MOUNTAIN-PLAINS CONSORTIUM

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Bridge Structure
Alternatives for Local Roads

MOUNTAIN-PLAINS CONSORTIUM REGION 8

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Bridge Structure Alternatives for Local Roads

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Disclaimer

ABSTRACT

Local governments have an immediate need for low life-cycle cost bridge replacement alternatives. Knowledge of available alternatives and construction planning processes hold potential for South Dakota local governments to replace more structurally deficient local bridges with limited funds. Through extensive literature review of research articles, reports, and existing practices within and outside South Dakota, a comprehensive list of short-span innovative bridge elements and systems that are suitable to implement at the local government level has been established. The list was converted into a catalog and divided into techniques, superstructures, substructures, materials, and entire bridge structures. The techniques include using prefabricated bridge elements and systems (PBES) and the jointless bridge. Emphasis was maximum economy with mass-production of prefabricated components. An estimate of cost was developed for the alternatives listed in the catalog. The cost for each alternative provides a somewhat reliable representation of the average cost of the item per square foot of deck, and was obtained from the literature and state Department of Transportation websites. A list of administrative requirements on local bridge replacements without South Dakota Department of Transportation (SDDOT) or federal assistance was ALSO compiled and included in this report. An evaluation procedure with simple inputs for use by local government decision making was developed. It is the intent that this checklist will lead decision makers through the process of cost and performance evaluation, and finally recommend if the project should be completed locally or using a federal program.

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Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
ABC	Accelerated Bridge Construction
ADT	Average Daily Traffic
AGC	Association of General Contractors
ASCE	American Society of Civil Engineers
BIG	Bridge Improvement Grant
CCS	Cellular Confinement System
CIP	Cast-in-place
DOT	Department of Transportation
EFLHD	Eastern Federal Land Highway Division
EPS	Expanded Polystyrene Geofoam
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GRS	Geosynthetic reinforced soil
HBRRP	Highway Bridge Replacement and Rehabilitation Program
MBISB	Modified Beam-In-Slab Bridge
MnDOT	Minnesota Department of Transportation
MSE	Mechanically Stabilized Earth
NCHRP	National Cooperative Contractors Structures Task Group
NEXT	Northeast Extreme Tee
NFIP	National Flood Insurance Program
NYDOT	New York Department of Transportation
PBES	Prefabricated bridge elements and systems
PCINE	Prestressed Concrete Institute Northeast
PMBISB	Precast Modified Beam-In-Slab Bridge
RRFC	Railroad Flat Car
SCC	Self-Consolidating Concrete
SD AGC	South Dakota Associated General Contractors Structures Task Group
SDDOT	South Dakota Department of Transportation
SIB	State Infrastructure Bank
STIP	Statewide Transportation Improvement Plan
STP	Surface Transportation Program
UHPC	Ultra-High Performance Concrete

EXECUTIVE SUMMARY

Local governments have an immediate need for low life-cycle cost bridge replacement alternatives. Knowledge of available alternatives and construction planning processes holds potential for South Dakota local governments to replace more structurally deficient local bridges with limited funds. Through extensive literature review of research articles, reports, and existing practices within and outside South Dakota, a comprehensive list of short-span innovative bridge elements and systems that are suitable to implement at the local government level has been established. The list was converted into a catalog and divided into techniques, superstructures, substructures, materials, and entire bridge structures. The techniques include using prefabricated bridge elements and systems (PBES) and the jointless bridge. Emphasis was maximum economy with mass-production of prefabricated components. The superstructures include: precast inverted tee beam, precast prestressed adjacent box beam, precast prestressed adjacent deck slab beam, precast double tee beam/the NEXT beam, precast modified beam-in-slab bridge (PMBISB) system, the ultra-high-performance concrete (UHPC) waffle bridge deck panel, the precast decked bulb tee beam, used railroad flatcars, wide-flange steel beams, and channel beams placed adjacent to each another. The substructures include the geosynthetic reinforced soil (GRS) abutment, mechanically stabilized earth (MSE) walls with single line pile abutments, and the sheet pile abutment. The materials include: UHPC, high performance/high strength lightweight concrete, self-consolidating concrete (SCC), expanded polystyrene (EPS) geofoam, cellular confinement system (CCS), and carbon fiber prestressing strands. The entire-bridge-structures include the large precast box culvert and the precast three-sided frame.

An estimate of cost was developed for the alternatives listed in the catalog. The cost for each alternative provides a somewhat reliable representation of the average cost of the item per square foot of deck, and was obtained from the literature and state Department of Transportation websites.

A list of administrative requirements on local bridge replacements without South Dakota Department of Transportation (SDDOT) or federal assistance was compiled and included in this report. Grant County has already conducted several local bridge replacements without federal assistance; and therefore, it was one source of information on administrative requirements on local bridge replacements without SDDOT or federal assistance. An evaluation procedure with simple inputs for use by local government decision making was developed. It is the intent that this checklist will lead decision makers through the process of cost and performance evaluation and finally recommend whether the project should be completed locally or using a federal program.

1. INTRODUCTION

South Dakota local governments own at least 1,100 bridges 40 feet or less in length and nearly half are in need of replacement (National Bridge Inventory, 2012). The South Dakota Department of Transportation's Local Government Assistance office provides local governments access to federal funding, technical expertise, and administrative assistance with bridge replacement projects; however, current funding limits only allow assistance with approximately 30 bridge replacements statewide per year. Local government bridge replacement projects funded with federal aid must comply with current SDDOT design standards and federal requirements. Some federal requirements significantly increase a project's construction time and cost. If federal funds are not used, short-span bridge projects could have more flexibility and potentially have significantly lower costs without compromising safety, structural capacity, or durability. Due to current funding limitations and increasing replacement needs, local governments are compelled to make selective replacement decisions and delay many other bridge replacements by imposing load limits and closing bridges.

Once the Local Government Assistance office has assisted in programing a local bridge in the Statewide Transportation Improvement Plan (STIP), there can be up to a 10-year wait before a bridge will be replaced. This length of time promulgates local government decision makers to post load limits or close bridges. Local governments have an immediate need for low life-cycle cost bridge replacement alternatives. Knowledge of available alternatives and construction planning processes holds potential for South Dakota local governments to replace more structurally deficient local bridges with limited funds.

Research is needed to develop guidance identifying applicable South Dakota local government bridge construction techniques, materials, and construction planning and administration process requirements to enable South Dakota local governments to more efficiently and cost effectively replace short-span bridges. The need is also being encouraged by the National Cooperative Highway Research Program (NCHRP) through their funded studies. Specific items of interest include structural design criteria, geometries, bridge railings, construction practices, agency teaming, and of course cost and funding (NCHRP, 2004). Of particular interest are construction practices using local agency forces verses traditional construction methods that may be of high cost.

2. RESEARCH OBJECTIVES

The study presented in this report was undertaken to address the following two main objectives:

1) Develop a catalog describing locally available bridge construction techniques and materials that can be performed by local contractors and local government workforces.

Through extensive literature review of research articles, reports, and existing practices within and outside South Dakota, a comprehensive list of short-span bridge construction techniques that are suitable to implement at the local government level were established. The list includes alternatives that are achievable through local contractors and/or local governments, and provide useful information regarding each alternative, including approximate cost, equipment and site requirements, and relevant experiences.

2) Develop construction planning and administration process guidance for local government bridge replacement.

A review of applicable federal and local regulations on construction planning and administration related to local bridge replacement was also conducted. Guidelines were developed to assist local officials in deciding viable funding mechanisms for bridge replacement projects. The guidelines will also help decision makers to identify low-cost alternative replacement methods when it is applicable.

3. RESEARCH TASK DESCRIPTIONS

In this section, each task of this project is briefly described. The results for the following tasks can be found in subsequent chapters. A listing and explanation of activities involved in each task follows.

3.1 Meet with Technical Panel

Task 1: Meet with the Technical Panel to review the project scope and work plan.
A kick-off meeting occurred December 2013 to introduce the scope and work plan of the project to the Technical Panel. The meeting provided an opportunity to obtain suggestions and comments from the Technical Panel to be incorporated into implementation of the project. Meeting minutes were recorded and attached to the first progress report.

3.2 Perform Literature Review

Task 2: Through literature review and surveys of other DOT's local government assistance offices, low life-cycle cost, innovative bridge construction materials and techniques that perform well and are applicable in South Dakota were identified.

A comprehensive literature review was conducted for this project. The literature review focused on the feasibility of alternatives with limited capacity of local workforces, and the cost of implementation. In addition to published literature, other DOT's local government assistance offices were contacted to conduct a survey about their experience with low life-cycle cost, innovative bridge construction materials and techniques for local roads. The survey was conducted using a designed questionnaire that was reviewed and approved by the project Technical Panel.

3.3 Interview Contractors and Suppliers

Task 3: Identify construction techniques and materials available by contacting fabricators, suppliers, and the South Dakota Associated General Contractors (SD AGC) Structures Task Group.

A list of fabricators and suppliers commonly used in local bridge replacement projects was provided by SDDOT and local county officials. The fabricators and suppliers were then contacted by the research team for information on existing construction capacity, techniques, and materials used in local bridge replacement. The SD AGC was also contacted to provide a list of commonly used design options and potential innovative solutions. The requests for information were conducted through combined methods of meeting – phone and email. It was the intent to identify alternatives that would be achievable through use of local government workforces, including county highway maintenance workers and local private contractors. These would include construction techniques that require limited specialized skilled labor. However, it should be noted that bridge construction is obviously by its very nature a specialized form of construction. This research identified *pathways* for local contractors/governments using existing bridge construction techniques/materials. This research was not intended to *create* new bridge construction techniques. In that regard, the research was designed to only identify existing methods/techniques, not find methods/techniques that only a small subset of local governments or contractors can perform.

3.4 Develop Catalog

Task 4: Develop a catalog describing construction techniques and materials applicable to local government bridge construction that can be constructed by local contractors and local government forces in South Dakota.

Based on the results from Tasks 2 and 3, a South Dakota-specific catalog for local bridge construction options was developed. It contained alternatives obtained from the literature review and other DOTs confirmed by the local workforce to be viable in South Dakota. The catalog served as the basis for implementing the remainder of this study. This research was developed with the understanding that only bridge replacement structures will be considered. Rehabilitation was not considered as part of this study.

3.5 Submit Technical Memorandum

Task 5: Prepare a technical memorandum, to be reviewed by the Technical Panel, summarizing results of Tasks 2 through 4.

The results from Task 2 through 4 were compiled in a technical memorandum and submitted to the Technical Panel for review on November 20, 2014. The research team met with the Technical Panel on November 20, 2014, to discuss and evaluate the completeness of the catalog. Changes to the catalog were applied as discussed with the Technical Panel.

3.6 Describe Cataloged Construction Techniques and Materials

Task 6: Summarize installation, durability, maintenance needs, and any pertinent factors associated with catalogued construction techniques and materials applicable to South Dakota local government bridge construction.

Basic information on installation, durability, maintenance needs, and other pertinent factors associated with catalogued construction techniques and materials was obtained from the literature review. Combining obtained information, a South Dakota local government bridge construction options catalog was developed with lists of alternatives and their corresponding considerations to implement.

3.7 Estimate Agency Costs

Task 7: Estimate agency costs of materials and techniques described in the catalog.

Cost estimates of the structural elements in the catalog were developed. The cost for each structural element was not exact but provided reliable representation of the average cost of construction using such a technique. Costs were obtained from literature and some of the state department of transportation websites. This report includes recommendations in the implementation plan on how the SDDOT can keep prices current through escalation factors.

3.8 Submit Technical Memorandum

Task 8: Prepare a technical memorandum, to be reviewed by the Technical Panel, summarizing results of Tasks 6 and 7.

The results from Tasks 6 and 7 were combined into a single catalog document and forwarded to the SDDOT for review on July 27, 2015, explaining the process and rationale adopted by the researchers to produce the final catalog.

3.9 Identify Process Requirements

Task 9: Identify the construction planning and administration process requirements allowing local governments to replace structures without SDDOT assistance by interviewing the Grant County Highway Department, SDDOT Local Government Assistance office, and Federal Highway Administration Bridge personnel.

Meetings and phone interviews with the Grant County Highway Department, SDDOT Local Government Assistance office, and Federal Highway Administration Bridge personnel were arranged to obtain information on the administrative procedure and requirements on local bridge replacements without SDDOT assistance. Because Grant County has already conducted local replacements, their experience was valuable for the research project. The goal of the interview was to systematically identify key administrative components of local bridge replacement projects so it can be potentially followed by other local governments in South Dakota. The SDDOT identified appropriate areas where administration process requirements could be needed in local bridge construction, and the research team assembled the requirements.

3.10 Develop Evaluation Procedure and Checklist

Task 10: Develop a simple evaluation procedure—including a checklist of construction planning and administration process requirements—to allow selection of the appropriate construction techniques and materials for local government bridges.

An evaluation procedure with simple inputs was developed for use by local government decision makers. The checklist leads the decision makers through the process of cost and performance evaluation, and finally, recommends if the project should be completed locally or using a federal program. The evaluation identified viable options in the bridge alternatives catalog with approximate cost estimates.

3.11 Summarize Evaluation Procedure and Checklist

Task 11: Prepare a technical memorandum, to be reviewed by the Technical Panel, summarizing the evaluation procedure and check list of construction planning and administration process requirements.

The results of the evaluation procedure developed in Task 10 and the administrative requirements list obtained in Task 9 were forwarded to the SDDOT on July 27, 2015, for review by the Technical Panel.

3.12 Submit Final Report

Task 12: Prepare a final report summarizing the research findings, conclusions, and recommendations.

This final report was prepared by the researchers in conformance with SDDOT guidelines. The final report documents all aspects of the project and recommendations; the report was primarily based on the technical information forwarded to the SDDOT in Tasks 5, 8 and 11. The final report was submitted to the Technical Panel for review and comments. The report was revised as needed to address the panel's comments.

3.13 Provide Executive Presentation

Task 13: Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

An executive presentation will be made by the Principal Investigator (PI) to the SDDOT Research Review Board in Pierre, South Dakota at the conclusion of the study. The presentation will summarize the research activities that were accomplished in this project and all conclusions and recommendations that resulted from the research.

4. LITERATURE REVIEW

A comprehensive literature review was completed for the purpose of this project. The main purpose of the literature review was to establish a list of short-span bridge construction techniques and elements suitable to implement at the South Dakota local government level. The literature review was conducted by reviewing peer reviewed articles. The search was conducted using various search utilities from the American Society of Civil Engineers (ASCE) Library, South Dakota State University Briggs Library, and the Federal Highway Administration and Google Scholar. The list established includes alternatives that are efficient, economical, and achievable through local workforces.
The purpose of the literature review performed for this project was to summarize the current innovative bridge techniques for local roads implemented across the United States to date. Several reports were studied to obtain this information, and the findings from these reports are summarized in this section. The categories for this section are innovative techniques, superstructures, substructures, materials, and entire-bridge-structures.

4.1 Techniques

Because low volume bridges built in the 1980s were designed according to the same specifications as urban highway bridges, many of the bridges were overly conservative and uneconomical (GangaRao, 1988). The suggestion in the 1980s was that less expensive bridges could be built by making modifications to the existing design specifications and with the use of prefabricated bridge components. It was also suggested that more efficient use of materials through mass production coupled with avoidance of costly and time-consuming conventional procedures could help in building more efficient and economical bridges.

4.1.1 Prefabricated Bridge Elements

The assertion that prefabricated components led to more cost efficient and durable bridges (GangaRao, 1988) was supported by Hallmark (Hallmark, 2012) 24 years later. It is important to note that the extent to which savings can be provided on bridges depends greatly on the scale of the prefabrication. That is, mass production of prefabricated bridge elements and systems would decrease the cost of production and construction. According to FHWA (FHWA, 2013b), prefabricated bridge construction offers a number of advantages over cast-in-place bridge construction. Bridges installed using prefabricated bridge elements and systems (PBES) with durable field connections can have a service life of 75 to 100 years. On the other hand, observations have shown that cast-in-place (CIP) bridges usually only have a life span of about 50 years. Prefabricated bridge elements include partial and full-depth deck panels, girders, pier caps, columns, footings, and foundations. Prefabricated bridge systems, which are comprised of prefabricated bridge elements, include complete superstructures, complete substructures, and entire bridges.

4.1.2 Jointless Bridge System

Another technique reviewed for economical and efficient low volume bridges is the jointless (single-span or continuous-span) bridge system. Jointless bridges have advantage over conventional bridges because they are more efficient and economical. Jointless bridges, unlike conventional bridges, do not have expansion joints, therefore do not experience problems due to bridge expansion joints. Joints and bearings are expensive to buy, install, maintain, and repair, and costlier to replace. Jointless bridges have been developed to ensure long-term serviceability, minimal maintenance, economical construction, and improved overall performance (Wolde-Tinsae, 1988). Figure 4.1 shows a diagram of a jointless bridge.

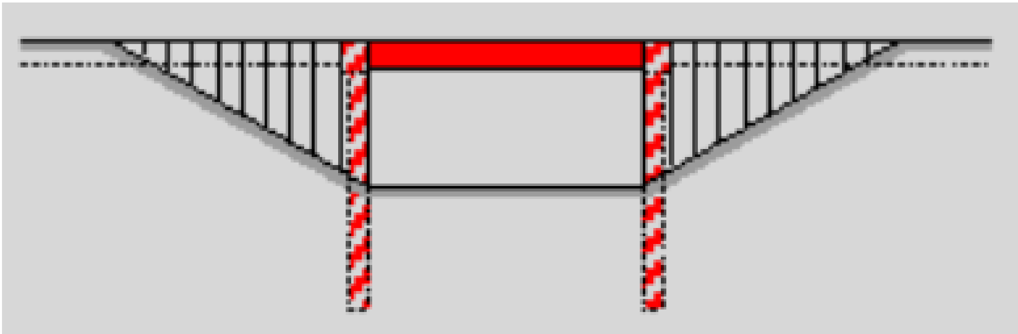


Figure 4.1 A single span bridge with wall-type abutments (LUSAS, 2014)

4.2 Superstructures

Conventional superstructures used in South Dakota are constructed using cast-in-place concrete. However, cast-in-place concrete has some shortcomings. Cast-in-place concrete requires a high amount of labor because of the need for formwork, and after the concrete is poured on site, a waiting period is required for the concrete to cure. The need for a competitive alternative is evident and as a result, some innovative superstructures that have been constructed in other states and can be built on South Dakota local roads were reviewed and included in this report. These superstructures are the precast inverted tee system, hollow core slabs, the double-tee beam, the precast modified beam-in-slab bridge system (PMBISB), the ultra-high performance concrete waffle deck panel system and the adjacent channel beam.

4.2.1 Precast Inverted Tee

The precast inverted tee system consists of longitudinal prestressed beams with an inverted tee-shaped cross section. They are adjacently placed, serving as stay-in-place formwork for a composite CIP topping. This reduces the construction time and labor work as it eliminates a large portion of false work required in CIP systems. Figure 4.2 shows the connection details for a precast inverted tee beam.

4.2.2 Hollow-Core Slabs

Hollow-core slabs also present a potential superstructure option. Two types of hollow-core slabs are precast deck slabs and precast box beams. The "deck slab system" is typically less than 21 inches deep and the "box beam system" is typically more than 21 inches deep. The beams are normally three feet or four feet wide. According to FHWA (FHWA, 2013a), it is stated that many states have used the deck slab system and adjacent box beam system as standard bridge systems for years.

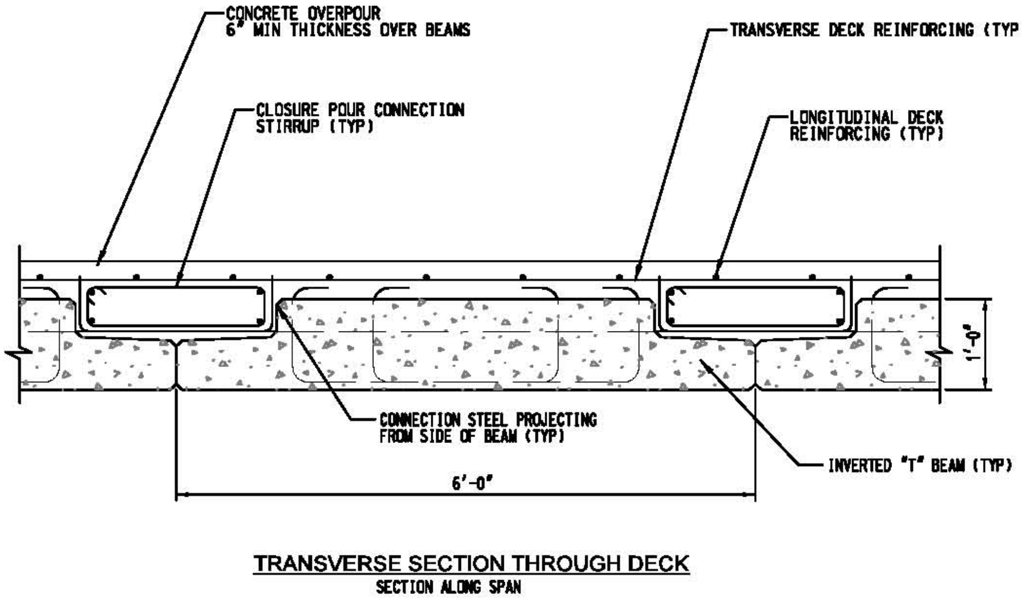


Figure 4.2 Connection details for a precast inverted tee beam (FHWA, 2013a)

Many states have noted that when these bridges are exposed to heavy truck traffic, there is a tendency for the joints between the beams to leak. In extreme cases, the joints have completely failed. However, for low volume road bridges, these systems perform very well. For example, Massachusetts has used these structures since the 1950s and recent inspection reports indicate that these local road bridges are performing very well, even after 50 years of service. Figure 4.3 (a) and (b) show the deck slab beam and the adjacent box beam respectively.

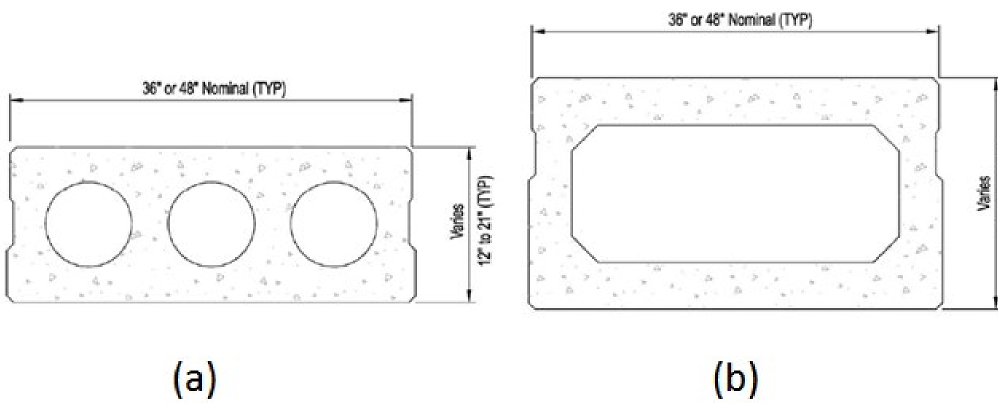


Figure 4.3 (a) Single precast prestressed deck slab beam (FHWA, 2013a) (b) single precast presetressed box beam (FHWA, 2013a)

4.2.3 Double-tee Beams

The double-tee beam option also provides a viable superstructure alternative. The double-tee beam is normally used for parking structures. A special design of the double-tee beam is the Northeast Extreme Tee (NEXT) Beam, which was developed by the Precast Concrete Institute Northeast (PCINE) (Roddenberry, 2012). PCINE serves the northeastern states including Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. This beam was developed to compete with the precast adjacent box beam superstructure system. The NEXT beam solves issues purely through its geometry. The open underside makes inspection easy because joints are visible. Utilities can be run parallel to the stems of the tee and, as long as they do not extend past the bottom of the stem, are hidden from sight. It is intended for use on medium span bridges with spans ranging from 40 feet to 90 feet. Figure 4.4 shows a schematic of the double-tee beam.

