number
	REPORTTYPE	Report Type	Short Text
Date	CRASH_DATE	Date of Crash (YYYYMMDD)	Number
	CRASH_DAY	Day of Week of Crash	Name
	TIMESTR	Time of Crash in String Format (HH:MM)	Number
Location	COUNTY	County	Name
	CITYBR	Base Records City Number	Short Text
	URBANAREA	FHWA Urban Area Code	Number
	LITERAL	Literal Description of Location	Short Text
	POINT_X	Longitudinal (Decimal)	Number
	POINT_Y	Latitude (Decimal)	Number
Road	ROADTYPE	Type of Roadway Junction/Feature	Short Text
	ROADCLASS	Road Classification	Name
	SYSTEM	Road System	Name
	PAVED	Paved or Not	Short Text
	SPEEDLIMIT	Speed Limit	Number
	INTCLASS	Intersection Class	Name
	ROUTE	Route	Number
	OVERUNDER	Overpass/Underpass Information	Short Text
	TRAFCONT	Traffic Controls	Short Text
	RAMP	Mainline or Ramp	Short Text
	RCONTCIRC	Roadway Contributing Circumstances	Short Text
	CSURFCOND	Surface Conditions	Short Text
Environment	ECONTCIRC	Environmental Contributing Circumstances	Short Text
	WEATHER1	Weather Conditions 1	Short Text
	WEATHER2	Weather Conditions 2	Short Text
	LIGHT	Light Conditions	Short Text
	LIGHTING	Derived Light Conditions	Short Text
	VISIONOBS	Vision Obscurement	Short Text

Table D-2. Data Elements from Iowa DOT Crash Database (Cont.)

Data Category	Element Name	Description	Data Type
Events	CRCOMANNER	Manner of Crash	Short Text
	SEQEVENTS1	Sequence of Events 1	Short Text
	SEQEVENTS2	Sequence of Events 2	Short Text
	SEQEVENTS3	Sequence of Events 3	Short Text
	SEQEVENTS4	Sequence of Events 4	Short Text
	FIRSTHARM	First Harmful Event	Short Text
	LOCFSTHARM	Location of First Harmful Event	Short Text
	MOSTHARM	Most Harmful Event	Short Text
	MAJORCAUSE	Major Cause	Short Text
	FIXOBJSTR	Fixed Object Struck	Short Text
	EMERSTATUS	Emergency Status	Short Text
	EMERVEH	Emergency Vehicle Type	Short Text
	PROPDMG	Amount of Property Damage ($)	Number
Injuries	CSEVERITY	Crash Severity	Short Text
	INJUREDAGE	Injured Person Age	Number
	INJUREDGEN	Injured Person Gender	Short Text
	INJSTATUS	Injury Status	Short Text
	INJURIES	Number of Injuries	Number
	UNKINJURY	Number of Unknown Injuries	Number
	POSSINJURY	Number of Possible Injuries	Number
	MININJURY	Number of Minor Injuries	Number
	MAJINJURY	Number of Major Injuries	Number
	FATALITIES	Number of Fatalities	Number
	TRAPPED	Occupant Trapped?	Short Text
	AIRBAGDEP	Airbag Deployment	Short Text
	EJECTION	Ejection	Short Text
	EJECTPATH	Ejection Path	Short Text
Non-Motorist	NM_TYPE	Non-Motorist Type	Short Text
	NM_COND	Non-Motorist Condition	Short Text
	NM_ACTION	Non-Motorist Action	Short Text
	NMCONTCIRC	Non-Motorist Contributing Circumstances	Short Text
	NM_LOC	Non-Motorist Location	Short Text
	NM_SAFETY	Non-Motorist Safety Equipment	Short Text
Work Zone	WZ_RELATED	Work Zone Related?	Yes/No
	WZ_TYPE	Work Zone Type	Short Text
	WZ_LOC	Work Zone Location	Short Text
	WORKERS	Workers Present?	Short Text

Table D-3. Data Elements from Iowa DOT Crash Database (Cont.)

Data Category	Element Name	Description	Data Type
Driver/Occupants	TOCCUPANTS	Total Number of Occupants	Number
	OCCUPANTS	Total Number of Occupants in Vehicle	Number
	PERSONNUM	Person Number	Number
	SEATING	Seating Position	Short Text
	OCCPROTECT	Occupant Protection	Short Text
	DCONTCIRC1	Driver Contributing Circumstances 1	Short Text
	DCONTCIRC2	Driver Contributing Circumstances 2	Short Text
	DRIVERAGE	Driver Age	Number
	DRIVERGEN	Driver Gender	Short Text
	DAGEBIN1	Driver Age by Primarily 5 Year Bins	Short Text
	CHARGED	Driver Charged?	Yes/No
	DRIVERCOND	Driver Condition	Short Text
	DL_STATE	Driver's License State	Name
	DRUGALCREL	Drug or Alcohol Related	Short Text
	ALCRESULT	Alcohol Test Results	Number
	DRUGRESULT	Drug Test Results	Short Text
Vehicles	VEHICLES	Number of Vehicles	Number
	UNITNUM	Vehicle Unit Number	Number
	MAKE	Vehicle Make	Name
	MODEL	Vehicle Model	Name
	VYEAR	Vehicle Year	Number
	STYLE	Vehicle Style	Short Text
	VCONFIG	Vehicle Configuration	Short Text
	CARGOBODY	Cargo Body Type	Short Text
	VLP_STATE	License Plate State	Name
	VLP_YEAR	License Plate Year	Number
	VACTION	Vehicle Action	Short Text
	DEFECT	Vehicle Defect	Short Text
	INITIMPACT	Point of Initial Impact	Short Text
	DAMAGE	Extent of Damage	Short Text
	MOSTDAMAGE	Most Damaged Area	Short Text
	REPAIRCOST	Approximate Cost to Repair Vehicle	Number
	INITDIR	Initial Direction of Travel	Name
	CARDINAL	Cardinal Direction of Vehicle	Short Text

Appendix E. Iowa DOT Accident Report Form

The accident report form, which is filled out for every accident within the state of Iowa that results in death, personal injury, or property damage of $1,500 or greater, is shown in this appendix. Two forms are shown, one which was used prior to 2015 and one which was used from 2015 onward. The database provided for this ISPE included the information collected in the accident report forms, shown in Appendix D.

