engineers + planners + land surveyors

PHASE 1: DEVELOPMENT OF COUNTY BRIDGE STANDARDS FOR SINGLE SPAN CONCRETE SLAB BRIDGES

IHRB Project TR 812

FINAL REPORT
September 2022

Sponsored by:

Iowa Highway Research Board (IHRB)

and

Federal Highway Administration –
State Transportation Innovation
Council

Disclaimer Notice

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the sponsors.

The sponsors assume no liability for the contents or use of the information contained in this document. This report does not constitute a standard, specification, or regulation. The sponsors do not endorse products or manufacturers. Trademarks or manufacturers' names appear in this report only because they are considered essential to the objectives of the document.

Statement of Non-Discrimination

Federal and state laws prohibit employment and/or public accommodation discrimination on the basis of age, color, creed, disability, gender identity, national origin, pregnancy, race, religion, sex, sexual orientation or veteran’s status. If you believe you have been discriminated against, please contact the Iowa Civil Rights Commission at 800-457-4416 or Iowa Department of Transportation's affirmative action officer. If you need accommodations because of a disability to access the Iowa Department of Transportation’s services, contact the agency's affirmative action officer at 800-262-0003.

Technical Report Documentation Page

1. Report No. IHRB Project TR-812	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle Phase 1: Development of County Bridge Standards for Single Span Concrete Slab Bridges	**5. Report Date** September 2022 **6. Performing Organization Code:**
7. Author(s) Bradley Fleming and Joshua Opheim	**8. Performing Organization Report No.**
9. Performing Organization Name and Address WHKS & Co. 1421 South Bell Ave., Suite 103 Ames, IA 50010	**10. Work Unit No.** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address Iowa Highway Research Board Iowa Department of Transportation 800 Lincoln Way Ames, IA 50010	**13. Type of Report and Period** Final Report **14. Sponsoring Agency Code**

15. Supplementary Notes

16. Abstract

Nearly 10.5% of all highway bridges in the United States are classified as concrete slab bridges according to the U.S. 2020 National Bridge Inventory (NBI). Concrete slab bridges are typically single spans (20-50 feet) or multiple spans for relatively short stream crossings. The Iowa Department of Transportation (Iowa DOT) currently has three-span continuous concrete bridge standards (J-series) with lengths between 70-150 feet, but there are no single span concrete slab bridge standards.

The objective of this project was to investigate the current practices, need, benefits, economy, constructability, and design criteria for cast-in-place (CIP) single span concrete slab (SSCS) standard bridge plans. A preliminary analysis was conducted to determine slab thickness and reinforcement requirements for various spans and roadway widths to compare costs with other bridge types and concrete box culverts in Iowa.

Examples of existing SSCS bridges and a summary of the bridge inventory for bridges less than 70 feet were presented to show the extent of short span bridge design and use in Iowa. Currently, Iowa has a lower inventory of concrete slab bridges (5.1%) compared to other bridge types less than 70 feet in length, such as concrete box culverts (33.1%) and steel stringer bridges (25.0%). The cost analysis shows that SSCS bridges with integral abutments have about the same costs per square foot of deck area (avg. \$195/ft^2) compared to standard concrete box culverts with 4 foot tall sidewalls (avg. \$203/ft^2) and steel stringer bridges with integral abutments (avg. \$194/ft^2) but are less expensive than standard precast box beam bridges with integral abutments (avg. \$235/ft^2). SSCS bridges with high abutments are less expensive (avg. \$294/ft^2) than standard concrete box culverts with 12 foot tall sidewalls (avg. \$431/ft^2) and standard precast box beam bridges with high abutments (avg. \$314/ft^2).

SSCS bridges have several advantages compared to concrete box culverts. Based on a survey submitted to Iowa county engineers, SSCS bridges have less right-of-way requirements, reduced streambed disturbance, and may more easily satisfy Army Corps of Engineers 404 permit requirements. Other advantages identified in the survey include improved hydraulic performance and less siltation/debris. Disadvantages include the need for a guardrail, longer construction, and potential maintenance/durability issues.

It is recommended to proceed with final design and development of the SSCS standard bridge plans following the design criteria recommendations provided in this report. The Iowa DOT Bridges and Structures Bureau (BSB) will maintain oversight and updates for the SSCS standard plans. The standards should be published to the BSB website to make them available to the county engineers.

Based on the findings, future work is recommended, as outlined at the conclusion of this report.

17. Key Words Bridge, concrete, slab, short span, single span, standards	**18. Distribution Statement** No restrictions.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 47	**22. Price** NA

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

PHASE 1: DEVELOPMENT OF COUNTY BRIDGE STANDARDS FOR SINGLE SPAN CONCRETE SLAB BRIDGES
IHRB Project TR-812

Final Report
September 2022

Principal Investigator:
Fouad Daoud, P.E. & S.E.

Co-Principal Investigators:
Joshua Opheim, P.E.
Bradley Fleming, P.E.

Authors:
Bradley Fleming and Joshua Opheim

Sponsored by the Iowa Highway Research Board (IHRB) and the Federal Highway Administration – State Transportation Innovation Council

Prepared by:

WHKS & Co.
1421 South Bell Ave., Suite 103
Ames, IA 50010
Phone: 515-663-9997
www.whks.com

whks
engineers + planners + land surveyors

Table of Contents

List of Figures

List of Tables

Acknowledgments

The investigators and authors would like to thank the Iowa Highway Research Board (IHRB) and the Federal Highway Administration – State Transportation Innovation Council for sponsoring this work. The authors would also like to thank members of the Technical Advisory Committee for their contributions and direction.

Executive Summary

Nearly 10.5% of all highway bridges in the United States are classified as concrete slab bridges according to the U.S. 2020 National Bridge Inventory (NBI). Concrete slab bridges are typically single spans (20-50 feet) or multiple spans for relatively short stream crossings. The Iowa Department of Transportation (Iowa DOT) currently has three-span continuous concrete bridge standards (J-series) with lengths between 70-150 feet, but there are no single span concrete slab bridge standards.

The objective of this project is to investigate the current practices, needs, benefits, economy, constructability, and design criteria for cast-in-place (CIP) single span concrete slab (SSCS) standard bridge plans. A preliminary analysis was conducted to determine slab thickness and reinforcement requirements for various spans and roadway widths to compare costs with other bridge types and concrete box culverts in Iowa including three-span continuous concrete slab bridges (J-series), precast box beam bridges (B-series), single span pretensioned prestressed concrete beam bridges (H-series), concrete box culverts with single, double, and triple barrels (RCB-, TWRCB-, TRRCB-series), and steel stringer bridges.

Examples of existing SSCS bridges and a summary of the bridge inventory for bridges less than 70 feet were presented to show the extent of short span bridge design and use in Iowa. Currently, Iowa has a lower inventory of concrete slab bridges (5.1%) compared to other bridge types less than 70 feet in length, such as concrete box culverts (33.1%) and steel stringer bridges (25.0%). The cost analysis shows that SSCS bridges with integral abutments have about the same costs per square foot of deck area (avg. \$195/ft^2) compared to standard concrete box culverts with 4 foot tall sidewalls (avg. \$203/ft^2) and steel stringer bridges with integral abutments (avg. \$194/ft^2) but are less expensive than standard precast box beam bridges with integral abutments (avg. \$235/ft^2). SSCS bridges with high abutments are less expensive (avg. \$294/ft^2) than standard concrete box culverts with 12 foot tall sidewalls (avg. \$431/ft^2) and standard precast box beam bridges with high abutments (avg. \$314/ft^2).

SSCS bridges have several advantages compared to concrete box culverts. Based on results of a survey submitted to Iowa county engineers, SSCS bridges have less right-of-way requirements, improved hydraulic performance, and less siltation/debris. New Army Corps of Engineers 404 permit requirements which encourage reduced streambed disturbance is likely to favor SSCS bridges. Disadvantages include the need for a guardrail, longer duration construction, and potential maintenance/durability issues.

It is recommended to proceed with final design and development of the SSCS standard bridge plans following the design criteria recommendations provided in this report. The Iowa DOT Bridges and Structures Bureau (BSB) will maintain oversight and updates for the SSCS standard plans. The standards should be published to the BSB website to make them available to the county engineers.

Based on the Iowa DOT *Bridge Design Manual*, the design of the slab is required to meet AASHTO's maximum live load deflections or minimum slab thickness, whichever results in a thinner slab. Future work is recommended for incorporating the stiffness of the barrier rails and bridge supports in the final design. This will improve calculating the live load deflections and facilitate the design of top longitudinal reinforcement by including fixity and thermal end moments at the supports. Evidence also showed that AASHTO LRFD Bridge Design Specifications are conservative for primary longitudinal reinforcement for skewed bridges but can be significantly unconservative for transverse (distribution) reinforcement and shear. A two-dimensional analysis is recommended to accurately calculate the effects of bridge skew as well as correctly design for bottom transverse (distribution) reinforcement and shear in the slab.

Introduction

1.1 Problem Statement

Concrete slab bridges are typically single span (20-50 feet) or multiple spans for relatively short stream crossings. They are generally regarded as a cost-effective option over bridges with beams. As a result, they are used widely in the United States. Nearly 10.5% of all highway bridges are classified as concrete slab bridges according to the U.S. 2020 National Bridge Inventory (NBI). The Iowa Department of Transportation (Iowa DOT) maintains county bridge standards for continuous concrete slab bridges (J-series) with three spans having bridge lengths between 70-150 feet, but there are no single span concrete slab bridge standards. Single span concrete slab bridges may be a preferred option over other standardized short span structures including box culverts and box beam bridges. Due to the number of short span bridges on secondary roads throughout the state in need of replacement and the limited resources for design, there is a need for additional bridge standards that can be easily and economically employed by Iowa counties and cities.

1.2 Objectives

The Phase 1 objectives of this project are to investigate the current practices, needs, benefits, economy, constructability, and design criteria for new county bridge standard plans incorporating cast-in-place (CIP) single span concrete slab (SSCS) bridges. A preliminary analysis will determine slab thickness and reinforcement requirements for various spans and roadway widths to compare costs with other bridge types. This investigation is intended to facilitate a future Phase 2 project including final design for SSCS bridges and developing standard plans.

1.3 Research & Analysis Overview

This project involves a review of current design practices for short span bridges. Examples of current SSCS bridges in Iowa are presented including rail types, abutment types, span lengths, slab thickness, reinforcement, and skew as well as an inventory of all short span structures (structure lengths between 20-70 feet) in Iowa. The inventory is sorted by structure length, skew, and year of construction. The number of SSCS bridges per group is compared to the number of other structure types in Iowa.

A survey was submitted to Iowa county engineers requesting input on preferred SSCS bridge features (e.g., abutment types, railing types, skew, maximum span length, etc.). It also asked engineers for their opinion on the benefits and drawbacks of SSCS bridges. The survey gauged interest among county engineers for constructing SSCS bridges in their counties. Variations and similarities in their responses are described.

A review of other state practices for the design of short span bridges was conducted. The review was based on bridge design manuals and standard bridge plans of DOTs in various states. A summary of bridge designs was created including typical bridge types, span lengths, roadway widths, skews, abutment types, and railing types. States that have standard bridge plans for short span bridges are noted.

A preliminary analysis and design of the slab for SSCS bridges was performed for span lengths 20-60 feet and roadway widths 24 and 30 feet. Minimum slab thickness, minimum flexural steel and maximum live load deflections are presented. Effects of skew were not included in the preliminary analysis, but they are discussed in terms of varying slab longitudinal and distribution steel. Design criteria for the development of standard bridge plans are presented.

A cost analysis of several bridges and culverts typically used in Iowa are presented. Structures from Iowa DOT standards (RCB-, TWRCB-, TRRCB-, B-, J-, and H-series), SSCS, and steel stringer bridges are included. Costs of SSCS bridges are based on preliminary analysis of the bridge slab as discussed in this report. Recommendations for developing SSCS standard bridge plans are based on cost analysis, hydraulics, and constructability.

Review of Current Practices

2.1 Existing Single Span Concrete Slab Bridge Examples

A few examples of existing SSCS bridges in Iowa are presented as case studies. These bridges have different railings, skew, span lengths, slab thickness, and reinforcement patterns.

Figure 1 shows a transverse cross-section of the existing Boone County (BROS-SWAP-C008(74)—SE-08) SSCS bridge on U Avenue over Montgomery Creek. This is a county bridge with a 50 foot span and 30 foot wide roadway. It has a 0 degree skew, integral abutments, and standard open barrier rails. The slab is 24 inches thick with 4 bottom longitudinal reinforcement bars per 18 inches width of the slab (4 ½ inch spacing). There are two #10 bars and two #11 bars in an alternating pattern of 1-#10 and 1-#11 across the bottom and three consecutive #11 bars under each barrier rail. The top longitudinal reinforcement bars are #6 at 18 inch spacing. The transverse reinforcement bars are #7 and #5 at 12 inch spacing across the bottom and top of the slab, respectively. Additional #5 transverse reinforcement bars at 12 inch spacing are placed below the barrier rails in the top of slab.

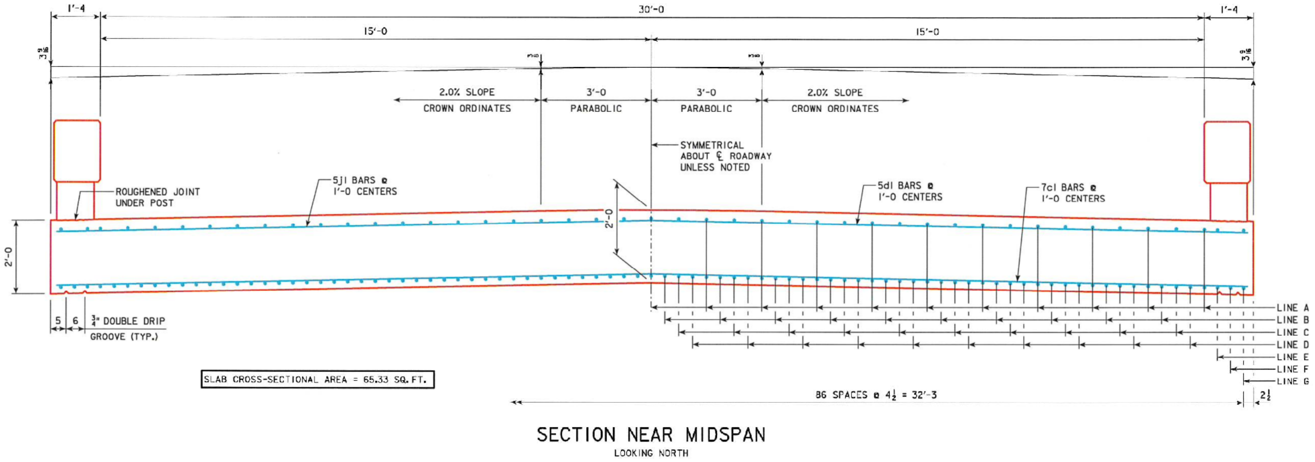


Figure 1. Boone County SSCS bridge transverse section (BROS-SWAP-C008(74)—SE-08)

Figure 2 shows a transverse cross-section of the existing Dubuque County (BROS-SWAP-C031(94)—SE-31) SSCS bridge on Arensdorf Road over Otter Creek. This is a county bridge with a 50 foot span and 30 foot wide roadway. It has a 0 degree skew, integral abutments, and standard F-shape barrier rails. The slab is 30 inches thick with 3 bottom longitudinal reinforcement bars per 18 inch width of the slab (6 inch spacing). All bottom reinforcement bars are #11. The top longitudinal reinforcement bars are #5 at 12 inch spacing. The transverse reinforcement bars are #7 and #5 at 12 inch spacing across the bottom and top of the slab, respectively. Additional #5 transverse reinforcement bars at 12 inch spacing are placed below the barrier rails in the top of slab.