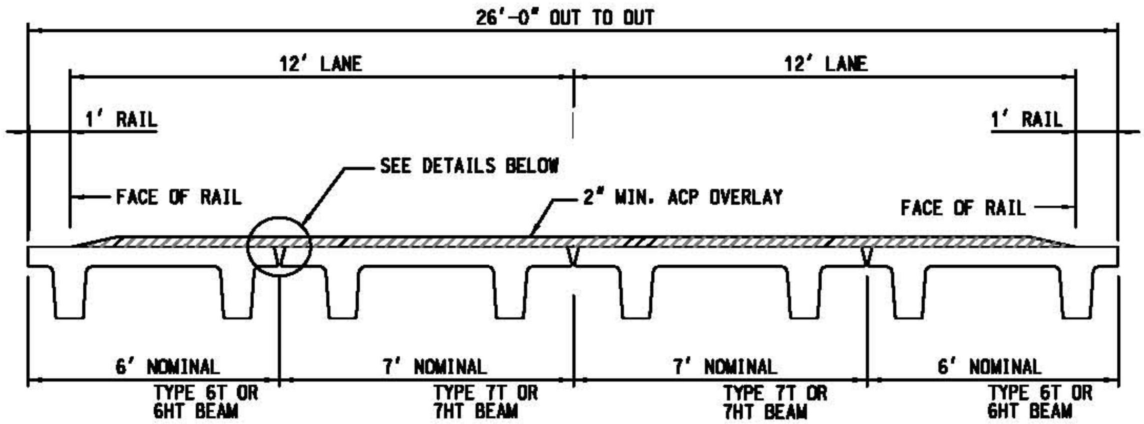


Figure 4.4 A typical double-tee bridge section (FHWA, 2013a)

4.2.4 Modified Beam Slab Bridge

The fourth superstructure reviewed was the precast modified beam-in-slab bridge (PMBISB) system. The PMBISB system consists of four precast panels fabricated at the county's facility, transported to the bridge site and joined with a cast-in-place concrete joint. The PMBISB design was developed to extend available funds, reduce in-field construction time and effort, provide year-round work for local forces (bridge crew), and support local superloads. Local superloads are vehicles that have a gross weight exceeding the weight permitted by counties and states on their local roads. The PMBISB system saved Black Hawk County approximately $16,000 or 17% per bridge compared to conventional bridges (Konda, 2007). The final design of the PMBISB is influenced by strength and serviceability criteria. The amount of required deck reinforcement is reduced by more than 50% compared with conventional reinforced concrete slab-on-girder decks commonly used in Iowa. Its span length is limited to 40 feet (Konda, 2007). Figure 4.5 shows a schematic of the precast modified beam-in-slab bridge.

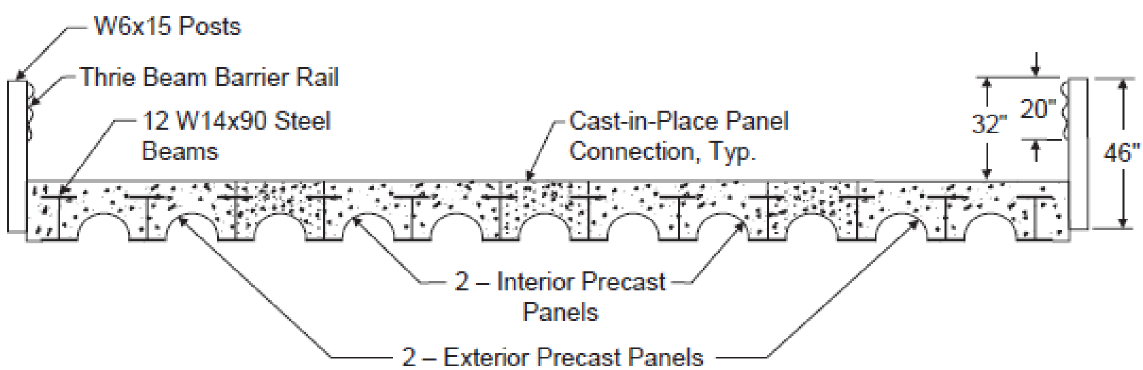


Figure 4.5 Typical cross section of a completed PMBISB (Konda, 2007)

4.2.5 Ultra-high-performance Concrete Waffle Deck Panels

The ultra-high-performance concrete (UHPC) waffle deck panel system provides superior durability against chlorides, freeze-thaw effects, salt scaling, abrasion, accidental impact, fatigue, and overload, thereby extending the useful life of the bridge deck (FHWA, 2013c). Combining the positive attributes of UHPC and the efficiency of the waffle panel design provides an extremely durable option that enables faster construction and longer girder spans through the efficient use of materials and reduced weight. Numerous DOTs and the FHWA have expressed significant interest in using full depth UHPC waffle deck panels. By demonstrating that this system is a viable solution to the problems encountered by design engineers, it is hoped that it will revolutionize the way bridges are designed in North America (FHWA, 2013c). Figure 4.6 (a) and (b) show the bottom side and the top side of a precast waffle bridge deck.

(a) (b)

Figure 4.6 UHPC waffle bridge deck panels. (a) bottom side of panel (Heimann 2013) (b) top side of panel (Heimann, 2013)

4.2.6 Adjacent Channel Beam

The adjacent channel beam is one of Alabama's standards for prefabricated bridges on secondary, low-volume roads and consists of precast concrete channel beams placed side by side between supports, eliminating the need for formwork or deck panels. The elements are transversely post-tensioned together using galvanized threaded bolts; however, in harsher environments, the use of stainless-steel bolts should be considered. One advantage of the adjacent channel beam is fast construction. The bottoms of the beams are open, which allows for easier inspection compared to box beams. Alabama also has standards for a precast concrete barrier to be used with this superstructure system that can be bolted onto the fascia of the exterior beam in a similar fashion as how the individual beams are connected together. One disadvantage is that access to the underside of the bridge is required for post-tensioning. There is no accommodation for skewed bridges. Also, spalling can occur around bolted connections. Figure 4.7 shows a schematic for the channel beams.

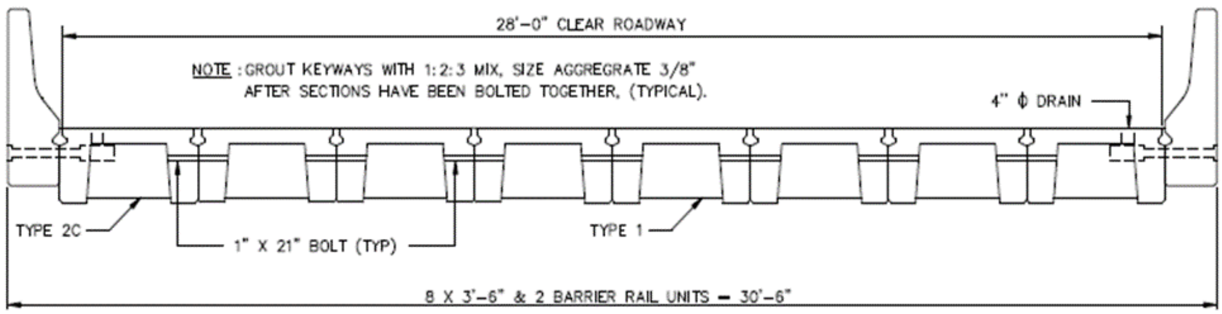


Figure 4.7 Typical channel beams placed adjacent to one another (Roddenberry, 2012)

4.3 Substructures

Conventional superstructures used in South Dakota include timber piles, H-piles and cast-in-place abutments. These alternatives have proven to work effectively; however, during the literature review, competitive alternatives were discovered. The alternatives include the geosynthetic-reinforced soil (GRS) abutment, mechanically stabilized earth (MSE) wall and sheet pile abutments. The next few paragraphs briefly discuss each alternative.

4.3.1 Geosynthetic-Reinforced Soil

The geosynthetic-reinforced soil (GRS) abutment is gaining acceptance in the transportation industry and has been adapted by the Eastern Federal Lands Highway Division (EFLHD) in several projects (Mohamed, 2011). Some GRS abutments used in the EFLHD projects are located on low-volume roads in remote areas. Such remote areas are difficult to access with heavy construction equipment; therefore, the GRS was the best alternative since it does not require heavy construction equipment. The GRS is also useful in emergency situations as it is a fast construction technique. GRS has many advantages, including simple design procedures, a relatively fast and easy construction process, potential cost savings, use of common construction equipment and materials, use in a wide range of subsurface soil conditions, the ability to tolerate relatively large differential settlements, and use as a temporary foundation. The use of GRS abutments for some projects has resulted in design and construction cost savings of 20%–30% compared with the use of conventional bridge foundations (Minnesota Department of Transportation, 2012). GRS abutments are not recommended for construction in areas susceptible to scour. Figure 4.8 shows a schematic of a typical GRS abutment.

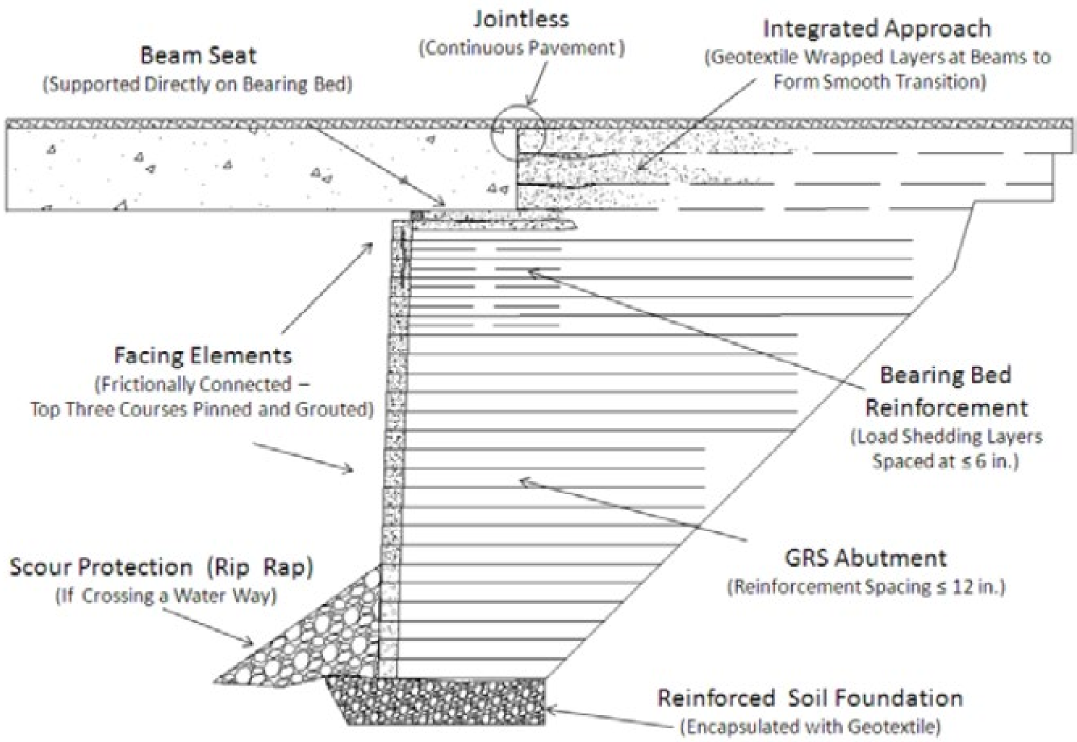


Figure 4.8 Geosynthetic reinforced soil (GRS) abutment (MnDOT, 2012)

4.3.2 Mechanically Stabilized Earth

Mechanically Stabilized Earth (MSE) walls with single line pile abutments also provide a viable alternative for an innovative substructure. In 2011, Steele County constructed a bridge that used integral abutments on single rows of piles behind MSE walls (Minnesota Department of Transportation, 2012). While no individual components of this abutment type are unique, their use in combination is innovative and unique on Minnesota's local road system. MSE walls with single line pile abutments are one of the innovative bridge systems recommended by MnDOT (Minnesota Department of Transportation, 2012). MSE walls use less concrete and less foundation piling than a typical cast-in-place abutment, which leads to a decrease in cost. MSE abutments settle less in compressible soils than spread footings and generally, are more tolerant to settlement. However, MSE walls have not been widely used on the local road system (Minnesota Department of Transportation, 2012). MSE walls are sensitive to pile alignment and cannot be used where buried utilities may need to be installed in the future. Figure 4.9 shows the picture of a bridge constructed with MSE abutment walls.

Figure 4.9 Geosynthetic reinforced soil (GRS) abutment (MnDOT, 2012)

Sheet pile abutments were the final substructure reviewed from the literature. Blue Earth County has constructed three bridges over Little Cobb and Big Cobb Rivers, which consist of an adjacent precast box beam superstructure supported on sheet pile abutments (Minnesota Department of Transportation, 2012). This design is similar to bridges used in New York for low-volume roads and was identified as having potential for use in Minnesota during a scanning tour to New York attended by the Blue Earth County Engineer (Minnesota Department of Transportation, 2012). Advantages of using the sheet pile abutment are that it prevents approach fill loss and has a shorter construction time than conventional cast-in-place abutments. The disadvantage of sheet pile abutments is corrosion. Figure 4.10 shows construction of a sheet pile abutment.

Figure 4.10 Sheet pile abutment (MnDOT, 2012)

4.4 Materials

Some innovative materials used for bridge construction were discovered in the literature. They include ultra-high-performance concrete (UHPC), high-strength lightweight concrete, expanded polystyrene (EPS) geofoam, self-consolidating concrete and the cellular confinement system (CCS). The following paragraphs give the descriptions and importance of the materials.

4.4.1 Ultra-high-strength Concrete

Ultra-high-performance concrete (UHPC) plays a major role increasing the span-to-depth ratio of a bridge. Almansour (Almansour, 2010) investigated replacing deteriorated bridge girders with bridge girders made of UHPC. UHPC provided high compressive strengths and exhibits improved tensile strength and durability properties that made it a promising material for bridge applications. UHPC has compressive strengths exceeding 30 ksi (200 MPa) and post-cracking tensile strengths of 1.5 ksi (10 MPa). UHPC has a low permeability to aggressive agents such as chlorides from de-icing salts or seawater. UHPC provides more advantages over high performance concrete (HPC) in terms of structural efficiency, durability, and cost-effectiveness over the long term. A good design using UHPC can result in a significant reduction in concrete volume and weight of the superstructure, which in turn leads to significant reduction in the dead load on the substructure, especially for the case of aging bridges, thus improving their performance. Replacing deteriorated bridge girders with bridge girders made of UHPC would significantly reduce the amount of life-cycle maintenance required and would ultimately result in low life cycle bridge costs. New York Department of Transportation (NYDOT) uses prefabricated bridge panels that are connected using ultra-high-performance concrete (UHPC) (Almansour, 2010).

4.4.2 Lightweight Aggregate Concrete

Lightweight aggregate concrete has been used to construct American bridges for over 50 years and as a result, there are more than 200 concrete and composite bridges containing lightweight aggregates in the United States and Canada (Ramirez, 2000). In the former USSR, about 100 bridges have been constructed using lightweight aggregates for the past 30 years, and in Europe, the numbers are increasing steadily. Lightweight aggregate concrete has been successfully used in applications ranging from simple reinforced concrete footbridges to long-span post-tension segmental box girder bridges. Weight savings of 30% on the superstructure can be achieved in some cases with consequent savings of reinforcing and prestressing steel. Size of the piers and foundations can also be reduced when lightweight concrete is used for the superstructure. Overall savings in cost of more than 10% can be expected after allowances have been made for the higher initial cost of lightweight aggregates (Ramirez, 2000).

4.4.3 Expanded Polystyrene Geofoam

Expanded polystyrene (EPS) geofoam is used in construction for the following reasons:

1) Ultralight weight – Its density is only about 1% of sand or soil.
2) Efficiency – It has a low overall construction cost.
3) Construction is simple and rapid – It does not need large machinery, and it can be handled by manpower.
4) Self-sustaining character – It has a small Poisson's ratio and a high self-sustaining property—it can decrease soil lateral pressure and is suitable as a backfill material for structures such as retaining walls, etc.

5) Superior cushion property – The individual air bubble body has the ability of reducing impact and vibration effects.
6) Waterproof ability – The individual air bubble body has the merits of water resistance (Lin, 2010). Figure 4.11 (a) and (b) shows installation of the EPS Geofoam and a schematic showing use in road and bridge construction.

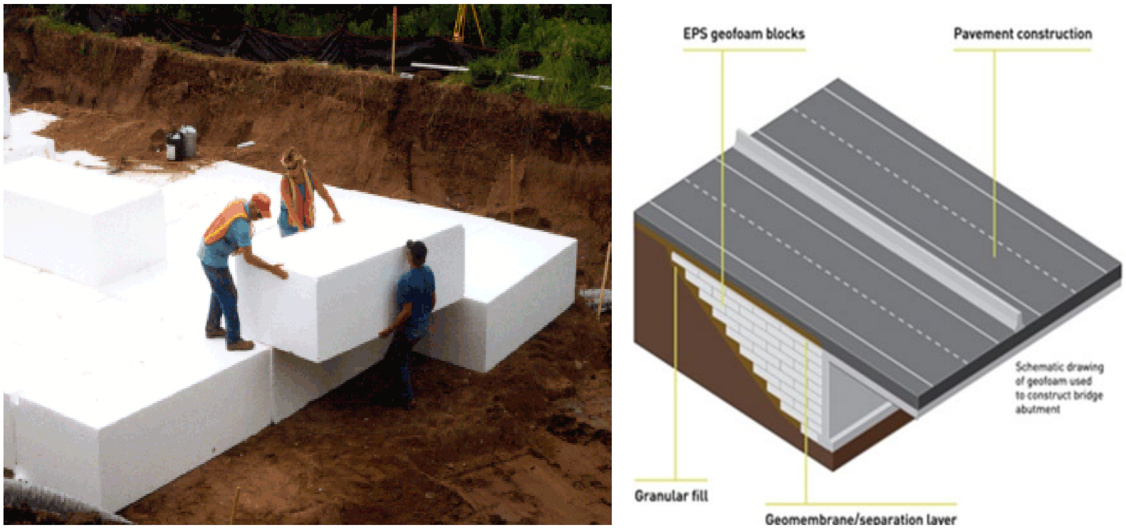


Figure 4.11 Expanded polystyrene (EPS) geofoam (a) installation (Royal Foam, 2010) (b) schematic showing use in road and bridge construction (AFM, 2015)

4.4.4 Self-Consolidating Concrete

Self-consolidating concrete (SCC) is a viable material for use as an innovative material. The Iowa Department of Transportation combined several accelerated bridge construction methods and innovative materials to replace a rural bridge — U.S. 6 over Keg Creek in Pottawattamie County — during a 16-day closure, saving motorists months of travel disruption (FHWA, 2013). Self-consolidating concrete was used to improve consolidation and increase the abutment piles' speed of construction. SCC, sometimes also referred to as "self-compacting concrete," can effortlessly fill and consolidate in complex structural shapes and around congested steel rebars, eliminating the need for mechanical vibration. SCC mixes are designed to ensure optimal flowability, passability (the ability to fill restrictive spaces), and stability. It reduces labor requirements and improves worker safety — workers no longer need to access unsafe areas to vibrate concrete. The use of SCC ensures quicker installations that translate to lower project costs. The use of SCC also results in longer lasting forms. The slump test indicates that the SCC mixture is very flowable. Figure 4.12 shows a picture of the SCC slump test.

4.4.5 Cellular Confinement System

A cellular confinement system (CCS) has the advantages of providing abutment face protection against erosion and shallow scour. Gabion baskets or segmental blocks can also be used for abutment face protection (Minnesota Department of Transportation, 2012). CCS also be used for ground stability improvement. Figure 4.13 shows a picture of the cellular confinement system.

Figure 4.12 Flowability of self-consolidating concrete (SCC) (EAC, 2014)

Figure 4.13 Cellular confinement system (CCS) (Cell-Tek, 2010)

4.5 Entire Bridge Structures

This category summarizes bridges prefabricated as a whole unit and transported to the site. The superstructure and part of the substructure are precast as one unit. The alternatives discovered for entire-bridge structures were the large precast box culvert and the three-sided structure.
Aitkin County in Minnesota replaced an existing bridge with a large precast box culvert structure on county road 73 over the Sandy River near McGregor, Minnesota (Minnesota Department of Transportation, 2012). The structure is 20 feet wide and eight feet high, which exceeds the maximum span of 16 feet covered by the MnDOT standard culvert designs tables. An engineer was retained to design the reinforcing and modify the MnDOT standards, and the culvert was constructed in 2011. A set of twin boxes was not desired at this location, so a large single box structure was chosen with the intent of maintaining the full waterway opening across the entire width of the box. From conducting bridge inspections for a number of years, the county engineer noted that double and triple box culvert

installation often did not function hydraulically as envisioned. An amount of channel change had frequently been required during construction to align or modify the channel in an attempt to direct the flow through the double/triple boxes. However, the stream quickly migrated back to its natural flow and primarily used only one of the culvert barrels. The second or third box would silt in with sediment or debris, no longer providing the full hydraulic cross section. During the design phase, the size of the box structure was reviewed for constructability. The county and designer believed local contractors would not have issues building the culvert. This assessment was confirmed when eight bidders competed for the project. These bidders were typical small contractors that bid on other projects in Aitkin County. No company expressed concerns to the county regarding the box size or constructability. Advantages of the large precast box culvert innovation include easy construction, and inspection is the same as for all precast box culverts. One disadvantage of the innovation is that for some sites, access and placement of larger box sections may be an issue. Also, shipping weight and size of boxes may be an issue for trucking. Figure 4.14 shows a large precast box culvert under construction.

Figure 4.14 Precast arge box culvert (MnDOT, 2012)

In addition to large precast box structures, there has been an increased use of three-sided structures for local roads. Three-sided structures are precast box culverts that do not have a bottom slab. The legs bear on footings that cast in place on the site. Spans for the three-sided structures can approach 60 feet; however, common spans are typically 28 to 42 feet (Minnesota Department of Transportation, 2012). Similar to box culverts, the structure is built from a series of precast sections sized for shipping and lifting. The benefits of three-sided structures include that, as a culvert, it is a low maintenance structure, and the stream bottom is undisturbed and maintains a natural bottom. The natural bottom is preferred in streams with concerns for fish migration or habitat. Limitations include the fact that scour-susceptible sites can require a pile foundation, which increases the cost of the structure significantly. The roadway barrier on top of the structure is typically a moment slab, where the railing is anchored into the pavement to prevent the railing from overturning from traffic impacts. The three-sided structure is not designed to anchor the barrier railing directly. Costs are usually higher than precast box culverts, so use of a three-sided structure is typically at sites where the open bottom is needed, or the arch-like appearance is desired for aesthetics. Figure 4.15 shows installation of the three-sided frame.

Figure 4.15 Three-sided frame (Ohio DOT, 2015)

Table 4.1 presents the organization of the bridge alternatives obtained from the literature review.