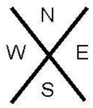
IOWADOT
Form 433014 (04-18)

INVESTIGATING OFFICER'S REPORT OF MOTOR VEHICLE ACCIDENT CODE SHEET

Vehicle Characteristics

Initial Travel Direction (prior to coded Vehicle Action)

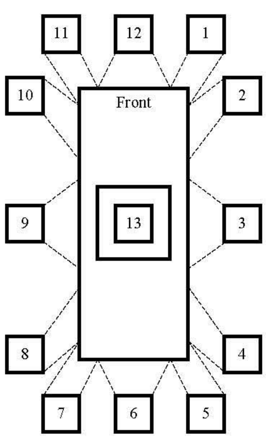
1 - North
2 - East
3 - South
4 - West
99 - Unknown



Vehicle Action

1 - Movement essentially straight
2 - Turning Left
3 - Turning right
4 - Making U-turn
5 - Overtaking/passing
6 - Changing lanes
7 - Entering traffic lane (merging)
8 - Leaving traffic lane
9 - Backing
10 - Slowing/stopping (decelerating)
11 - Stopped in traffic
12 - Legally parked
13 - Illegally parked/unattended
14 - Negotiating a curve
15 - Starting in road
16 - Accelerating in road
17 - Leaving a parked position
18 - Entering a parked position
98 - Other (explain in narrative)
99 - Unknown

Point of Initial Impact Most Damaged Area



14 - Undercarriage
15 - Non-collision/no damage
16 - Cargo loss
98 - Other (explain in narrative)
99 - Unknown

Vehicle Configuration

1 - Passenger car
2 - Four-tire truck (pick-up)
3 - Sport utility vehicle
4 - Passenger van (seats <9)
5 - Passenger van (seats 9-15)
6 - Cargo/panel van
7 - Single-unit truck (2-axle, 6-tire)
8 - Single-unit truck (>=3 axles)
9 - Other light truck (<=10,000 lbs)
10 - Vehicle <=10,000lbs, placarded for hazardous materials
11 - Truck/trailer
12 - Truck tractor (bobtail)
13 - Tractor/semi-trailer
14 - Tractor/doubles
15 - Tractor/triples
16 - Other heavy truck (>10,000 lbs) (cannot classify)
17 - Motorcycle
18 - 3-wheeled, enclosed
19 - 3-wheeled, unenclosed
20 - Moped
21 - Motor home/recreational vehicle
22 - School bus (seats >15)
23 - Small school bus (seats 9-15)
24 - Other bus (seats >15)
25 - Other small bus (seats 9-15)
26 - Farm tractor
27 - Farm equipment (explain in narrative)
28 - All-terrain vehicle (ATV)
29 - Snowmobile
30 - Golf cart
31 - Street legal, low-speed vehicle
32 - Limousine/taxi (seats 8 or less)
33 - Limousine/taxi (seats 9-15)
34 - Limousine/taxi (seats >15)
35 - Maintenance/construction vehicle
36 - Train
98 - Other (explain in narrative)
99 - Unknown

Vehicle Defect

1 - None
2 - Brake system
3 - Steering
4 - Blowout
5 - Other tire defect (explain in narrative)
6 - Wheels
7 - Windows/windshield
8 - Wipers
9 - Mirrors
10 - Trailer hitch/truck coupling, safety chain
11 - Headlights
12 - Tail lights
13 - Turn signal
14 - Body/doors
15 - Power train
16 - Suspension
17 - Exhaust
18 - Safety systems
98 - Other (explain in narrative)
99 - Unknown

Towed Field

1 - Driven away
2 - Disabled - privately arranged
3 - Disabled - officer arranged
4 - Not disabled - privately arranged
5 - Not disabled - officer arranged
6 - Abandoned/left at scene

Extent of Damage

1 - None
2 - Minor Damage
3 - Functional damage
4 - Disabling damage
5 - Severe, vehicle totalled
9 - Unknown

Commercial Motor Vehicle

Converter Dolly

1 - Yes
2 - No dolly used
3 - No information/label or unreadable
9 - Unknown

Gross Vehicle Weight Rating (GVWR)

1 - 10,000 lbs or less
2 - 10,001 lbs -26,000 lbs
3 - 26,001 lbs or more

Hazardous Materials (cargo only)

Involvement

1 - Yes
2 - No
3 - Not applicable
99 - Unknown

Placard

1 - Yes
2 - No
3 - Not applicable
99 - Unknown

Released

1 - Yes
2 - No
3 - Not applicable
99 - Unknown

Underride / Override

1 - None
2 - Underride, compartment intrusion
3 - Underride, no compartment intrusion
4 - Underride, compartment intrusion unknown
5 - Override, moving vehicle
6 - Override, parked/stationary vehicle
8 - Other
9 - Unknown

Cargo Body Type

1 - Not applicable
2 - Van/enclosed box
3 - Dump (grain/gravel)
4 - Cargo tank
5 - Flatbed
6 - Concrete mixer
7 - Auto transporter
8 - Garbage/refuse
9 - Hopper (grain, chips, gravel)
10 - Pole trailer
11 - Log trailer
12 - Intermodal container chassis
13 - Small utility trailer (one-axle)
14 - Large utility trailer (2+axles)
15 - Boat
16 - Camper
17 - Large mobile home
18 - Oversize load
19 - Towed vehicle
20 - Bus
98 - Other (explain in narrative)
99 - Unknown

Special Vehicles

Special Function of Vehicle

1 - No special function
2 - Police
3 - Fire
4 - Ambulance
5 - Incident response vehicle
6 - Non-transport emergency service vehicle
7 - Military
8 - Snow plow
9 - Taxi
10 - School
98 - Other (explain in narrative)
99 - Unknown

Emergency Status

1 - Not applicable
2 - Yes, warning equipment used
3 - Yes, warning equipment not used
4 - No, non-emergency, non-transport
5 - No, non-emergency, transport
99 - Unknown

Bus Use

1 - School (public or private)
2 - Transit/commuter
3 - Intercity
4 - Charter/tour
5 - Shuttle
6 - Modified for personal/private use
7 - Church
98 - Other (explain in narrative)
99 - Unknown

Page 1 of 4

Figure E-1. Iowa Accident Report Form (Prior to 2015) – Page 1

IOWADOT
Form 433014 (04-18)