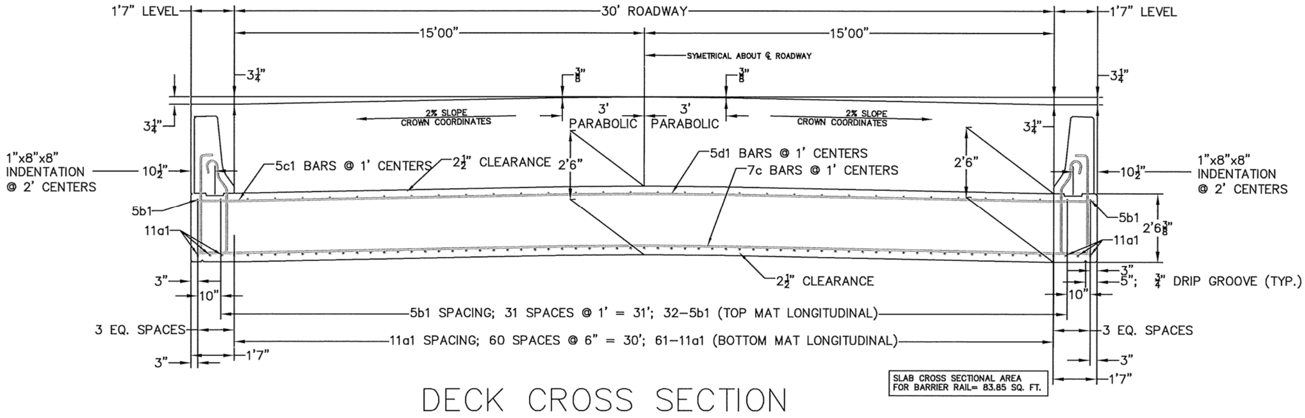


Figure 2. Dubuque County SSCS bridge transverse section (BROS-SWAP-C031(94)—SE-31)

Figure 3 shows a transverse cross-section of the existing Dubuque County (L-B-18(02)—73-31) SSCS bridge on Stoffel Road over a stream. This is a county bridge with a 30 foot span and 30 foot wide roadway. It has a 30 degree skew, high integral abutments (encased steel piling), and standard F-shape barrier rails. The slab is 20 inches thick with 3 bottom longitudinal reinforcement bars per 18 inch width of the slab (6 inch spacing). All bottom reinforcement bars are #9. The top longitudinal reinforcement bars are #4 at 12 inch spacing. The transverse reinforcement bars are #6 and #5 at 12 inch spacing across the bottom and top of the slab, respectively. Additional #5 transverse reinforcement bars at 12 inch spacing are placed below the barrier rails in the top of slab.

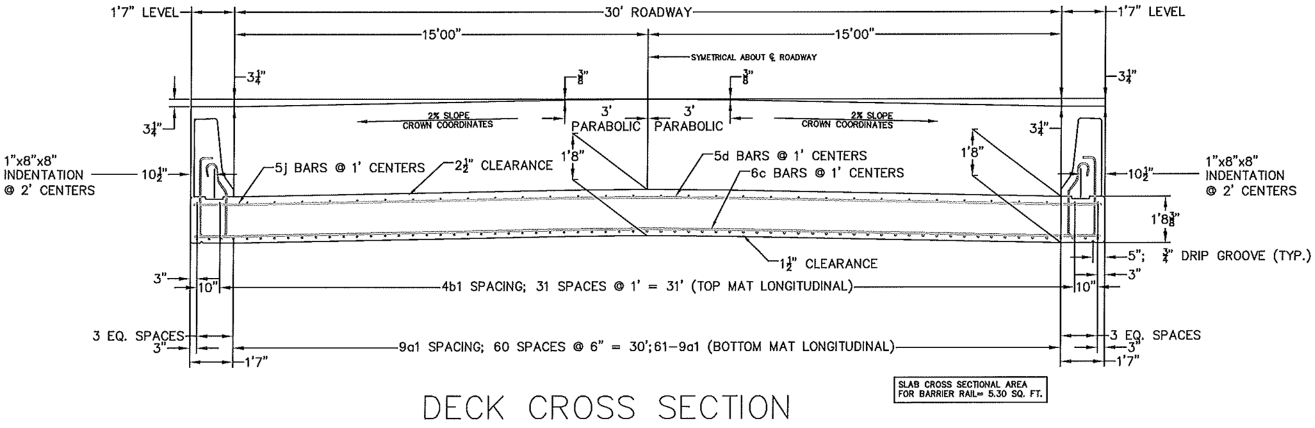


Figure 3. Dubuque County SSCS bridge transverse section (L-B-18(02)—73-31)

2.2 Short Structure Inventory

Details were gathered from the Iowa DOT's Structure Inventory and Inspection Management System (SIIMS) for short structures (lengths 20-70 feet) on primary and secondary roads. A total of 12,174 structures were collected. Data were sorted by structure type, length, skew, and year of construction. Structure type is sometimes subjective or inaccurate with multiple descriptions for one structure type. For example, "Steel Slab" bridge may refer to a "Steel Stringer" bridge. In-depth review of NBI records to verify structure types or other data was not performed. In addition, only the top ten structure types were included in the comparisons. As a result, about 8.5% of the structures were ignored. They are mostly composed of the less used steel slabs, concrete stringers, wood slabs, concrete tee beams, and continuous concrete slabs less than 70 feet long. Refer to Appendix A for the complete list of structure types and the number of structures, including structure length, skew, and year of construction.

Figure 4 shows the number of structures in Iowa sorted by structure type for structures less than 70 feet long. 38.6% of the structures are concrete and steel culverts and 25.0% are steel stringer bridges. Other structure types in this comparison are in the 2-8% range. This includes concrete slab bridges which comprises about 5.1% the total number of structures.

Figure 5 shows the number of structures and structure types sorted by structure lengths in 10-foot increments. The structure length is recorded in SIIMS as the total structure length including the sum of all spans in multiple span structures. Based on this review, there is a higher number of structures with low structure lengths compared to structures with high structure length. About 40.1% the total number of structures have structure lengths between 20-29 feet. Concrete and steel culverts in this range comprise 26.6% of the total number of structures. The highest percentage of concrete slab bridges are in structure lengths between 30-39 feet, comprising 2.5% of the total number of structures. The highest percentage of steel stringer bridges are in structure lengths between 30-49 feet, comprising 13.7% of the total number of structures. Only 7.9% the total number of structures have structure length between 60-70 feet. Most of the structures in this range are wood and steel stringer bridges, comprising 4.4% of the total number of structures. There are only 22 concrete and steel culverts (0.18%) and 2 concrete slab bridges (0.02%) in this range.

Figure 6 shows the number of structures and structure types sorted by skew. The skew is recorded in SIIMS as the angle between the centerline of the roadway and a line drawn perpendicular to the abutment bearing line. Based on this review, 12.9% of the total structures have approximately 30-degree skews, 9.7% of the total structures have approximately 15-degree skews, and 5.7% of the total structures have approximately 45-degree skews. Zero-degree skew bridges are not shown because they make up 71.5% of the total bridges and would make the chart illegible if included. 60-degree skews only comprise 0.2% of the total number of structures. Generally, the number of structures in a structure type is proportional among varying skews. Therefore, none of the structure types seem to favor one skew over the other.

Figure 7 shows the number of structures and structure types sorted by year of construction. Based on this review, about 30.0% of the total number of structures were built prior to 1960. It is anticipated that most of these structures will need replacing soon, considering bridges constructed during this time typically have a life expectancy of about 50-60 years. Steel and wood stringer bridges built prior to 1960 make up most of the structures from that time, comprising 17.0% of the total number of structures. After 1960, steel and concrete culverts increased in use significantly and comprise 32.8% of the total number of structures. That is nearly half of the structures built after 1960. Concrete slab bridges built after 1960 comprise only 3.2% of the total number of structures.

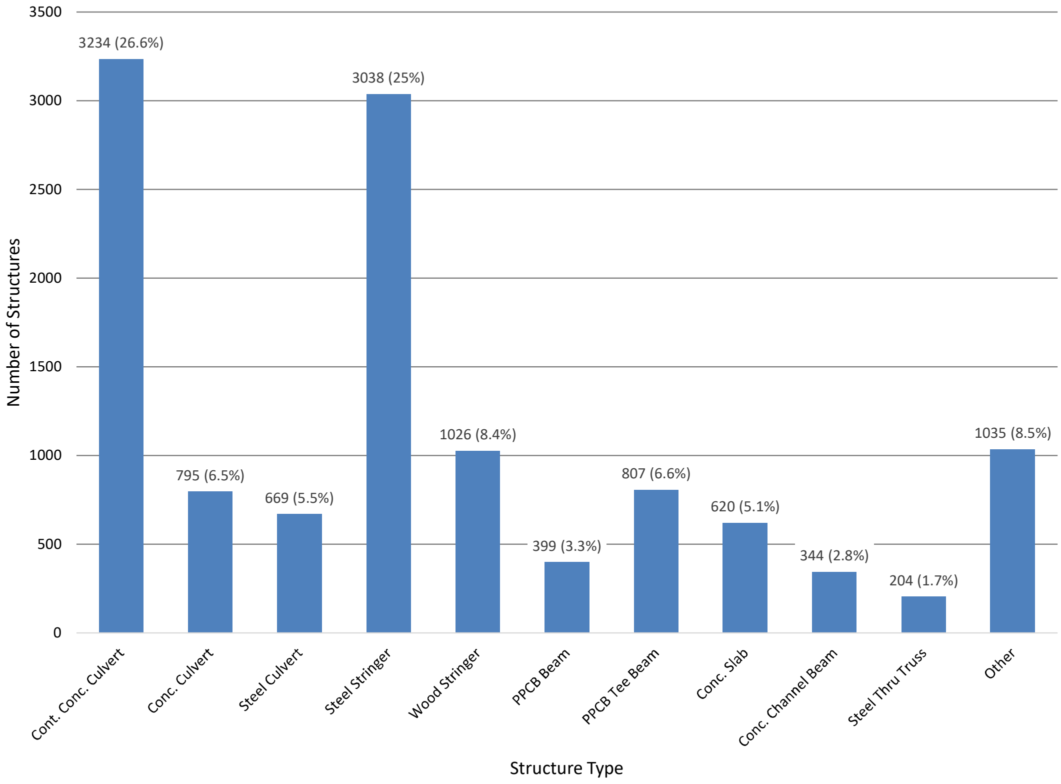


Figure 4. Structure Types and Number of Structures (bridge lengths 20-70 feet)

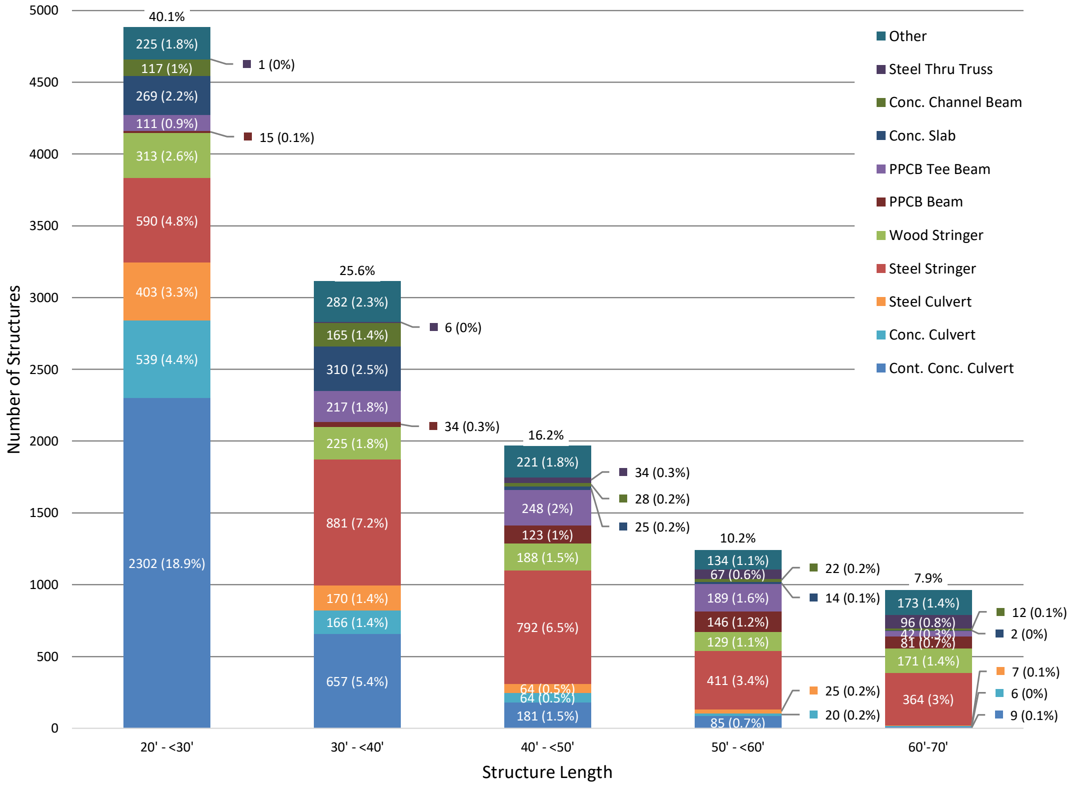


Figure 5. Structure Type Sorted by Length (bridge lengths 20-70 feet)

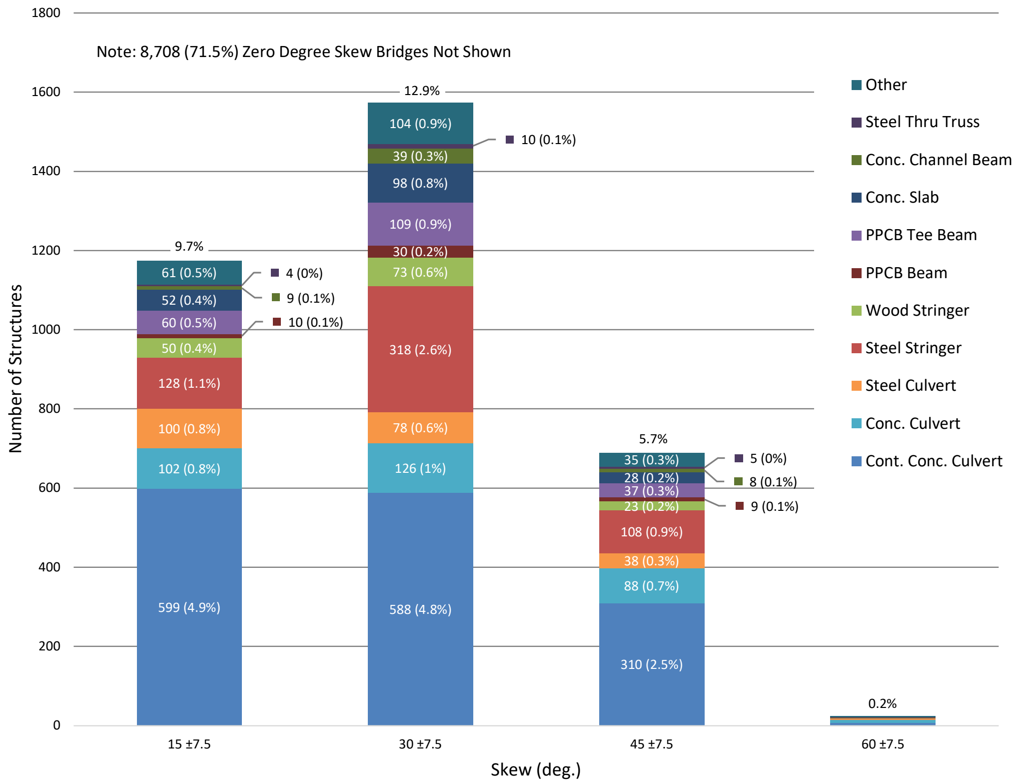


Figure 6. Structure Type Sorted by Skew (bridge lengths 20-70 feet)

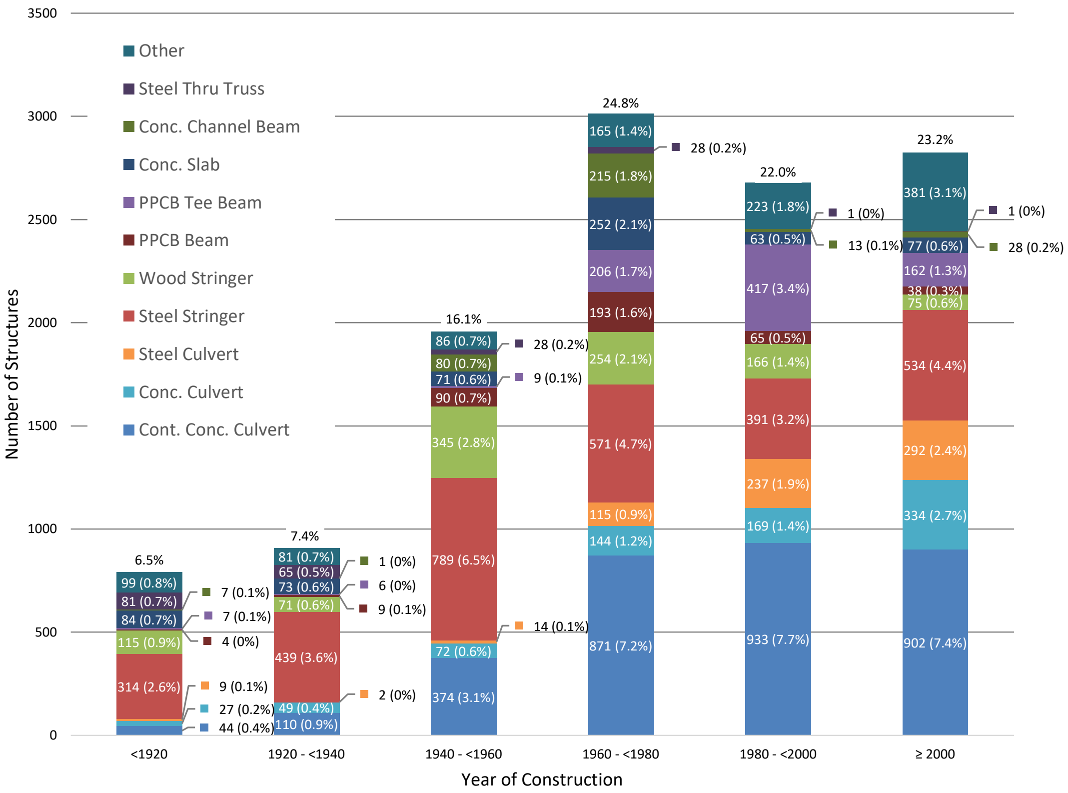


Figure 7. Structure Type Sorted by Year of Construction (bridge lengths 20-70 feet)

2.3 County Engineer Survey

A survey was circulated to Iowa county engineers asking for input on current design practices for short span structures, preferred SSCS bridge features to be included in standard bridge plans, and opinions on the benefits and drawbacks of SSCS bridges. A total of 64 responses were received and about 73% of the respondents answered the survey completely. 17% answered the multiple-choice questions but did not provide short answer opinions. Only six respondents (9%) did not complete the survey. Percentages described below are based on the total number of responses to the question. See Appendix B for a summary of responses and individual answers to the survey questions.