Table 4.1 Organization of Structure Alternatives from Literature Review

Category	Structure Alternatives
Techniques	Prefabricated Bridge Elements and Systems (PBES)
	Jointless bridge
Superstructure	MnDOT's Precast Inverted Tee Beam
	Precast Prestressed Box Beams
	Precast Prestressed Deck Slab Beams
	Precast Double-T Beam/The NEXT Beam
	Precast Modified Beam-in-slab Bridge System
	UHPC Waffle Bridge Deck Panels
Substructure	Geosynthetic Reinforced Soil (GRS) Abutments
	MSE Walls with Single Line Pile Abutments
	Sheet Pile Abutments
Materials	Ultra-high-performance Concrete (UHPC)
	High-Performance/High-Strength Lightweight Concrete
	Self-consolidating Concrete
	EPS Geofoam
	Cellular Confinement System
Entire Bridge Structure	Precast Large Box Culverts
	Precast Three-sided Frame
	Adjacent Channel Beams

5. PRESENTATION AND ANALYSIS OF THE SURVEY

This chapter presents the results of two surveys conducted and implications of the results relative to this research project. This survey was conducted to verify and supplement results obtained from the literature review. The first part of this chapter is a summary of how this survey was designed, conducted and results obtained from it. Before the survey was conducted, the research team interviewed Grant County personnel to document their off-system construction practice, because Grant County has had success with constructing bridges without SDDOT and federal assistance. A summary of Grant County's off-system road bridge replacement practices concludes this chapter.

5.1 Survey Goals and Process

The main goal of the survey was to verify and supplement the off-system bridge techniques, elements and systems obtained from the literature review. The survey was in two phases as two groups of responders were considered.

The first phase involved a questionnaire sent to fabricators and contractors in the state of South Dakota to obtain a list of commonly used design and potential innovative solutions for off-system bridges. The list of fabricators, suppliers, and contractors were provided by the South Dakota Associated General Contractors Structures Task Group (SD AGC).

The second phase of the survey involved a questionnaire sent by mail to each department of transportation of the states that surround South Dakota. The main purpose of the questionnaire was to inquire professional opinion on the structure alternatives discovered from the literature review and to obtain information on any other cost-effective and durable off-system bridge element, system or technique not discovered in the literature review. Survey feedback was intended to provide details on why to use a particular alternative over the others and why not to use a particular alternative at all. The response and analyses of the survey conducted follows.

5.2 Designing the Survey

The surveys were designed to obtain information on cost-effective solutions for off-system bridges used or known by South Dakota bridge contractors and the states surrounding South Dakota. The information obtained from the surveys were meant to verify and supplement the off-system bridge techniques, elements and systems obtained from the literature review. The surveys were also designed to provide knowledge about the responders' preference for prefabricated, partially prefabricated or cast-in-place structures, epoxy coated rebar or fiber reinforced polymer. Knowledge about the preferential choices of the responders enabled the research team to discover additional advantages and disadvantages of the alternatives in the surveys because reasons were given for the preferential choices.

5.3 SD AGC Responses

In July 2014, two members of the SD AGC were interviewed to gather information on the current practice of cost-effective off-system bridges used in South Dakota and applicability of a preliminary list of innovative bridges discovered from the literature review. The SD AGC suggested including in the preliminary list the precast bulb tee girder, old rail cars, steel girders, glulam timber, and post-tensioning. The final list was incorporated in a short survey questionnaire sent by email to six of the contractors belonging to SD AGC. The contractors that did not reply within one week were contacted by phone. The next few paragraphs present SD AGC's response to the survey questionnaire. The list of SD AGC's survey contacts is shown in Table 5.1.

Table 5.1 SD AGC Interview and Survey Contacts

SD AGC	Contact	Form of Contact	Received Feedback
Executive Vice President	Toby L. Crow	Interview	Yes
Cretex Concrete Products, Inc.	Dan Bjerke	Phone	Yes
Egger Steel Co.	Jim Larson	Email	Yes
SFC Civil Constructors	Jared Gusso	Interview and Email	Yes
Heavy Constructors	Dave Dailey	Email	Yes
Swingen Construction Co.	Jason Odegard	Phone	Yes
TrueNorth Steel	Levi Christman	Phone	Yes

The response from Egger Steel included a suggestion to use preassembled, wide flange steel beams for short simple-span bridges. Spans of the steel beams could be assembled in the shop and shipped to the jobsite in units to provide for a cost-effective method of construction. Egger Steel also stated that wide flange steel beams are readily available and are produced from virtually 100% recycled materials.

SFC Civil Constructors recommended using steel girders and the inverted tee. The reason for the steel girders is that if weathering steel is used, there will be low maintenance after installation. There will also be the ability to use a shallow section, and the bridge will be lighter in weight.

Heavy Constructors reported working with the GRS system, precast bulb tee girders, sheet pile abutments, old rail cars and steel girders. Heavy Constructors stated that the most cost-effective structures they have built used salvaged steel girders from on-system structures they removed. Very little equipment was needed to build those structures. They stated that a significant consideration in bridge construction cost is the variability of materials used. For example, piling installation requires a pile hammer, which requires mobilizing a crane to the site. When considering cost, Heavy Constructors was more concerned about the distance of the construction site from civilization, mobilization costs, and the cost of materials. Heavy Constructors gave the following example for a cost-effective off-system bridge: bulb tees supported on steel piles, binwall or galvanized sheet pile abutment walls, and precast plank or treated timber also being used for remote structures. Heavy Constructors stated that they had no qualified or certified post-tensioning contractors in their company. The only experience they had in post-tensioning was on a 3.3-million-gallon water tank, and they had to hire a subcontractor to meet the qualification requirements. They stated that personnel certified for post-tensioning adds an experience requirement for the installer, which then makes the work one of a specialty contractor and likely raises construction costs and increases construction time.

Cretex Concrete Products reported that the girders they manufacture are I-beams, double tee beams and bulb tee beams. The reported compressive strength of the concrete they use is between 6,000 psi and 10,000 psi, which is in the high-performance concrete (HPC) range according to the American Concrete Institute (ACI, 2015). The other ranges are normal strength concrete (3000 psi to 6000 psi) and ultra-high-performance concrete (above 18,000 psi).

Swingen Construction Co. stated that with their experience, on average, steel girders were more cost-effective than concrete girders. They stated they have worked on bridge projects spanning from about 20 feet to over one mile in length. From their experience, they were almost certain that for off-system bridges, the most cost is from mobilization. Their recommendation was that for bridge projects, the distance from where bridge elements are to be manufactured and from where the equipment is to be hauled from should be minimal from the project site.

TrueNorth Steel prefabricates steel girders and steel box culverts for bridges. They stated that the majority of the steel they use in prefabricating is obtained from the Nucor Corporations site, and most of the steel materials consist of up to about 90 percent recycled materials. The corrosion mitigation measures used by TrueNorth Steel include: the use of 588 grade 50 material, which is a specialized steel that rusts to protect itself from further corrosion; tainted or galvanized steel; and cor-ten, which is the steel material typically preferred.

Based on the SD AGC survey response, the additional bridge elements and systems not included in the literature review that are recommended in off-system bridge construction are the wide flange steel beam, the precast decked bulb tee beam and used rail flatcars. The survey revealed that only a few innovative bridge elements, systems and techniques listed in the survey questionnaire had been used in the state of South Dakota. This was not unexpected since most of the bridge elements, systems and techniques listed in the survey questionnaire were found from bridge construction practices outside the state of South Dakota, and South Dakota does not have an established off-system bridge construction program.

5.4 State DOT Responses

As previously noted, a different survey questionnaire was sent to the DOTs of states that surround South Dakota. Of these, Minnesota, Nebraska, and Wyoming replied. Table 5.2 shows the responders of the survey.

Table 5.2 State DOT Survey Contacts

Other States	Contact	Form of Contact	Recieved Feedback
Minnesota	David Conkel	Email	Yes
Nebraska	Fouad Jaber	Email	Yes
Wyoming	Keith Fulton	Email	Yes

Minnesota reported using HPC, UHPC, EPS geofoam, fiber reinforced polymer, and self-consolidating concrete materials. They also reported using the GRS system, PBES, precast inverted-tee beam, MSE walls with single line pile abutments, sheet pile abutments, jointless bridge, precast prestressed adjacent box beams, precast double tee beams, large precast box culverts, and the precast three-sided frame. Minnesota said that until a deck-cracking issue they experienced is fully resolved, they will not expand the use of the precast inverted-tee beam on the local road system. They have had good success using fiber reinforced deck concrete for inverted tee beams. Minnesota is trying more inverted-tee beam projects using fiber reinforcement, and based on their performance, will formally develop standard designs and details for statewide implementation. They only have two inverted-tee bridges on their local road system; most of the others have been experimental projects on state roads. Minnesota suggested the use of carbon fiber prestressing strands and reinforcement, which is used by the Michigan DOT. They said that the CIP slab span bridge remains their primary low-cost bridge. Minnesota does not select local bridges for funding based solely on low life-cycle costs; however, they are moving in that direction. Minnesota said it has been shown that repetitive use of precast systems has reduced in costs. Their best life cycle cost bridge is multiple lines of precast concrete box culverts. Minnesota prefers to use epoxy-coated rebar over fiber reinforced polymer for off-system bridges. The reasons they might choose the use of fiber reinforced polymer over epoxy coated rebar are if: 1) the bridge is to be built in a high corrosive environment (deicing salts), and 2) there will be transverse post-tensioning of the adjacent precast panels.

Nebraska has used UHPC, EPS geofoam, fiber-reinforced polymer, and SCC materials. Nebraska has used the GRS, PBES, MSE walls with single-line pile abutments, sheet pile abutments, jointless bridge, precast prestressed adjacent box beams and slab beams. Nebraska prefers partially precast bridge components. Nebraska prefers epoxy-coated rebar to fiber reinforced polymer in their off-system bridges. The reason they only choose the use of fiber-reinforced polymer over epoxy-coated rebar is if the fiber reinforced polymer option is cheaper.

Wyoming has not used any innovative materials presented in the survey questionnaire. However, they believe they have the capacity to produce such innovative materials when needed. Wyoming has used PBES, sheet pile abutments, jointless bridges, and large precast box culverts. Wyoming prefers prefabricated bridge components to cast-in-place bridge components, and they prefer cast-in-place bridge components to partially prefabricated bridge components. Wyoming prefers to use epoxy-coated rebar over fiber-reinforced polymer in their off-system bridge elements and systems. Wyoming has had problems with prefabricated girders; however, they have had no problems with precast slabs and abutments. The issue they had with prefabricated girders was difficulty aligning prestressed girders due to different cambers. Wyoming recycles bridge materials and used steel girders that have a large portion of recycled steel in them. A county in Wyoming occasionally reuses portions of removed bridges for repairs on other bridges. In Wyoming, material availability and transportation cost are the most important factors for off-system bridge construction. Based on the survey responses from Minnesota, Nebraska and Wyoming, the additional alternative to consider in this research study is the carbon fiber prestressing strand.

5.5 Summary of Survey Responses

Most contractors contacted for this study prefer cast-in-place concrete to prefabricated bridge components. Survey responses from adjacent state DOTs take preference to prefabricated bridge components over cast-in-place concrete; however, one state indicated that the lowest cost bridges were constructed of cast-in-place concrete. Conventional cast-in-place concrete bridges are generally cheaper than prefabricated bridges but are slow to construct and less durable. Prefabricated bridges offer faster onsite construction and greater durability than conventional cast-in-place concrete bridges but are usually more expensive to construct. Based on these responses, both prefabricated and cast-in-place concrete elements should be used in construction to obtain the benefits of faster construction, greater durability, and less expensive bridges. The additional structure alternatives for local roads obtained from the survey responses are shown in Table 5.3.

Table 5.3 Organization of Additional Structure Alternatives from Survey

Category	Innovative Bridge System
Superstructure	Precast Decked Bulb Tee Girder
	Old Rail Flatcars
	Wide Flange Steel Girder
Material	Carbon Fiber Prestressing Strand

5.6 Grant County Bridge Construction

The research team met with Grant County personnel led by Kerwin Schultz at Milbank, SD, on October 10, 2015, to learn about their off-system bridge construction program. Grant County has experienced success replacing short-span bridges without federal aid using their in-house bridge construction team. Grant County noted that the main programmatic differences between an off-system and on-system bridge consist of: 1) a formal hydraulic study, 2) a scour study, 3) right-of-way issues,

4) historical studies, 5) environmental studies, and 5) Army Corps of Engineers permitting. Their off-system bridge construction practice summary follows.

Grant County's general approach is to identify older functioning bridges that have either observed or perceived low scour. These are the bridges that undergo bridge replacement first. If the hydraulics of the bridge are "questionable" (angle of attack, flow rates, etc.), then an engineering firm is hired to review the bridge site and perform a hydraulic analysis. Formal analyses to date have resulted in low predicted scour depths. The off-system process is not used on bridges considered to have major flow conditions.

Grant County's bridge system is made of prefabricated box beams placed on cast-in-place abutments bearing on shallow spread footings. The majority of their off-system bridge spans typically average 35 feet in length and range from 24 feet to 40 feet. Since 1998, Grant Count has replaced 42 off-system bridges. There are typically two to three bridges built per year with seven the most built per year. Repairs of off-system bridges to date have only consisted of re-riprapping abutments at three bridge locations.

The footing dimensions are typically eight feet wide by two feet thick. A six-inch-layer of rock is usually placed under the shallow footings. The abutment walls are typically two feet inboard and range from five to 11 feet in height. The reinforcing in the abutment wall is typically two rows of #4 bars spaced nine inches longitudinal and 12 inches vertical. The bend at the stem wall has double the amount of reinforcing to prevent the bend from overstressing due to the impact of flow. The railings used are open metal, and Grant County has not noted any problems with their performance to date. The cost of an off-system bridge typically ranges from $55,000 to $60,000 and exclusively uses local money. Federally funded bridges require the use of a berm-style bridge and have averaged in cost of $240,000 with a 20% Grant Count cost-share. Engineering fees have averaged $30,000 with a $7,000 Grant County cost-share.

Local forces (county personnel and local contractors) build the bridges. Major equipment typically includes a crane to place the deck, an excavator for concrete demolition (if required) and a commercial pump truck. Construction typically takes 13–30 working days (30–45 calendar days) to complete bridge construction. The box beams are pre-engineered and prefabricated by Cretex (in Watertown, SD) according to the length of the bridge being replaced. The bridge replacement is programmed for a 70-year performance life. Construction materials (concrete, steel placement, compaction) are not tested on the construction site; however, Grant County does have experienced personnel on-site, observing these items during construction.

Periodically, sheet piles are installed at the abutment if the flowline is going to intersect the abutment. The load used for design of the box beams by Cretex is AASHTO HS-20. Inspections are performed on all bridges over 20 feet. The Manual on Uniform Traffic Control Devices is used for bridge signage. Figure 5.1a through Figure 5.1x were provided by Grant County that show the replacement of Bridge 250-116 using the off-system method in 2010.

(a) Looking north prior to replacement

(b) Looking south prior to replacement

(c) Looking east prior to replacement

(d) Looking west prior to replacement

(e) Weight limit sign prior to replacement

(f) Looking west prior to replacement

Figure 5.1 Grant County bridge construction

(g) Crack in 16th plank from north prior to replacement

(h) Crack in 25th plank from north prior to replacement

(i) Selective bridge demolition

(j) Selective bridge Demolition

(k) Preparing site for abutment construction

(l) Preparing site for abutment construction

Figure 5.1 Grant County bridge construction

(m) Preparing site for abutment construction

(n) Gravel placement prior to installation of reinforcing

(o) Abutment footing reinforcement

(p) Concrete placement with abutment reinforcement

(q) **Abutment wall reinforcement**

(r) **Abutment wall formwork**

Figure 5.1 Grant County bridge construction

(s) Placement of abutment wall concrete

(t) Abutment backfill and riprap placement

(u) Completed abutments

(v) Abutment backfill and riprap

(w) Placement of adjacent box slabs

(x) Grade restored and railings installed. Project complete

Figure 5.1 Grant County bridge construction

6. STRUCTURE ALTERNATIVES FOR LOCAL ROADS CATALOG

This chapter presents the catalog constructed for alternatives obtained from the literature review and survey responses. This chapter also discusses the more detailed profiles written for each alternative and a user-friendly format created in Microsoft Excel for the catalog.

6.1 The Catalog

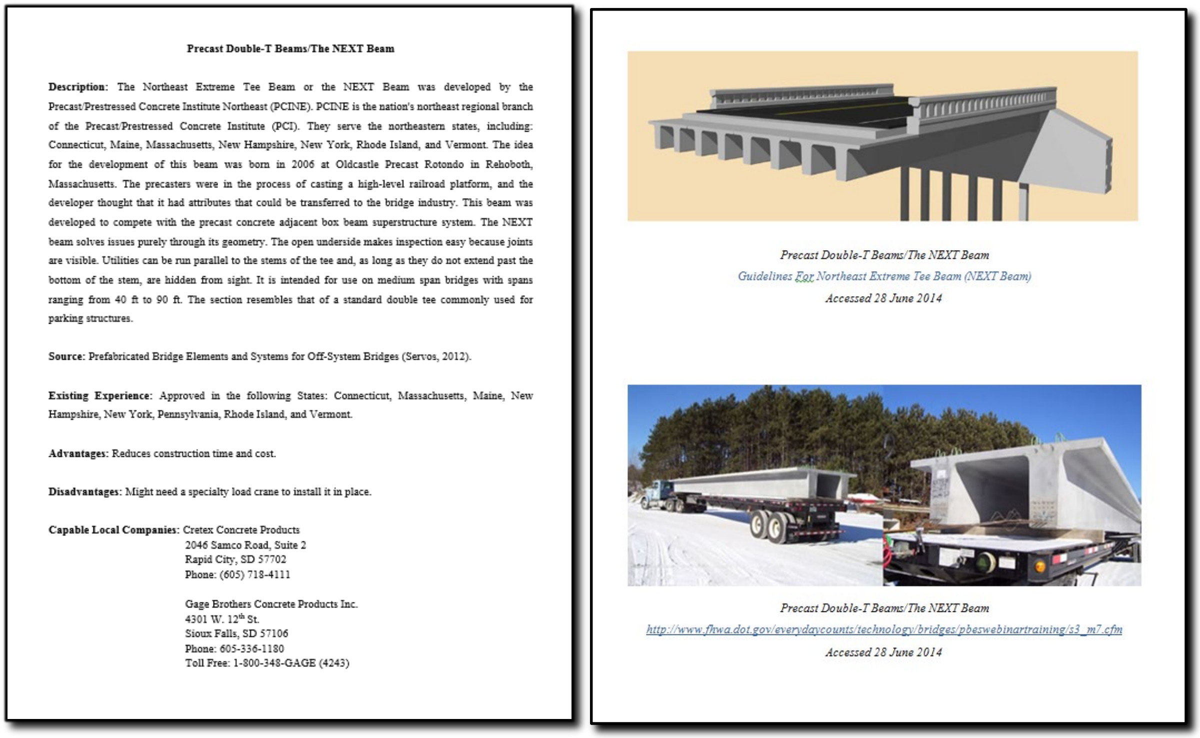
A catalog was developed for the alternatives obtained through the literature review and survey. The catalog is categorized into techniques, superstructure, substructure, materials, and entire-bridge structures. It contains 24 bridge alternatives for local roads and a summary of relevant information about each alternative. Such relevant information includes the description of each structure, its advantages, disadvantages, companies in South Dakota that can potentially help build the structure, locations of existing experience, installation factors, durability factors, maintenance factors, cost per square foot of deck, and other pertinent factors. Costs listed in the catalog are cost per square foot of the deck area for each bridge element or system and not the cost of an entire project. Note that costs are for each individual element or system.

Most structures in the catalog have not been built in the state of South Dakota. Therefore, for many of the local workforces in South Dakota, it will likely be their first time constructing bridges using such alternatives. This means that in the beginning, construction project costs might be higher than expected. But with time, the local workforces will become familiar with the alternatives, leading to the cost of projects declining. The catalog is in Appendix D.

The catalog enables local governments in South Dakota to have more options in selecting a bridge for off-system bridge construction and use of conventional practices. The catalog serves as a basis for local governments to develop their own innovative low volume road bridges similar to other counties such as Black Hawk County in Iowa (Konda, 2007). Black Hawk County developed the Precast Modified Beam-In-Slab Bridge (PMBISB) system from the Modified Beam-In-Slab Bridge (MBISB) system developed by Iowa State University. A derivative of the MBISB design was developed by county engineers in Black Hawk County that used MBISB design concepts combined with precast concrete technologies. Black Hawk County also developed precast backwall panels and precast abutment caps that can work well with the PMBISB system (Konda, 2007).

6.2 Bridge Element/System/Technique/material Profiles

The catalog is presented in a table format with some information presented that is related to the bridge elements, systems, and techniques. Details of each alternative are presented in a profile document developed to contain information supplementing that in the catalog. The profiles include a concise description of the alternative, source of information, existing experience, advantages, disadvantages, and capable fabrication and construction companies in South Dakota. The profiles were created from information obtained from the literature review and the surveys, and then used to populate the catalog. The layout and appearance of a sample profile is shown in Figure 6.1.



Precast Double-T Beams/The NEXT Beam

Description: The Northeast Extreme Tee Beam or the NEXT Beam was developed by the Precast/Prestressed Concrete Institute Northeast (PCINE). PCINE is the nation's northeast regional branch of the Precast/Prestressed Concrete Institute (PCI). They serve the northeastern states, including: Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. The idea for the development of this beam was born in 2006 at Oldcastle Precast Rotondo in Rehoboth, Massachusetts. The precasters were in the process of casting a high-level railroad platform, and the developer thought that it had attributes that could be transferred to the bridge industry. This beam was developed to compete with the precast concrete adjacent box beam superstructure system. The NEXT beam solves issues purely through its geometry. The open underside makes inspection easy because joints are visible. Utilities can be run parallel to the stems of the tee and, as long as they do not extend past the bottom of the stem, are hidden from sight. It is intended for use on medium span bridges with spans ranging from 40 ft to 90 ft. The section resembles that of a standard double tee commonly used for parking structures.

Source: Prefabricated Bridge Elements and Systems for Off-System Bridges (Servos, 2012).

Existing Experience: Approved in the following States: Connecticut, Massachusetts, Maine, New Hampshire, New York, Pennsylvania, Rhode Island, and Vermont.

Advantages: Reduces construction time and cost.

Disadvantages: Might need a specialty load crane to install it in place.

Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
Phone: (605) 718-4111

Gage Brothers Concrete Products Inc.
4301 W. 12th St.
Sioux Falls, SD 57106
Phone: 605-336-1180
Toll Free: 1-800-348-GAGE (4243)

Precast Double-T Beams/The NEXT Beam
Guidelines For Northeast Extreme Tee Beam (NEXT Beam)
Accessed 28 June 2014

Precast Double-T Beams/The NEXT Beam
http://www.fhwa.dot.gov/everydaycounts/technology/bridges/pbeswebinartraining/s3_m7.cfm
Accessed 28 June 2014

Figure 6.1 Example structure alternative profile

6.3 Organizational Format

Throughout the process of populating the structure alternative catalog, a significant amount of information posed the challenge of how to effectively organize information for ease of use. The catalog has several columns and rows and viewing all that information at once can be cumbersome. Making the catalog user-friendly was integral for simplicity and efficiency. Without it, searching through the catalog would be time-consuming. The catalog information was compiled into a pivot table using Microsoft Excel® to provide that user-friendly interface. Pivot tables allow the catalog user to apply information filters that narrow down the information of interest. Figure 6.2 portrays an example of the pivot table with the dropdown filters applied.