**INVESTIGATING OFFICER'S REPORT OF MOTOR VEHICLE ACCIDENT
CODE SHEET**

Driver Characteristics

Contributing Circumstances, Driver (up to two)

1 - Ran traffic signal
2 - Ran Stop sign
3 - Exceeded authorized speed
4 - Driving less than the posted speed limit
5 - Driving too fast for conditions
6 - Lost control
7 - Followed too close
8 - Operating vehicle in a reckless, erratic careless, negligent manner
9 - Improper or erratic lane changing
10 - Aggressive driving/road rage
11 - Made improper turn
12 - Failed to yield to emergency vehicle
13 - Traveling wrong way/on wrong side
14 - Traveling on prohibited traffic way
15 - Over-correcting/over-steering
16 - Failed to keep in proper lane
17 - Failure to signal intentions
18 - Swerved to avoid: vehicle, object non-motorist, or animal in roadway
19 - Starting or backing improperly
20 - Failure to dim lights/have lights on
21 - Vehicle stopped on railroad tracks
22 - Vehicle drove around grade crossing gates

Passing
30 - On wrong side
31 - Where prohibited by signs/markings
32 - With insufficient distance/inadequate visibility
33 - Through/around barrier
96 - Other passing (explain in narrative)

Failed to yield right-of-way (FTYROW):
40 - From Stop sign
41 - From Yield sign
42 - Making left turn
43 - Making right turn on red signal
44 - From driveway
45 - From parked position
46 - To non-motorist
47 - At uncontrolled intersection
97 - Other FTYROW (explain in narrative)

Other (explain in narrative):
50 - Vision obstructed
51 - Operating without required equipment
52 - Failure to obey displayed vehicle warnings or instructions
53 - Disregarded signs/road markings
54 - Illegal off-road driving
55 - Towing improperly
56 - Getting off/out of vehicle
57 - Overloading/improper loading with passengers/cargo

58 - Operator inexperience

88 - No improper action

98 - Other (explain in narrative)
99 - Unknown

Driver Re-Examination Needed:

1 - Yes (explain in narrative)
2 - No

Driver Distraction:

1 - Not applicable/no driver
2 - Not distracted

Electronic devices:
3 - Manual operation of an electronic communication device (texting, typing, dialing)
4 - Talking on hand-held device
5 - Talking on hands free device
6 - Adjusting devices (radio, climate)
96 - Other activity with electronic device (explain in narrative)

Other distraction inside vehicle:
10 - Passenger
11 - Unrestrained animal
12 - Eating or drinking related
13 - Smoking related
14 - Reaching for object(s)/fallen object(s)
15 - Inattentive/lost in thought
16 - Looked but did not see
97 - Other distraction inside vehicle (explain in narrative)

98 - Distraction outside vehicle (explain in narrative)
99 - Unknown

Driver Condition

1 - Apparently normal
2 - Emotional (e.g., depressed, angry)
3 - Asleep/fatigued
4 - Illness/fainted
5 - Medical condition (seizure, reaction)
6 - Under the influence of alcohol
7 - Under the influence of drugs/meds
8 - Physical impairment
9 - Walks with a cane/crutches
10 - Paraplegic/wheelchair restricted
11 - Impaired due to previous injury
12 - Hearing impaired/deaf
13 - Visually impaired
98 - Other (explain in narrative)
99 - Unknown

Vision Obscured

1 - Not obscured
2 - Trees/crops
3 - Embankment
4 - Hillcrest
5 - Building(s)
6 - Sign/billboard
7 - Parked vehicle(s)
8 - Moving vehicle(s)
9 - Person/object in or on vehicle
10 - Blinded by sun or headlights
11 - Broken/dirty windshield
12 - Frosted windows/windshield
13 - External mirrors
14 - Blowing snow
15 - Fog/smoke/dust
16 - Splash/spray of passing vehicle
17 - Inadequate vehicle lighting
18 - Exterior angle/blind spot on vehicle
98 - Other (explain in narrative)
99 - Unknown

Alcohol/Drug Testing

Alcohol Test Given
1 - None
2 - Blood
3 - Urine
4 - Breath
5 - Vitreous
9 - Refused

Drug Test Given
1 - None
2 - Blood
3 - Urine
4 - Breath
5 - Vitreous
9 - Refused

Drug Test Result
1 - Negative
2 - Cannabis
3 - Central Nervous Sys. depressants
4 - Central Nervous Sys, stimulants
5 - Hallucinogens
6 - Inhalants
7 - Narcotic Analgesics
8 - Disociative Anesthetic (PCP)
9 - Prescription Drug
98 - Other (explain in narrative)

Accident Environment

Location of First Harmful Event

1 - On roadway
2 - Shoulder
3 - Median
4 - Roadside
5 - Gore
6 - Outside trafficway
7 - In parking lane/zone
8 - Continuous left turn lane
9 - Separator
98 - Other (explain in narrative)
99 - Unknown

Manner of Crash/Collision

1 - Non-collision (single vehicle)
2 - Head-on (front to front)
3 - Rear end (front to rear)
4 - Angle, oncoming left turn
5 - Broadside (front to side)
6 - Sideswipe, same direction
7 - Sideswipe, opposite direction
8 - Rear to rear
9 - Rear to side
98 - Other (explain in narrative)
99 - Unknown

Weather Conditions (up to two)

1 - Clear
2 - Cloudy
3 - Fog, smoke, smog
4 - Freezing rain/drizzle
5 - Rain
6 - Sleet, hail
7 - Snow
8 - Blowing snow
9 - Severe winds
10 - Blowing sand, soil, dirt
98 - Other (explain in narrative)
99 - Unknown

Surface Conditions

1 - Dry
2 - Wet
3 - Ice/Frost
4 - Snow
5 - Slush
6 - Mud, dirt
7 - Water (standing or moving)
8 - Sand
9 - Oil
10 - Gravel
98 - Other (explain in narrative)
99 - Unknown

Light Conditions

1 - Daylight
2 - Dusk
3 - Dawn
4 - Dark, roadway lighted
5 - Dark, roadway not lighted
6 - Dark, unknown roadway lighting
9 - Unknown

Page 2 of 4

Figure E-2. Iowa Accident Report Form (Prior to 2015) – Page 2

IOWADOT
Form 433014 (04-18)

INVESTIGATING OFFICER'S REPORT OF MOTOR VEHICLE ACCIDENT CODE SHEET

Work Zone Related?