Regarding current design practices, 56% of the respondents currently build single span bridges between 30-60 feet. However, the bridge types built vary considerably by county. Most common responses included proprietary precast slab/tee (e.g. Oden Enterprises), cast-in-place slabs, steel I-beams with metal or concrete deck, and “beam-in-slab” designs. For steel beam and prestressed girder bridges, spans ranged from 20-80 feet but were predominantly 40-50 feet. The most common abutment types were steel H-piles with concrete or steel pile caps and steel sheet pile backwalls (high abutments).

Respondents were asked to provide construction methods and costs for recently constructed short span bridges. Construction was nearly evenly split between in-house crews and contracted work. It was mentioned that there is a pool of Iowa contractors that are very good and efficient at building slab bridges. Costs varied widely, so no conclusions could be drawn from this data.

A strong majority (70%) of respondents favored the development of new Iowa DOT county bridge standards for SSCS bridges. Respondents were asked to provide preferred uses and features for SSCS bridges. 41% of the responses suggested using them on Farm-to-Market roads and 53% suggested using them on secondary roads. Abutment types were almost evenly split among concrete high abutments (32%), sheet pile high abutments (31%), and integral abutments with berms (31%). Geosynthetic reinforced soil abutments were mentioned by 8 respondents. Skews of 0 degree, 15 degrees, 30 degrees, and 45 degrees were all selected by a significant number of respondents for inclusion in the standards. There was a slight preference for 0 to 30-degree skews. A majority (54%) preferred Iowa standard post and beam open rail. 40% chose guardrail continuous through the bridge, and a small number (6%) chose F-shape/Jersey or other rail types.

When asked for opinions on the advantages of using SSCS bridges over box culverts, many respondents cited less right-of-way requirements, reduced streambed disturbance, and new Army Corps of Engineers 404 permit requirements which may favor bottomless structures. Other potential advantages included improved hydraulic performance and less siltation/debris. Disadvantages included the need for a guardrail, longer duration construction, and potential maintenance/durability issues.

Opinions on construction cost received mixed responses since this is a relatively unused bridge type in the state. Some were concerned that SSCS bridges would be higher cost because of falsework. They noted that SSCS bridge formwork would be difficult to build with in-house or day labor. One respondent mentioned that a precast option would be helpful to reduce falsework requirements and allow winter work. Others cited potential lower costs because use of high abutments would permit shorter bridges, as well as saving cost in situations with high fills and severe skews compared to culverts. Reducing guardrail requirements on low-volume roads and high concrete abutments received several mentions.

Overall, there seemed to be broad support for SSCS bridge standards as “another tool in the toolbox”. There was consensus that more options are needed for short span bridges on Farm-to-Market and local roads.

2.4 Current Iowa Practice

Continuous concrete slab (CCS) bridges are routinely built on primary and secondary roads in Iowa. The Iowa DOT maintains three-span CCS J-standards for widths of 24, 30, 40, and 44 feet; span lengths of 70 to 150 feet; and skews of 0 to 45 degrees. The 24- and 30-feet widths are intended for secondary roads while the 40- and 44-feet widths are intended for primary roads. Railing types include standard F-shape and Iowa post and beam open rail. Abutments are integral with the slab and low profile with spill-though berms. Design requirements are included in Chapter 5.6 of the *Bridge Design Manual*.

Non-standard SSCS bridges have been constructed, as demonstrated by the examples described in Section 2.1. These have been primarily built by counties on secondary roads for situations requiring a small slab thickness due to grade or hydraulics.

2.5 Review of Other State Practices

A cursory review of other state DOT practices was conducted to determine how they design short span bridges. Culverts are widely used in almost every state, so they were not included in the investigation. Table 1 shows a summary of state practices based on bridge design manuals and standard bridge plans available at the time of this report. Sources were selected from mostly Midwest states. A few states from outside the Midwest are included because they were observed having good examples of short span bridges.

Short span bridges in other states are composed of CIP concrete slab and precast/prestressed slab beam bridges. For example, Wisconsin, Texas, Ohio, and Kentucky maintain standard plans for SSCS bridges. They generally have span lengths between 20-40 feet, skews between 0-30 degrees, integral abutments, and roadway widths greater than 20 feet. Most plans and design manuals show almost all railing types are used including concrete parapet, open concrete rail, and steel rail and posts. It was evident from the review that SSCS bridges are widely used in other states and are generally included in standard plans.

Table 1. Summary of Other State Practices for the Design of Short Span Bridges

State DOT	Superstructure Type	Structure Length	Roadway Width	Skew	Abutment Type	Railing Type	Std. Plans Available?
FL	Prestressed Slab Beams	< 65’	By Engineer	0° - 30°	Semi-Integral	Concrete Parapet	Beams Only
	Prestressed Deck Beams w/ CIP Concrete or HMA Surface	15’ – 100’	By Engineer	0° - 35°	Fixed or Stub	Any	No
	CIP Concrete Slab	≤ 40’	≤ 45’ w/o Joint	Δ 0° - 50°	Fixed or Stub	Any	No
KY	CIP Concrete Slab	12’ – 40’ in 2’ Increments	≥ 12’, No Max. Limit	0°	Integral	Steel Guardrail	Yes
MN	Prestressed Slab Beam	32’ – 64’	By Engineer				No
NE	Three-Span Continuous Concrete Slab	40’ – 140’	By Engineer				No
	Precast Concrete Planks	≤ 40’					
	Inverted Tee Girder	40’ – 80’					
OH	CIP Concrete Slab	11’ – 38’ in 1’ Increments	≥ 18’, No Max Limit	0° - 30°	Integral	Any	Yes
SD	CIP Concrete Slab	≤40’	By Engineer				No
TX	Single and Multiple Span Concrete CIP Slab	25’ Spans	24’, 28’, 30’, 38’, & 44’	0°, 15°, & 30°	Fixed Stub	Any	Yes
	Prestressed Concrete Box Beam with CIP Concrete Deck	30’ – 65’	24’, 28’, & 30’	0°	Stub	Any	Yes
	Prestressed Concrete X-Beam (Alt. Box Beam) w/ CIP Concrete Deck	40’ – 105’	32’, 38’, 40’, & 44’	0°, 15°, & 30°	Stub	Any	Yes
	Prestressed Concrete I-Girder	40’ – 115’	24’, 28’, 30’, 32’, 38’, 40’, & 44’	0°, 15°, 30°, & 45°	Stub	Any	Yes
	Rolled Steel Beam or Plate Girder and Concrete Deck	30’ – 120’	24’, 28’, & 30’	0°, 15°, & 30°	Stub	Any	Yes
	Prestressed Slab Beams with CIP Concrete Deck	25’ – 50’	24’, 28’, & 30’	0°, 15°, & 30°	Stub	Any	Yes
	Prestressed Decked Slab Beams	30’ – 60’	24’, 28’, & 30’	0°, 15°, & 30°	Stub	Any	Yes
	Concrete Slab & Girder (Pan Form)	30’ & 40’	24’	14°, 27°, 37°, & 45°	Stub	Any	Yes
WI	CIP Concrete Slab	24’ – 48’ in 4’ Increments	24’ – 30’ in 2’ Increments	0° - 20° in 5° Increments	Integral	Any	Yes
	Three-Span Continuous Concrete Slab	48’ – 168’	By Engineer				No
	Timber Deck	17’ – 36’					
	Prestressed Box Girder	24’ – 80’					
	Rolled Steel Girder	≤ 80’					

$^{\Delta}$ Special requirements apply for design of transverse reinforcing for slab bridges with skew

Preliminary Design

3.1 Methodology

A preliminary analysis was performed to determine the minimum slab depth and bottom longitudinal reinforcement of the SSCS bridge slab for varying span lengths and roadway widths. The analysis was limited to checking stresses at the points of maximum moment and shear in the slab. Flexural restraining forces at the supports and the effects of skewing the abutments were not considered.

The evaluated span lengths were between 20-60 feet in increments of 10 feet. This range includes NBI structures with span lengths less than the Iowa DOT's continuous concrete bridge standards (J-series).

Roadway widths were 24 feet and 30 feet, similar to the Iowa DOT's county road bridge standards. Concrete open rail was used in the analysis. Reinforcing bar sizes were limited to the range of #4 to #11 and bar spacing were limited to either 6 inches or 4.5 inches (3 bars or 4 bars per 18 inch width of the deck). A sacrificial layer of ½ inch at the top of the slab was included in the analysis.

Preliminary design was based on the provisions of *AASHTO LRFD Bridge Design Specifications (BDS), 9th Edition* and the *Iowa DOT Bridge Design Manual* Chapter 5.6. The assumed concrete strength was 4.0 ksi and steel reinforcement yield strength was 60 ksi. Slabs were loaded with the HL-93 live load (truck and tandem), dynamic load allowance, and lane load. The transverse live load distribution of stresses in the slab were established using AASHTO's simplified equivalent strip widths for interior strips (4.6.2.3) and edge beams (4.6.2.1.4). One-lane and two-lane interior beams were included in the analysis, but the two-lane condition always controlled. A future wearing surface of 0.020 ksf was included as dead load and the weight of the barrier rails was distributed per *Bridge Design Manual* policy (50% to edge beam and 50% uniformly distributed to the entire superstructure width).

Dead and live load analysis and total factored moments and shears was determined with Excel spreadsheets for various span lengths. Slab minimum flexural reinforcement and shear strength was checked using a MathCad program developed for designing singly-reinforced concrete beams.

Minimum reinforcement area and spacing for the bottom longitudinal steel in the slab was established based on the following AASHTO Code provisions:

- Flexural capacity (5.6.3.2.3)
- Flexural resistance greater than the cracking moment or 1.33 times greater than the factored moment (5.6.3.3)
- Bar spacing for crack control (5.6.7)
- Service steel stress less than 60% of the yield stress (5.6.7)
- Shrinkage and temperature reinforcement (5.10.6)

Maximum reinforcement area for the bottom longitudinal steel in the slab was based on limiting the slab to be in a tension-controlled condition only (Φ = 0.9). Therefore, the maximum steel area was established at the onset of transitioning to a compression-controlled condition. Maximum reinforcement was also limited by the Iowa DOT's preference for a #11 maximum bar size and minimum transverse bar spacing of 4½" (4 bars in 18" wide strip).

Slab depth was determined based on two different methods:

Method 1: AASHTO's recommended minimum slab depth (2.5.2.6.3)

Method 2: Higher priority placed on reducing slab depth compared to reducing longitudinal steel. Note: the Iowa DOT's continuous concrete slab J-standards use slab depths that are 5% to 13% less than AASHTO's minimums.

In Method 2, the slab depth was reduced until the maximum steel area and the minimum steel area were about the same. The configuration of the reinforcement was chosen to result in a steel area to be between the minimum and maximum values. If a configuration could not be found meeting these criteria, the slab was thickened slightly, and a new bar configuration was chosen.

Maximum live load deflection was calculated using service loads and the effective moment of inertia following AASHTO 5.6.3.5.2. The slab was treated as a simple span, ignoring the restraining moments at the supports. AASHTO recommends using a live load deflection limit of *L*/800 (2.5.2.6.2), where *L* is equal to the span length. This value was calculated as a reference. It was not used in the preliminary design of the slab.

3.2 Results

3.2.1 General

Results of the preliminary analysis to determine slab thickness and reinforcement for various span lengths and roadway widths are shown below. Generally, moment in the slab controlled the design. The design tandem controlled for spans 40 feet and less and the design truck controlled for 50 and 60 foot spans. Shear was checked for all bridge and loading configurations, but it did not control.

3.2.2 Deflection

Note that maximum live load deflections are presented for reference only. Generally, all the designs presented have maximum live load deflections higher than the *L*/800 limit as shown in Figure 8. Using Method 1 to determine slab depth (AASHTO minimum depth), as described in the previous section, results in live load deflections that are closer to (but still exceeding) *L/800*. Computed deflection assumes that supports are free to rotate and excludes the stiffness of barrier rails. A more comprehensive analysis such as a linear finite element analysis (LFEA) may significantly reduce the deflection.

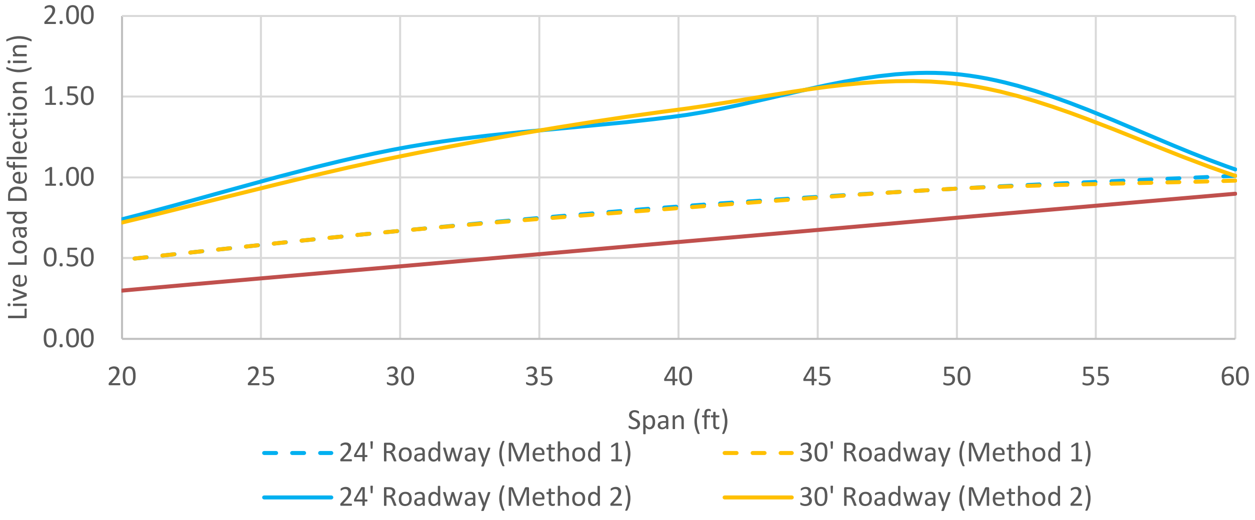


Figure 8. Live Load Deflection and AASHTO Deflection Limit

3.2.3 *Flexure*

Tables 2 and 3 show the results of the preliminary analysis using Method 1 to determine slab depth (AASHTO minimum depth), as described in the previous section, for 24 foot and 30 foot roadways, respectively. Slab depth ranges between 14.5 inches for a 20 foot span to 33.5 inches for a 60 foot span. Generally, longitudinal reinforcement at the bottom of the slab for the 24 foot roadway is slightly higher than the 30 foot roadway because of the narrower equivalent internal beam associated with the smaller roadway width. Conservatively, reinforcement area per 18 inch strip width using Method 1 ranges between 2.18 in^2 (2-#8 & 1-#7 bars) for 20 foot span and 6.24 in^2 (4-#11 bars) for the 60 foot span. A three-bar configuration may be used for spans 40 feet or less. #10 and #11 four-bar configurations are required for 50 foot and 60 foot spans, respectively. Generally, reinforcement design was controlled by the minimum strength of the section for 20 and 30 foot spans, and by the maximum service steel stress (60% the yield stress of steel) for 40 foot spans and longer.