Category	Substructure

Structure Alternatives	Description	Advantages	Disadvantages	Potentially Capable Companies	Existing Experience	Installation	Durability	Maintenance	Other pertinent factors	Cost
Geosynthetic Reinforced Soil (GRS) Abutments	The GRS system is composed of alternating layers of geosynthetic fabric with backfill in 4 inch to 8 inch layers. The fabric is polypropylene which provides the reinforcement for the system, and together with the soil layers transfers the horizontal load that would exert active pressure on the back face of traditional abutments back beyond the failure plane of the backfill.	Time-savings due to faster construction. Low initial cost, and use of common construction materials and techniques. Can be used to strengthen weak soils.	Cannot be used for bridges with potentially high scour.	INF	MnDOT - Rock County - Bridge 67564	The FHWA recommends the bridge span be limited to 140 feet, to limit the reaction and resulting bearing pressure on the GRS system. There is also a limit to the abutment height that is generally controlled by what has been successfully been used elsewhere, which is currently about 24 feet.	The scour potential of the abutment structure for this system is a concern. Streams with flood potential, rapid flows, and locations that could be inundated would not be good candidates. Where water is present, the flow would need to be negligible, such as a channel between lakes, for the system to be considered.	A gravel-filled CCS can be used at the face of the abutments, as a conservative measure, to protect against erosion and scour and improve the long-term durability of the GRS abutments.	A geotechnical investigation is required to verify the subgrade can support the GRS system, and to design for adequate safety factors for global stability and sliding. The required bearing pressure capacity of the subgrade is 4,000 psf. FHWA estimates cost savings of 25-60% on their website.	$28 per sf
MSE Walls with Single Line Pile Abutments	In 2011, Steele County constructed a bridge that utilized integral abutments on single rows of piles behind MSE walls. While none of the individual components of this abutment type is unique, their use in combination is innovative and unique on Minnesota's local road system.	Uses less concrete and less piling than a typical cast-in-place abutment. This would lead to a decrease in cost. There are no expansion joints on the bridge. Settles less in compressible soils than a spread footing, and is more tolerant to settlement. Lower cost.	Not widely used on the local road system. Sensitive to pile alignment. Cannot be used were buried utilities may need to be installed in the future.	Cretex Concrete Products	MnDOT - Steel County - Bridge 74551	The designer suggests allowing enough space between the front face of the abutment and the MSE wall to allow for more construction tolerance.	Disturbance of the reinforcing straps within the MSE backfill can threaten the structural integrity of the wall system.	-	This abutment type is sensitive to pile alignment, which was an issue on this project; so for future use, the design engineer suggested paying particular attention to those details and including more stringent plan notes to that effect.	$45 per sf
Sheet Pile Abutments	Blue Earth County has constructed three bridges that consist of an adjacent precast box beam superstructure supported on sheet pile abutments. This design is similar to bridges used in New York for low-volume roads, and was identified as having potential for use in Minnesota during a scanning tour to New York that the Blue Earth County Engineer attended.	Prevents approach fill loss. Shorter construction time than conventional cast-in-place abutments.	Corrosion	N/A	MnDOT - Blue Earth County - Bridges 07547 and 07593	The first bridge built in Minnesota using the sheetpile abutment used the sheetpile abutments as the bearing support, which resulted in excessive sheet pile lengths and extensive cutting and grinding the top of the sheeting to provide a level bearing surface. At the subsequent locations, the superstructure was supported on a steel wide flange welded to the top of a single row of steel pipe piles.	According to the designer, the cost of this bridge was approximately 25% lower than what the alternative 3-span structure would have cost.	Important to include some form of sacrificial steel to account for corrosion.	-	$37 per sf

Figure 6.2 Example of user-friendly pivot table

6.4 SDDOT Conventional Off-System Bridge Cost

SDDOT has been routinely using prestressed/precast bridge girders and beams and precast box culverts for several decades. SDDOT Bridge Design Office and the Bid Letting Office maintained an access database containing the current conventional bridge construction costs from 2004 to 2013 (Mcmullen, 2013). Average data cost was determined for the prestressed girder bridges, steel girder bridges, and continuous concrete bridges and are shown in Table 6.1.

Table 6.1 Average, Minimum, and Maximum Conventional Construction Costs

Bridge Type	Average Cost/SF	Minimum Cost/SF	Maximum Cost/SF
Steel Girder	$145.04	$80.12	$160.48
Continuous Concrete	$175.18	$87.97	$188.56
Prestressed Girder	$132.48	$66.76	$195.03

Average costs were obtained from 31 bridge construction projects. These average costs can be compared with the total costs obtained from the innovative off-system evaluation tool discussed in section 4.5. All project data used for these average costs are attached to this thesis in Appendix E.

6.5 Evaluation Tool

A structure alternative evaluation tool was developed to allow local governments to evaluate applicability of the alternatives for any given project. The purpose of the tool is to assist local governments in determining the most cost-effective and durable bridge alternative to be built on an off-system road. The evaluation tool has two stages. The first stage determines whether to use an innovative system or a conventional system. If an innovative system is chosen, the evaluation proceeds to the second stage. The second stage determines the most cost-effective innovative system for the project.

Each stage of the evaluation procedure has several inputs used with predetermined weighting factors to develop an output indicator. In the first stage, the output indicator is used with a flowchart to determine if an innovative system would be more desirable than a conventional system. In the second stage, the output is the total approximate cost of constructing a bridge. The three outputs in the second stage that signify the total cost for three innovative off-system bridges can be compared to obtain the final bridge desired. The final bridge desired will typically be the bridge with the lowest total cost.

6.5.1 Existing Tools

Designing the innovative off-system evaluation tool for local governments in South Dakota involved the study of two existing tools. One of the tools was the FHWA Manual entitled "Framework for Prefabricated Bridge Elements and Systems (PBES) Decision-Making" (FHWA, 2012). The other tool was developed in a prior study in South Dakota that examined Accelerated Bridge Construction (Pei, 2013).

6.5.1.1 FHWA Evaluation Manual (FHWA, 2012)

The FHWA evaluation process was based on a set of questions regarding specific constraints of each project. If certain thresholds were met, the use of prefabricated elements and systems were recommended. The evaluation manual was created because the FHWA believed that for a variety of reasons, a prefabricated bridge can be the cost-effective construction method of choice to achieve rapid onsite bridge installation. Also, the use of prefabrication can reduce traffic and environmental disruption and improve work-zone safety, and it offers other advantages, depending on site constraints. The FHWA evaluation tool is divided into four sections. The first section describes the purpose and format of the tool. The second section is a flowchart that assists users in making a decision on whether a prefabricated bridge might be an economical and effective choice for the specific bridge under consideration. The flowchart is shown in Figure 6.3. The third section is a matrix that provides users with more detail about questions in the flowchart. The matrix is shown in Figure 6.4. The fourth section contains discussions on questions in the flowchart and matrix. The discussions are meant to help the user in making a more in-depth evaluation on the use of prefabrication.

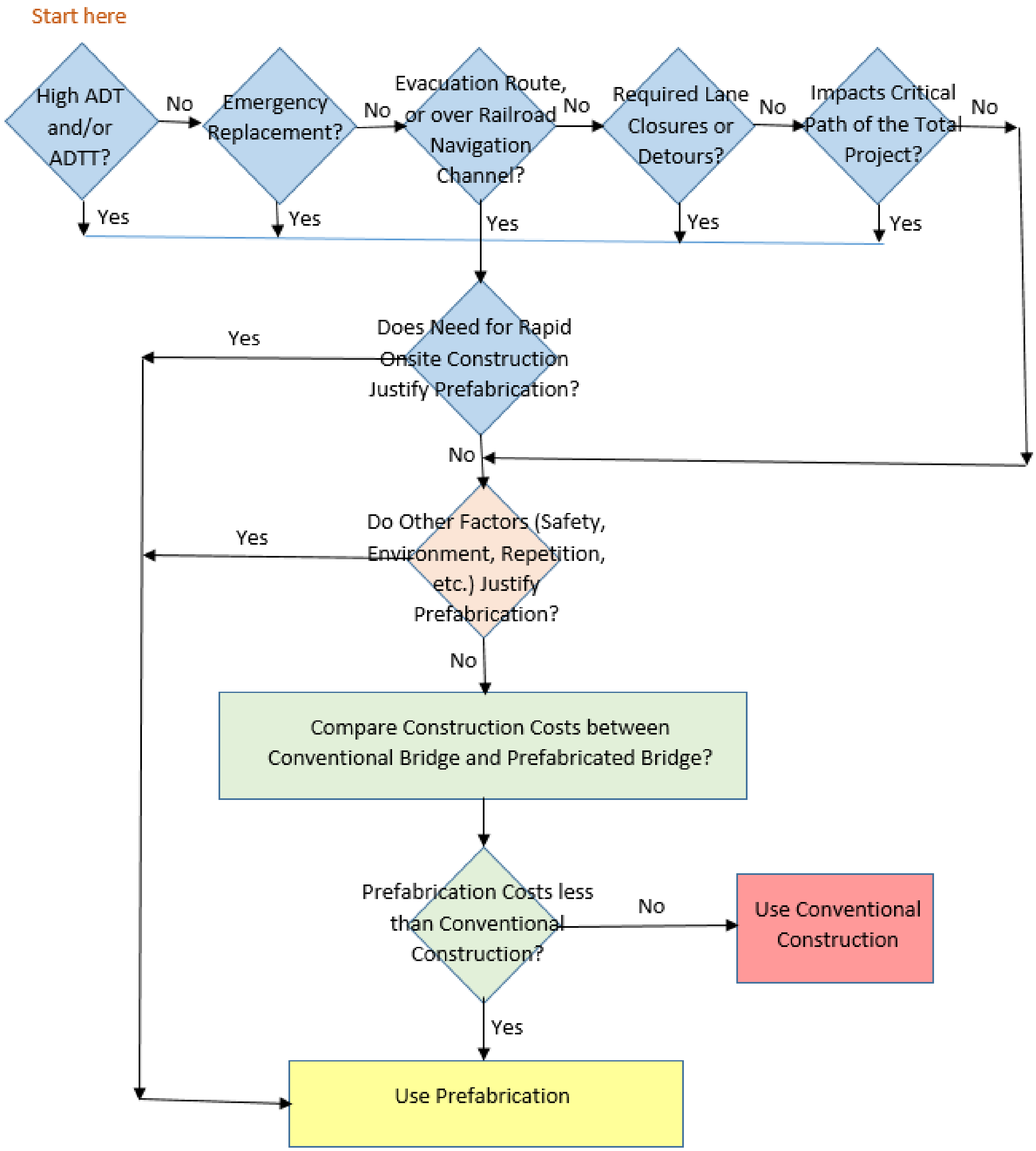


Figure 6.3 Flowchart for high-level decision on whether a prefabricated bridge should be used in any given project

Question	Yes	Maybe	No
Does the bridge have high average daily trafic (ADT)or average daily truck traffic (ADTT), or is it over an existing high-traffic-volume highway?			
Is this project an emergency bridge replacement?			
Is the bridge on an emergency evacuation route or over a railroad or navigable waterway?			
Will the bridge construction impact traffic in terms of requiring lane closures or detours?			
Will the bridge construction impact the critical path of the total project?			
Can the bridge be closed during off-peak traffic periods, e.g., nights and weekends?			
Is rapid recovery from natural/manmade hazards or rapid completion of future planned repair/replacement needed for this bridge?			
Is the bridge location subject to construction time restrictions due to adverse economic impact?			
Does the local weather limit the time of year when cast-in-place construction is practical?			
Do worker safety concerns at the site limit conventional methods, e.g., adjacent power lines or over water?			
Is the site in an environmentally sensitive area requiring minimum disruption (e.g., wetlands, air quality, and noise)?			
Are there natural or endangered species at the bridge site that necessitate short construction time windows or suspension of work for a significant time period, e.g., fish passage or peregrine falcon nesting?			
If the bridge is on or eligible for the National Register of Historic Places, is prefabrication feasible for replacement/rehabilitation per the Memorandum of Agreement?			
Can this bridge be designed with multiple similar spans?			
Does the location of the bridge site create problems for delivery of ready-mix concrete?			
Will the traffic control plan change significantly through the course of the project due to development, local expansion, or other projects in the area?			
Are delay-related user costs a concern to the agency?			
Can innovative contracting strategies to achieve accelerated construction be included in the contract documents?			
Can the owner agency provide the necessary staffing to effectively administer the project?			
Can the bridge be grouped with other bridges for economy of scale?			
Will the design be used on a broader scale in a geographic area?			

Figure 6.4 Matrix questions for high-level decision on whether a prefabricated bridge should be used in any given project

6.5.1.2 SDDOT Evaluation Tool (Pei, 2013)

The purpose of the SDDOT evaluation tool was twofold: 1) Use a simplified procedure to eliminate projects definitely not suitable for Accelerated Bridge Construction (ABC) with a simplistic approximate procedure, and 2) use a more detailed procedure to provide quantitative evaluation for projects that do show some potential for ABC implementation.

The process developed by Pei was adapted by this project for evaluation of innovative bridge construction and is a two-stage evaluation. The first stage eliminates projects with little to no applicability for off-system bridge implementation. The second and more rigorous stage provides a more detailed level of information about whether an off-system bridge construction technique in the catalog should be used for a given construction project that had been determined in the first stage of the evaluation process.

The tool developed for this project involves four basic inputs for Stage 1. These inputs are entered within given ranges. For example, if the average daily traffic through a given construction project is 17,000 per day, the input for average daily traffic would be a 4 on a scale from 0 to 5. Each input is given a predetermined weighting factor, which can either be kept constant through all the projects or changed for specific projects if the need arises. Then, based on the inputs and the predetermined weighting factors, an output indicator is calculated for the bridge construction project. The predetermined weighting factors and output indicator sections of the decision tool are displayed in Figure 6.5. The weighting factors were assigned based on experience of similar tools by other states.

ABC Rating Score Procedure

Stage 1 Decision-Making Process

Inputs

Average Annual Daily Traffic	4	0	No traffic impacts
Combined value of 100% on and 25% under		1	Less than 5000
18300		2	5000 to less than 10000
		3	10000 to less than 15000
		4	15000 to less than 20000
		5	20000 or more
Out of Distance Travel	3	0	No detour
Detour distance in miles:		1	Less than 5
12		2	5 to less than 10
		3	10 to less than 15
		4	15 to less than 20
		5	20 or more
Daily Road User Costs	4	0	No user costs
(AADT+2*ADTT)(OODT)(Mileage Rate)=		1	Less than $10000
$82,000		2	$10000 to less than $50000
		3	$50000 to less than $75000
		4	$75000 to less than $100000
		5	$100000 or more
Economy of Scale	1	0	1 span
Total number of spans:		1	2 or 3 spans
2		2	4 or 5 spans
		3	6 spans or more

ABC Rating Score Factors and Weights

	Score	Factor	Adjusted Score	Max. Score	Adjusted Score
AADT	4	10	40	5	50
OODT	3	10	30	5	50
DRUC	4	10	40	5	50
EOS	1	5	5	3	15
		Total Score:	115	Max. Score:	165
		ABC Rating Score:		**70**	

Figure 6.5 Stage one of SDDOT evaluation tool

Decision-making flowcharts were adapted in the evaluation process. An output indicator of 49 or less is recommended for conventional construction techniques, while an output indicator of 50 or higher is sent through to the second stage of the evaluation process. The flowchart for the first stage of the evaluation tool is shown in Figure 6.6.

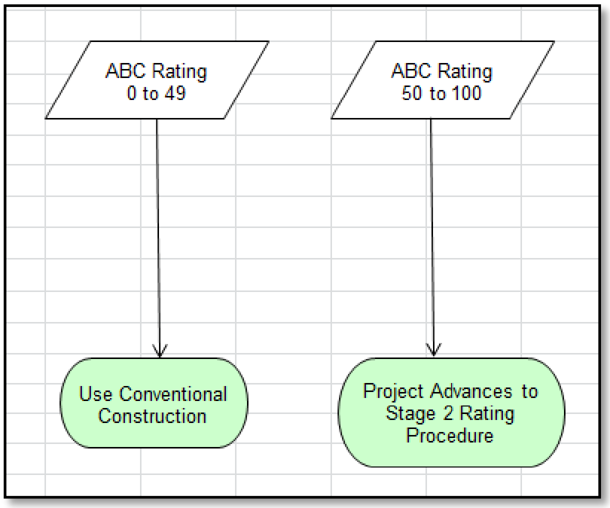


Figure 6.6 Stage one decision-making flowchart

For the second stage of the process, five inputs were involved, and the additional cost of using ABC techniques were approximated. The higher the additional cost of implementing a bridge construction technique, the less likely the use of a technique would be recommended for the project being considered. The non-innovative costs input is used to approximate what the construction costs would be per square foot of bridge if conventional construction alone was used. The higher the approximate conventional costs, the more likely innovative techniques would be used for the project. Stage 2 of the evaluation tool is shown in Figure 6.7.

Stage 2 Decision-Making Process

Inputs

Direct Costs	3	0	More than $100000 additional cost
Input approximate costs for superstructure,		1	$75000 to $100000 additional cost
substructure, and/or placement:		2	$50000 to $75000 additional cost
$32,000		3	$25000 to $50000 additional cost
		4	$0 to $25000 additional cost
		5	Lesser cost than conventional
Indirect Costs	2	0	No user costs
Transfer info from Road User Cost tool:		1	Less than $10000
$12,000		2	$10000 to less than $50000
		3	$50000 to less than $75000
		4	$75000 to less than $100000
		5	$100000 or more
Non-ABC Conventional Costs	3	0	$0-$50/SF of bridge
Transfer info from SDDOT cost data:		1	$50-$75/SF of bridge
$112/SF		2	$75-$100/SF of bridge
		3	$100-$125/SF of bridge
		4	$125-$150/SF of bridge
		5	$150 or more/SF of bridge
Schedule Constraints	3	0	No schedule constraints
i.e. emergency repairs, seasonal deadlines, etc.		1	Slight schedule constraints
		2	Moderate schedule constraints
		3	Substantial schedule constraints
Site Constraints	1	0	No site constraints
i.e. critical path, geographic constraints, etc.		1	Slight site constraints
		2	Moderate site constraints
		3	Substantial site constraints

ABC Rating Score Factors and Weights

	Score	Factor	Adjusted Score	Max. Score	Adjusted Score
DC	3	10	30	5	50
IC	2	10	20	5	50
NCC	3	10	30	5	50
SchC	3	10	30	3	30
SC	1	10	10	3	30
		Total Score:	120	Max. Score:	210
		ABC Rating Score:		**57**	

Figure 6.7 Stage two of evaluation tool

The second stage of the evaluation process involved a more complicated decision-making flowchart. Although the projects with a rating over 50 from stage 1 will enter stage 2, the rating of these projects must be re-calculated based on more detailed data input. Recall that the input for the stage 2 evaluation is different than for stage 1 (see Section 5.2.1), thus, the stage 2 rating of the same project may not be the same as its own rating in stage 1. When determining if using innovative techniques within the project design is feasible, flowchart questions are applied to the output indicator value range of 20-49. This is the range where the benefits and costs of using innovative techniques are approximately equal. When the output indicator is in the range 0-19, conventional construction methods are recommended. Similarly, if the output indicator is in the range 50-100, an innovative approach for the project is recommended. The questions posed in the flowchart for the range of 20-49 are shown in the decision-making flowchart shown in Figure 6.8.

The evaluation tool was calculated based on predetermined weighting factors. The maximum score for each input was multiplied by the predetermined weighting factor to obtain a maximum adjusted score. Then, the assigned score for each input was multiplied by each predetermined weighting factor to obtain the project adjusted score. The maximum adjusted scores and the project adjusted scores were added, and the total project adjusted score divided by the maximum adjusted score (presented as a percentage) is the output indicator for the project being analyzed by the evaluation tool. This calculation process is shown in Equations 6-1, 6-2, and 6-3.

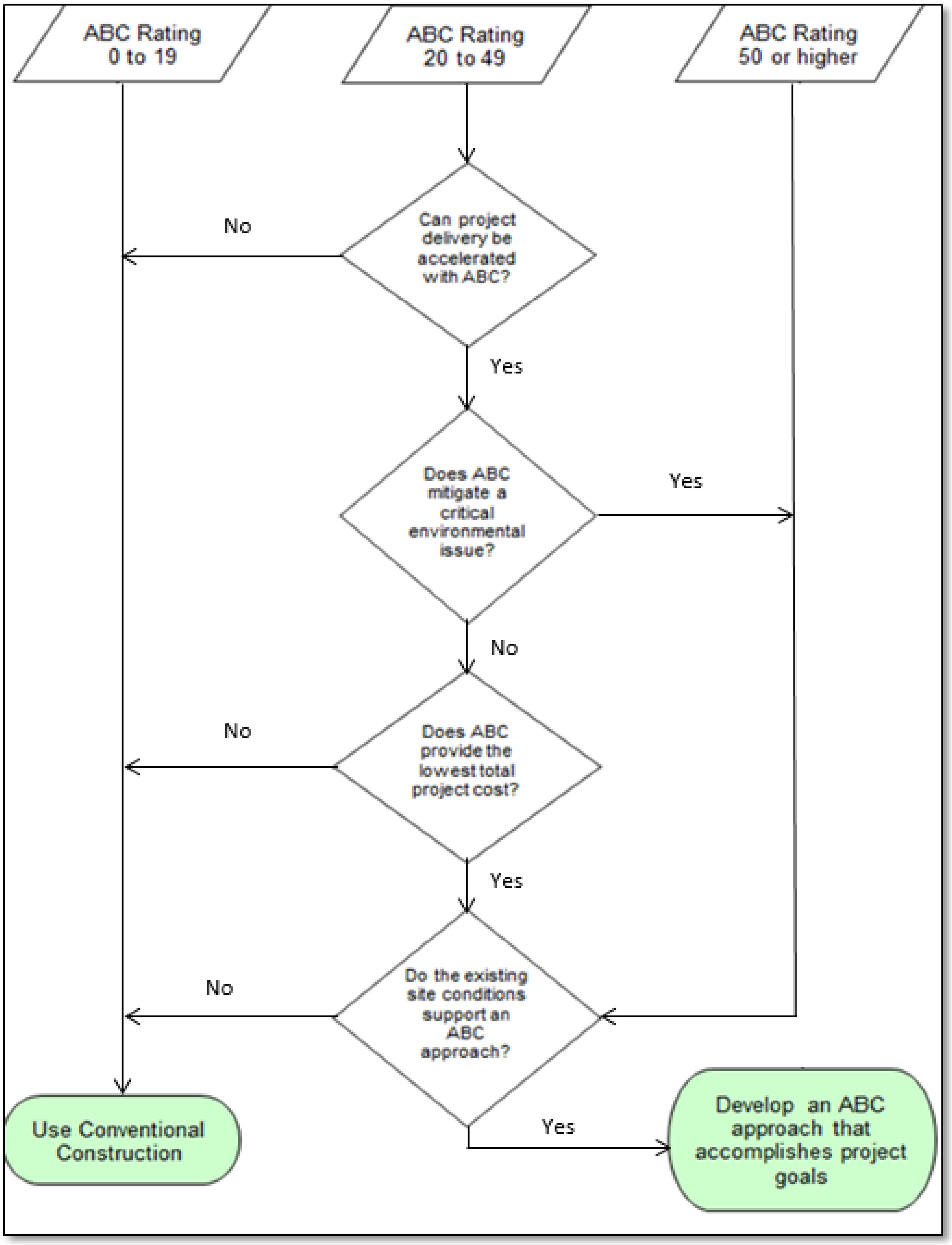


Figure 6.8 Stage two decision-making flowchart

$$Project\ Adjusted\ Score = Input\ Score * Weighting\ Factor \quad (6\text{-}1)$$

$$Maximum\ Adjusted\ Score = Maximum\ Input\ Score * Weighting\ Factor \quad (6\text{-}2)$$

$$Output\ Indicator = \frac{\sum Project\ Adjusted\ Score}{\sum Maximum\ Adjusted\ Score} * 100\% \quad (6\text{-}3)$$

6.5.2 Details of Off-System Bridge Evaluation Tool

For each stage of the evaluation procedure, several inputs are used with predetermined weighting factors to develop an output indicator. The inputs for each stage are shown in Table 6.2.