Work Zone Activity

1 - Construction
2 - Maintenance
3 - Utility
98 - Other (explain in narrative)
99 - Unknown

Location

1 - Before work zone warning sign
2 - Advance warning area
3 - Transition area
4 - Within or adjacent to work activity
5 - Termination area
98 - Other (explain in narrative)
99 - Unknown

Type

1 - Lane closure
2 - Lane switch/crossover
3 - Work on shoulder or median
4 - Intermittent or moving work
98 - Other (explain in narrative)
99 - Unknown

Workers Present?

1 - Workers only
2 - No workers present
3 - Workers and officer present
4 - Law enforcement only
5 - No one present
98 - Other (explain in narrative)
99 - Unknown

Harmful Events

Sequence of Events --- Most harmful Event --- First Harmful Event

Pre-crash events:
1 - Ran off road, right
2 - Ran off road, straight
3 - Ran off road, left
4 - Crossed centerline (undivided)
5 - Crossed median (divided)
6 - Evasive action (swerve, panic braking, avoidance)
7 - Downhill runaway
8 - Cargo/equipment loss or shift
9 - Equipment failure (tires, brakes, etc.)
10 - Towed portion came apart (separation of units)
11 - Loss of traction
12 - Trailer fishtailing or swaying
13 - Animal (avoided hitting)
94 - Other pre-crash (explain in narrative)

Non-collision events:
20 - Overturn/rollover
21 - Jackknife
22 - Non-contact vehicle (phantom)
23 - Vehicle went airborne
24 - Fell/jumped from vehicle
95 - Other non-collision (explain in narrative)

Collision with:
30 - Thrown or falling object
31 - Animal
32 - Non-motorist (see non-motorist section - NOT a unit)
33 - Vehicle in traffic
34 - Re-entering roadway
35 - Parked motor vehicle
36 - Work zone maintenance equipment
37 - Railway vehicle/train
38 - Struck/struck by object/cargo/person from other vehicle
96 - Other non-fixed object (explain in narrative)

Collision with fixed object:
40 - Bridge overhead structure
41 - Bridge pier or support
42 - Bridge/bridge rail parapet
43 - Curb/island/raised median
44 - Ditch
45 - Embankment
46 - Ground
47 - Culvert/pipe opening
48 - Guardrail - face
49 - Guardrail - end
50 - Concrete traffic barrier (median or right side)
51 - Other traffic barrier (explain in narrative)
52 - Cable barrier
53 - Impact attenuator/crash cushion
54 - Utility pole/light support
55 - Traffic sign support
56 - Traffic signal support
57 - Other post/pole/support (explain in narrative)
58 - Fire hydrant
59 - Mailbox
60 - Tree
61 - Landscape/shrubbery
62 - Snow bank
63 - Fence
64 - Wall
65 - Building
97 - Other fixed object (explain in narrative)

Miscellaneous events:
70 - Fire/explosion
71 - Immersion
72 - Hit and run
73 - Eluding law enforcement
74 - Gas inhalation/asphyxiation
75 - Vehicle out of gear/rolled
98 - Other (explain in narrative)
99 - Unknown

Roadway Characteristics

Contributing Circumstances, Environment

1 - None apparent
2 - Weather conditions
3 - Visual obstruction
4 - Non-motorist action
5 - Glare
6 - Animal in roadway
7 - Severe crosswind
98 - Other (explain in narrative)
99 - Unknown

Contributing Circumstances, Roadway

1 - None apparent
2 - Surface condition (e.g., wet, icy)
3 - Debris
4 - Ruts, holes, bumps
5 - Work Zone (roadway-related)
6 - Slippery, loose, or worn surface
7 - Obstruction in roadway
8 - Traffic control obscured
9 - Shoulders (none, low, soft, high)
10 - Non-highway work
11 - Traffic backup, prior crash
12 - Traffic backup, regular congestion
13 - Traffic backup, prior non-recurring incident
14 - Disabled vehicle
98 - Other (explain in narrative)
99 - Unknown

Type of Roadway Junction/Feature

Non-intersection:
1 - Non-junction/no special feature
2 - Bike lanes
3 - Railroad grade crossing
4 - Driveway access (within)
5 - Driveway access (related, not in)
6 - Alley
7 - Crossover-related
96 - Other non-intersection (explain in narrative)

Intersection-related:
10 - Roundabout
11 - Traffic circle
12 - Four-way intersection
13 - T-intersection
14 - Y-intersection
15 - Five points or more
16 - L-intersection
17 - Shared use path or trail
18 - Intersection with ramp
97 - Other intersection (explain in narrative)

Interchange-related:
20 - On-ramp merge area
21 - Off-ramp, diverge area
22 - On-ramp
23 - Off-ramp
24 - Mainline, between ramps
98 - Other interchange (explain in narrative)

99 - Unknown

Traffic Controls

1 - No controls present
2 - Traffic signals
3 - Flashing traffic control signal
4 - Stop signs
5 - Yield signs
6 - No passing zone (marked)
7 - Warning sign
8 - School zone signs
9 - Railway crossing device
10 - Traffic director (person)
11 - Work zone sign
12 - Inoperative (not functioning properly)
13 - Traffic sign missing
98 - Other (explain in narrative)
99 - Unknown

Horizontal Alignment (curve):

1 - Straight
2 - Traversing curve to left
3 - Traversing curve to right
98 - Other (explain in narrative)
99 - Unknown

Vertical Alignment (grade):

1 - Level
2 - At crest
3 - Traversing uphill
4 - Traversing downhill
5 - At sag (bottom of hill)
98 - Other (explain in narrative)
99 - Unknown

Page 3 of 4

Figure E-3. Iowa Accident Report Form (Prior to 2015) – Page 3

IOWADOT
Form 433014 (04-18)

INVESTIGATING OFFICER'S REPORT OF MOTOR VEHICLE ACCIDENT CODE SHEET

Injury/Protective Devices

Injury Status

1 - Fatal
2 - Suspected serious/incapacitating
3 - Suspected minor/non-incapacitating
4 - Possible (complaint of pain/injury)
5 - Uninjured
7 - Fatal, not crash-related
9 - Unknown