Table 2. Slab Depth and Bottom Longitudinal Steel Results Using Method 1 for 24 Foot Roadway Width

Span Length (ft.)	Reinforcement (in^2 & qty. size) per 18 in. wide strip	Method 1 Slab Depth (in.)	Max Live Load Deflection (in.)	Deflection Limit, L/800 (in.)	Controlling Limit

Table 3. Slab Depth and Bottom Longitudinal Steel Results using Method 1 for 30 Foot Roadway Width

Span Length (ft.)	Reinforcement (in^2 & qty. size) per 18 in. wide strip	Method 1 Slab Depth (in.)	Max Live Load Deflection (in.)	Deflection Limit, L/800 (in.)	Controlling Limit
60	6.24 (4-#11)	33.50	0.98	0.90	$f_{ss} \leq 0.6*f_y$
50	4.81 (3-#10 & 1-#9)	28.75	0.93	0.75	$f_{ss} \leq 0.6*f_y$
40	3.72 (2-#11 & 1-#7)	24.00	0.81	0.60	$f_{ss} \leq 0.6*f_y$
30	2.79 (2-#9 & 1-#8)	19.25	0.67	0.45	Strength
20	2.15 (1-#10 & 2-#6)	14.50	0.49	0.30	Strength

Tables 4 and 5 show the results of the preliminary analysis using Method 2 to determine slab depth, as described in the previous section, for 24 foot and 30 foot roadways, respectively. Slab depth ranges between 12 inches for a 20 foot span to 33 inches for a 60 foot span. The slab depths are approximately 4-6 inches thinner than the slab depths determined by Method 1 (AASHTO minimum depth). Reinforcement area per 18 inch strip width using Method 2 ranges between 3.00 in^2 (3-#9 bars) for 20 foot span and 6.24 in^2 (4-#11 bars) for the 60 foot span. Generally, reinforcement design was controlled by the minimum depth of the section and the maximum reinforcement limit (Φ = 0.9), except for the 60 foot span. The depth of the 60 foot span was controlled by the preferred maximum steel area (4-#11) and steel service stress. Larger bar sizes or smaller spacing of the bottom longitudinal reinforcing would reduce the thickness of the slab.

Table 4. Slab Depth and Bottom Longitudinal Steel Results Using Method 2 for 24 Foot Roadway Width

Span Length (ft.)	Reinforcement (in^2 & qty. size) per 18 in. wide strip	Method 2 Slab Depth (in.)	Max Live Load Deflection (in.)	Deflection Limit, L/800 (in.)	Controlling Limit

Table 5. Slab Depth and Bottom Longitudinal Steel Results Using Method 2 for 30 Foot Roadway Width

Span Length (ft.)	Reinforcement (in^2 & qty. size) per 18 in. wide strip	Method 2 Slab Depth (in.)	Max Live Load Deflection (in.)	Deflection Limit, L/800 (in.)	Controlling Limit
60	6.24 (4-#11)	33.00	1.01	0.90	$f_{ss} \leq 0.6*f_y$
50	6.24 (4-#11)	22.00	1.58	0.75	Strength
40	4.68 (3-#11)	18.50	1.42	0.60	Strength
30	3.91 (2-#11 & 1-#8)	15.00	1.13	0.45	Strength
20	2.85 (2-#10 & 1-#5)	12.00	0.72	0.30	Strength

3.3 Skew Effects

Effects of skew on SSCS bridges were investigated to determine additional design criteria for the development of standard bridge plans. Existing research on the effects of skew in slab bridges as well as Iowa DOT Bridges and Structures Bureau policy and *AASHTO LRFD BDS* were reviewed for recommendations. The consensus in the literature states that less stress occurs along the longitudinal axis of the slab in skewed bridges compared to non-skewed bridges. This occurs because the direction of the principal stresses is skewed relative to the longitudinal axis of the bridge as shown in Figure 9. Therefore, the total principal stress has components in the longitudinal and transverse directions. According to the simplified method specified in AASHTO (4.6.2.3), longitudinal force effects for the interior strip of the slab may be reduced by the following factor:

$$r = 1.05 - 0.25\tan \quad \leq 1.00 \tag{1}$$

Table 6. Skew Reduction Factor for Longitudinal Stresses per AASHTO

Skew Angle (deg.)	r
0	1.00
15	0.98
30	0.91
45	0.80

Where, *r* is equal to the reduction factor to apply to the maximum moment and shear in the slab, and *θ* is equal to the skew angle. Table 6 shows the relative reduction factor for various common skew angles. Iowa DOT conservatively ignores this effect in the design of slab bridges. Longitudinal reinforcing is placed parallel to the centerline of bridge and designed without regard for skew. In addition, the design of edge beams, according to AASHTO (4.6.2.1.4), does not include this effect.

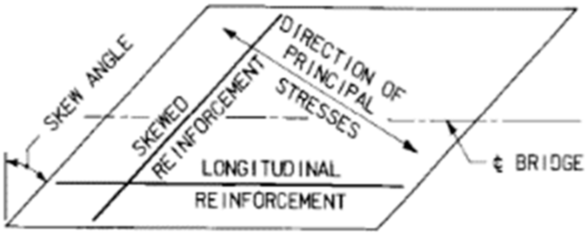


Figure 9. Direction of Principal Stresses in a Skewed SSCS Bridge (Figure from AASHTO LRFD 9th Edition)

Iowa DOT policy (5.6.2.1.1) prohibits orienting longitudinal reinforcing perpendicular to supports for skews greater than 25 degrees. This seems counterintuitive since the direction of principal stresses, as shown above, is oriented perpendicular to the supports. The reason may be constructability and the number of variable length bars that this would require. However, this policy seems to be a misapplication of AASHTO 9.7.1.3 which applies to deck slabs on beams, not slab-type bridges. AASHTO requires transverse deck reinforcing to be oriented perpendicular to the beams for skews greater than 25 degrees so that it resists a portion of the principal stresses. Placement of the transverse bars along the skew would render them ineffective since they would be normal to the direction of principal stress. To eliminate confusion, this sentence in the *Bridge Design Manual* could be deleted since the policy requirement that longitudinal reinforcement is placed parallel to the centerline of bridge is already clear.

According to AASHTO (5.12.2.1), the amount of bottom transverse (distribution) reinforcement may be determined by two-dimensional analysis or by using a percentage of the bottom longitudinal reinforcement. The percentage of longitudinal steel area to be used for distribution steel area is calculated using the following:

$$\frac{100}{\sqrt{L}} \leq 50\% \qquad (2)$$

Where, *L* is equal to the span length in feet. Note that longitudinal steel is reduced for skewed bridges compared to zero skew bridges as previously described. In this case, distribution reinforcement also decreases for skewed bridges. This is contrary to the fact that transverse stresses increase with increasing skew angles. Therefore, the option for two-dimensional analysis may be prudent in this case.

Moya et al. (2021) investigated skew effects for SSCS bridges using linear finite element analysis (LFEA) and compared the results to AASHTO's simplified method. Some of the key findings of their research included:

- AASHTO's simplified procedures (*r* factor, Eq. 1) were unable to accurately capture the reduction in magnitude of longitudinal bending moments as the skew angle increased. AASHTO's reduction factors were only comparable to LFEA for skew angles up to 15°, after which they were conservative.
- Distribution reinforcement per AASHTO could not be used for the design of skewed slab bridges. As the skew increased, additional transverse reinforcement had to be provided to meet the transverse moment demands.
- AASHTO's simplified procedures did not capture skew effects for shear design. Therefore, Lipari's (2020) and Lantsoght's (2017) suggestions are recommended for use in practice with the AASHTO LRFD design provisions for skewed reinforced concrete slab bridges.
- Using AASHTO's simplified procedures instead of LFEA for obtaining design longitudinal bending moments was conservative for skewed reinforced concrete slab bridges but could be unconservative for obtaining design transverse bending moments and shears.
- Using LFEA for analysis instead of AASHTO's simplified procedures generally led to a reduction in total reinforcement steel and could thus be considered cost-effective.

The Illinois DOT (IL DOT) designs SSCS bridges following AASHTO's simplified method except for the design of transverse distribution reinforcement. This policy was introduced in 2015 in response to instances of atypical cracking in several slab bridges. According to IL DOT, the AASHTO distribution reinforcement requirements are deficient and should be designed using the following equations:

$$A_{s(bot,trans)} = \beta_{total\ (bot)}\, A_{s(bot,\ long)} \qquad (3)$$

$$\beta_{total\ (bot)} = \left(0.21 + \beta_{skew} + \beta_{length} + \beta_{width}\right) \leq 0.70 \qquad (4)$$

$$\beta_{skew} = 0.35 \tan \quad (1 + 0.02(L - 20)) \qquad (5)$$

$$\beta_{length} = 0.30 - 0.0075\, L \ \geq 0.0 \qquad (6)$$

$$\beta_{width} = 0.02\sqrt{W - 24} \ \geq 0.0 \qquad (7)$$

Where, *L* is equal to the span length in feet, *W* is equal to the edge-to-edge width of the bridge in feet, and *θ* is equal to the skew angle. Table 7 shows the percentage of distribution reinforcement calculated by IL DOT (Eq. 4) and compares it to AASHTO's distribution reinforcement (Eq. 2). Note that IL DOT distribution reinforcement increases with increasing skew. It also increases with decreasing span length for zero skewed bridges, much like AASHTO, but it is almost two times larger than AASHTO. Percentage of distribution reinforcement for skewed bridges are high for the 60 foot span, reduce to the lowest value at about the 40 foot span, and increase again at the 20 foot span, except for 45 degree skew bridges which is constant for all spans. This trend is a result of the influences of β_{skew} (Eq. 5) and β_{length} (Eq. 6). As span length decreases, β_{skew} decreases and β_{length} increases. Therefore, β_{skew} influences distribution reinforcement percentage more than β_{length} at large span lengths and the opposite is true for small span lengths. It should be noted here that the IL DOT does not recommend constructing simple span SSCS bridges longer than 40 feet. The validity of using the distribution reinforcement equations for larger span lengths will require additional investigation.

Table 7. Distribution Reinforcement Percentages of Main Longitudinal Reinforcement for 24 Foot Wide Roadway (27'-2" Edge-to-Edge) SSCS Bridges

	IL DOT Distribution Reinforcement Percentage				AASHTO Dist.
Span Length (ft)	0° Skew	15° Skew	30° Skew	45° Skew	Reinf. %
60	25%	41%	61%	70%	13%
50	25%	40%	57%	70%	14%
40	25%	38%	53%	70%	16%
30	32%	43%	56%	70%	18%
20	40%	49%	60%	70%	22%

3.4 Rail Type

Multiple rail types are considered for SSCS bridge standards to provide flexibility in application for urban versus rural as well as paved and unpaved roadways. Current Iowa DOT J-standards for CCS bridges include F-shape solid parapet barriers and standard Iowa open rail. Both are crash tested to NCHRP TL-4. The county engineer survey showed a strong preference (54%) for open rail and guardrail continuous through the bridge (40%). Only five respondents indicated a desire for solid parapet rail.

Iowa DOT is currently in the process of obtaining FHWA approval for a new MASH TL-4 open concrete bridge rail. Midwest Roadside Safety Facility (MwRSF) has performed crash-testing and is developing the final report and eligibility letter for approval. There are several differences between the current and proposed open rail, but the biggest change is the height of rail which increases from 32 inches to 39 inches. The proposed SSCS standards will incorporate the new MASH TL-4 open concrete bridge rail for both 24- and 30-ft bridge widths.

Since there was a small desire for a solid parapet or wall-type rail, it should be considered for inclusion in the SSCS standards. There is a precedent for F-shape rail in the J-standards for 30-foot and larger roadway widths. Iowa DOT is currently also developing a new single-slope bridge rail for use on the state primary highway system to replace the conventional 34-inch F-shape rail. The single-slope rail is 17 ½ inches wide at the base and 38 inches tall. The rail meets MASH TL-4 criteria and draft standards are available. It is proposed that the SSCS standards incorporate the draft standard single-slope rail for 30-foot bridge width only.

MwRSF has developed two MASH TL-3 eligible standard designs for post-installed weak post guardrail systems shown below in Figure 10 and Figure 11. They are compatible with the Midwest Guardrail System (MGS) used by Iowa DOT. These were originally developed to continue W-beam guardrail systems across large box culverts but could be applied to SSCS bridges due to similarities in the depth of slab if proper anchor embedment and edge distances are satisfied. Both are very similar to MGS Bridge Rail (FHWA Ref. B-228) except for socket length and attachment hardware. A stiffness transition between the weak-post bridge rail and standard MGS installation is not necessary. However, the following guardrail recommendations included in the FHWA eligibility letters should be included in the SSCS standards or future Iowa DOT Standard Road Plans:

- 75-inch spacing between the last weak post on the bridge and the first standard guardrail post.
- First standard guardrail post should be placed a minimum of 12 inches from the bridge end.
- Adjacent MGS may be either blocked or non-blocked.
- Minimum length of 12.5-foot of standard MGS between the first weak post and the near end of guardrail end terminal.
- Minimum barrier length of 50-foot before or after the first weak post on the bridge (includes standard MGS and end terminal).
- For flared guardrail, minimum length of 25-foot between first weak post and start of the flared section.

We recommend that the weak-post guardrail option be included in the SSCS standards for the 24-foot and 30-foot bridge widths. It is generally intended that guardrail be used for low-volume unpaved roads, but project engineers-of-record are best able to determine if a TL-3 rail is acceptable based on site conditions. Further review will be needed to determine which option (top or side mounted) is preferred.

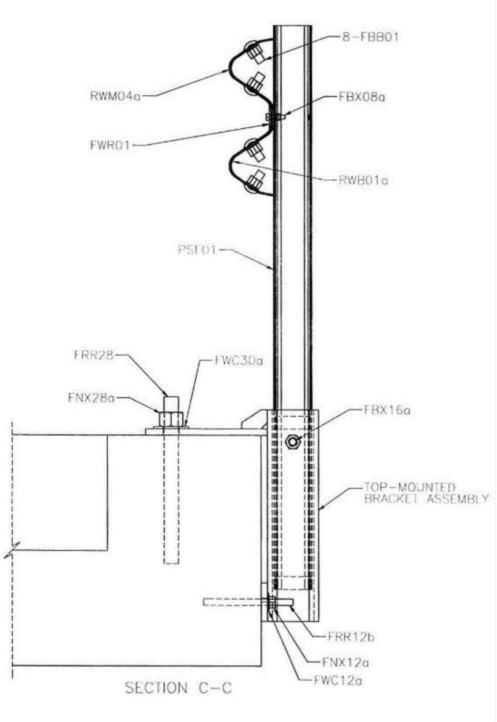


Figure 10. Top-Mounted Guardrail (FHWA Ref. B-262)

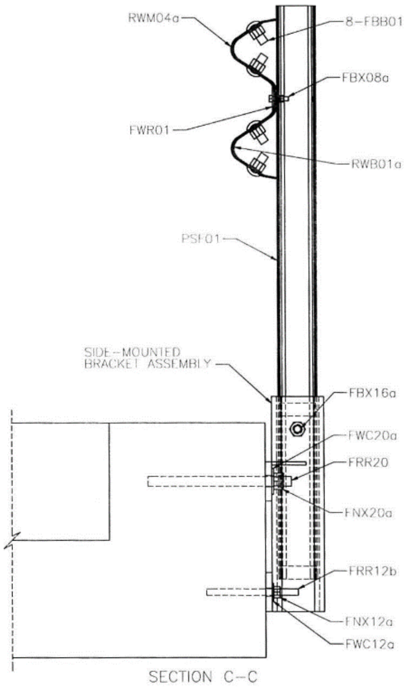


Figure 11. Side-Mounted Guardrail (FHWA Ref. B-264)

Cost Analysis

A cost analysis was performed to determine bridge and culvert construction material and labor costs and to compare total costs of different types of structures. Material quantities were based on Iowa DOT standard bridge and culvert plans, if available. Excavation and roadway quantities were not included in the analysis. Table 8 shows a summary of structures in the analysis and the average costs per square feet of the deck.

Material and labor cost rates were estimated using cost data on iPDweb for new bridge construction and bridge replacement projects completed in Iowa. Cost data was collected for various construction materials in the past two years (2020-2022). A least squared error-based regression was conducted on the cost data to determine appropriate cost rates with respect to the quantity of the items in the project. If iPDweb did not have cost data for a particular item, costs were estimated from awarded bid records found on Bid Express online database for the Iowa DOT.