Table 6.2 Evaluation Tool Inputs

Stage	Input	Description
One	Initial Material Cost	Considers existing budget allocation for initial material cost.
	Construction Cost	Considers existing budget allocation for construction cost.
	Design Cost	Considers existing budget allocation for design cost.
	Ease of Construction/Safety Cost	Considers if the bridge alternative is safe to construct.
	Material Availability	Considers the cost of acquiring bridge materials.
	Abutment Soil Condition	Considers the cost of designing and building the bridge to withstand adverse soil conditions at the construction site.
	Potential of Scour	Considers the cost of designing and building the bridge to withstand scour.
Two	Bridge Dimensions	Anticipated length and width of deck.
	Anticipated Deck	Suitable deck that can be used.
	Anticipated Superstructure	Suitable superstructure that can be used with chosen deck.
	Anticipated Substructure	Suitable substructure that can be used with chosen deck and superstructure.
	Anticipated Entire-Bridge Structure	Suitable entire-bridge structure that can be used. If an option is chosen in this category, an option in the deck, superstructure, or substructure categorie is not selected.
	Type of Bridge	Jointless bridge or bridge with joints.
	Anticipated Material Availability	Cost of acquiring bridge materials to construct bridge.
	Anticipated Cost of Labor	Estimate of cost of labor based on past experience.
	Anticipated Cost of Design	Estimate of cost of desgning the bridge based on past experience.
	Anticipated Ease of Construction	Estimate of the additional cost due to safety.
	Additional Materials	Estimate of cost of other or innovative materials to be included in the project.
	Accessibility to Construction Site	Estimate of cost of mobilization.
	Contingency	Estimate of contingency fee.
	Anticipated Total Cost of Bridge	The estimated total cost of the bridge based on the inputs in stage 2 above.

The predetermined weighting factors are used in the evaluation tool to perform calculations required to obtain the output indicator. The output indicator aids in using the decision-making flowchart for Stage One and selecting the most cost-effective innovative bridge alternative for Stage Two. Predetermined weighting factors for Stage One were assigned based on information gathered from the literature review and the survey. As of now, there are no formal guidelines on how to calibrate these factors for South Dakota due to lack of innovative off-system bridge experiences. Therefore, these factors may be adjusted based on actual data obtained through future construction of innovative off-system bridges in South Dakota. The predetermined weighting factors for Stage Two were obtained from a combination of innovative off-system bridge data and judgement. It is important to note that the predetermined weighting factors for Stage Two are the calculated cost per square foot of each alternative and not the cost per square foot of an entire project. The exceptions to this were predetermined weighting factors for the type of bridge anticipated, anticipated material availability, anticipated ease of construction, and accessibility to construction site. The predetermined weighting factors for these four were based on experience analyzing bridge cost from the literature review. Existing innovative off-system bridge cost data found for the calibration of the weighting factors is in Appendix F. Cost analyses for the existing cost data are in Appendix G. The predetermined weighting factors for each stage are shown in Table 6.3.

Table 6.3 Evaluation Tool Predetermined Weighting Factors

Stage	Input	Predetermined Weighting Factors	
One	Initial Material Cost	50	
	Construction Cost	25	
	Design Cost	25	
	Ease of Construction	10	
	Material Availability	30	
	Abutment Soil Condition	15	
	Potential of Scour	10	
Two	Bridge Dimensions	No predetermined weight factor	
	Anticipated Deck	None	0
		UHPC Waffle Bridge Deck	89
	Anticipated Superstructure	None	0
		Precst Inverted Tee Beam	-
		Precast Prestressed Adjacent Box Beams	45
		Precast Prestressed Adjacent Deck Slab Beams	36
		Precast Double Tee Beams	60
		Precast Modified Beam-In-Slab Bridge System	46
	Anticipated Superstructure	Old Rail Flatcars	15
		Channel Beams	42
		Precast Decked Bulb Tee Beam	60
		Wide Flange Steel Girder – Rolled Steel Beam	12
		Wide Flange Steel Girder – Steel Plate Girder	19
	Anticipated Substructure	None	0
		Geosynthetic Reinforced Soil (GRS) Abutment	28
		Mechanically Stabilized Earth (MSE) Walls	45

		Sheet Pile Abutments	37
		Sheet Pile Abutments - Anchored	42
	Anticipated Entire-Bridge Structure	None	0
		Large Precast Box Culverts	181
		Precast Three-Sided Frames	-
		Grant County's Bridge Construction	42
	Type of Bridge	A jointless bridge incurs no additional cost. A bridge with joints incurs $1,100 additional cost for bearings.	
	Anticipated Material Availability	For the first 25 miles of travel, there is no additional cost. After that, for every 25 mile increment, the cost is increased by $1,100.	
	Anticipated Cost of Labor	No predetermined weight factor	
	Anticipated Cost of Design	No predetermined weight factor	
	Anticipated Ease of Construction	Very easy and safe	$0
		Medium	$1100
		Not easy and safe	$2,200
	Additional Materials	Riprap	$3,300
		Ultra High Performance Concrete	$3,300
		Self-Consolidating Concrete	$3,300
		Expanded Polystrene (EPS) Geofoam	$5,500
		Cellular Confinement System	$3,300
		Bituminous Pavement	$13,200
		Open Metal Guard Rail	$5,500
		Carbon Fiber Prestressing Strand	$11,000
	Accessibility to Construction Site	Easily Accessible	$0
		Slight Problems	$550
		Not easily accessible	$1,100
	Contingency	No predetermined weight factor	
	Anticipated Total Cost of Bridge	No predetermined weight factor	

The first stage of the evaluation tool is shown in Figure 6.9 and Figure 6.10, with Figure 6.9 showing the inputs required, the predetermined weighting factors and part of the decision-making flowchart. Figure 6.10 shows the full flowchart.

Stage 1: Decision-Making Process

(Deciding whether to use a conventional system or an innovative system)

	Write the Number In This Box	
Initial Material Cost/Cost of Production	1	1 greater than $70,000 3 between $60,000 and $70,000 7 between $50,000 and $60,000 10 less than $40,000
Construction Cost/ Labor Cost	7	1 greater than $25,000 2 between $25,000 and $20,000 5 between $20,000 and $15,000 7 between $15,000 and $10,000 10 less than $10,000
Design Cost	5	1 greater than $25,000 2 between $25,000 and $20,000 5 between $20,000 and $15,000 7 between $15,000 and $10,000 10 less than $10,000
Ease of Construction/Safety Costs	10	10 Very easy and safe to construct 5 Could be slightly dangerous to construct 1 Definitely dangerous to construct
Material Availability	1	10 Less than 25 miles 8 Between 25 and 50 miles 6 Between 50 and 75 miles 4 Between 75 miles and 100 miles 2 Between 100 miles and 150 miles 1 above 150 miles
Abutment soil condition	6	10 Mainly sands and gravels 6 Sands and gravels with some clay or silt 1 Clay and Silt
Potential of Scour	10	1 High 5 Medium 10 Low

Item	Score	Factor	Adjusted Score	Max. Score	Adjusted Score
Initial Material Cost/Cost of Production	1	50	50	10	500
Construction Cost/ Labor Cost	7	25	175	10	250
Design Cost	5	25	125	10	250
Ease of Construction/Safety Costs	10	10	100	10	100
Material Availability	1	30	30	10	300
Abutment soil condition	6	15	90	10	150
Potential of Scour	10	10	100	10	100
		Total Score:	670	Max. Score:	1650
		Score Rating:		**41**	

Figure 6.9 Stage one – input table and output indicator table with predetermined weighting factors

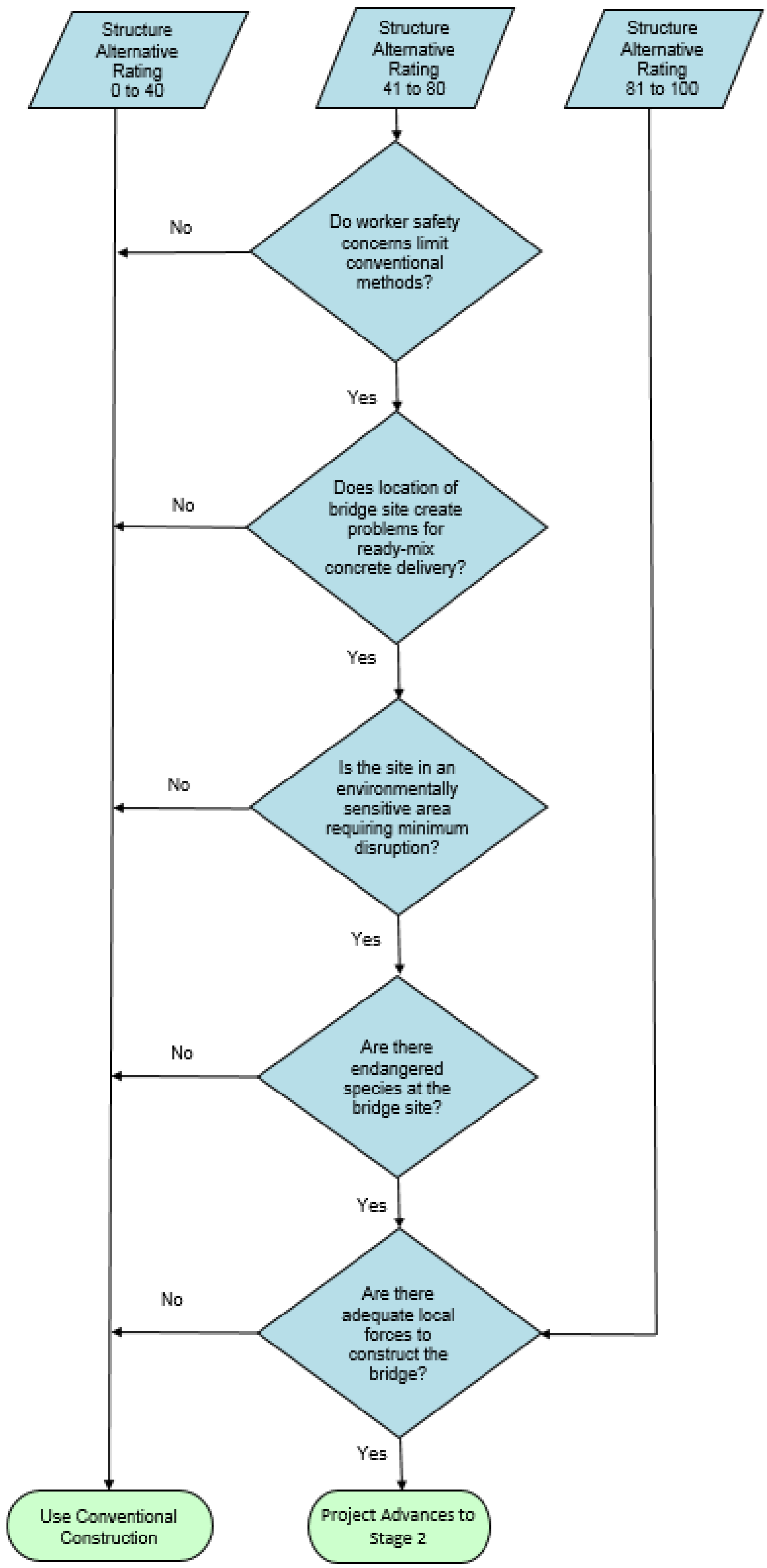


Figure 6.10 Stage one – deciding whether to use an innovative or conventional system

Equations 6.4 through 6.6 are the formulas used to calculate the output indicator in Stage 1 with sample calculations.

$$\text{Adjusted Score} = \text{Input Score} * \text{Weighting Factor} \qquad (6.4)$$

Example:

Adjusted Score=1*50(Initial Material Cost) + 7*25(Construction Cost) + 5*25(Design Cost) + 10*10(Ease of Construction) + 1*30(Material Availability) + 6*15(Abutment Soil Condition) + 10*10(Scour Potential) = 670

$$\text{Maximum Adjusted Score} = \text{Maximum Input Score} * \text{Weighting Factor} \qquad (6.5)$$

Example:

Maximum Adjusted Score=10*50(Initial Material Cost) + 10*25(Construction Cost) + 10*25(Design Cost)+10*10(Ease of Construction) + 10*30(Material Availability) + 10*15(Abutment Soil Condition) + 10*10(Scour Potential)
Maximum Adjusted Score = 1650

$$\text{Output Indicator} = \frac{\sum \text{Adjusted Score}}{\sum \text{Maximum Adjusted Score}} * 100\% \qquad (6.6)$$

Example:

Output Indicator = 670/1650*100% = 41

6.5.2.1 Stage One Flowchart Questions

The questions in the Stage One flowchart are discussed next. The discussions are meant to help the user in making a more indepth evaluation on the use of innovative off-system bridges.

a) Do worker safety concerns at the site limit conventional methods, e.g., working adjacent to power lines or over water?

   In general, construction crew safety in the work zone increases with reduced exposure time during the construction period. Reduced exposure time is even more important when the construction crew is exposed to unsafe working conditions at the site such as adjacent power lines or working over water. These unsafe working conditions at the site may necessitate the use of innovative systems to limit the amount of time the construction crews are exposed to these hazards.

b) Does the location of the bridge site create problems for delivery of ready-mix concrete?

   Conventional cast-in-place construction typically requires the on-site placement of concrete from a ready-mix concrete batching plant. Long haul distances from the batching plant to the bridge site can make it difficult or impossible to meet concrete discharge time limits. Continuous concrete placements can be compromised if a load is rejected since a second load to take its place may not be immediately available. These concerns must be addressed by the contractor in his bid, with a likely effect of increasing the bid price. The above concerns are significantly lessened with the use of prefabricated, innovative off-system bridges since they require limited on-site cast-in-place concrete, e.g., for the closure joints.

c) Is the site in an environmentally sensitive area requiring minimum disruption?

Environmentally sensitive areas, such as wetlands or urban areas where air and water quality and noise pollution are issues, limit the amount of construction work that can be done on site, or how much time can be allotted in a season. Offsite prefabrication and rapid onsite installation can be done with limited impact to the site.

d) Are there natural or endangered species at the bridge site that necessitate short construction time windows or suspension of work for a significant time period, e.g., fish passage or peregrine falcon nesting?

Prefabrication for rapid onsite installation provides the contractor more flexibility when environmental restrictions require short construction windows or prevent work during significant time periods.

e) Are there contractors available in the area with sufficient skill, experience, and construction capacity to perform prefabricated bridge construction?

Construction of prefabricated bridges no more difficult than conventional construction but does require some different skills and areas of experience from key people on the contractor's team such as the construction superintendent. As with any type of work, contractors with the proper training, equipment, and experience can provide the best guarantee of a successful outcome.

In the second stage, the output indicator is the total cost of constructing an innovative off-system bridge. Three different innovative systems can be analyzed at the same time and compared to each other to obtain the final off-system bridge desired. The final off-system bridge desired will typically be the bridge with the lowest total cost. The cost of the innovative off-system bridge chosen from the evaluation tool can be compared to the cost of conventional bridges given in section 4.4.

In Stage 2, input values are entered in the boxes with blue instructions only and corresponding cost appears in the "Do not write in this box" boxes. The input values to enter into the boxes with blue instructions are the values immediate to the left of the alternatives/options in each box. The values to the left of the anticipated deck section, the anticipated superstructure section, the anticipated substructure section and the anticipated entire-bridge structure section, are the calculated cost per square foot of each alternative and not the cost per square foot of an entire project. The spreadsheet for stage 2 could not fit on one page and therefore has been divided into three and is shown in Figure 6.11.

Stage 2: Cost of Anticipated Off-System Bridge

Please Type Only In the Boxes with Blue Instructions

	Length	Width	Do not write in this box
Bridge Dimensions	35 ft	30 ft	1050 ft²
	Do not write in this box	Write Appropriate Number to the Right In This Box	
Anticipated Deck	$ 0	0	0 None 89 UHPC Waffle Bridge Deck
	Do not write in this box	Write Appropriate Number to the Right In This Box	
Anticipated Superstructure	$ 47250	45	0 None - Precast Inverted Tee Beam 45 Precast Prestressed Adjacent Box Beams 36 Precast Prestressed Adjacent Deck Slab Beams 60 Precast Double Tee Beams 46 Precast Modified Beam-In-Slab Bridge System 15 Old Rail Flatcars 42 Channel Beams 60 Precast Decked Bulb Tee Beam 12 Wide Flange Steel Girder - Rolled Steel Beam 19 Wide Flange Steel Girder - Steel Plate Girder
	Do not write in this box	Write Appropriate Number to the Right In This Box	
Anticipated Substructure	$ 17640	28	0 None 28 Geosynthetic Reinforced Soil (GRS) Abutment 45 Mechanically Stabilized Earth (MSE) Walls 37 Sheet Pile Abutments 42 Sheet Pile Abutments - Anchored

	Do not write in this box	Write Appropriate Number to the Right In This Box	
Anticipated Substructure	$ 17640	28	0 None 28 Geosynthetic Reinforced Soil (GRS) Abutment 45 Mechanically Stabilized Earth (MSE) Walls 37 Sheet Pile Abutments 42 Sheet Pile Abutments - Anchored

	Do not write in this box	Write Appropriate Number to the Right In This Box	
Anticipated Entire-Bridge Structure	$ 0	0	0 None 181 Large Precast Box Culverts - Precast Three-Sided Frames 42 Grant County's Bridge Construction
	Do not write in this box	Write Appropriate Number to the Right In This Box	
Type of Bridge	$ 1100	2	1 Jointless or Continuous 2 With Joints
	Do not write in this box	Write Appropriate Number to the Right In This Box	
Anticipated Material Availability	$ 1100	2	1 Less than 25 miles 2 Between 25 and 50 miles 3 Between 50 and 75 miles 4 Between 75 miles and 100 miles 5 Between 100 miles and 150 miles 6 above 150 miles
	Write Cost In This Box		
Anticipated Cost of Labor	$ 15000		
	Write Cost In This Box		
Anticipated Cost of Design	$ 20000		

Figure 6.11 Stage two – off-system bridge total cost spreadsheet

Anticipated Cost of Design	Write Cost In This Box $ 20000		
Anticipated Ease of Construction	Do not write in this box $ 1100	Write Appropriate Number to the Right In This Box 2	1 Very easy and safe to construct 2 Could be dangerous to construct 3 Definitely dangerous to construct
Additional Materials	Do not write in this box $ 11000	Write Appropriate Number to the Right In This Box 10	Add Up All The Numbers That Apply 3 Riprap 3 Ultra High Performance Concrete 3 Self-Consolidating Concrete 5 Expanded Polystrene (EPS) Geofoam 3 Cellular Confinement System 12 Bituminous Pavement 5 Open Metal Guard Rail 10 Carbon Fiber Prestressing Strand
Accessibility to Construction Site	Do not write in this box $ 550	Write Appropriate Number to the Right In This Box 2	1 Easily accessible by a truck and a crane 2 Slight problems with truck and crane accessibility 3 Not easily accessible by a truck and a crane 4 Not accessible by a truck and a crane
Contingency	Do not write in this box $ 17211	Write Percentage In This Box 15 %	
Anticipated Total Cost of Bridge	Do not write in this box $ 131951		

Figure 6.11 Stage two – off-system bridge total cost spreadsheet (continued)

7. CONSTRUCTION PLANNING AND ADMINISTRATIVE PROCESS

This chapter contains factors local governments will need to consider in the construction planning and administrative process of an off-system bridge. It also contains recommendations on how costs can be kept current through escalation factors and viable funding mechanisms for off-system bridge construction.

7.1 Local Government Bridge Replacement Procedures

7.1.1 Hydraulics

The effect of hydraulics on the planning and design of a bridge is a critical step in its construction. The accumulation of debris, ice or woody materials must be considered. Therefore, damage from ice or reports of ice must be checked. Talking to local landowners who use the existing bridge regularly is a good way to obtain information about debris that flow toward the structure.

The susceptibility of the existing bridge to overtopping is an important factor to consider. If the bridge to be replaced is at the bottom of a roadway sag, it is likely that it could be inundated in high flows. Knowing how often the existing bridge is inundated and how many feet of water overtop the bridge is useful in designing and constructing a better replacement bridge.

The attack angle of flow to the structure should be considered. Check if the stream crossing is square with the existing bridge and the existing bridge is square with the road. If the stream has a crossing angle toward the bridge, the angle should be considered in design and construction.

For local roads bridge replacement projects, hydraulic design will normally be for the 10-year flood. Bridge replacement projects on non-state highway rural collector roads and urban collector streets will normally be designed to pass the 25-year flood. If the ADT is less than 100, use the 10-year flood (SDDOT, 2013).

To the maximum extent practicable, the preconstruction course, condition, capacity, and location of open waters must be maintained for each activity, including stream channelization and storm water management activities, except if it benefits the aquatic environment (e.g., stream restoration or relocation activities) (USACE, 2014).

Scour underneath or around an existing structure compromises the integrity of the structure and could lead to bridge failure. The FHWA Technical Advisory (TA 5140.23) dated October 1991 requires a scour evaluation for existing and proposed on-system bridges over waterways (FHWA, 1991). For off-system bridges, the requirement is recommended, but not required. Refer to HEC 18 for a thorough discussion on scour and scour prediction methodologies (FHWA, 2001). Refer to HEC 23 for a discussion on designs for scour countermeasures (FHWA, 2009). Once the bridge waterway opening has been established, a hydraulic designer should evaluate the estimated scour that will occur at each of the bridge elements. For most bridges, pier scour will be accommodated by adjusting the pier design in cooperation with the geotechnical and structural design, and abutment scour will be mitigated with countermeasures. However, the most cost-effective design may be to modify the opening to reduce the amount of scour or the cost of the scour countermeasures. Considerable judgment will be necessary to make this determination (SDDOT, 2013).

The National Flood Insurance Program (NFIP) should be considered. The NFIP is administered by the Federal Emergency Management Agency (FEMA). The amended National Flood Insurance Act of

1968 established the NFIP, which requires communities (whether city, county or State) to adopt adequate land use and control measures to qualify for flood insurance in riverine flood-prone areas (SDDOT, 2013).

7.1.2 Environmental

The effect of the construction process on the environment should be considered in constructing a replacement bridge. Some threatened and endangered species could be killed if this step is not taken. There are provisions in the Nationwide Permit that protect threatened and endangered species.

The Nationwide Permit does not authorize any activity likely to jeopardize the continued existence of a threatened or endangered species or which will destroy or adversely modify the critical habitat of such species (USACE, 2014). Non-federal permittees must submit a preconstruction notification to the District Engineer if any listed species or designated critical habitat might be in the vicinity of the project. Nonfederal permittee shall not begin work on the activity until notified by the District Engineer that the requirements of the Endangered Species Act (ESA) have been satisfied and that the activity is authorized. For activities that might affect federally listed endangered or threatened species or designated critical habitat, the preconstruction notification must include the name(s) of the endangered or threatened species that might be affected by the proposed work. The District Engineer will determine whether the proposed activity "may affect" or will have "no effect" to listed species and designated critical habitat and will notify the non-federal applicant of the Corps' determination within 45 days of receipt of a complete preconstruction notification. In cases where the nonfederal applicant has identified listed species or critical habitat that is in the vicinity of the project, and has so notified the Corps, the applicant shall not begin work until the Corps has provided notification that the proposed activities will have "no effect" on listed species or critical habitat, or until ESA section 7 consultation has been completed. If the nonfederal applicant has not heard back from the Corps within 45 days, the applicant must still wait for notification from the Corps (USACE, 2014).