Died at Scene/Enroute

1 - Not applicable
2 - Died at scene
3 - Died enroute
4 - Died at hospital
5 - Died later (w/in 30 days)
98 - Other (explain in narrative)
99 - Unknown

Source of Transport

1 - Not transported
2 - EMS air
3 - EMS ground
4 - Law enforcement
5 - Parent/spouse/friend
6 - Self
7 - To funeral home/morgue
98 - Other (explain in narrative)
99 - Unknown

Non-motorist (see non-motorist section below)

1 - Pedestrian
2 - Pedalcyclist (bicycle, tricycle, unicycle, pedal car)
3 - Pedalcycle passenger
4 - In or on building
5 - Horse and Buggy
6 - Skater, personal conveyance, wheelchair
98 - Other non-motorist (explain in narrative)
99 - Unknown

Seating Position

1	2	3	1st Row
4	5	6	2nd Row
7	8	9	3rd Row
10	11	12	4th Row
13	14	15	5th Row

16 - In 6th row or greater
17 - In enclosed passenger/cargo area
18 - In unenclosed passenger/cargo area
19 - Sleeper
20 - Trailing unit
21 - Riding on exterior of vehicle
22 - Hanging onto vehicle
23 - Passenger of motorcycle/moped/ATV
98 - Other vehicle-related (explain in narrative)
99 - Unknown

Trapped/Extricated

1 - Not trapped/applicable
2 - Extricated by non-mechanical means
3 - Extricated by mechanical means
9 - Unknown

Ejection

1 - Not applicable
2 - Not ejected
3 - Partially ejected
4 - Totally ejected
9 - Unknown

Type of Primary Incident

1 - Vehicle Crash
2 - Traffic Stop
3 - Roadway Debris
4 - Motorist Assist
5 - Other (Explain in narrative)

Occupant Protection

1 - Not applicable
2 - None used
3 - Shoulder and lap belt used
4 - Lap belt only used
5 - Shoulder belt only used
6 - Child safety seat (forward-facing)
7 - Child safety seat (rear-facing)
8 - Child safety seat (type unknown)
9 - Booster seat
10 - Helmet (DOT compliant)
11 - Helmet (other)
98 - Other (explain in narrative)
99 - Unknown

Airbag Deployment

1 - Not applicable
2 - Airbag turned off
3 - Not deployed
4 - Deployed front of person
5 - Deployed side of person
6 - Deployed both front/side
7 - Deployed curtain
98 - Other deployment (explain in narrative)
99 - Unknown

Ejection Path

1 - Not ejected/not applicable
2 - Through front windshield
3 - Through side window
4 - Through side door
5 - Through roof
6 - Through back window
7 - Through back door/tailgate opening
98 - Other (explain in narrative)
99 - Unknown

Non-Motorist

Location (prior to impact)

Intersection:

1 - Within marked crosswalk
2 - Within unmarked crosswalk
3 - Not within crosswalk
4 - Unknown location

Non-intersection (midblock):

5 - Within marked crosswalk
6 - Within unmarked crosswalk
7 - Not within crosswalk
8 - Unknown location

9 - Parking lane/zone
10 - Pedalcycle lane
11 - Sidewalk
12 - Driveway access
13 - Shared path or trail
14 - Shoulder/roadside
15 - Median/crossing island
16 - Non-trafficway
17 - Travel lane, other location

98 - Other (explain in narrative)
99 - Unknown

Action (prior to crash)

1 - Entering or crossing roadway
2 - Waiting to cross roadway
3 - Going to/coming from school
4 - Working in trafficway
5 - Approaching or leaving vehicle
6 - Entering/exiting vehicle
7 - Playing on or working on vehicle
8 - Disabled vehicle-related/pushing vehicle

Movement:

10 - Along roadway with traffic
11 - Along roadway against traffic
12 - Along roadway (direction unknown)
13 - On shoulder/median
14 - On sidewalk

98 - Other (explain in narrative)
99 - Unknown

Condition

1 - Apparently normal
2 - Emotional (e.g., depressed, angry)
3 - Asleep/fatigued
4 - Illness/fainted
5 - Medical condition (seizure, reaction)
6 - Under the influence of alcohol
7 - Under the influence of drugs/meds
8 - Physical impairment
9 - Walks with a cane/crutches
10 - Paraplegic/wheelchair restricted
11 - Impaired due to previous injury
12 - Hearing impaired/deaf
13 - Visually impaired/blind

98 - Other (explain in narrative)
99 - Unknown

Safety Equipment

1 - Not applicable
2 - None
3 - Helmet
4 - Reflective clothing
5 - Lighting
6 - Protective pads
7 - Multi-equipment (explain in narrative)
98 - Other (explain in narrative)
99 - Unkown

Contributing Circumstances

1 - No improper action
2 - Not visible (dark clothing)
3 - Improper crossing
4 - Darting/dashing
5 - Inattentive (talking, eating, texting)
6 - Riding/walking on wrong side of road
7 - Failure to obey traffic signs, signals, or officer
8 - Failure to yield right-of-way
9 - Failure to have lights on when required
10 - Operating without required equipment
11 - Improper riding (more riders than seats)
12 - Improper turn/merge
13 - Improper passing
14 - Passing with insufficient distance or inadequate visibility
15 - Improper/erratic lane changing
16 - Failure to remain in proper lane
17 - Operating in a reckless, erratic, careless, negligent manner
18 - Improper exit/entry from trafficway
19 - In roadway improperly (standing, sitting, lying, working, playing)
20 - Disabled vehicle-related (working on, pushing, leaving/approaching)
21 - Entering/exiting parked/standing vehicle
98 - Other (explain in narrative)
99 - Unknown

Page 4 of 4

Figure E-4. Iowa Accident Report Form (Prior to 2015) – Page 4

Form 433002 (04 -17)

IOWADOT

IOWA ACCIDENT REPORT FORM

An accident occurring anywhere within the State of Iowa causing death, personal injury, or total property damage of $1,500.00 or more must be reported on this accident report form. Please return form to our office as soon as estimates can be obtained.

Instructions

Please print or type all information. Use black or dark blue ink.

Step 1. Begin completing the "Report of Motor Vehicle Accident" form by entering accident date, day of week, time, number of vehicles, total number killed, number injured, and the total amount of damage to all vehicles and any property other than vehicles.