Table 8. Summary of Cost Analysis Structures and Average Costs per Square Feet of Deck

Structure Type	Structure Length	Roadway Width	Skews	IA DOT Std. Plans	Avg. Cost ($ per ft^2 of Deck)
SSCS Bridge w/ Integral Abutment	20’ – 60’	24’ & 30’	0°, 15°, & 30°	NA	$195/ft^2
SSCS Bridge w/ High Abutment	20’ – 60’	24’ & 30’	0°, 15°, & 30°	NA	$294/ft^2
Conc. Box Culvert w/ 4’ Tall Sidewalls	20’ – 36’	30’	0°, 15°, & 30°	RCB, TWRCB, & TRRCB	$203/ft^2
Conc. Box Culvert w/ 12’ Tall Sidewalls	20’ – 36’	30’	0°, 15°, & 30°	RCB, TWRCB, & TRRCB	$431/ft^2
3-Span Conc. Slab Bridge	70’ – 130’	24’ & 30’	0°, 15°, & 30°	J24 & J30	$151/ft^2
Precast Box Beam Bridge w/ Integral Abutment	30’ – 70’	24’ & 30’	0°, 15°, & 30°	B24 & B30	$235/ft^2
Precast Box Beam Bridge w/ High Abutment	30’ – 70’	24’ & 30’	0°	B24 & B30	$314/ft^2
Single Span Precast I-Beam (PPCB) Bridge	46’-8” – 110’	30’	0°, 15°, & 30°	H30SI	$155/ft^2
Steel Stringer (Rolled Beam) Bridge w/ Integral Abutments	40’ & 60’	30’	0°, 15°, & 30°	NA	$194/ft^2

SSCS bridge quantities were based on the results of the preliminary analysis described above. The quantities for the abutments were assumed similar to the J-series integral abutments and the B-series high abutment walls. Concrete box culvert sidewall heights of 4 feet and 12 feet were chosen because they roughly result in the same opening area as other bridge types in this analysis using integral and high abutments, respectively. Steel stringer bridge quantities were estimated using preliminary design details determined by eSpan140 online tool.

Figure 12 shows the cost estimates for each bridge and culvert condition summarized in Table 8. Multiple data points of the same structure type and length show the difference in cost due to various skews. Generally, structure costs decrease as the structure length and width increase due to efficiencies in materials. Costs typically increase with increasing skew due to complexities in layout, formwork, and reinforcing bar placement. Overall, for spans of interest (20 to 60 feet), SSCS bridges appear to be cost competitive with RCBs for the corresponding types (i.e., 4’ high RCB with integral abutments, 12’ high RCB with high abutments). SSCS bridges are less expensive than box beam bridges and roughly equivalent to steel stringer bridges (comparing integral abutments only). H30SI, J24, and J30 bridges can’t be compared directly due to the differences in span length but appear to be less expensive. This is likely due to the long history of use in Iowa and contractor familiarity, efficiency of scale due to longer spans, and overall bridge type economy.

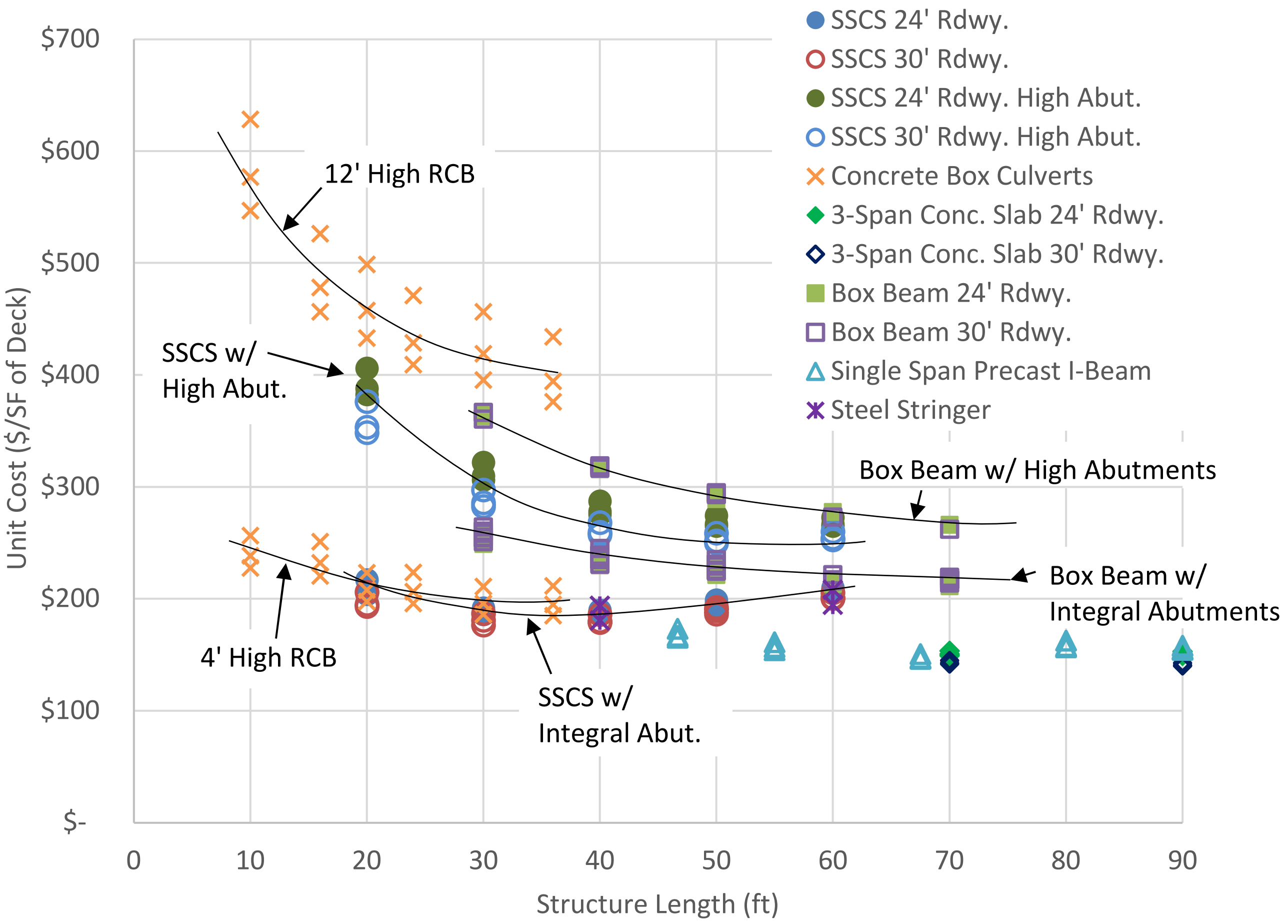


Figure 12. Cost Estimates for Various Structure Types and Span Lengths

Conclusions and Recommendations

Based on the preliminary analysis, the 60 foot span SSCS bridge requires a 34 inch thick slab. This thickness may be challenging for most contractors to construct. Most other state practices limit SSCS bridge spans to about a 40 foot maximum. A maximum span length of 48 feet is used in Wisconsin. Therefore, it is recommended to limit span lengths between 20-50 feet. Table 9 shows the recommended slab thickness based on the preliminary analysis. Inclusion of thermal end moments and fixity at the supports instead of assuming simple spans may increase the slab thickness in final design.

Table 9. Recommended SSCS Slab Thickness for Various Span Lengths

Span Length (ft)	Slab Thickness (in)
50	24
40	20
30	18
20	14

It is recommended that all reinforcement in the slab be epoxy coated. Bottom longitudinal reinforcement will be placed parallel to the roadway centerline. The amount of bottom longitudinal steel will be based on moment demands in the slab. Based on the preliminary analysis, the typical four-bar and three-bar configurations per 18 inch width of the slab used by the Iowa DOT may be used for SSCS bridge standards. Bar cut-offs based on development length of the bar and the reduction of force effects on skewed bridges (*AASHTO LRFD 9th Ed*. 4.6.2.3) should be incorporated to improve material cost efficiencies. Top longitudinal reinforcement will depend on the fixity at the supports, soil pressure on the backwall from bridge expansion, and minimum steel requirements such as temperature and shrinkage. For skews less than 15°, the transverse reinforcement shall be placed parallel to the skew, otherwise, it shall be placed perpendicular to the roadway centerline. Currently, the Iowa DOT uses AASHTO's provisions for designing transverse distribution reinforcement (5.12.2.1). This policy has performed well for CCS bridges. However, evidence shows that for short span SSCS bridges, the distribution reinforcement is more dependent on bridge skew (Moya et al., 2021 and IL DOT, 2019). Therefore, it is recommended the amount of bottom transverse (distribution) reinforcement be based on a two-dimensional analysis and calibrated distribution factors, similar to the IL DOT method, to capture the effects of bridge length, width, and skew. It is not recommended to perform two-dimensional analysis to design components that will interfere with current permitting and bridge rating practices. Top transverse reinforcement shall be designed based on minimum steel requirements for temperature and shrinkage and flexural strength for barrier rail loads.

The Iowa DOT recommends checking live load deflection of the slab if AASHTO's minimum slab thickness are not met. An example of this is in Figure 8Table 8; therefore, deflections will be checked conforming to AASHTO's deflection limits (2.5.2.6.2). Although deflection limits were not met in the preliminary analysis, it is anticipated that deflections will improve after including slab fixity at the supports and rigidity of the barrier rails in the analysis. If the deflection limits are not met, the slab thickness will be increased but will not exceed AASHTO's minimum thickness (2.5.2.6.3).

High abutments such as steel sheet pile backwalls/wingwall and integral were the preferred abutment types based on county engineer input. High abutments have an improved hydraulic performance compared to sloping berms. Berms used for integral abutments fill in most of the hydraulic opening and narrow the stream bed. This is exacerbated by SSCS bridges having short span lengths. On the other hand, integral abutments are easier to construct and maintain. They can also be used to cross smaller streams, roadways, or pedestrian trails. It is recommended that both abutment types be incorporated into SSCS standard plans. Typical abutment designs in the Iowa DOT county bridge standards can be adopted for SSCS bridge standards. The sheet pile abutment details in the box beam county bridge standards (B-series) can be used as high abutments, modifying the pile cap to be integral with the slab. Skews of 15°, 30°, and 45° will also need to be added to the high abutment details as these are not included in box beam bridge standards. The integral abutment details in the CCS county bridge standards (J-series) can be used unchanged for the SSCS bridge standards. Typical county roadway widths of 24 and 30 feet and skews of 15°, 30°, and 45° are recommended for adoption.

SSCS bridges have the convenience of accepting almost all barrier rail types. Therefore, most of the Iowa DOT standard barrier rails may be incorporated into the SSCS bridge standards. However, it is anticipated that MASH TL-4 compliant open concrete rails, currently under development, will be included in the standard plans. Other potential rail types may include MASH TL-3 approved top-mounted or side-mounted weak-post guardrails (FHWA Ref. B-262 and B-264, respectively). These guardrail details are developed by the Midwest Roadside Safety Facility and based on the Midwest Guardrail System used by Iowa DOT. It is recommended to include guardrail details for attaching the guardrail to the bridge in the SSCS bridge standard plans. In addition, end treatment shall be included at the abutments to accept the standard approach guardrail and end terminal.

5.1 Design Criteria

Table 10 shows a summary of the recommended design criteria for the development of SSCS standard bridge plans based on the preliminary analysis.

Table 10. Recommended SSCS Bridge Design Criteria

Roadway Width	Bridge Length	Slab Thickness	Needs Deflection Check?	Skews	Rail Type	Abutment Type	Pile Type
24’	50’	24”	Yes	0° 15° 30°	• MASH TL-4 Open Concrete Bridge Rail • MASH TL-4 Single Slope Barrier • MASH TL-3 Top (B-262) or (B-264)	• Integral • High Abut. w/ Sheet Pile Backwall	Steel HP
	40’	20”	Yes				
	30’	18”	Yes				
	20’	14”	Yes				
30’	50’	24”	Yes				
	40’	20”	Yes				
	30’	18”	Yes				
	20’	14”	Yes				

Table Notes:

- All reinforcing to be Grade 60 epoxy coated
- Concrete to be normal weight, f'c=4.0 ksi

5.2 Implementation

It is recommended to proceed with final design and development of the SSCS standard bridge plans following the design criteria recommendations above. The Iowa DOT Bridges and Structures Bureau (BSB) will maintain oversight and updates for the SSCS standard plans. The standards should be published to the BSB website to make them available to county engineers.

5.3 Future Research

Based on the findings of this project, future research is recommended in the following areas:

- Slab support fixity: Conservatively determine minimum rotational stiffness at the supports of the slab. Investigate slab end negative moments from gravity loads and thermal expansion to design top longitudinal reinforcement. Slab end moments may also increase slab thickness and bottom longitudinal reinforcement depending on the effect of thermal contraction. Include fixity to the ends of the slab to reduce the live load deflections and make it possible to verify AASHTO maximum deflection limits. Include these effects for both integral and high abutments.
- Barrier rail stiffness: Include the stiffness of concrete barrier rails to reduce live load deflections of the slab.
- Bridge skew: Moya & Lantsoght (2021) showed that AASHTO LRFD BDS is conservative for primary longitudinal reinforcing for skewed bridges but can be significantly unconservative for bottom transverse (distribution) reinforcing and shear. Recommend possible changes to Iowa design policy for reducing longitudinal reinforcing, increasing distribution reinforcing, and verifying shear strength for skewed bridges.
- Two-dimensional slab analysis: AASHTO 5.12.2.1 defines distribution reinforcement and is based on relatively small span structures. According to AASHTO C5.12.2.1, “Any significant deviation from successful past practice for larger units that may become both structurally and economically feasible under these specifications should be reviewed carefully.” It is recommended to perform a two-dimensional analysis of the slab to verify bottom transverse (distribution) reinforcement and shear in the slab, except where two-dimensional analysis interferes with current permitting and bridge rating practices.

References

AASHTO. 2020. *LRFD Bridge Design Specifications*. 9th Edition. American Association of State Highway and Transportation Officials, Washington, DC.

BidExpress. *Iowa DOT Project Bid Information Service.* Product of infotech. Available online: https://www.bidx.com/ia/lettings. Accessed on 5/20/2022.

eSpan 140. *Web-Based Steel Bridge Design Tool.* Product of Short Span Steel Bridge Alliance. Available online: https://www.espan140.com/. Accessed on 6/28/2022.

FDOT. 2020. *Instructions for Developmental Design Standards – D20450 Series Florida Slab Beams.* Florida Department of Transportation, Structures Design Office, Tallahassee, FL. Available online: https://www.fdot.gov/docs/default-source/roadway/ds/dev/idds/IDDS-D20450.pdf.

FHWA. 2020. *U.S. Federal Highway Administration's 2020 National Bridge Inventory Data*. U.S. Federal Highway Administration, Washington, DC. Available online: https://www.fhwa.dot.gov/bridge/nbi/ascii2020.cfm.

FHWA. 2016. *FHWA Side-Mounted Weak-Post Guardrail Approval Letter (FHWA Ref. B-264).* Midwest Roadside Safety Facility, Federal Highway Administration, Washington, DC. Available online: https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/barriers/pdf/b264.pdf.

FHWA. 2016. *FHWA Top-Mounted Weak-Post Guardrail Approval Letter (FHWA Ref. B-262).* Midwest Roadside Safety Facility, Federal Highway Administration, Washington, DC. Available online: https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/barriers/pdf/b262.pdf.

FHWA. 2011. *FHWA Midwest Guardrail System (MGS) Bridge Rail Approval Letter (FHWA Ref. B-228).* Midwest Roadside Safety Facility, Federal Highway Administration, Washington, DC. Available online: https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/barriers/pdf/b228.pdf.

FHWA. 1995. *Recording and Coding Guide for the Structure Inventory and Appraisals of the Nation's Bridges*. Report No. FHWA-PD-96-001. US Federal Highway Administration, Washington, DC.

IL DOT. 2019. 3.2.11 – *LRFD Slab Bridge Design Guide.* Illinois Department of Transportation, Bureau of Bridges and Structures, Springfield, IL. Available online: https://idot.illinois.gov/Assets/uploads/files/Doing-Business/Memorandums-&-Letters/Highways/Bridges/BM-Design-Guides/BM%203.2.11%20LRFD%20Slab%20Bridge%20Design.pdf.

IL DOT. 2012. *Bridge Manual.* Illinois Department of Transportation, Bureau of Bridges and Structures, Springfield, IL. Available online: https://idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Bridges/Bridge%20Manual%202012.pdf.

Iowa DOT. 2022. *LRFD Bridge Design Manual*. Iowa Department of Transportation, Bridges and Structures Bureau, Ames, IA. Available Online: https://iowadot.gov/bridge/policy/LRFDBridgeDesignManual.pdf.

Iowa DOT. *County Bridge Standards*. Iowa Department of Transportation, Bridges and Structures Bureau, Ames, IA. Available Online: https://iowadot.gov/bridge/Bridge-and-Culvert-Standards/County-Bridge-Standards.

Iowa DOT. *Culvert Standards*. Iowa Department of Transportation, Bridges and Structures Bureau, Ames, IA. Available Online: https://iowadot.gov/bridge/Bridge-and-Culvert-Standards/LRFD-Culvert-Standards.

iPDweb. *Iowa DOT Construction Cost Estimating.* Product of ExeVision. Accessed on 5/20/2022.