Construction near a water supply intake nearby could cause contamination to the water supply. As a result, the United States Corps of Engineers have decided that no activity may occur in the proximity of a public water supply intake, except where the activity is for the repair or improvement of public water supply intake structures or adjacent bank stabilization (USACE, 2014).

Impoundments or reservoirs caused by dams and constructing activities restrict the free flow of water. As a result, the United States Corps of Engineers have decided that if an activity creates an impoundment of water, adverse effects to the aquatic system due to accelerating the passage of water, and/or restricting its flow, it must be minimized to the maximum extent practicable (USACE, 2014).

There is a tendency for heavy equipment to cause soil disturbance. Therefore, heavy equipment working in wetlands or mudflats must be placed on mats (USACE, 2014). Other measures must be taken to minimize soil disturbance. Also, with regards to soil erosion and sediment control, appropriate soil erosion and sediment controls must be used and maintained in effective operating condition during construction, and all exposed soil and other fills, and any work below the ordinary high water mark or high tide line must be permanently stabilized at the earliest practicable date (USACE, 2014). Permittees are encouraged to perform work within water of the United States during periods of low-flow or no-flow. Also, temporary fills must be removed in their entirety and the affected areas returned to pre-construction elevations. The affected areas must be revegetated, as appropriate (USACE, 2014).

It is important to consider if wetlands are adjacent and if mitigation will be required. Mitigation is required if the activity will impact more than 0.1 acre of wetland (USACE, 2014).

With respect to aquatic life movements (aquatic organism passage), the United Sates Corps of Engineers have decided that no activity may substantially disrupt the necessary life cycle movements of those species of aquatic life indigenous to the water body, including those species that normally migrate through the area, unless the activity's primary purpose is to impound water (USACE, 2014). Also, all permanent and temporary crossings of water bodies shall be suitably culverted, bridged, or otherwise designed and constructed to maintain low flows to sustain the movement of those aquatic species.

A diversion channel or dewatering plan might be necessary for construction. A dewatering plan is necessary any time water is to be transferred, or moved, from one place to another out of the natural water channel (SDDOT, 2013). This can include cofferdams, diversions, re-routing streams, work areas, etc. The plan should be submitted with the Construction Permit's Notice of Intent. The Notice of Intent is an application form to obtain coverage under the General Permit for Storm Water Discharges Associated with Construction Activities (SDDENR, 2014). A draft plan showing options for each construction phase should be available on plan sets as an aid for the Contractor's compliance (SDDOT, 2013). The Contractor and project engineer should then revise the plan appropriately once construction is active.

A Storm Water Pollution Prevention Plan (SWPPP) is required under the industrial and construction storm water general permits (SDDOT, 2013). The purpose of a SWPPP is to identify possible pollutant sources to storm water and to identify Best Management Practices (BMPs) that, when implemented, will reduce or eliminate any possible water quality impacts. BMPs are physical, structural and/or managerial practices that, when used singly or in combination, prevent or reduce pollution of storm water. The SWPPP is a living document and must reflect actual on-the-ground conditions at all times.

7.1.3 Site Survey

Survey data collection will be required and includes gathering of all necessary information for bridge design including the hydraulic analysis if performed (SDDOT, 2013). This should include such information as topography and other physical features, land use and culture, any existing flood studies of the stream, historical flood data, basin characteristics, precipitation data, geotechnical data, historical high-water marks, existing structures, channel characteristics and environmental data. A site plan showing the bridge location should be developed on which much of the data can be presented (SDDOT, 2013).

The cross-sections upstream and downstream of the structure, and the stream's entire profile may need to be surveyed in support of a hydraulic study. The roadway cross sections and profile may be useful in bridge elevation design. Any existing utilities that may impact project development and construction should also be located and surveyed.

7.1.4 Geotechnical

Knowledge about soils at the bridge site is an important step in planning and designing a replacement bridge. A subsurface investigation, including borings and soil tests, should be conducted in accordance with the provisions of Article 10.4 (AASHTO, 2012) to provide pertinent and sufficient information for the design of substructure units.

The current topography of the bridge site should be established via contour maps and photographs. Such studies should include the history of the site in terms of movement of earth masses, soil and rock erosion, and meandering of waterways (AASHTO, 2012).

7.1.5 Design

It is necessary to outline the design objectives to serve as a guide through the design process. The design objectives for a replacement bridge should include safety and serviceability, constructability, economy, and bridge aesthetics (AASHTO, 2012). Some considerations for future widening include durability, inspectability, maintainability, readability, utilities, and deformations.

Other thoughts when designing are that the design should be based on hydraulic data, survey data, geotechnical information, existing use (traffic), future development, and budget. The design should not change the 100-year water elevation in areas participating in the NFIP. The design should avoid destruction of wetlands, address any threatened and endangered species, and provide aquatic organism passage. The design should not cause property damage and should be easily constructed with available materials and labor to be cost effective.

7.1.6 Construction

A section 404 permit is required for construction of bridges that involve the discharge of "dredged or fill material" into "waters of the United States" (SDDOT, 2013). The section 404 permit is also known as a Fill and Dredge permit and it is as a result of the Clean Water Act. The purpose of the section 404 program is to ensure that the physical, biological and chemical quality of our nation's water is protected from irresponsible and unregulated discharges of dredged or fill material that could permanently alter or destroy these valuable resources (SDDOT, 2013). Some activities, such as emergency reconstruction or maintenance of bridge structures, are exempt from obtaining 404 permits, but any use that was not pre-existing must be evaluated and permitted (NCHRP, 2004).

Activities in spawning areas during spawning seasons must be avoided to the maximum extent practicable (USACE, 2014). Activities that result in the physical destruction (e.g., through excavation, fill, or downstream smothering by substantial turbidity) of an important spawning area are not authorized. Activities in waters of the United States that serve as breeding areas for migratory birds must also be avoided to the maximum extent practicable (USACE, 2014).

Good quality materials should be used for construction. The contract documents should require quality materials and the application of high standards of fabrication and erection. Structural steel should be self-protecting or have long life coating systems or cathodic protection. Reinforcing bars and prestressing strands in concrete components, which may be expected to be exposed to airborne or waterborne salts, should protected by an appropriate combination of epoxy and/or galvanized coating, concrete cover, density, or chemical composition of concrete, including air-entrainment and a nonporous painting of the concrete surface or cathodic protection. Prestressing strands in cable ducts should be grouted or otherwise protected against corrosion. Attachments and fasteners used in wood construction should be of stainless steel, malleable iron, aluminum, or steel that is galvanized, cadmium-plated, or otherwise coated. Wood components should be treated with preservatives. Aluminum products should be electrically insulated from steel and concrete components. Protection should be provided to materials susceptible to damage from solar radiation and/or air pollution. Consideration should also be given to the durability of materials in direct contact with soil and/or water (AASHTO, 2012). Material used for construction or discharged must be free from toxic pollutants in toxic amounts.

It is necessary to use the right tools to get the job done. Certain labor requires certain certifications, for example, welding requires a certified welder. Certain equipment requires certified operators, for example, a crane requires a certified operator. Also consider if the contractor is experienced in the type of construction to be performed and if his crew have the required certifications.

The bridge structure should be properly maintained in the subsequent years. The United States Corps of Engineers have decided that any authorized structure or fill should be properly maintained to ensure public safety and compliance with applicable Nationwide Permit general conditions, as well as any activity-specific conditions added by the District Engineer to a Nationwide Permit authorization (USACE, 2014).

The bridge construction activity must be a single and complete project. The same Nationwide Permit cannot be used more than once for the same single and complete project (USACE, 2014).

The United States Corps of Engineers have also decided that no construction activity may impair reserved tribal rights, including, but not limited to, reserved water rights and treaty fishing and hunting rights (USACE, 2014).

7.2 Recommendations on How Prices Can be Kept Current through Escalation Factors

When anticipating the future expenditure for a construction project, two types of analysis should be considered: cost (what are the anticipated costs) and risk (what are the unanticipated costs). Cost analysis considers the inflation rate from the initial cost estimate year to the construction year. However, it is possible that several materials could increase in cost above the rate of inflation. To account for this possibility, the risk analysis is considered to find out the probability of a future uncertain event and its consequences. The risk analysis is usually accommodated through contingency fees and escalation allowances. Contingency is an allowance to cover unforeseen work, while the escalation allowance is the additional construction cost that covers the increase in costs from one time period to another. For example, additional work may occur due to unforeseen ground conditions, while prices for key materials (steel, asphalt, etc.) may rise due to changes in world markets (URS Corporation, 2009).

It is important to note that inflation and escalation are not the same. While escalation can be driven by general inflation related to the money supply, escalation is also driven by changes in technology, practices, and particularly supply-demand imbalances that are specific to a good or service in a given economy. For example, while general inflation in the United States was less than 5% for 2003 to 2007, steel prices escalated by over 50% because of supply-demand imbalance (URS Corporation, 2009). Escalation cannot be controlled but can be managed and the following paragraphs are recommendations on how to keep prices current through escalation.

It is important to develop a budget at project inception. To be a truly effective tool, budgets need to be reviewed and confirmed during the beginning of the project. By devising the conceptual estimate on day one, local governments can obtain a more objective decision if the project is feasible. If the cost review is deferred to a later date, the initial work may be wasted if the project is deemed more expensive than the budget and therefore not feasible. To be thorough, the cost estimate must include a bill of quantities providing a description of materials, a clear definition of the quantities and costs of the materials, and the cost of labor (Squire, 2009).

One method in managing costs in the future is to manage risk by applying contingencies. The estimator should ensure that an adequate level of contingency is budgeted within the project. Estimating contingencies, design contingencies, and construction contingencies are incorporated into the base cost to allow for variances in design, minor changes in unit pricing, and unforeseen conditions (Squire, 2009).

Another method in managing costs is to familiarize yourself with historical experience in estimating escalation rates. Past experience in estimating, appraising, and acquisition of escalation rates should not be overlooked as judgment and experience aid the estimator in determining the proper rate. Also, understand where escalation is at the moment and which market conditions will have an effect on escalation rates. Use this information to make an informed prediction for the short-term future (Squire, 2009).

Improved methods of determining proper rates should be continually sought. Escalation rates are influenced by many factors, such as legislation, and general economic conditions. The effect of these factors can be estimated but cannot be determined with any real certainty; therefore, improved methods of determining proper rates should be continuously sought (Squire, 2009).

Revisit and adjust the escalation every year with current escalation rates and re-forecast escalation using predicted future rates. Update the cost estimate at regular intervals based on known market variables. This allows the unit rates to be revisited and adjusted to reflect current pricing at the updated base date. Construction costs can also be escalated to the year of construction, except where unusual circumstances dictate otherwise (Squire, 2009).

Use an expert in addition to books. Use an experienced cost consultant such as a quantity surveyor in addition to pricing books with generic unit rate allowances to add credibility and provide a project-specific budget (Squire, 2009).

7.3 Viable Off-System Bridge Funding Mechanisms

The innovative off-system bridge techniques, elements and systems in the catalog will be built by local governments in South Dakota without financial help from SDDOT or the federal government. As a result, viable funding mechanisms for the local government bridge construction were obtained and have been included in this report. The following are the viable funding mechanisms for off-system bridge construction:

7.3.1 The Highway Bridge Replacement and Rehabilitation Program's (HBRRP) Provision for Off-system Bridges

The HBRRP is a safety program that provides federal aid to local agencies to replace and rehabilitate deficient locally owned public highway bridges. This provision includes only bridges in the federal definition that are not on federal aid highways (rural local, rural minor collector, and urban local systems). The allocation of HBRRP funds to local agency projects is managed through a 10-year programming plan. The average annual apportionment available to local agencies is about $160 million (California DOT, 2001).

7.3.2 State Initiative (State Infrastructure Bank program)

The State Infrastructure Bank (SIB) is a mechanism for financing state and local road improvement projects (NCHRP, 2004). The SIB program is a bank with initial seed money provided by a combination of federal and local governments that allows for innovative financing of various types of road improvements. The various financial programs that exist within the SIB program include loans, lines of credit, and debt service guarantees. States are allowed to deposit certain portions of their federal aid highway funds into SIB for seed money. They are required to contribute 25% of the federal aid highway funds (a total of 20% of the entire invested sum) (NCHRP, 2004). The SIB program can be used to assist local governments, in particular, those without the financial market access required to raise the funds for local improvements. Although, at present a pilot program in many states, the SIB concept is one of several innovative financing tools available to local governments through partnering at the state level.

7.3.3 Local Initiatives

Local initiatives such as sales tax, special ownership tax, wheel tax, severance tax, bonds, cost participation, traffic violations, and telephone tax can serve as innovative financing methods used to offset the costs of rural road bridge construction and operation.

The sales tax is a uniform tax on all, or a select class of goods, purchased in a county. The special ownership tax provides a mechanism whereby only special classes of items (i.e., the luxury tax concept) are taxed. The wheel tax is a vehicle registration fee and part of the fee is sometimes used for road and bridge maintenance (NCHRP, 2004). Severance taxes are based on the extraction of natural resources from a particular area. Bonds are a traditional funding mechanism used to raise short-term funds that require the set aside of future revenues to repay the principal and interest on the borrowed money. Cost participation involves partnering with other local agencies to pool funds for the completion of projects that are mutually beneficial. The use of traffic fines is also considered a revenue source, although in sparsely populated areas, the density is not sufficient for this to be a reliable source of funds. Finally, the establishment of a telephone tax has been used in certain areas whereby the telephone utility is the vehicle for tax collection, with a certain portion of the funds being earmarked for highway and bridge improvements.

7.3.4 Surface Transportation Program's Provision for Off-system Bridges

The Surface Transportation Program (STP) was established in 1991 (NCHRP, 2004). Funds from the STP may be used for bridge construction, reconstruction, rehabilitation, restoration, and improvement. Funds are generally limited to federal aid highways for roadway projects; however, any bridge on a public road is eligible for STP funds. The funding split for off-system bridges is a traditional 80% federal/20% local match for all projects. State STP apportionments are divided into several set-aside areas and an amount not less than 15% of the state's 2009 Highway Bridge Program apportionment is set aside for off-system bridges (FHWA, 2014). This 15% is not taken from amounts suballocated to areas in the state in proportion of their relative shares to the state's population (50% is suballocated). In 1999, bridge expenses were approximately 4.7% of the total STP funding of non-NHS projects, indicating that bridge projects are not a significant portion of the STP program budget (NCHRP, 2004).

8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This project involved two objectives that achieve the goal of developing a decision-making process concerning the use of off-system road bridge techniques. The first objective was to develop a catalog describing locally available bridge construction techniques and materials that can be built by local contractors and local government workforces. The second objective was to develop construction planning and administration process guidance for local government bridge replacement. This chapter will summarize what was done and present conclusions and recommendations.

8.1 Summary

The first objective involved the development of a catalog composed of off-system road bridge techniques, elements and systems to inform the user of what has been used in the past and how each alternative was implemented into the construction of a bridge. This catalog will enable local governments in South Dakota to have more options in selecting a bridge for off-system road construction in addition to the use of conventional practices. This catalog will serve as a basis for local governments to develop their own innovative low volume road bridges. To accomplish the objective of developing the catalog, an in-depth literature review was conducted on current off-system bridge techniques that are being used across the United States. The information found throughout the course of this literature review was used to create off-system bridge technique profiles and these profiles were designed to inform the reader of the application of each off-system bridge technique.

Additionally, two interviews were completed to obtain information about innovative off-system bridges. An interview was held with SD AGC to gather information on the current practice of cost-effective off-system bridges used in the state of South Dakota and to gather information on the applicability of a preliminary list of innovative bridges discovered from the literature review. Grant County was also interviewed because it has conducted several local bridge replacements without federal or SDDOT assistance. The interview results were used to finalize the list of off-system road bridge techniques that was obtained from the literature review.

Based on the literature review and the interview, two surveys were conducted. One survey was sent out to several contracting companies that belong to the SD AGC and the other survey was sent out to the state DOTs that surround South Dakota. Minnesota, Nebraska and Wyoming responded to the survey, and the information obtained, in addition to the literature review was used to populate the various cells of the off-system bridge techniques catalog. An estimate of cost was developed for the bridge techniques and systems listed in the catalog and was represented as the cost per square foot of the deck area. It is important to note that the cost in the catalog is not the cost of an entire bridge construction project — it is the cost of each individual bridge element or system. An estimate of convention off-system bridge cost is also included in this thesis.

An evaluation tool with simple inputs for use by local government decision making was developed. It is the intent that this tool will lead decision makers through the process of cost evaluation, and finally recommend if the project should be completed using innovative methods or conventional methods.

The second objective of this project was to develop construction planning and administration process guidance for local government bridge replacement. A list of local government bridge replacement procedures was obtained from the United States Corps of Engineers Nationwide Permit document, South Dakota drainage manual, AASHTO LRFD bridge design specification and the South Dakota department of Environment and Natural Resources. The list of procedures obtained was converted into paragraphs and included in this report. A section on viable funding mechanisms is also included.

9. IMPLEMENTATION RECOMMENDATIONS

Several conclusions and recommendations were developed during the research process.
First, the off-system bridge catalog is to be used as a reference tool for determining which technique or system should be used on a given bridge construction project after the decision has been made that innovative off-system alternatives are applicable for the project.

Second, costs used for generation of the second stage inputs should not be considered as project-specific cost estimates of off-system bridge techniques and systems. Costs for a given alternative in the catalog can vary greatly from project to project, and exact costs could not be obtained for use of off-system bridge techniques, elements and systems. Therefore, a general estimation of the cost of some of the alternatives were generated. These estimations should not be considered accurate estimations of the actual cost of implementing the techniques, elements and systems into a given bridge construction project. If a more accurate cost of implementing the off-system bridge techniques, elements and systems is desired, a South Dakota contractor must be contacted to obtain a bid price for the alternative desired.

Finally, although the evaluation tool developed in this study laid out the framework for a simplified assessment for innovative off-system bridge applicability in South Dakota, the available data related to actual cost is limited. It is recommended that through future use of the tool in realistic SDDOT projects, additional data be collected and used to calibrate the weighting factors used in the evaluation tool. It will be beneficial to run realistic project scenarios through the evaluation tool to see if the indicator reflects realistic decision-making conditions. As such data is currently unavailable in South Dakota, the results from the proposed process remain partially subjective and must be used with caution.

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APPENDIX A: SD AGC QUESTIONNAIRE

Project Questionnaire on Innovative Low-life Cycle Cost Bridge Materials and Techniques

This questionnaire has been sent out to several South Dakota bridge contractors to conduct a survey about their experience in low life-cycle cost, innovative bridge construction materials and techniques for local roads. The intent of this survey is to identify the alternatives that would be feasible through the use of local government workforces. The result of the survey is primarily intended to help the state of South Dakota replace existing deteriorating bridges with the use of innovative low life-cycle cost bridge materials and techniques. Please take your time and fill the questionnaire as completely as possible. Thank you for your time and contribution.

Section 1

1. Please enter in the box below, the name of the contracting company filling out this questionnaire.

2. Have you ever used any of the following innovative bridge elements or systems in construction of off-system bridges? Please enter “yes” or “no” in each box below.

    - Geosynthetic Reinforced Soil (GRS)
    - Precast bulb tee girders
    - Precast Modified Beam-In-Slab Bridge System (Iowa DOT)
    - Precast Inverted Tee Beam (Minnesota DOT)
    - Cellular Confinement System (CCS)
    - MSE Walls with Single Line Pile Abutments
    - Sheet Pile Abutments
    - Jointless Bridge
    - Precast Prestressed Adjacent Slab Beams

- Precast Prestressed Adjacent Box Beams
- UHPC Waffle Bridge Deck Panels
- Precast Double-T Beam/The NEXT Beam
- Large Precast Box Culverts (Minnesota DOT)
- Precast Fiber Reinforced Bridge Panels/Slabs/Decks/Girders
- Precast Three-Sided Frame
- Alabama DOT Precast Slab System
- Old rail cars
- Steel girders
- Glulam timber girders and decks

3. With your professional experience, which of the innovative bridge systems in question 2 would you not recommend for off-system bridge construction based on low life-cycle cost and durability? Please include any reasons why.

4. Please list any other innovative bridge elements or system(s) you know or have heard about in the box below (This is the main reason for the survey).

5. How can post-tensioning be incorporated into bridge design without increasing bridge cost?

APPENDIX B: STATE DOT QUESTIONNAIRE

Project Questionnaire on Innovative Low-life Cycle Cost Bridge Materials and Techniques

South Dakota State University and the South Dakota Department of Transportation is conducting a research project on low life-cycle cost, innovative bridge construction materials and techniques for local roads. As part of our literature search, the following questionnaire is being forwarded to state Department of Transportations to conduct a survey about their experience in innovative bridge construction materials and techniques for local roads. The intent of this survey is to identify construction and material alternatives that would be feasible through the use of local workforces (government and private contractors). The result of the survey is intended to help local governments in replacing existing deteriorating bridges with the use of innovative low life-cycle cost bridge materials and techniques.

Please note this survey is intended for single span bridges less than 65 feet in length.

We would appreciate it if you would take about 15 to 30 minutes to respond to this questionnaire as completely as possible. You are free to print this out and provide written answers or fill the form out and return electronically.

Thank you for your time and contribution. If you have any questions, please do not hesitate to contact Allen Jones, PE (Principal Investigator) at 605-688-6467 at South Dakota State University.

Section 1

1. Please enter in the box below, the name of the state that your response to this questionnaire applies to.

2. Have you ever used any of the following innovative bridge materials in construction? Please enter "yes" or "no" in each box below.

- High-Performance/High-Strength Lightweight Concrete
- Ultra-High-performance Concrete (UHPC)
- EPS Geofoam
- Geocell
- Fiber Reinforced Polymer
- Self-Consolidating Concrete (SCC)

3. Do your state manufacturing companies have the capacity to manufacture or obtain the following innovative bridge materials? Please enter "yes" or "no" in each box below.

High-Performance/High-Strength Lightweight Concrete	
Ultra-High-performance Concrete (UHPC)	
EPS Geofoam	
Geocell	
Fiber Reinforced Polymer	
Self-Consolidating Concrete (SCC)	

4. What are the other innovative bridge materials you are currently using for low-volume road bridges that are worth mentioning? You can also include innovative materials you are not currently using but have knowledge that other states may be using.

Geosynthetic Reinforced Soil (GRS)	
Prefabricated Bridge Elements and Systems (PBES)	
Precast Modified Beam-In-Slab Bridge System (Iowa DOT)	
Precast Inverted Tee Beam (Minnesota DOT)	
Cellular Confinement System (CCS)	
MSE Walls with Single Line Pile Abutments	
Sheet Pile Abutments	

- Jointless Bridge
- Precast Prestressed Adjacent Slab Beams
- Precast Prestressed Adjacent Box Beams
- UHPC Waffle Bridge Deck Panels
- Precast Double-T Beam/The NEXT Beam
- Large Precast Box Culverts (Minnesota DOT)
- Precast Fiber Reinforced Bridge Panels/Slabs/Decks/Girders
- Precast Three-Sided Frame
- Alabama DOT Precast Slab System

6. With your professional experience, which of the innovative bridge systems in question 5 would you not recommend for off-system bridge construction based on low life-cycle cost? Please include any reasons why.