Step 2. Enter the information pertaining to all drivers and vehicles involved in the accident. Important: Be sure to include the driver's name, driver license number, and driver license state. Also include the vehicle owner's name, license plate number, and license plate state and year. If more than two drivers or two vehicles were involved, use an extra report form or sheet of paper making sure that the extra vehicles and drivers are numbered 3, 4, 5, etc. Total occupants are all persons in the vehicle, driver included.

If you were involved in an accident with a pedestrian, print PEDESTRIAN in the driver space provided for vehicle No. 2 and complete pedestrian information in Step 7. If you were involved in an accident with a pedalcyclist (bicycle, etc.) print 'Bike' in the driver space provided for Vehicle 2 and complete information for Non-Motorist in Step 7.

If one of the vehicles involved was parked at the time of the accident, print PARKED in the driver space and complete the vehicle owner information.

Step 3. Please use the following codes when completing the box marked VEHICLE TYPE CODE:

01 - Passenger Car
02 - Four-tire truck (pick-up)
03 - Sport utility vehicle
04 - Passenger van (seats <9)
05 - Passenger van (seats 9 - 15)
06 - Cargo/panel van
07 - Single-unit truck (2-axle, 6-tire)
08 - Single-unit truck (> = 3 axles)
09 - Other light truck (<=10,000 lbs.)
10 - Vehicle <=10,000 lbs., placarded for hazardous materials
11 - Truck/Trailer
12 - Truck tractor (bobtail)
13 - Tractor/semi-trailer
14 - Tractor/doubles
15 - Tractor/triples
16 - Other heavy truck (>10,000 lbs.) (cannot classify)
17 - Motorcycle
18 - 3-wheeled, enclosed
19 - 3-wheeled, unenclosed
20 - Moped
21 - Motor home/recreational vehicle
22 - School bus (seats >15)
23 - Small school bus (seats 9 -15)
24 - Other bus (seats >15)
25 - Other small bus (seats 9 - 15)
26 -Farm tractor
27 - Farm equipment (explain in narrative)
28 - All-terrain vehicle (ATV)
29 - Snowmobile
30 - Golf cart
31 - Street legal, low-speed vehicle
32 - Limousine/taxi (seats 8 or less)
33 - Limousine/taxi (seats 9 - 15)
34 - Limousine/taxi (seats >15)
35 - Maintenance/construction vehicle
36 - Train
98 - Other (explain in narrative)
99 - Unknown

Step 4. The location of the accident is very important. Please be as specific as possible.

Step 5. To the best of your ability, complete the Accident Codes section for **your own vehicle** using codes provided on page 2 of this form.

Step 6. If there is damage to property other than the vehicles involved complete the property damage information.

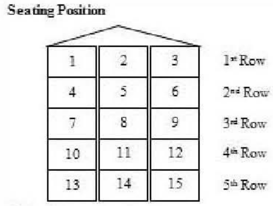
Step 7. Injury information should be entered in the space provided. Make sure that the vehicle number in which the injured party was riding is complete, describe the nature of the injury, and check the box under the column most appropriate for the injury severity. NOTE: Include all drivers whether injured or not. The codes are:

Injury Status
01 - Fatal
02 - Suspected serious/incapacitating
03 - Suspected minor/non-incapacitating
04 - Possible (complaint of pain/injury)
05 - Uninjured
07 - Fatal, not crash-related
09 - Unknown

Ejection Path
01 - Not ejected/not applicable
02 - Through front windshield
03 - Through side window
04 - Through side door
05 - Through roof
06 - Through back window
07 - Through back door/tailgate opening
98 - Other (explain in narrative)
99 - Unknown

Occupant Protection
01 - Not applicable
02 - None used
03 - Shoulder and lap belt used
04 - Lap belt only used
05 - Shoulder belt only used
06 - Child safety seat (forward-facing)
07 - Child safety seat (rear-facing)
08 - Child safety seat (type unknown)
09 - Booster seat
10 - Helmet (DOT compliant)
11 - Helmet (other)
98 - Other (explain in narrative)
99 - Unknown

Seating Position



Airbag Deployment
01 - Not applicable
02 - Airbag turned off
03 - Not deployed
04 - Deployed front of person
05 - Deployed side of person
06 - Deployed both front/side
07 - Deployed curtain
98 - Other deployment (explain in narrative)
99 - Unknown

Type Non-Motorist (see non-motorist section below)
01 - Pedestrian
02 - Pedalcyclist (bicycle, tricycle, unicycle pedal car)
03 - Pedalcycle passenger
04 - In or on building
05 - Horse and buggy
06 - Skater, personal conveyance, and wheelchair
98 - Other (explain in narrative)
99 - Unknown

Seating position codes continued on Page 2

(Instructions continued on page 2)

-1-

Figure E-5. Iowa Accident Report Form (2015 Onward) – Page 1

Form 433002 (04 -17)

(Instructions continued from page 1)

Step 8. To the best of your ability, complete the accident diagram and description as briefly as possible. Important: If you are vehicle No. 1 in Step 2 make sure that your vehicle is vehicle No. 1 in the description and diagram. Indicate if there has been a Peace Officer investigation.

Step 9. Complete the insurance information on the back of the report. Failure to complete insurance coverage information may result in a suspension of your driving and registration privileges.

Step 10. Sign the accident report and tear at the perforated line and return accident report to:

Iowa Department of Transportation
Driver & Identification Services
6310 SE Convenience Boulevard
Ankeny, IA 50021

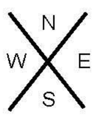
ACCIDENT CODES *(See Step 5)*

Seating Position Codes (cont.)