KYTC. 2020. *Slab Bridge Standard Drawing (BDP-013-04).* Kentucky Department of Transportation, Division of Structural Design, Frankfort, KY. Available online: https://transportation.ky.gov/Highway-Design/Standard%20Drawings%20DGNS%202020/BDP013.pdf.

Lantsoght, E.O.L., De Boer, A., and Van der Veen, C. 2017. *Distribution of Peak Shear Stress in Finite Element Models of Reinforced Concrete Slabs*. Eng. Struct. 2017, 148, 571–583.

Lipari, A. A. 2020. *Comparative Study of Shear Design Methods for Straight and Skew Concrete Slabs*. Eng. Struct. 2020, 208, 1–16.

MnDOT. *LRFD Bridge Design Manual.* Minnesota Department of Transportation, St. Paul, MN. Available online: https://www.dot.state.mn.us/bridge/lrfd.html.

Moya, L. and Lantsoght, E.O.L. 2021. *Parametric Study on the Applicability of AASHTO LRFD for Simply Supported Reinforced Concrete Skewed Slab Bridges*. Infrastructures 2021, 6, 88.

NCHRP. 2021. *Recommended Guidelines for the Selection of Test Levels 2 Through 5 Bridge Railings.* National Cooperative Highway Research Program, Transportation Research Board, Washington DC.

NDOR. 2016. *Bridge Office Policies and Procedures.* Nebraska Department of Roads, Bridge Division, Lincoln NE. Available online: https://dot.nebraska.gov/media/2912/bopp-manual.pdf.

ODOT. 2021. *Single Span Slab Bridges Standard Bridge Drawing (SB-1-08).* Ohio Department of Transportation, Columbus, OH. Available online: https://www.dot.state.oh.us/Divisions/Engineering/Structures/standard/Bridges/Standard%20Drawings/SB-1-08.pdf.

SDDOT. *Bridge Design Manual.* South Dakota Department of Transportation, Office of Bridge Design, Pierre, SD. Available online: https://dot.sd.gov/inside-sddot/forms-publications/manuals.

SIIMS. *Structure Inventory and Inspection Management System*. Iowa Department of Transportation, Bridges and Structures Bureau, Ames, IA. Accessed on 2/1/2022.

TxDOT. *Bridge Standards.* Texas Department of Transportation, Austin, TX. Available online: https://www.txdot.gov/insdtdot/orgchart/cmd/cserve/standard/bridge-e.htm.

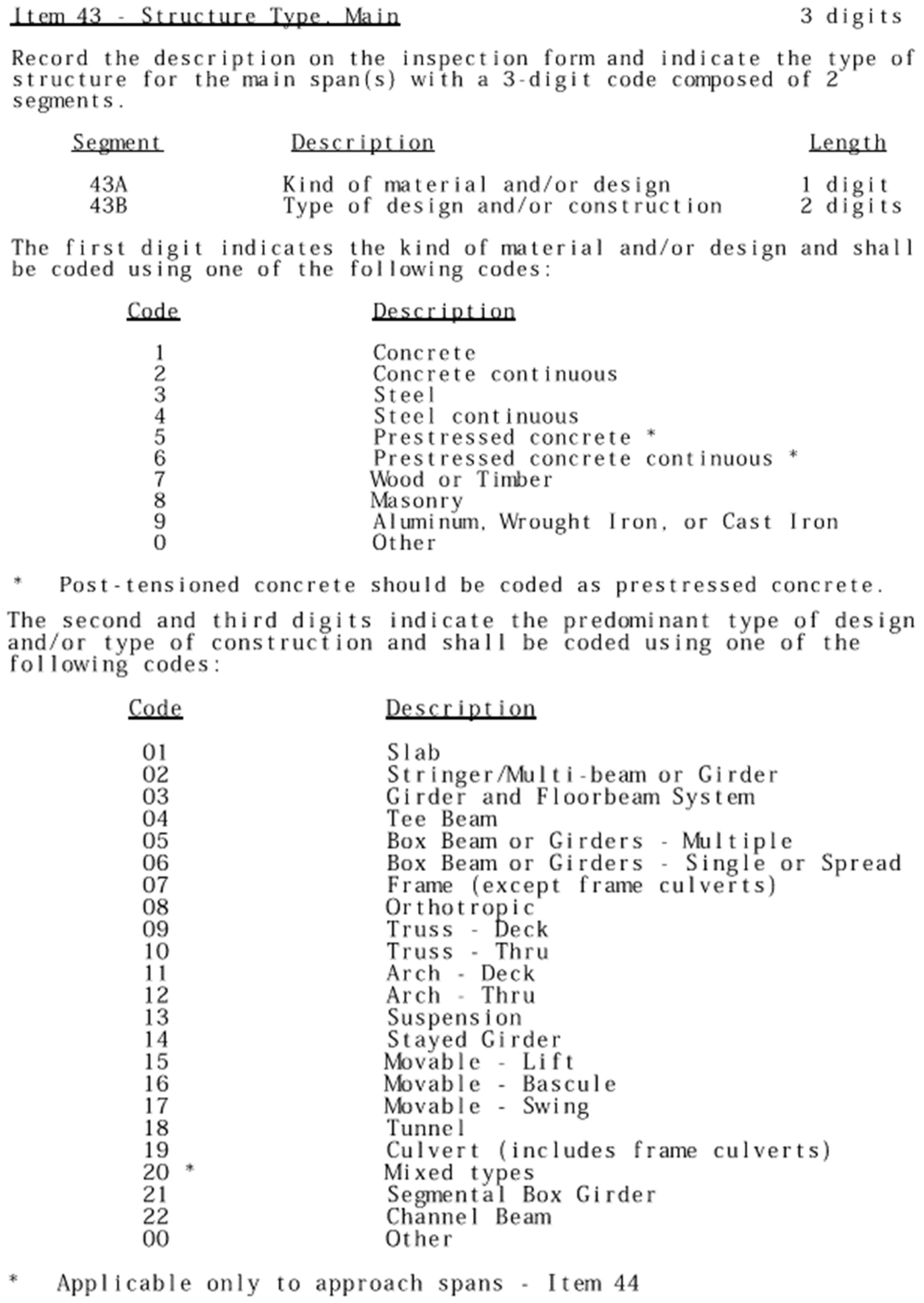
WisDOT. 2020. *WisDOT Bridge Manual.* Wisconsin Department of Transportation, Bureau of Structures, Madison, WI. Available online: https://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/strct/bridge-manual.aspx.

WisDOT. *Bridge Manual Standard Drawings.* Wisconsin Department of Transportation, Bureau of Structures, Madison, WI. Available online: https://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/strct/bridge-manual-standards.aspx.

WisDOT. *Standard Bridge Design Tool.* Wisconsin Department of Transportation, Bureau of Structures, Madison, WI. Available online: https://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/strct/standard-bridge-tool.aspx.

Appendix A: Inventory Summary Tables

Table 11. Structure Type Code Definitions (Text from Recording and Coding Guide for the Structure and Inventory Appraisal of the Nation's Bridges, 1995)



Item 43 - Structure Type, Main 3 digits

Record the description on the inspection form and indicate the type of structure for the main span(s) with a 3-digit code composed of 2 segments.

Segment	Description	Length
43A	Kind of material and/or design	1 digit
43B	Type of design and/or construction	2 digits

The first digit indicates the kind of material and/or design and shall be coded using one of the following codes:

Code	Description
1	Concrete
2	Concrete continuous
3	Steel
4	Steel continuous
5	Prestressed concrete *
6	Prestressed concrete continuous *
7	Wood or Timber
8	Masonry
9	Aluminum, Wrought Iron, or Cast Iron
0	Other

* Post-tensioned concrete should be coded as prestressed concrete.

The second and third digits indicate the predominant type of design and/or type of construction and shall be coded using one of the following codes:

Code	Description
01	Slab
02	Stringer/Multi-beam or Girder
03	Girder and Floorbeam System
04	Tee Beam
05	Box Beam or Girders - Multiple
06	Box Beam or Girders - Single or Spread
07	Frame (except frame culverts)
08	Orthotropic
09	Truss - Deck
10	Truss - Thru
11	Arch - Deck
12	Arch - Thru
13	Suspension
14	Stayed Girder
15	Movable - Lift
16	Movable - Bascule
17	Movable - Swing
18	Tunnel
19	Culvert (includes frame culverts)
20 *	Mixed types
21	Segmental Box Girder
22	Channel Beam
00	Other

* Applicable only to approach spans - Item 44

Table 12. Structure Type Quantities Grouped by Structure Length (Bridge Lengths 20-70 feet)

Structure Type Code	Quantity of Structures Grouped by Structure Length					Totals
	20' <30'	30' <40'	40' <50'	50' <60'	60' 70'	
219	2302	657	181	85	9	3234
119	539	166	64	20	6	795
319	403	170	64	25	7	669
302	590	881	792	411	364	3038
702	313	225	188	129	171	1026
502	15	34	123	146	81	399
504	111	217	248	189	42	807
101	269	310	25	14	2	620
122	117	165	28	22	12	344
310	1	6	34	67	96	204
301	32	56	52	45	10	195
102	30	78	30	14	10	162
701	64	23	64	8	2	161
104	22	59	13	12	6	112
201	12	8	9	10	59	98
402	9	16	13	4	15	57
111	14	11	13	6	6	50
300	0	0	1	5	33	39
303	1	4	4	2	11	22
522	3	5	5	2	1	16
105	0	2	4	8	1	15
505	0	1	1	7	6	15
103	5	4	4	1	0	14
501	4	6	2	1	1	14
919	10	2	0	1	0	13
719	10	0	0	0	0	10
107	2	0	4	2	0	8
401	0	0	0	1	5	6
305	0	1	0	0	3	4
519	3	1	0	0	0	4
311	0	1	2	0	0	3
112	0	0	0	2	0	2
811	1	0	0	0	1	2
819	0	2	0	0	0	2
207	0	0	0	0	1	1
211	0	0	0	1	0	1
304	1	0	0	0	0	1
403	0	1	0	0	0	1
503	0	1	0	0	0	1
380	0	0	0	0	0	0
506	0	0	0	0	0	0
Other	2	0	0	2	2	6
Totals	4885	3113	1968	1242	963	12171

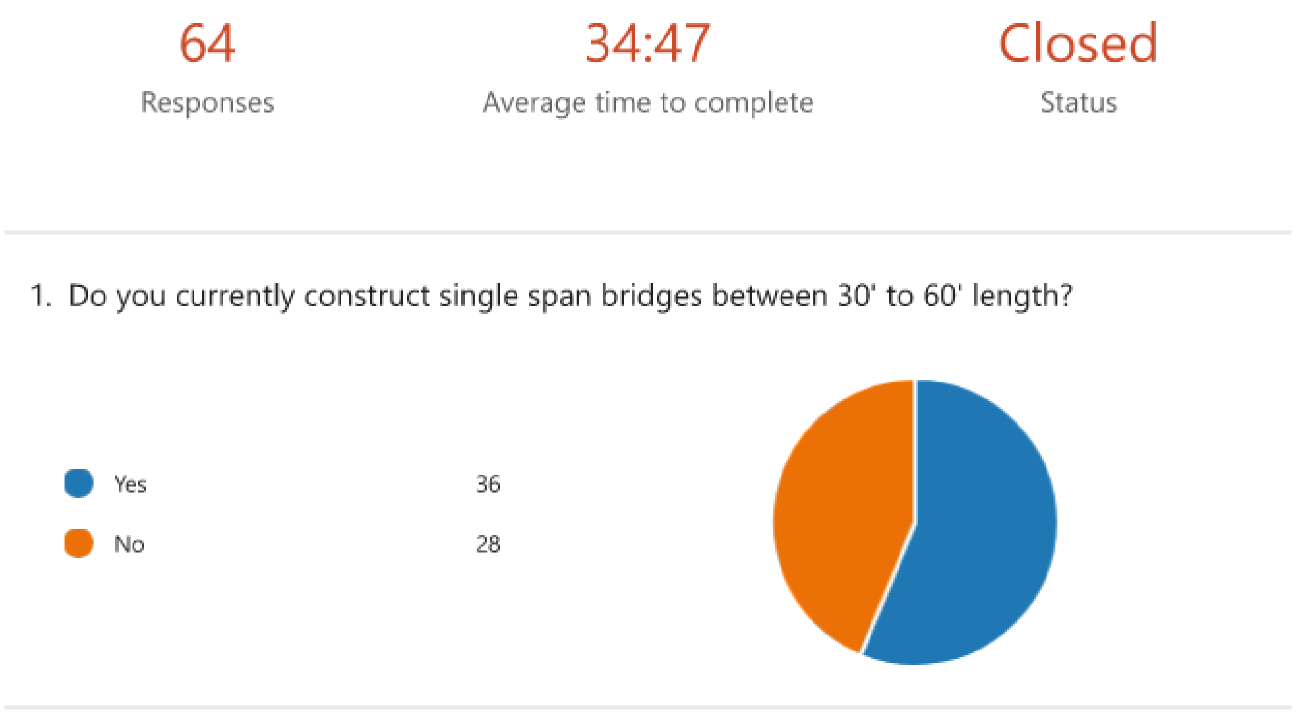
Table 13. Structure Type Quantities Grouped by Year of Construction (Bridge Lengths 20-70 feet)

Structure Type Code	Quantity of Structures Grouped by Year of Construction						Totals
	<1920	1920 <1940	1940 <1960	1960 <1980	1980 <2000	≥ 2000	
219	44	110	374	871	933	902	3234
119	27	49	72	144	169	334	795
319	9	2	14	115	237	292	669
302	314	439	789	571	391	534	3038
702	115	71	345	254	166	75	1026
502	4	9	90	193	65	38	399
504	7	6	9	206	417	162	807
101	84	73	71	252	63	77	620
122	7	1	80	215	13	28	344
310	81	65	28	28	1	1	204
301	5	0	0	4	51	135	195
102	43	17	17	25	13	47	162
701	1	1	3	23	85	48	161
104	11	10	15	51	15	10	112
201	2	13	10	26	16	31	98
402	6	7	14	16	10	4	57
111	15	18	0	0	10	7	50
300	0	0	1	0	0	38	39
303	6	5	4	3	2	2	22
522	0	0	9	4	3	0	16
105	0	0	0	0	0	15	15
505	0	1	0	2	2	10	15
103	4	5	5	0	0	0	14
501	0	1	1	0	4	8	14
919	0	0	0	0	2	11	13
719	0	1	1	8	0	0	10
107	0	1	3	2	2	0	8
401	0	0	0	0	1	5	6
305	1	0	0	0	1	2	4
519	0	0	0	0	3	1	4
311	0	1	2	0	0	0	3
112	2	0	0	0	0	0	2
811	2	0	0	0	0	0	2
819	1	0	0	1	0	0	2
207	0	0	0	0	1	0	1
211	0	0	0	0	1	0	1
304	0	0	0	0	0	1	1
403	0	0	1	0	0	0	1
503	0	0	0	0	0	1	1
380	0	0	0	0	0	0	0
506	0	0	0	0	0	0	0
Other	0	0	0	0	1	5	6
Totals	791	906	1958	3014	2678	2824	12171

Table 14. Structure Type Quantities Grouped by Structure Skew (Bridge Lengths 20-70 feet)

Structure Type Code	Quantity of Structures Grouped by Structure Skew					Totals
	0° ±7.5°	15° ±7.5°	30° ±7.5°	45° ±7.5°	60° ±7.5°	
219	1729	599	588	310	7	3233
119	471	102	126	88	7	794
319	450	100	78	38	3	669
302	2482	128	318	108	2	3038
702	879	50	73	23	1	1026
502	349	10	30	9	1	399
504	601	60	109	37	0	807
101	440	52	98	28	2	620
122	288	9	39	8	0	344
310	185	4	10	5	0	204
301	163	6	21	5	0	195
102	122	10	17	13	0	162
701	136	4	15	5	1	161
104	81	14	17	0	0	112
201	66	12	14	6	0	98
402	47	6	4	0	0	57
111	42	3	4	1	0	50
300	38	0	0	1	0	39
303	22	0	0	0	0	22
522	15	0	1	0	0	16
105	13	0	2	0	0	15
505	12	1	1	1	0	15
103	10	0	1	3	0	14
501	11	1	2	0	0	14
919	13	0	0	0	0	13
719	8	0	2	0	0	10
107	7	0	1	0	0	8
401	4	1	1	0	0	6
305	4	0	0	0	0	4
519	3	1	0	0	0	4
311	3	0	0	0	0	3
112	2	0	0	0	0	2
811	2	0	0	0	0	2
819	2	0	0	0	0	2
207	1	0	0	0	0	1
211	1	0	0	0	0	1
304	1	0	0	0	0	1
403	1	0	0	0	0	1
503	0	1	0	0	0	1
380	0	0	0	0	0	0
506	0	0	0	0	0	0
Other	4	1	1	0	0	6
Totals	8708	1175	1573	689	24	12169

Appendix B: Summary of Survey Results



64
Responses

34:47
Average time to complete

Closed
Status

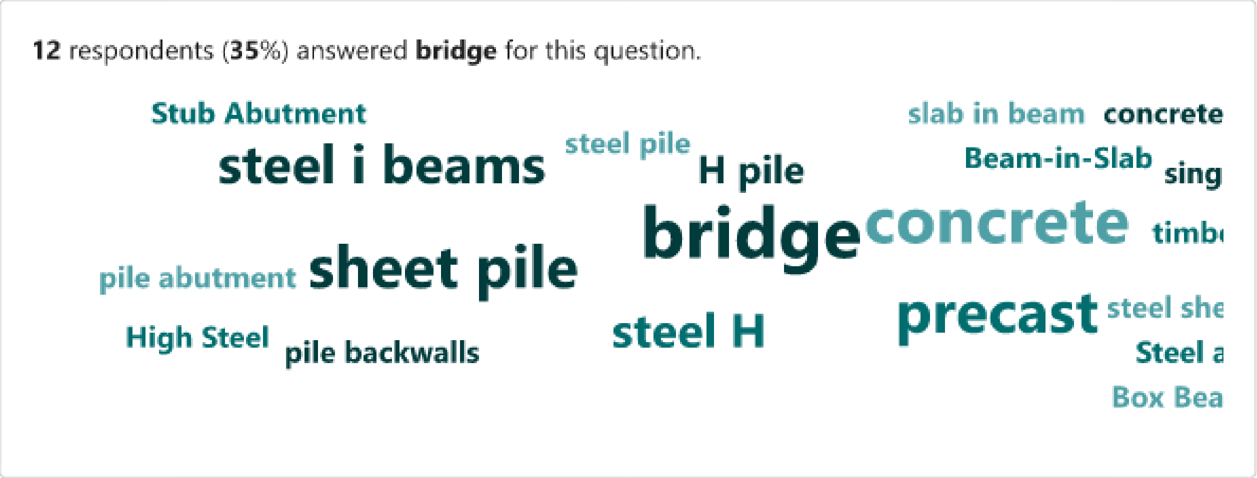
1. Do you currently construct single span bridges between 30' to 60' length?