7. Please list any other innovative bridge elements or system(s) you know or might recommend in the box below.

8. Is your county currently enrolled in the Accelerated Bridge Construction (ABC) program? The focus of this program is to reduce construction time on the site to potentially incur low initial costs, while ensuring better safety, durability and overall performance of the bridge to ensure low life-cycle costs.

9. Please indicate your order of preference by entering the numbers 1 (highest) – 3 (lowest) in the box next to each option. In the large box below please state the reason you prefer one over the other.

   - Cast-in-place Bridge components
   - Precast/Prefabricated Bridge components
   - Partially Precast/Prefabricated Bridge components

10. Would you prefer epoxy coated rebar reinforcement to fiber polymer reinforcement in your panels/slabs/beams/girder?

11. In what situation would you prefer fiber polymer reinforcement over epoxy coated rebar reinforcement?

12. Have you ever had any problems with the following prefabricated bridge elements and systems (PBES)? If so, please state the type of problem in the large box below the PBES options.

- Prefabricated Decks
- Prefabricated Slabs/Panels/Beams
- Prefabricated Girders
- Prefabricated Abutment Pile Caps
- Prefabricated Abutment Wing walls and Face walls
- Prefabricated Piers/Bents
- Prefabricated Pier/Bent Caps
- Prefabricated Rails or Parapets

13. Do you recycle bridge materials?

14. If you recycle bridge materials, what do you use the recycled materials for?

15. With respect to low lifecycle (75 years) bridge replacement cost, please rate the following in order of importance? Please select them by entering the numbers 1 (highest) – 5 (lowest) in each box.

    - Initial material cost
    - Construction Cost
    - Subsequent Maintenance costs
    - Ease of construction/Safety costs
    - Material Availability/Transportation cost

16. Please rate the following off-system bridge funding systems according to preference (high, medium or low).

    - The Highway Bridge Replacement and Rehabilitation Program's provision for off-system bridges. This provision includes only bridges in the federal definition that are not on Federal-Aid Highways (rural local, rural minor collector, and urban local systems).
    - Surface Transportation Program's provision for off-system bridges. This provision includes only off-system bridges on public roads.
    - FHWA's Innovative Bridge Research and Construction Program.
    - State Initiative (State Infrastructure Bank program).
    - Local Initiatives (Sales tax, Special ownership tax, Wheel tax, Rural improvement and special assessment districts, Severance tax, Bonds, Cost participation, Traffic violations, and Telephone tax).

17. Please list any other sources of off-system bridge funding not listed in number 16 in the box below. Please include any comments about any of the aforementioned funding systems in number 16.

18. Please list the names of fabricators and suppliers commonly used in local bridge replacement projects.

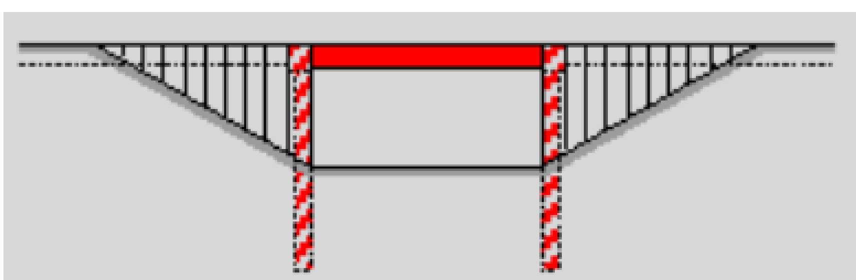
APPENDIX C: STRUCTURE ALTERNATIVE PROFILES

Prefabricated Bridge Elements and Systems (PBES)

Description: PBES are elements and systems that are pre-made before onsite bridge construction. They only need to be installed during construction which causes a reduction in construction time. These systems were created to accelerate bridge construction; however, they have proven to be more durable than conventional CIP elements and systems. The total cost of using prefabricated bridge elements (PBES) depends greatly on the scale of the prefabrication. One disadvantage is that construction might need specialty equipment and personnel for prefabrication and construction. Construction might also need to use field welds, grouted keyways, or transverse post-tensioning to establish shear transfer between adjacent slabs.
Source: Precast Bridge Construction across Europe and America (Hallmark, 2012), Innovator (FHWA, 2013)
Existing Experience: Washington State DOT and many other state DOTs
Advantages: It leads to a much faster construction due to elimination of falsework. It is more durable than conventional CIP bridge elements and systems.
Disadvantages: Might need specialty equipment for prefabrication and construction.
Capable Local Companies: Redi Mix Inc.
E Prospect Ave. 271
Chamberlain, SD
Phone: 605-734-5741

Jointless Bridge

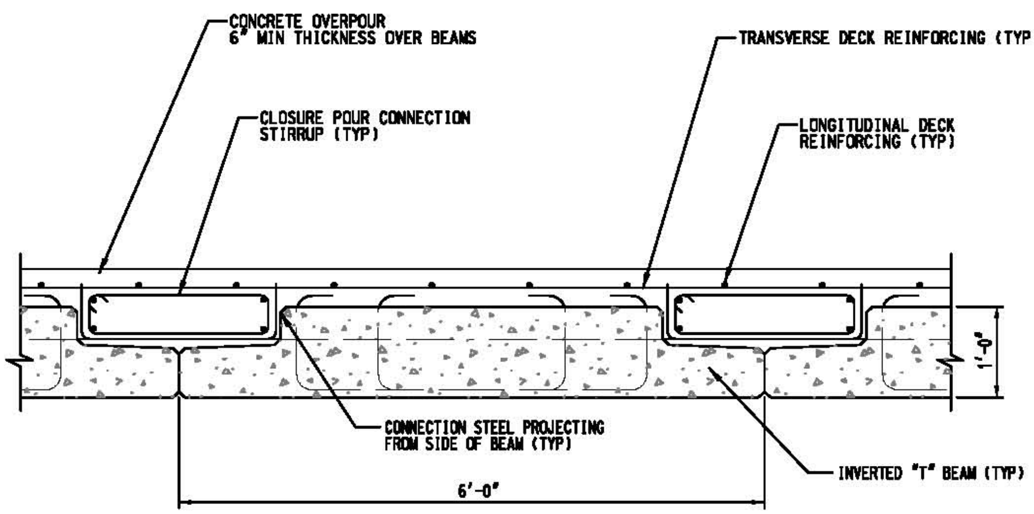
Description: Jointless bridges are bridges without expansion joints. They have been used in other states for a long time. In the past, deck expansion joints performed poorly resulting in structural distress and other ill effects, and to remedy this situation, jointless bridges have been developed. Tennessee has had the most extensive experience with jointless bridges in the United States, and they are pleased with the performance of these bridges, which in many cases has resulted in immediate cost savings during construction and reduces maintenance expenditures in the long run. However, the Tennessee Department of Transportation encountered problems during the development of their jointless bridges. In one case, an integral abutment was tied into rock. The resulting lack of flexibility at the abutment caused the bridge to crack at the end, and part of the necessary repairs included the installation of an expansion joint in the structure. Bridges currently built on rock or rock fill are founded on piles driven through predrilled oversize holes or through an earth core in rock embankment to improve the translational capability of the abutment. Other problems with these bridges were caused by the development of cracks in the abutments or wingwalls. Although these cracks were minor and caused no serviceability problems, careful design and an increase in reinforcing steel has effectively eliminated cracking in these areas. During the on-site inspection of several jointless bridges in Tennessee, no evidence of abnormal stresses were apparent, and these structures appeared to be performing as intended. Several instances were noted where settlement and cracking of the approach slabs had developed. The Tennessee DOT expects some eventual localized pavement failure and bumps to develop at the bridge ends but considers these problems to be minimal when compared to the expenditures and maintenance effort necessary to maintain expansion joints and rehabilitate damaged bridges. By moving problems away from the bridge to the approach-slab area, the serviceability of these bridges is extended. New York DOT assumes that construction costs are lower than for conventional bridges due to the simplicity of the abutment and wingwall design and the use of fewer piles. New York DOT only have a few minor problems with the jointless bridges. They report minor cracking of the approach slab near the backwall.
Source: Performance of Jointless Bridges (Wolde-Tinsae, 1988).
Existing Experience: Tennessee DOT, New York DOT, California DOT.
Advantages: Ensure long-term serviceability of the structure, minimal maintenance requirements, economical construction, and improved overall performance of the facility.
Disadvantages: Approach slab settlement and approach fill erosion occur on longer spans.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
tel: (605) 718-4111
Gage Brothers Concrete Products Inc.
4301 W. 12th St.
Sioux Falls, SD 57106
Phone: 605-336-1180
Toll Free: 1-800-348-GAGE (4243)



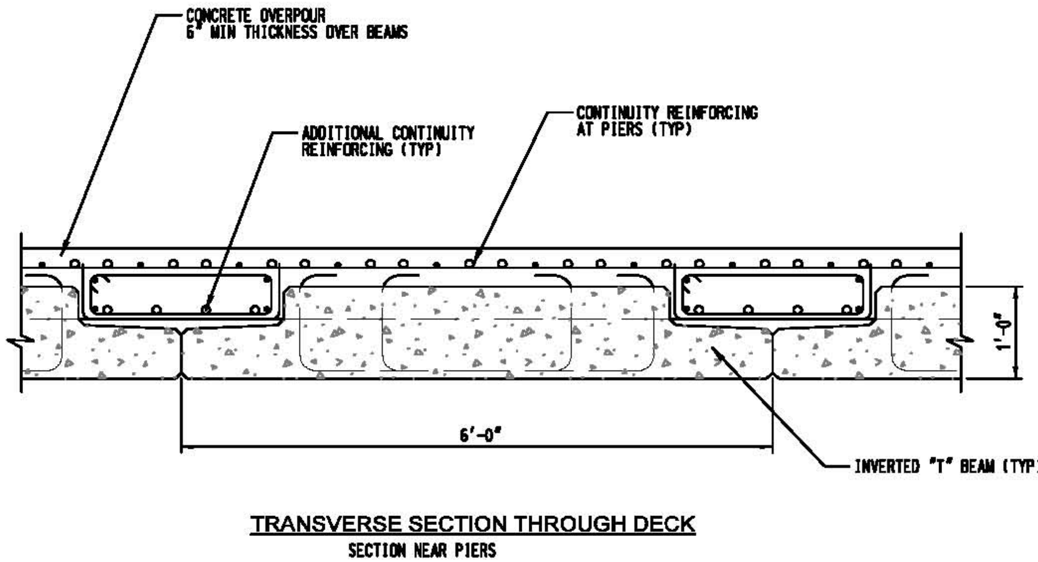
Jointless Bridge (LUSAS, 2014)

Precast Inverted-tee Beam

Description: In 2005, MnDOT developed a new precast system for slab span bridges based on a similar section that was in use in France (the Poutre Dalle System). The 2004 AASHTO and FHWA scanning tour of Prefabricated Bridge Elements and Systems identified this concept as a technology for potential use in the United States. MnDOT involved local fabricators in developing the standards for the precast inverted tee section and the first bridges were built in 2005. As of 2011, MnDOT has constructed 11 bridges using this section, with several additional bridges planned. The prestressed inverted tee sections are placed side by side, providing a structural beam and the bottom form for the composite deck pour. A reinforcing cage is set in the joint area between sections and cast-in-place (CIP) concrete is placed over the top of the sections, filling the joint and forming the roadway surface. The reinforced joints provide load transfer between sections, enabling the entire system to act as a solid slab span. The University of Minnesota has conducted extensive research on the inverted tee section, instrumenting bridges in the field and conducting load tests. Additionally, fatigue testing of the sections was conducted in the Structures Laboratory at the University to assist MnDOT in confirming the durability and composite behavior and provide data to improve the design. The section can span to approximately 60 feet and is good for jointless bridges.
Source: Innovative Bridge Construction for Minnesota Local Roads (Minnesota Department of Transportation, 2012)
Existing Experience: MnDOT Scott County (Bridge No. 70548)
Chisago County (Bridge No. 13521)
Advantages: It decreases construction time (no falsework required). It is easy to construct (does not require skilled labor for erection). It is durable and does not require frequent inspection and maintenance.
Disadvantages: While a few precast inverted tee beam bridges have been constructed in the U.S., the connection joints for these bridges continue to be a durability concern.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
tel: (605) 718-4111



TRANSVERSE SECTION THROUGH DECK
SECTION ALONG SPAN



Precast Inverted Tee Beam (FHWA, 2013a)

Precast Prestressed Adjacent Box Beams

Description: Many states have used precast prestressed adjacent box beam bridges as standard bridge systems for years. The "adjacent box beam system" is typically more than 21 inches deep and three feet or four feet wide. Some states have used wider sections. Massachusetts has used this structure since the 1950s. Recent inspection reports indicate that these local road bridges are doing well even after 50 years of service.
Source: FHWA - Bridge Construction – Chapter 2-Superstructure Connections (http://www.fhwa.dot.gov/bridge/prefab/if09010/02b.cfm)
Existing Experience: MnDOT - Blue Earth County, MassDOT.
Advantages: Time saving, durable and long lasting compared to CIP panels.
Disadvantages: Many states have noted that when these bridges are exposed to heavy truck, there is the tendency for the joints between the beams to leak. In extreme cases, the joints have completely failed.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
tel: (605) 718-4111
Redi Mix Inc.
E Prospect Ave. 271
Chamberlain, SD
Phone: 605-734-5741
Gage Brothers Concrete Products Inc.
4301 W. 12th St.
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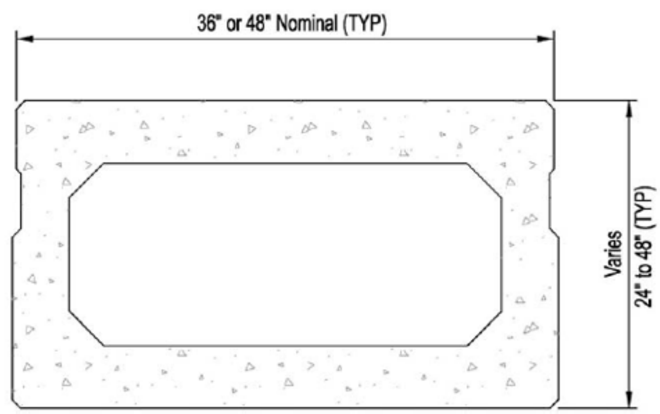

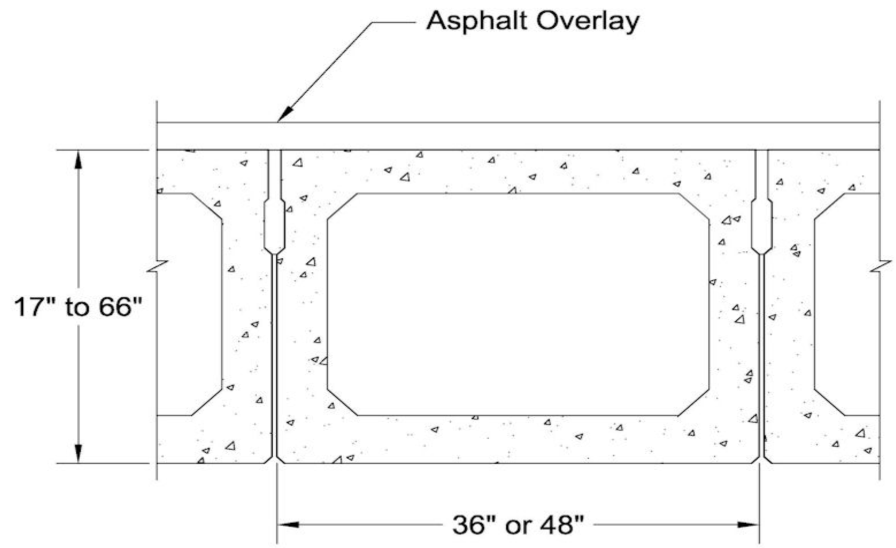

Precast Prestressed Box Beam (FHWA, 2013a)

Precast Prestressed Adjacent Deck Slab Beams

Description: Many states have used precast prestressed adjacent deck slab bridges as standard bridge systems for years. The "slab system" or "deck slab system" is typically less than 21 inches deep. The beams are normally three feet or four feet wide; however, some states have used wider sections. Massachusetts has used this structure since the 1950s. Recent inspection reports indicate that these local road bridges are doing well even after 50 years of service.
Source: FHWA- Bridge Construction – Chapter 2-Superstructure Connections (http://www.fhwa.dot.gov/bridge/prefab/if09010/02b.cfm)
Existing Experience: MassDOT
Advantages: Time saving, durable and long lasting compared to CIP panels.
Disadvantages: Many states have noted that when these bridges are exposed to heavy truck, there is the tendency for the joints between the beams to leak. In extreme cases, the joints have completely failed.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
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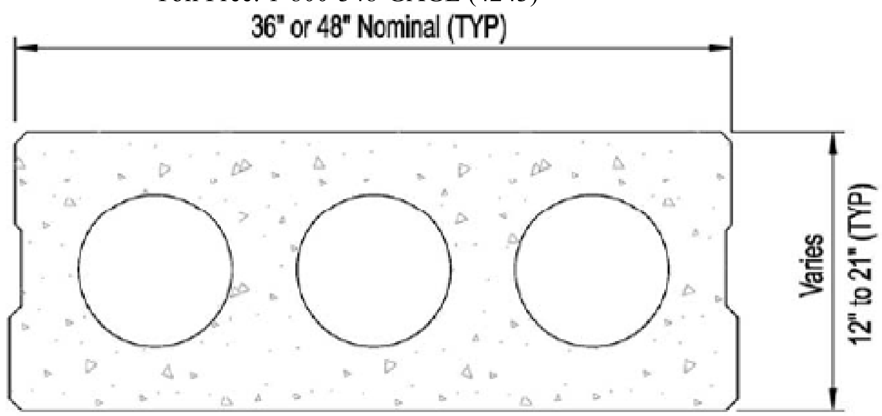
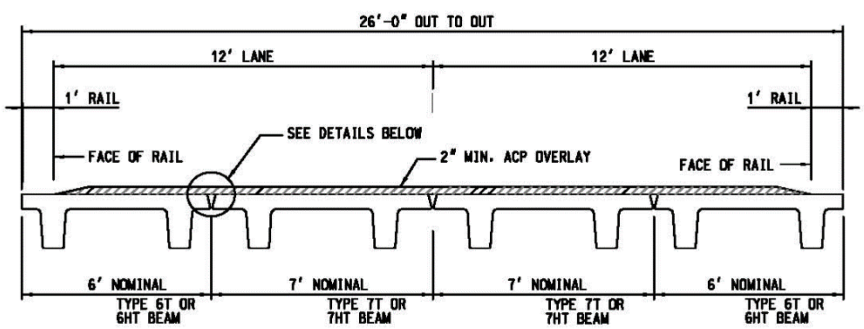


Single Precast Prestressed Deck Slab Beam (FHWA, 2013a)

Precast Double-T Beams/The NEXT Beam

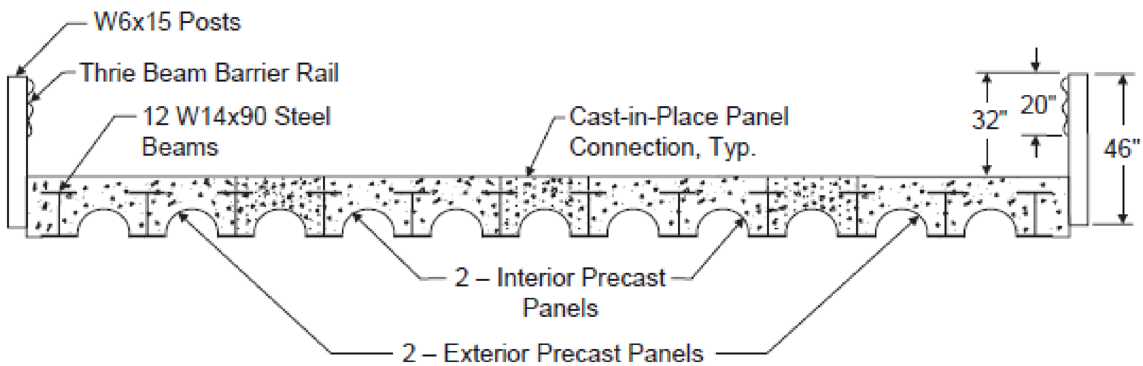
Description: The Northeast Extreme Tee Beam or the NEXT Beam was developed by the Precast/Prestressed Concrete Institute Northeast (PCINE). PCINE is the nation's northeast regional branch of the Precast/Prestressed Concrete Institute (PCI). They serve the northeastern states, including Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. The idea for the development of this beam was born in 2006 at Oldcastle Precast Rotondo in Rehoboth, Massachusetts. The precasters were in the process of casting a high-level railroad platform, and the developer thought that it had attributes that could be transferred to the bridge industry. This beam was developed to compete with the precast concrete adjacent box beam superstructure system. The NEXT beam solves issues purely through its geometry. The open underside makes inspection easy because joints are visible. Utilities can be run parallel to the stems of the tee and, as long as they do not extend past the bottom of the stem, are hidden from sight. It is intended for use on medium span bridges with spans ranging from 40 feet to 90 feet. The section resembles that of a standard double tee commonly used for parking structures.
Source: Prefabricated Bridge Elements and Systems for Off-System Bridges (Roddenberry, 2012).
Existing Experience: Approved in the following States: Connecticut, Massachusetts, Maine, New Hampshire, New York, Pennsylvania, Rhode Island, and Vermont.
Advantages: Reduces construction time and cost.
Disadvantages: Might need a specialty load crane to install it in place.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
tel: (605) 718-4111
Gage Brothers Concrete Products Inc.
4301 W. 12th St.
Sioux Falls, SD 57106
Phone: 605-336-1180
Toll Free: 1-800-348-GAGE (4243)



Precast Double-T Beam (FHWA, 2013a)

Precast Modified Beam-in-slab Bridge System

Description: This Precast Modified Beam-in-slab Bridge (PMBISB) was developed by Iowa State University. The PMBISB consists of four precast panels fabricated at the county's facility, transported to the bridge site and joined with a cast-in-place concrete joint. The PMBISB design was developed to: (1) Extend available funds; (2) Reduce in-field construction time and effort; (3) Provide year-round work for local forces (bridge crew); and (4) Support local superloads. The PMBISB system saves Black Hawk County approximately $16,000 or 17% per bridge compared to conventional bridges. The final design of the PMBISB was influenced by strength and serviceability criteria. The amount of required deck reinforcement is reduced by more than 50% compared with conventional reinforced concrete slab-on-girder decks commonly used in Iowa. Its span length is limited to 40 feet. Other innovations by this county include: (1) Precast Backwall Panels; (2) Precast abutment caps. A demonstration bridge was constructed. During construction, the individual panels were lifted into place and set on the prepared abutments, as shown in Figure. In the case of the first PMBISB, the girders rested directly on the steel abutment cap. Because of slight variances between the cap and the girders, full contact was not readily achieved, which required the use of steel shims. Neoprene bearing pads have been used on subsequent PMBISBs, eliminating the need to shim the girders.
Source: Precast Modified Beam-in-Slab Bridge System (Konda, 2007)
Existing Experience: Iowa DOT
Advantages: This bridge was developed to save construction time, extend available funds by reducing cost, provide year-round work for local forces, and to support superloads. Required deck reinforcement is reduced by about 50%.
Disadvantages: Its span is limited to 40 feet.
Capable Local Companies: None



Precast Modified Beam-In-Slab Bridge System (Konda, 2007)