16 - In 6th row or greater
17 - In enclosed passenger/cargo area
18 - In unenclosed passenger/cargo area
19 - Sleeper
20 - Trailing unit
21 - Riding on exterior of vehicle
22 - Hanging onto vehicle
23 - Passenger of motorcycle/moped/ATV
98 - Other vehicle-related (explain in narrative)
99 - Unknown

A Initial Travel Direction

01 - North
02 - East
03 - South
04 - West
99 - Unknown



B Vehicle Action

01 - Movement essentially straight
02 - Turning Left
03 - Turning right
04 - Making U-turn
05 - Overtaking/passing
06 - Changing lanes
07 - Entering traffic lane (merging)
08 - Leaving traffic lane
09 - Backing
10 - Slowing/stopping (decelerating)
11 - Stopped in traffic
12 - Legally parked
13 - Illegally parked/unattended
14 - Negotiating a curve
15 - Starting in road
16 - Accelerating in road
17 - Leaving a parked position
18 - Entering a parked position
98 - Other (explain in narrative)
99 - Unknown

C Driver Condition

01 - Apparently normal
02 - Emotional (e.g., depressed, angry)
03 - Asleep/fatigued
04 - Illness/fainted
05 - Medical condition (seizure, reaction)
06 - Under the influence of alcohol
07 - Under the influence of drugs/meds
08 - Physical impairment
09 - Walks with a cane/crutches
10 - Paraplegic/wheelchair restricted
11 - Impaired due to previous injury
12 - Hearing impaired/deaf
13 - Visually impaired
98 - Other (explain in narrative)
99 - Unknown

D Vision Obscured

01 - Not obscured
02 - Trees/crops
03 - Embankment
04 - Hillcrest
05 - Building(s)
06 - Sign/billboard
07 - Parked vehicle(s)
08 - Moving vehicle(s)
09 - Person/object in or on vehicle
10 - Blinded by sun or headlights
11 - Broken/dirty windshield
12 - Frosted windows/windshield
13 - External mirrors
14 - Blowing snow
15 - Fog/smoke/dust
16 - Splash/spray of passing vehicle
17 - Inadequate vehicle lighting
18 - Exterior angle/blind spot on vehicle
98 - Other (explain in narrative)
99 - Unknown

E Traffic Controls

01 - No controls present
02 - Traffic signals
03 - Flashing traffic control signal
04 - Stop signs
05 - Yield signs
06 - No passing zone (marked)
07 - Warning sign
08 - School zone signs
09 - Railway crossing device
10 - Traffic director (person)
11 - Work zone sign
12 - Inoperative (not functioning properly)
13 - Traffic sign missing
98 - Other (explain in narrative)
99 - Unknown

F First Harmful Event

Non-collision events:

20 - Overturn/rollover
21 - Jackknife
22 - Non-contact vehicle (phantom)
23 - Vehicle went airborne
24 - Fell/jumped from vehicle
95 - Other non-collision (explain in narrative)

Collision with:

30 - Thrown or falling object
31 - Animal
32 - Non-motorist **(do not fill as a unit)**
33 - Vehicle in traffic
34 - Re-entering roadway
35 - Parked motor vehicle
36 - Work zone maintenance equipment
37 - Railway vehicle/train
38 - Struck/struck by object/cargo/person from other vehicle
96 - Other non-fixed object (explain in narrative)

F First Harmful Event (cont.)

Collision with fixed object:

40 - Bridge overhead structure
41 - Bridge pier or support
42 - Bridge/bridge rail parapet
43 - Curb/island/raised median
44 - Ditch
45 - Embankment
46 - Ground
47 - Culvert/pipe opening
48 - Guardrail - face
49 - Guardrail - end
50 - Concrete traffic barrier (median or right side)
51 - Other traffic barrier (explain in narrative)
52 - Cable barrier
53 - Impact attenuator/crash cushion
54 - Utility pole/light support
55 - Traffic sign support
56 - Traffic signal support
57 - Other post/pole/support (explain in narrative)
58 - Fire hydrant
59 - Mailbox
60 - Tree
61 - Landscape/shrubbery
62 - Snow bank
63 - Fence
64 - Wall
65 - Building
97 - Other fixed object (explain in narrative)

Miscellaneous events:

70 - Fire/explosion
71 - Immersion
72 - Hit and run
73 - Eluding law enforcement
74 - Gas inhalation/asphyxiation
75 - Vehicle out of gear/rolled
98 - Other (explain in narrative)
99 - Unknown

G Location of Accident

01 - On roadway
02 - Shoulder
03 - Median
04 - Roadside
05 - Gore
06 - Outside trafficway
07 - In parking lane/zone
08 - Continuous left turn lane
09 - Separator
98 - Other (explain in narrative)
99 - Unknown

H Manner of Crash/Collision

01 - Non-collision (single vehicle)
02 - Head-on (front to front)
03 - Rear end (front to rear)
04 - Angle, oncoming left turn
05 - Broadside (front to side)
06 - Sideswipe, same direction
07 - Sideswipe, opposite direction
08 - Rear to rear
09 - Rear to side
98 - Other (explain in narrative)
99 - Unknown

I Light Conditions

01 - Daylight
02 - Dusk
03 - Dawn
04 - Dark, roadway lighted
05 - Dark, roadway not lighted
06 - Dark, unknown roadway lighting
09 - Unknown

J Weather Conditions (up to two)

01 - Clear
02 - Cloudy
03 - Fog, smoke, smog
04 - Freezing rain/drizzle
05 - Rain
06 - Sleet, hail
07 - Snow
08 - Blowing snow
09 - Severe winds
10 - Blowing sand, soil, dirt
98 - Other (explain in narrative)
99 - Unknown

K Surface Conditions

01 - Dry
02 - Wet
03 - Ice/Frost
04 - Snow
05 - Slush
06 - Mud, dirt
07 - Water (standing or moving)
08 - Sand
09 - Oil
10 - Gravel
98 - Other (explain in narrative)
99 - Unknown

L Type of Roadway Junction

Non-Intersection

01 - Non-junction/no special feature
02 - Bike lanes
03 - Railroad grade crossing
04 - Driveway access (within)
05 - Driveway access (related, not in)
06 - Alley
07 - Crossover-related
96 - Other non-intersection (explain in narrative)

Intersection-related

10 - Roundabout
11 - Traffic circle
12 - Four-way intersection
13 - T-intersection
14 - Y-intersection
15 - Five points or more
16 - L-intersection
17 - Shared use path or trail
18 - Intersection with ramp
97 - Other intersection (explain in narrative)

Interchange-related

20 - On-ramp merge area
21 - Off-ramp, diverge area
22 - On-ramp
23 - Off-ramp
24 - Mainline, between ramps
98 - Other interchange (explain in narrative)
99 - Unknown

-2-

Figure E-6. Iowa Accident Report Form (2015 Onward) – Page 2

Form 433002 (04 -17)

IOWADOT

REPORT OF MOTOR VEHICLE ACCIDENT

See instructions on completing *(please print or type)*

Did accident occur on private property? ☐ Yes ☐ No

Step 1.