🔵	Yes	36
🟠	No	28

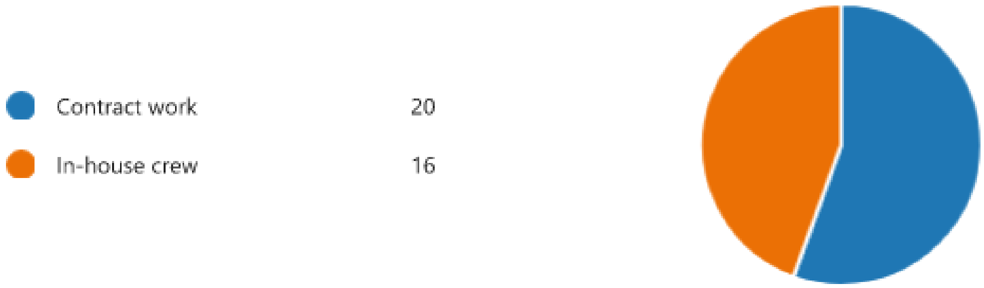
2. If so, please describe the superstructure type, substructure type, and span length built within the past 5-10 years. Please include cost data if available.

35
Responses

Latest Responses
"I install a structure generally referred to as a Beam and Slab. ...


12 respondents (**35**%) answered **bridge** for this question.

3. Were the bridges contracted or built with in-house maintenance crews?



4. In your county, is there current or future use for new Iowa DOT county bridge standards for cast-in-place single span slab bridges 30' to 60' length?

5. Select the proposed route types/classification you would most likely use single span slab bridges. (Select all that apply)

●	Farm-to-market (paved)	43
●	Secondary (gravel)	55
●	Other	6

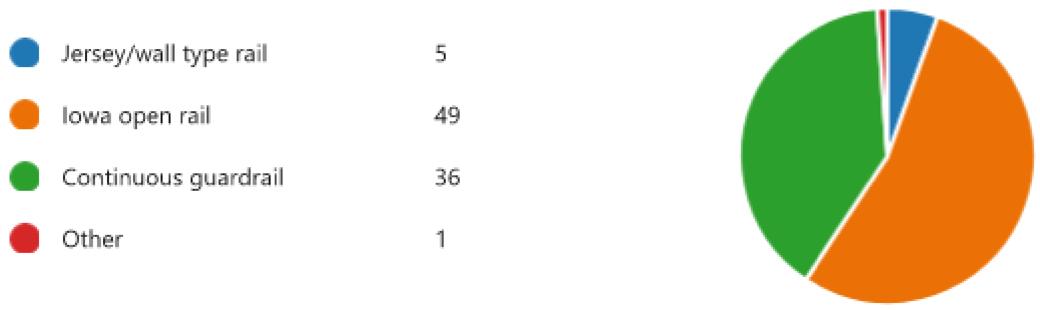
6. Select the type(s) of abutment that would be most useful in your county considering subsurface conditions, site topography, hydraulics, constructability, and maintenance. (Select all that apply)

●	Concrete high abutments	41
●	Sheet pile abutments	40
●	Integral abutments with sloping...	40
●	GRS abutments	8
●	Other	1

7. Select the necessary skew(s) to be included in the proposed standards. (Select all that apply)

●	0 degrees	58
●	15 degrees	48
●	30 degrees	46
●	45 degrees	32
●	Other	2

8. Select the preferred traffic rail(s) to be included in the proposed standards. (Select all that apply)



●	Jersey/wall type rail	5
●	Iowa open rail	49
●	Continuous guardrail	36
●	Other	1

---

9. In your opinion, what are the advantages or disadvantages of using short span slab bridges instead of box culverts or other bridge types (i.e. cost, constructability, ROW, hydraulics/permitting, etc)?

47

Responses

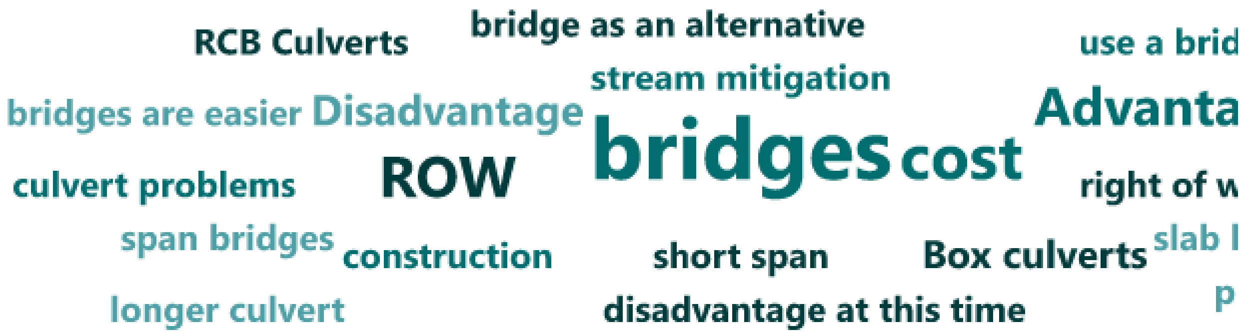
Latest Responses

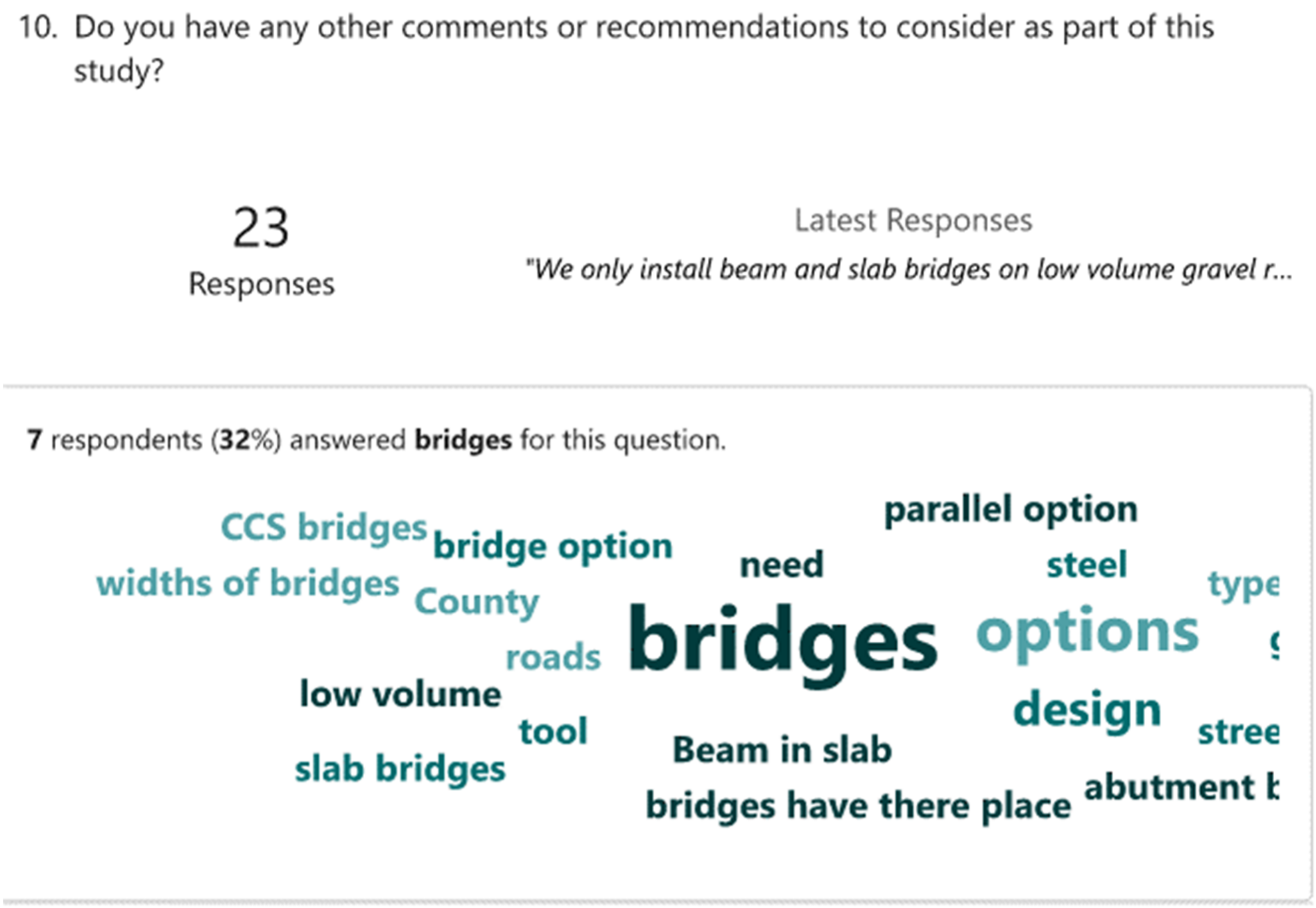
"Debris"

"At a certain span (~30'-40') the RCB options are no longer a c...

"We have a lot of drainage ditches that stand full of water. Som...

17 respondents (**39**%) answered **bridges** for this question.





10. Do you have any other comments or recommendations to consider as part of this study?

23
Responses

Latest Responses
"We only install beam and slab bridges on low volume gravel r...

7 respondents (**32**%) answered **bridges** for this question.

Table 15. Individual County Engineer Survey Answers to Questions 1-4

Respondent ID	Do you currently construct single span bridges between 30 to 60 length?	If so, please describe the superstructure type, substructure type, and span length built within the past 5 10 years. Please include cost data if available.	Were the bridges contracted or built with in house maintenance crews?	In your county, is there current or future use for new Iowa DOT county bridge standards for cast in place single span slab bridges 30 to 60 length?
1	Yes	Quad-Tee - 50 ft span	Contract work	Yes
2	No			Yes
4	Yes	Reused steel i beams with timber decks and precast units. Both are set on timber or sheet pile backwalls on wood or steel H pile.	Contract work	Yes
6	Yes	50 foot single span slab bridge. And a 56 foot single span prestressed beam bridge	Contract work	Yes
7	No			Maybe
8	No			No
9	No			Yes
10	Yes	Steel beams, pcc deck, steel h pile, steel sheet pile back wall. 40' - 60' in length	In-house crew	Maybe
11	No			Yes
12	No			Yes
14	Yes	Odin type bridges - precast super, steel pile / sheet pile abutment. (No bridges constructed within the last 5 years.) 40-50 ft. UHPC Box Beam Grant bridge. Stub Abutment. 50 ft.	Contract work	Yes
16	Yes	New bridges are steel beam and plank on steel H pile with timber backwall. We have rehabbed some with steel beam and plank on whatever the existing abutment is.	Contract work	Maybe
18	Yes	Mostly have been precast ODEN style bridges	Contract work	Yes
19	No			
20	No			Yes
22	Yes	In house we construct single span bridges, generally 45'-60' in length. Substructure is steel H piling, 10x42, superstructure is salvaged steel beams, and deck is timber.	In-house crew	No
24	No			Yes
25	Yes	Precast Superstructure/cast in place abutment. 30 to 46 feet. About 20% higher than concrete deck on Steel of same size. Concrete Deck on Steel beams / Cast in place abutment. 60 feet. About $100/sf pre-inflation Wood deck on steel beams. Steel abutment. 60' feet. No recent relevant costs, just reuse of scrap.	In-house crew	Maybe
26	Yes	We've done a couple different supers. We've done quite a few concrete slab in beam (Petermeier Design) anywhere from 20 ft to 70 ft in length and a couple of 30 ft with used I beams with timber deck. We drive HP10x42 pile with HP12x53 cap and steel sheet pile for backing.	In-house crew	Maybe
27	Yes	30'-0 x 30'-0 CCSB with vertical high concrete abutments and wings on steel h-piles. Total project cost $562k including HMA approach pavement. 50'-0 x 30'-0 CCSB with vertical high concrete abutments and wings on steel h-piles. Total project cost $863k including significant approach grading with macadam & choke stone surfacing.	Contract work	Yes
28	Yes	Beam in slab	In-house crew	Maybe
29	Yes	Our latest structures have been the Oden precast slabs. We have not built one within the last 4 years so our cost date would not be comparable.	Contract work	Yes
30	Yes	We are currently working on our first single slab CCS bridge. 40' span 30.5' wide. Our latest estiamte is $386,832.	Contract work	Yes

32	Yes	Steel pile with "Beam-in-Slab" type deck in 40 to 50 foot lengths, 24-ft wide, sheet pile backwall	In-house crew	Maybe
34	No			Yes
36	No			Yes
37	No			Yes
38	Yes	Steel HPile abutments with sheet pile back. Super structure either steel beam with timber deck or steel beam with concrete poured between beams. Length 25 to 70 feet single span.	In-house crew	Yes
39	No			Yes
40	Yes	Sac County has built 4 or 5 single span 40-45ft bridges in the past 10 yrs. All have been Oden bridges with steel piles, steel sheetpile abutments, and precast reinforced concrete panel decks.	Contract work	Yes
41	No			Yes
42	Yes	oden enterprise bridges	Contract work	Yes
44	No			Maybe
46	No			Maybe
47	Yes		In-house crew	Yes
48	No			Yes
49	No			Yes
50	No			Yes
51	No			Yes
52	Yes	Steel I-Beam with high steel abutment (60'), Concrete beam with integral spill through abutment (75'-10 & 80'-0)	In-house crew	Maybe
53	No			Yes
54	Yes	Benton Co style 40' & 50'	Contract work	No
55	No			Maybe
56	Yes	Steel Girder timber deck construction. A 50'x24' bridge will generally run in the $75k range	In-house crew	Yes
58	Yes	Superstructure Types: Oden Precast Deck Slab Beams and Prestressed Concrete Double Tee or Quad Tee Beams. Substructure: Steel H Piles with concrete cap and steel sheet pile backwall and wings. Span Lengths: 55' x 30'-10 ($224,524), 38' x 31'-2 ($169,832), and 46' x 34' ($204,786).	In-house crew	Yes
60	Yes	Super - Precast Double T Sub- Stub Abutment with Wood Piling Span- 50' Cost~$75,000	In-house crew	No
62	Yes	I install a structure generally referred to as a Beam and Slab. The sub-structure is H-Piling with sheet piling for a back wall. We use a concrete cap. The super-structure is W16 beams spaced 2' on center, then concrete is poured between the beams. We have a contractor install the sub-structure. County crews install the super-structure and do the site grading. I'd be happy to provide cost data but it's been a few years and I would need to spend some time to compile the information.	Contract work	Yes
63	No			Yes
64	No			Yes

Table 16. Individual County Engineer Survey Answers to Questions 5-7

Respondent ID	Select the proposed route types/classification you would most likely use single span slab bridges. (Select all that apply)	Select the type(s) of abutment that would be most useful in your county considering subsurface conditions, site topography, hydraulics, constructability, and maintenance. (Select all that apply)	Select the necessary skew(s) to be included in the proposed standards. (Select all that apply)
1	Farm-to-market (paved);Secondary (gravel);	Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
2	Secondary (gravel);	Concrete high abutments;Sheet pile abutments;	0 degrees;
3	Farm-to-market (paved);Secondary (gravel);Secondary (Paved) & Farm-to-market (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;45 degrees;22.5 Degrees;
4	Secondary (gravel);Farm-to-market (paved);	Concrete high abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
5	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;
6	Farm-to-market (paved);Secondary (gravel);	Integral abutments with sloping berms;Sheet pile abutments;	0 degrees;15 degrees;30 degrees;
7	Secondary (gravel);Farm-to-market (paved);	Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
8			
9	Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;GRS abutments;	0 degrees;15 degrees;30 degrees;
10	Secondary (gravel);Farm-to-market (paved);	Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;
11	Secondary (gravel);Farm-to-market (paved);	Concrete high abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;
12	Secondary (gravel);Farm-to-market (paved);	Sheet pile abutments;Concrete high abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
13	Secondary (gravel);Unsurfaced (dirt);	Sheet pile abutments;Concrete high abutments;	0 degrees;15 degrees;30 degrees;
14	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Integral abutments with sloping berms;	0 degrees;30 degrees;
15	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;GRS abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
16	Secondary (gravel);	Integral abutments with sloping berms;Sheet pile abutments;GRS abutments;	0 degrees;15 degrees;30 degrees;
17	Farm-to-market (paved);Secondary (gravel);All locations would be viable;	Concrete high abutments;Integral abutments with sloping berms;	0 degrees;45 degrees;22.5;
18	Secondary (gravel);	Concrete high abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
19	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;	0 degrees;
20	Secondary (gravel);Farm-to-market (paved);	Concrete high abutments;Sheet pile abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
21	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
22			
23	Secondary (gravel);Farm-to-market (paved);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
24	Farm-to-market (paved);Secondary (gravel);	Integral abutments with sloping berms;Sheet pile abutments;	0 degrees;15 degrees;30 degrees;
25	Farm-to-market (paved);Secondary (gravel);	Integral abutments with sloping berms;Sheet pile abutments;Concrete high abutments;	0 degrees;
26	Farm-to-market (paved);	Concrete high abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
27	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;	0 degrees;15 degrees;30 degrees;
28	Secondary (gravel);	Sheet pile abutments;	0 degrees;15 degrees;30 degrees;
29	Secondary (gravel);	Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
30	Secondary (gravel);Farm-to-market (paved);	Concrete high abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;
31	Secondary (gravel);Farm-to-market (paved);	Integral abutments with sloping berms;Sheet pile abutments;Concrete high abutments;	45 degrees;30 degrees;15 degrees;0 degrees;

32	Farm-to-market (paved);	Sheet pile abutments;Concrete high abutments;	15 degrees;0 degrees;
33	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;
34	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;GRS abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
35	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;GRS abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
36	Secondary (gravel);Farm-to-market (paved);	Sheet pile abutments;Concrete high abutments;	0 degrees;15 degrees;30 degrees;
37	Farm-to-market (paved);Secondary (gravel);all my roads;	Sheet pile abutments;Concrete high abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
38	Secondary (gravel);Farm-to-market (paved);	Sheet pile abutments;H pile with sheet pile back;	0 degrees;15 degrees;30 degrees;
39	Farm-to-market (paved);Secondary (gravel);	Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
40	Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
41	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
42	Secondary (gravel);Farm-to-market (paved);	Concrete high abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
43	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
44	Farm-to-market (paved);Secondary (gravel);	Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
45			
46	Secondary (gravel);	Integral abutments with sloping berms;Concrete high abutments;Sheet pile abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
47	Secondary (gravel);	Sheet pile abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
48	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
49	Secondary (gravel);Farm-to-market (paved);	Sheet pile abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
50	Secondary (gravel);	Concrete high abutments;	0 degrees;
51	Secondary (gravel);Farm-to-market (paved);	Concrete high abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
52	Secondary (gravel);Farm-to-market (paved);level b;	Integral abutments with sloping berms;Sheet pile abutments;Concrete high abutments;	0 degrees;15 degrees;30 degrees;45 degrees;
53	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;GRS abutments;	0 degrees;15 degrees;30 degrees;
54			
55	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;	45 degrees;30 degrees;15 degrees;0 degrees;
56	Secondary (gravel);	Integral abutments with sloping berms;Sheet pile abutments;	0 degrees;
57	Secondary (gravel);Farm-to-market (paved);	Integral abutments with sloping berms;	0 degrees;15 degrees;
58	Farm-to-market (paved);Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;45 degrees;
59			
60			
61	Farm-to-market (paved);Secondary (gravel);	Sheet pile abutments;Integral abutments with sloping berms;	0 degrees;15 degrees;30 degrees;
62	Lower volume paved roads regardless of classification. Possibly everywhere depending on cost effectiveness. ;	Sheet pile abutments;	0 degrees;
63	Secondary (gravel);	Integral abutments with sloping berms;Sheet pile abutments;Concrete high abutments;GRS abutments;	0 degrees;15 degrees;
64	Secondary (gravel);	Concrete high abutments;Sheet pile abutments;Integral abutments with sloping berms;GRS abutments;	0 degrees;15 degrees;30 degrees;45 degrees;

Table 17. Individual County Engineer Survey Answers to Questions 8 and 9

Respondent ID	Select the preferred traffic rail(s) to be included in the proposed standards. (Select all that apply)	In your opinion, what are the advantages or disadvantages of using short span slab bridges instead of box culverts or other bridge types (i.e. cost, constructability, ROW, hydraulics/permitting, etc)?
1	Iowa open rail;	ROW
2	Continuous guardrail;	
3	Iowa open rail;Continuous guardrail;	Advantages are less creek debris build-up, less army corp stream mitigation, less ROW Disadvantage cost.
4	Continuous guardrail;	I think the short span bridges will allow us to maintain natural stream bottoms through roadway openings. I am concerned about burying culverts, even oversized, as during flash flooding events, I am worried about the stream material within the culvert flushing and the culvert scouring our outlets down to the lowered flow line. Even setting a culvert slightly too deep during construction has caused outlet scour problems in the Loess soils we have in western Iowa.
5	SL-1 Bolt on rails or MGS rail;	constructability and flow line changes
6	Iowa open rail;	Short span slab bridges are easier to maintain am open channel. You don't have to have as extensive of excavation requiring Far less temporary easement. None of the structure is continuously wet so the concrete lasts longer on a gravel road that receives no salt
7	Iowa open rail;	
8		
9	Iowa open rail;	
10	Continuous guardrail;Iowa open rail;	
11	Iowa open rail;	cost
12	Iowa open rail;Continuous guardrail;	If I were able to use a bridge instead of a culvert I would not have to worry about stream mitigation.
13	Iowa open rail;	Historically, we have always used RCB Culverts in short span scenarios. Given the latest COE stream mitigation silliness, a bottomless structure may be in order.
14	Iowa open rail;Continuous guardrail;	ROW Constraints, Wetland / Stream mitigation issues, Cost - If they become a well used standard.
15	Iowa open rail;Continuous guardrail;	Cost, ROW, high fills on narrow ROW for culverts
16	Iowa open rail;Continuous guardrail;	Box culverts are still our #1 choice. Bridges are better for timber areas were we get a lot of debris in the streams, multi-barrel RCB do not play nice with flood debris.
17	Iowa open rail;	Advantage would be ability to pass debris and open channel's ability to handle more water. Also they would be less prone to scour and erosion than boxes. Much greater potential for not needing ROW. Site grading for ditches is easier. More contractors are capable of building - good competitive bidding. Disadvantage would be guardrails still present. Deck deterioration issues with de-icing. Limited repair options. Difficult to widen.
18	Iowa open rail;	cost. more consistent channel
19	Iowa open rail;Continuous guardrail;	Cost is a huge advantage. Typically would allow more drainage than a box culvert, but would avoid replacing a bridge with a structure 25% longer than previously there to accommodate DOT's berm standards.
20	Jersey/wall type rail;Iowa open rail;Continuous guardrail;	Advantages: continued HBP funds for structure, minimal waterway footprint, no ROW needs Disadvantages: construction time, guardrail maintenance, Cost is unknown on whether it will be an advantage or disadvantage at this time.
21	Iowa open rail;Continuous guardrail;	Would help in the future to minimize stream disturbance. Would allow for minimal stream work.
22		
23	Iowa open rail;Continuous guardrail;	ROW and Cost
24	Iowa open rail;Continuous guardrail;	
25	Continuous guardrail;Iowa open rail;	Advantage: It could help reduce an clearance issues. Disadvantage: The falsework seems prohibitive for a day labor project. Disadvantage: There is more work over the channel.
26	Continuous guardrail;Iowa open rail;	ROW & Hydraulics/permitting
27	Iowa open rail;	Advantages - can achieve hydraulic requirements, straight forward construction, minimizes ROW needs and environmental impacts. Disadvantages - can still be expensive.
28	Continuous guardrail;	
29	Iowa open rail;Continuous guardrail;	Advantages might be less right of way needed, COE stream mitigation not needed. Disadvantages might be width restriction, cost, time of construction compared to precast boxes.
30	Iowa open rail;	They have a benefit of requiring less right of way to contruct versus box cuvlerts. Also, now with the stream bed requirement of less than 0.03 acres along with no/limited mitigation banks, short span bridges are going to be our goto now. I do NOT like bottomless culverts. We also have a great group of contractors that are very efficient at building multi span CCS bridges. This type of bridge falls right in place with their specialty.

31	Iowa open rail;	No channel floor. Less debris buildup from channel.
32	Iowa open rail;Continuous guardrail;	Small standardized bridges that can be built in-house would be a cost-effective approach. Larger skews would not work well with the short span. An affordable option for short spans (>50, <90') is the area we could use a contractor or in-house solution other than homemade bridges.
33	Iowa open rail;Continuous guardrail;	these bridges would be difficult to build with day labor due to the amounts of falsework and decking that needs to be built.
34	Continuous guardrail;	Double and triple boxes have siltation problems that a bridge doesn't.
35	Jersey/wall type rail;Iowa open rail;Continuous guardrail;	Takes less ROW, easier to maintain waterway opening.
36	Iowa open rail;	Once you get into needing a double or triple box the cost isn't all that different than putting up a bridge. Also if there is a larger fill the bridge tends to become a lot cheaper. With a longer culvert now it will become more difficult in the permitting process as well.
37	Iowa open rail;	The use of these bridges reduces the impact on the stream bottom, reducing impacts that lead to DNR and other regulatory issues.
38	Continuous guardrail;	
39	Iowa open rail;Continuous guardrail;	Right-of-way constraints. RCB culvert cells regularly fill up and need to be cleaned out routinely. Severe stream skews can cause lengthy box culverts that can be reduced with single span bridges.
40	Iowa open rail;Continuous guardrail;	Box Culvert are getting costly, often don't fit within the ROW.
41	Iowa open rail;	
42	Iowa open rail;Continuous guardrail;	row
43	Iowa open rail;Continuous guardrail;	Advantages: Hydraulics, permitting, less right-of-way, new streambed mitigation Disadvantages: Cost, inspection, maintenance
44	Iowa open rail;	The slab bridge (bridge) as an alternative to a Precast Box Culvert (box) has a disadvantage with life of structure, time of construction, width of agriculture equipment using the roadway, snow removal, maintenance of approach guard rail and an end post for motorists to collide with to mention a few. The bridge as an alternative to a box has an advantage if a box can not be used because of environmental restrictions. The bridge as an alternative to other precast bridge solutions would have a disadvantage with time of construction.
45		
46	Iowa open rail;Continuous guardrail;	It is a bridge that we will have to continue to inspect at a more in depth level than a twin/triple box culvert, this will lead to additional expenses.
47	Continuous guardrail;	
48	Iowa open rail;Continuous guardrail;	all of the items noted and additionally potential reduced maintenance
49	Iowa open rail;	
50	Iowa open rail;Continuous guardrail;	
51	Iowa open rail;	Advantage: Permitting with the stream mitigation issues may be less expensive. Multicell culvert problems with siltation, potentially constructed in less right of way. Disadvantages: Potentially more expensive to construct bridges presently
52	Continuous guardrail;	Box culverts provide for an open nonrestricted roadway which is desirable. triple cell box culverts are prone to siltation, this is where short span slab bridges may provide an additional alternative. short span slab bridges are potentially easier to construct than box culverts for counties that like to build bridges in house.
53	Jersey/wall type rail;Iowa open rail;Continuous guardrail;	all of the above and possibly ease of construction
54		
55	Iowa open rail;	Minimal. We have been using Reinforced Concrete Box Culverts for short spans for many years. The biggest advantage to these RCBC's is the quick construction time to build them. The next best thing is that in wind country, there is no guardrail to cause drifting on the bridges or approaches.
56	Iowa open rail;Continuous guardrail;	Hydraulics
57	Iowa open rail;	Reduce stream impacts, siltation and permitting.
58	Iowa open rail;Continuous guardrail;	cost, constructability, ROW, ability to use de-icing materials on the deck, hydraulics/permitting
59		
60		
61	Iowa open rail;	Better hydraulics than a multi-barrel RCB.
62	Continuous guardrail;Iowa open rail;	We have a lot of drainage ditches that stand full of water. Sometimes culverts allow these channels to become blocked by dams or debris. Short span slabs keep the structure as short as possible while also keeping open channel flow. In other areas, we'll use short span bridges to minimize the risk of debris plugging a culvert.
63	Jersey/wall type rail;	At a certain span (~30'-40') the RCB options are no longer a cost effective option, but the DOT's J Standard Bridges are too big.
64	Jersey/wall type rail;Iowa open rail;Continuous guardrail;	Debris

Table 18. Individual County Engineer Survey Answers to Question 10

Respondent ID	Do you have any other comments or recommendations to consider as part of this study?
1	
2	
3	Beam in slab design with foam to limit concert quantity.
4	
5	The new environmental rules may dictate these changes.
6	I love this idea and don't know why it took till now
7	
8	
9	
10	
11	
12	I would like to see widths of bridges at 24' and 30'
13	Is there a price differential between epoxy and black steel that makes a choice between the two meaningful?
14	It just makes sense to have this tool in the tool box.
15	Manufacturer designed systems like box beams, metal arch culverts or rolled streel bridges. More options to help lower costs.
16	This would a good project, another tool in the toolbox.
17	Guthrie County is very excited about this prospect. It would be a great tool to have with the reintroduction of Federal-Aid and for in house design.
18	
19	
20	We've been begging for a standard for high concrete abutment bridges, I'm very happy to see that this is in the works! we would be interested!!! please include 30' widths. An option for reduce guardrail requirements for low volume rural roads would also be a plus! Thanks, Ben Loots
21	
22	
23	
24	
25	I'd prefer a precast option for these lengths. It is friendlier for winter work and negates the need for falsework.
26	
27	In favor of developing standards!
28	
29	
30	I have seen two different types of wings on the abutments. Flared and parallel. I prefer the flared but it does typically require us to purchase a little bit of right of way. I would love to have a parallel option if I were to get into a sensitive area both right of way or environmental.
31	
32	Counties willing to us tanker cars and flat cars can have good solutions for <70' needs. But it may not be feasible on FM routes. In any case, a smaller bridge option for FM routes is needed. I would also support some consultant developed flatcar details to help standardize their rating process.
33	
34	
35	Should include a standard beam-in-slab superstructure/deck because they can be built with minimal equipment and labor. They also take less time and can greatly reduce overall project time and road closures.
36	
37	I eagerly await the results.
38	
39	
40	
41	
42	
43	Find better and smaller guardrail systems.
44	

45	
46	
47	
48	I think it is absolutely worthwhile and offer my support
49	
50	
51	Dallas County has plans being developed by Origin Design for two - 50' slab bridges with High Abutments but have not constructed either one.
52	
53	No
54	
55	The short span CCS bridges have there place, but there are too many advantages with RCBC's.
56	Not sure how cost effective these will be compared to the relatively, inexpensive, simple and easy to build steel girder bridges. Our day labor type bridges are generally built on very low volume roads, (less than 50 vpd with many on roads with less than 25vpd)
57	
58	
59	
60	
61	
62	We only install beam and slab bridges on low volume gravel roads with no accident history because we do not install standard guardrail. New standard short span bridges would be good especially to use in areas where guardrail cannot be reduced or eliminated.
63	
64	