Accident Date (Mo/Day/Year)	Day of Week	Time ☐ AM ☐ PM	Number of Vehicles	Total Killed	Total Injured	Total Estimated Damage $

Step 2. **No. 1 (YOUR VEHICLE)** — **No. 2 (OTHER VEHICLE)**

DRIVER

Date of Birth	Sex	Dr. Lic. State	Driver License Number
Last Name of Driver 1	First Name	Middle Initial	
Number and Street	City	State	ZIP Code

Date of Birth	Sex	Dr. Lic. State	Driver License Number
Last Name of Driver 2	First Name	Middle Initial	
Number and Street	City	State	ZIP Code

OWNER

Last Name of Owner 1	First Name	Middle Initial	
Number and Street	City	State	ZIP Code

Last Name of Owner 2	First Name	Middle Initial	
Number and Street	City	State	ZIP Code

VEHICLE

No. of Occupants	Plate Number	State of Registration	Year
Vehicle Identification Number (VIN)	Estimated Cost of Repairs		
Vehicle Year and Make	**Step 3.** Vehicle Type Code		

No. of Occupants	Plate Number	State of Registration	Year
Vehicle Identification Number (VIN)	Estimated Cost of Repairs		
Vehicle Year and Make	**Step 3.** Vehicle Type Code		

Step 4. **LOCATION OF ACCIDENT**

County | Accident occurred within corporate limits of (city)

If accident occurred outside of city limits, describe distance to city ______ miles N NE E SE S SW W NW ◯◯◯◯◯◯◯◯ of nearest city ______

Name of Road, Street, or Highway ______ At intersection with ______

Note: Unless accident occurred at an intersection which is completely described above, use the space below to give the exact location from a milepost or definable intersection, bridge, or railroad crossing using two distances and directions if necessary.

Feet ____ or Miles ____ N NE E SE S SW W NW ◯◯◯◯◯◯◯◯ and Feet ____ or Miles ____ N NE E SE S SW W NW ◯◯◯◯◯◯◯◯ of ______

Milepost Number Or Definable intersection, bridge, or railroad crossing

Step 5. Accident codes *(on page 2)* for your own vehicle:

A Direction of Travel	B Vehicle Action	C Driver Condition	D Vision Obscured
E Traffic Controls	F First Harmful Event	G Location of Accident	H Manner of Crash
I Light Conditions	J Weather Conditions	K Surface Conditions	L Type of Roadway Junction/Feature

Step 6. Identify Damaged Property Other Than Vehicles | Owner | Amount of Damage

Step 7. **Injury Section:** Fill Out Space Below For Every Person Injured Or Killed In The Accident *(Attach additional sheets if necessary)*

Insert Correct Code *(See Step 7 of Instructions)*

Name and Address	In Vehicle Number	Date of Birth	Gender	Describe Injuries	Seating Position	Type Non-Motorist	Injury Status	Occupant Protection	Airbag Deployment	Ejection	Date of Death

-3-

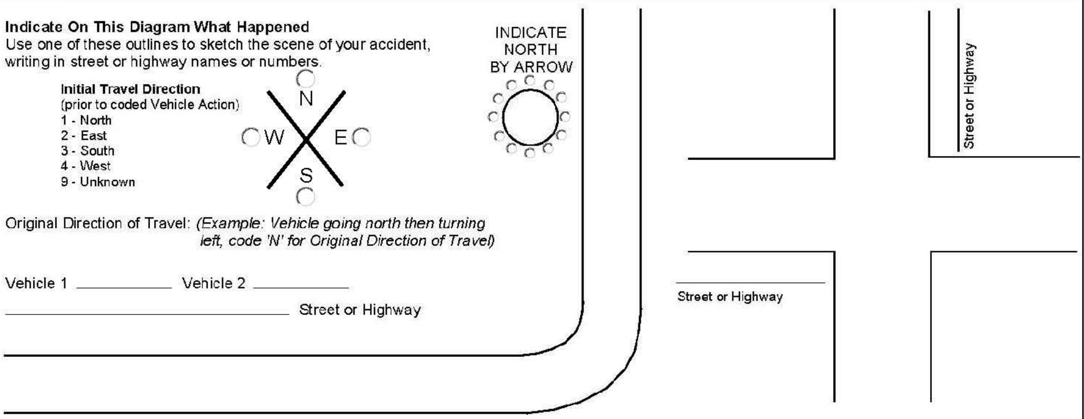
Figure E-7. Iowa Accident Report Form (2015 Onward) – Page 3

Form 433002 (10 -13)

Step 8.

Indicate On This Diagram What Happened
Use one of these outlines to sketch the scene of your accident, writing in street or highway names or numbers.

Initial Travel Direction
(prior to coded Vehicle Action)
1 - North
2 - East
3 - South
4 - West
9 - Unknown



Original Direction of Travel: *(Example: Vehicle going north then turning left, code 'N' for Original Direction of Travel)*

Vehicle 1 __________ Vehicle 2 __________

Description

Did Peace Officer investigate? ☐ Yes ☐ No Department ____________________

If you did not have automobile liability insurance coverage for this accident, please check this box ☐.

If you had automobile liability insurance coverage for this accident, please complete insurance information below:

Failure To Complete Insurance Coverage Information Requested Below May Result In A Suspension Of Your Driving And/Or Registration Privileges.

Step 9.

Name of Insurance Company **(Not Agent)** Providing Insurance To Cover Your Liability For Damage Or Injury To Others:

Name of Agent Who Sold Policy ____________________

Agent Address ____________________

Policy No. __________ Policy Period: From __________ Agent Phone No. __________

V.I.N. No. (if not previously given) ____________________

Name of Driver ____________________

Name of Owner ____________________

Name of Policyholder ____________________

Step 10.

Date	Signature of Driver of Vehicle No. 1	If Signed By Person Other Than Driver, Give Reason

IMPORTANT: This accident should also be reported directly to your insurance company. Failure to report may jeopardize your automobile liability insurance.

-4-

Figure E-8. Iowa Accident Report Form (2015 Onward) – Page 4

END OF DOCUMENT