UHPC Waffle Bridge Deck Panels

Description: Researchers at the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center began investigating potential cost effective and efficient bridge deck panels in the year 2000. Prototype designs of full depth ultra-high-performance concrete (UHPC) waffle deck panel systems have been in development over the past six years in Europe and the United States. UHPC provides superior durability against chlorides, freeze-thaw effects, salt scaling, abrasion, accidental impact, fatigue, and overload, thereby extending the useful life of the bridge deck. Combining these positive attributes of UHPC and the efficiency of the waffle panel design provides an extremely durable option that enables faster construction and longer girder spans through the efficient use of materials and reduced weight. Many DOTs and the FHWA have expressed significant interest in using full depth UHPC waffle deck panels. By demonstrating that this system is a viable solution to the problems encountered by design engineers, it is hoped that it will revolutionize the way bridges are designed in North America.
Source: Innovator (FHWA, 2013).
Existing Experience: Wapello County, Iowa,
Advantages: Extremely durable option, fast construction, longer girder spans through the efficient use of materials, reduced weight.
Disadvantages: New technology and not widely used yet.
Capable Local Companies: None

UHPC Waffle Bridge Deck Panels (Heimann, 2013)

Channel Beams Placed Adjacent To One Another

Description: One of Alabama's standards for prefabricated bridges on secondary, low-volume roads consist of precast concrete channel beams that are placed side by side between supports eliminating the need for formwork or deck panels. The elements are transversely post-tensioned together using galvanized threaded bolts, however in harsher environments, the use of stainless-steel bolts should be considered.
Source: Prefabricated/Precast Bridge Elements and Systems (PBES) for Off-System Bridges (Roddenberry, 2012)
Existing Experience: Alabama DOT
Advantages: Fast construction. The bottoms of the beams are open, which allows for easier inspection compared to box beams. Alabama also has standards for a precast concrete barrier to be used with this superstructure system that can be bolted onto the fascia of the exterior beam in a similar fashion as how the individual beams are connected.
Disadvantages: Access to the underside of the bridge is required for post-tensioning. No accommodation for skewed bridges. Spalling can occur around bolted connections.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
tel: (605) 718-4111
Redi Mix Inc.
E Prospect Ave. 271
Chamberlain, SD
Phone: 605-734-5741
Gage Brothers Concrete Products Inc.
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Sioux Falls, SD 57106
Phone: 605-336-1180
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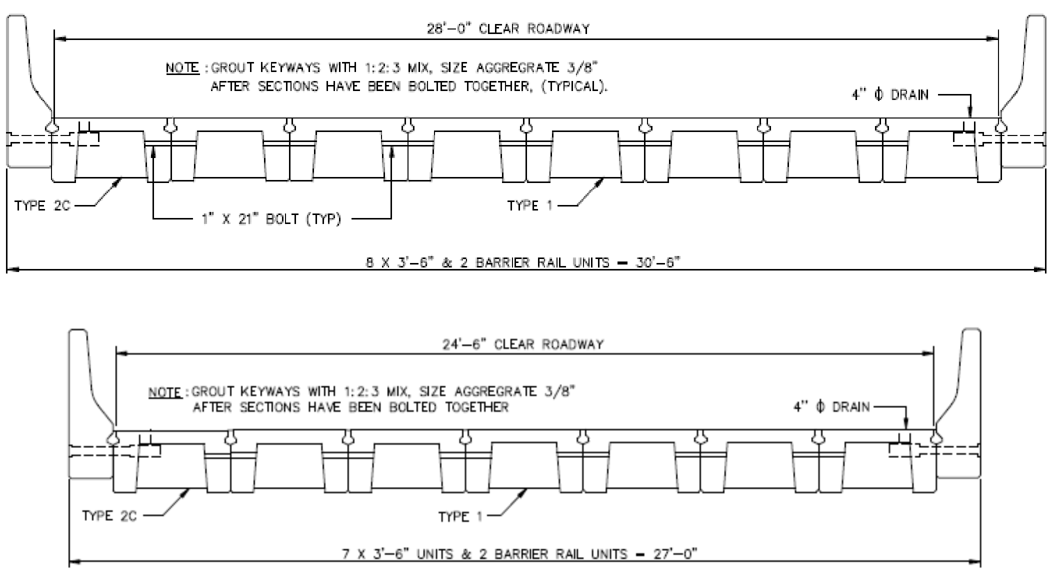


Typical channel beams placed adjacent to one another (Roddenberry, 2012)

Old Rail Flatcars

Description: Old railcars are recycled rail cars, which are converted to bridges. These recycled rail cars are also called "flat cars." TTX Co. of Chicago has the nation's largest pool of railcars. Several counties build bridges with flatcars to save money. Lonoke County has 20 or more railcar bridges on their county roads, and they have never had a problem with them. Potlatch Corp. has placed railcar bridges throughout its forestland in south Arkansas.
Source: Camden Company Recycles Railcars into Affordable Bridges (Arkansas Business, 2006).
Existing Experience: Lonoke County, Vinton County.
Advantages: Old rail cars are much cheaper than conventional concrete and steel bridges. Installations are fast allowing more bridges to be built per year.
Disadvantages: It is difficult to rate the load they are capable of handling. Not allowed on state highways.
Capable Local Companies: None

Old Rail Flatcars http://www.fhwa.dot.gov/hfl/partnerships/hif13031/chapt02.cfm#fig05 Accessed 28 June 2014

Precast Decked Bulb-T Beam

Description: Researchers are evaluating the use of prestressed decked bulb T-beams, which have a wider upper flange than I-beams, giving them a T-shaped cross-section. These upper flanges form the deck of the bridge, which allows for faster construction with less traffic disruption, and the T-shaped cross-section provides enough space at the bottom of the bridge for periodic inspection and maintenance.
Source: New Beam Design May Double Bridge Service Life (Juntunen, 2014).
Existing Experience: Michigan DOT (Ongoing Research)
Advantages: Researchers predict a decked bulb T-beam bridge will last twice as long as current bridges and require far less maintenance, leading to significant cost-savings for Michigan taxpayers. As a prefabricated bridge system, it will also have the potential for accelerated bridge construction and deconstruction, resulting in minimal traffic disruption. Finally, the use of decked bulb T-beams would eliminate problems associated with inspecting and repairing box-beam structures.
Disadvantages: Bridge cost might be high for a start. Not widely practiced yet.
Capable Local Companies:

Wide Flange Steel Girder

Description: A wide flange steel girder is also known as a W-beam. The web resists shear forces while the flanges resist most of the bending moment experienced by the beam.
Existing Experience: Sevier River Axtell - Utah Wheeler Bridge, Latah City, Idaho.
Advantages: The wider the flange, the more bending moment it can resist.
Disadvantages: It could be susceptible to corrosion. Bridge decks will have to be manufactured for the girders.
Capable Local Companies: TrueNorth Steel
Egger Steel

Geosynthetic Reinforced Soil (GRS) Abutments

Description: The GRS system is composed of alternating layers of geosynthetic fabric with backfill in 4-inch to 8-inch layers. The fabric is polypropylene which provides the reinforcement for the system, and together with the soil layers transfers the horizontal load that would exert active pressure on the back face of traditional abutments back beyond the failure plane of the backfill. The GRS mass is stabilized internally by interaction of the reinforcing fabric and backfill. The front facing of the abutment is typically gravity stacked using 8-inch concrete blocks. The Federal Highway Administration (FHWA) has developed a website with a sample design for GRS systems and project information. Several structures have been built in Defiance County, Ohio, examples of which are on the FHWA website. The standards published by the FHWA show abutment heights up to 24 feet. A high-quality granular fill is required for the soil in the GRS system, and a compaction of 95% of maximum dry weight. A geotechnical investigation is required, similar to other bridges, to verify the subgrade can support the GRS system and to design for adequate safety factors for global stability and sliding. The required bearing pressure capacity of the subgrade is 4,000 psf. The FHWA also recommends the bridge span be limited to 140 feet to limit the reaction and resulting bearing pressure on the GRS system. There is also a limit to the abutment height generally controlled by what has been successfully been used elsewhere, which is currently about 24 feet. The scour potential of the abutment structure for this system is a concern. Streams with flood potential, rapid flows, and locations that could be inundated would not be good candidates. Where water is present, the flow would need to be negligible, such as a channel between lakes, for the system to be considered. The FHWA estimates cost savings of 25-60% on their website.
Source: Innovative Bridge Construction for Minnesota Local Roads (Minnesota Department of Transportation, 2012)
Existing Experience: MnDOT - Rock County - Bridge 67564
Defiance County, Ohio
Founders/Meadows Parkway Bridge, crossing I-25 approx. 20 miles south of Denver, CO
Advantages: Time-savings due to faster construction. Low initial cost and use of common construction materials and techniques. Can be used to strengthen weak soils.
Disadvantages: Cannot be used for bridges that might potentially experience high scour.
Capable Local Companies: Many

Geosynthetic Reinforced Soil (GRS) Abutment
http://www.fhwa.dot.gov/hfl/partnerships/hif13031/chapt02.cfm#fig05
Accessed 28 June 2014

MSE Walls with Single Line Pile Abutments

Description: In 2011, Steele County constructed a bridge that used integral abutments on single rows of piles behind MSE walls. While none of the individual components of this abutment type are unique, their use in combination is innovative and unique on Minnesota's local road system. Bridge 74551 is located on CSAH 7 over the DM&E railroad in Owatonna. Due to a highly compressible clay layer at the project site, the embankments were surcharged for approximately four months prior to abutment construction. This abutment type is sensitive to pile alignment, which was an issue on this project. For future use, the design engineer suggested paying particular attention to those details and including more stringent plan notes to that effect. The designer also suggested that future projects allow enough space between the front face of the abutment and the MSE wall to allow for more construction tolerance. Additionally, MSE systems generally should not be used where buried utilities may need to be installed in the future. Disturbance of the reinforcing straps within the MSE backfill can threaten the structural integrity of the wall system. According to the designer, the cost of this bridge was approximately 25% lower than what the alternative three-span structure would have cost.
Source: Innovative Bridge Construction for Minnesota Local Roads (Minnesota Department of Transportation, 2012)
Existing Experience: MnDOT - Steel County - Bridge 74551
Advantages: Uses less concrete and less piling than a typical cast-in-place abutment. This would lead to a decrease in cost. There are no expansion joints on the bridge. Settles less in compressible soils than a spread footing and is more tolerant to settlement.
Disadvantages: Not widely used on the local road system. Sensitive to pile alignment. Cannot be used were buried utilities may need to be installed in the future.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
tel: (605) 718-4111

Mechanically Stabilized Earth (MSE) Wall
http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/001.cfm
Accessed 28 June 2014

Abutment Piles in a Straight Line
http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/001.cfm
Accessed 28 June 2014

Sheet Pile Abutments

Description: Blue Earth County has constructed three bridges: 07586 over Little Cobb River and 07593 and 07547 over Big Cobb River, which consist of an adjacent precast box beam superstructure supported on sheet pile abutments. This design is similar to bridges used in New York for low volume roads and was identified as having potential for use in Minnesota by a Blue Earth County Engineer who attended a scanning tour to New York. Bridges 07593 and 07547 were constructed with bituminous overlays over waterproofing membranes at the joints, while Bridge 07586 was built with a five-inch composite CIP reinforced concrete deck due to the higher ADT on CR 168. In 2012, the County is planning to construct two more bridges with ADTs in the 3,000-4,000 range that will use precast adjacent box beams with a six-inch reinforced concrete composite/non-composite deck.
Source: Innovative Bridge Construction for Minnesota Local Roads (Minnesota Department of Transportation, 2012)
Existing Experience: Minnesota DOT - Blue Earth County - Bridges 07547, 07593, and 07586 over Little Cobb River
Advantages: Prevents approach fill loss. Has a shorter construction time than conventional cast-in-place abutments.
Disadvantages: Corrosion
Capable Local Companies: None

Sheet Pile Abutment
http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/001.cfm
Accessed 28 June 2014

Sheet Pile Abutment
http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/001.cfm
Accessed 28 June 2014

Ultra-high-performance Concrete (UHPC)

Description: The use of UHPC is consistent with the strategic plan of the New Mexico DOT (NMDOT) and the FHWA for improving highway system performance — particularly its safety, reliability, effectiveness, and sustainability.
Source: Case Studies Using Ultra-high-performance Concrete for Prestressed Girder Bridge Design (Taylor, 2013).
Existing Experience: New Mexico DOT
Advantages: UHPC provides more advantages over high performance concrete (HPC) in terms of structural efficiency, durability, and cost-effectiveness over the long term. Replacing deteriorated bridge girders with bridge girders made of UHPC would drastically reduce the amount of maintenance required and this would result in low life cycle bridge costs. UHPC provides high compressive strengths and exhibits improved tensile strength and durability properties that make it a promising material for bridge applications. It has low permeability to aggressive agents such as chlorides from de-icing salts or seawater. A good design using UHPC can result in a significant reduction in concrete volume and the weight of the superstructure, which in turn leads to significant reduction in the dead load on the substructure, especially for the case of aging bridges, thus improving their performance.
Disadvantages: Cracks easily.
Capable Local Companies: Concrete Materials
1201 W. Russel St.
Sioux Falls, SD 57104
Phone: 605-357-6000
GCC Ready Mix
Aberdeen, Big Stone City, Brookings, De Smet, Flandreau.

High-performance/High-strength Lightweight Concrete

Description: Lightweight aggregate concrete has been used in the construction of American highway bridges for over 50 years and there are more than 200 concrete and composite bridges containing lightweight aggregates in the United States and Canada. In the former USSR, about 100 bridges have been constructed using lightweight aggregates in the past 20 years and in Europe, the numbers are increasing steadily. Lightweight aggregate concrete has been successfully used in applications ranging from simple reinforced concrete footbridges to long span post tension segmental box girder bridges. Weight savings of 30 % on the superstructure can be achieved in some cases, with consequent savings of reinforcing and prestressing steel. The size of the piers and foundations can also be reduced. Overall savings on cost of more than 10% can be expected after allowances have been made for the higher initial cost of lightweight aggregates. It is important to adequately soak the lightweight aggregate prior to batching, otherwise early and later-age strengths will be reduced.
Source: Performance of Bridge Decks and Girders with Lightweight Aggregate Concrete (Ramirez, 2000)
Existing Experience: Georgia's I-85 Ramp crossing State Route 34
Advantages: Results in reduced bridge dead load. Durable and long lasting.
Disadvantages: Initial costs might be higher than for conventional concrete girders.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
tel: (605) 718-4111
Gage Brothers Concrete Products Inc.
4301 W. 12th St.
Sioux Falls, SD 57106
Phone: 605-336-1180
Fax: 6053300560
Toll Free: 1-800-348-GAGE (4243)

GCC Ready Mix
Aberdeen, Big Stone City, Brookings, De Smet,
Flandreau, Huron, Redfield, Sisseton, Watertown, Webster.

High Strength Lightweight Girders
http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/001.cfm
Accessed 28 June 2014

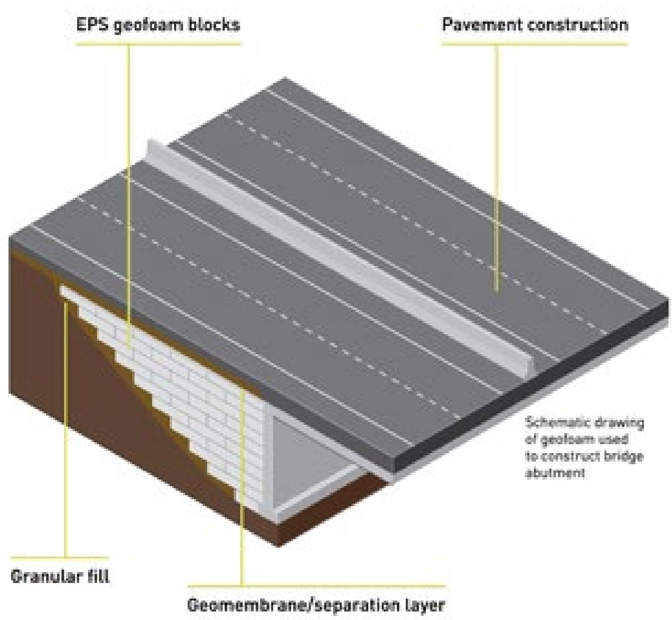
Self-consolidating Concrete (SCC)

Description: The Iowa Department of Transportation combined several accelerated bridge construction methods and innovative materials to replace a rural bridge during a 16-day closure, saving motorists months of travel disruption. Self-consolidating concrete was used to improve consolidation and increase the speed of construction of the abutment piles. Self-consolidating concrete (SCC), sometimes referred to as self-compacting concrete, can effortlessly fill and consolidate in complex structural shapes and around congested steel rebars, eliminating the need for mechanical vibration. SCC mixes are designed to ensure optimal flowability, passability (the ability to fill restrictive spaces), and stability.
Source: Innovator (FHWA, 2013) – Issue 37
Existing Experience: U.S. 6 over Keg Creek in Pottawattamie County – Iowa DOT
Advantages: Reduced labor requirements and improved worker safety: workers no longer have need to access unsafe areas to vibrate concrete. Ensures quicker installations: quicker installation process translates to lower project costs. Longer lasting forms.
Disadvantages: N/A
Capable Local Companies: None

High Strength Lightweight Girdershttp://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/001.cfm Accessed 28 June 2014

Expanded Polystyrene (EPS) Geofoam

Description: Geofoam has the scientific name of “expanded polystyrene” (EPS). A block of EPS is made from particles of polystyrene through an expanding and melting process in an automatic mold machine by adding steam. The geofoam construction method employs large EPS blocks with unit weights between 12 and 30 kg/m^3 (0.75 and 1.9 pcf). In the 1970s, the use of EPS as a lightweight embankment in highway and earthwork developed concurrently in the United States and Norway. Most notably, in 1972, the Norwegian Road Research Laboratory placed geofoam in the approach fill of the Flom Bridge. The advantages of geofoam are that it can be used not only to replace ground fill material but also to reduce the load applied to the foundation. There are many factors such as manufacturing procedure, etc., which will cause differences in EPS product quality. Project quality control methods are used to maintain a suitable quality of the EPS products for construction and safety consideration. When using the EPS in the construction of a backfill, one must pay attention to several factors such as mechanics, thermology, and physical property, etc., which must maintain a certain level of quality.
Source: Evaluation of Geofoam as a Geotechnical Construction Material (Lin, 2010).
Existing Experience: Many parts of the United States and Norway.
Advantages: Ultralight weight: (density is only about 1/100 of sand or soil). Efficiency: short construction period, small digging amount, low maintenance cost, and low overall construction cost. Construction is simple and rapid and it can be handled by just manpower; Good self-sustaining character: small Poisson’s ratio, h,igh self-sustaining property, it can decrease soil lateral pressure and is suitable as a backfill material for structures such as retaining walls. Superior cushion property: the individual air bubble body has the ability to reduce impact and vibration effects. Good, waterproof ability: the individual air bubble body has the merits of water resistance, nondistortion character. Geofoam could be used as a base for approach slabs. It could also be used as a backfill for abutments.
Disadvantages: Untreated Geofoam is a fire hazard. If Geofoam comes into contact with a pretroleum substance, it will turn into a glue-like substance. Forces developed because of buoyancy can result in dangerous uplift forces. If Geofoam is not treated, insects can burrow into it, weakening the material.
Capable Local Companies: None



Expanded Polystyrene (EPS) Geofoam
http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/001.cfm
Accessed 28 June 2014

Cellular Confinement System

Description: Cellular Confinement Systems are widely used in construction for erosion control, soil stabilization on flat ground and steep slopes, channel protection, and structural reinforcement for load support and earth retention. Research and development of cellular confinement systems (CCS) began with the U.S. Army Corps of Engineers in September 1975 to test feasibility of constructing tactical bridge approach roads over soft ground. Engineers discovered that sand-confinement systems performed better than conventional crushed stone sections. They concluded that a sand-confinement system could be developed tp provide an expedient construction technique for building approach roads over soft ground and that the system would not be adversely affected by wet weather conditions. These early efforts led to the civilian commercialization of the first cellular confinement system known as Geoweb® by the Presto Products Company. The cellular confinement system was made from high density polyethylene (HDPE) that was light weight, strong and durable. This new Geoweb cellular confinement system was used first for load support applications in the United States in the early 1980s; second, for slope erosion control and channel lining in the United States in 1984; and third, for earth retention in Canada in 1986. Research on cellular confinement in these application areas in cooperation with Presto Products also started during the 1980s. Other names include Geoweb, Geocell etc.
Source: Applications and Performance of Geosynthetic-Reinforced Soil Abutments on Soft Subsurface Soil Conditions (Mohamed, 2011).
Existing Experience: U.S Army Corp of Engineers
Advantages: It has the advantage of providing abutment face protection against erosion and shallow scour. Can be used to stabilize fill underneath approach slabs and abutment backfill.
Disadvantages: Not very useful in high scour areas.
Capable Local Companies:

Cellular Confinement System (Cell-Tek, 2010)

Carbon Fiber Prestressing Strand

Description: Researchers are evaluating replacing traditional steel prestressing and post-tensioning strands and other reinforcement with corrosion-resistant carbon-fiber-reinforced polymer composite cables, or CFCCs.
Source: New Beam Design May Double Bridge Service Life (Juntunen, 2014).
Existing Experience: Michigan DOT
Advantages: It is corrosion resistant.
Disadvantages: It is less ductile than steel.
Capable Local Companies: N/A

Precast Large Box Culverts

Description: Aitkin County replaced an existing bridge with a large precast box culvert structure for Bridge No 01J31, County Road 73 over the Sandy River (Co. Ditch #42) near McGregor, Minnesota. The structure is 20 feet wide and 8 feet high (20' x 8') ,which exceeds the maximum span of 16 feet covered by the MnDOT standard culvert designs tables. An engineer was retained to design the reinforcing and modify the MnDOT standards, and the culvert was constructed in 2011. A set of twin boxes was not desired at this location, so a large single box structure was chosen with the intent of maintaining the full waterway opening across the entire width of the box. From conducting bridge inspections for several years, the County Engineer noted that double and triple box culvert installation often did not function hydraulically as envisioned. Quite frequently some amount of channel change had been required during construction to align or modify the channel to direct the flow through the double/triple boxes. The stream would soon migrate back to its natural flow and primarily use only one of the culvert barrels. The second or third box would silt in with sediment or debris, no longer providing the full hydraulic cross section. After observing this tendency for a multiple barrel structure to partially silt in, the county developed a preference for a single-span structure where feasible. During the design phase, the size of the boxes was reviewed for constructability. The county and designer believed local contractors would not have any issues building the culvert. This assessment was confirmed by the fact that eight bidders competed for the project, the typical small contractors that bid on other projects in Aitkin County. No company expressed concerns to the County regarding the box size or constructability.
Source: Innovative Bridge Construction for Minnesota Local Roads (Minnesota Department of Transportation, 2012)
Existing Experience: MnDOT - Aitkin County - Bridge 01J31
Advantages: Easy to construct, inspection is the same as for all precast box culverts.
Disadvantages: For some sites, access and placement of larger box sections may be an issue. Shipping weight and size of boxes may be an issue for trucking.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
tel: (605) 718-4111

Expanded Polystyrene (EPS) Geofoam
http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/001.cfm
Accessed 28 June 2014

Precast Three-sided Frame

Description: There has been an increased use of three-sided structures for local roads. Three-sided structures are precast but do not have a bottom slab. The legs bear on a footing that cast in place on the site. Spans for the three-sided structures can go up to 60 feet, however common spans are typically 28 to 42 feet *(Minnesota Department of Transportation, 2012)*. Similar to box culverts, the structure is built from a series of precast sections sized for shipping and lifting. The benefits of three-sided structures include that it is a low maintenance structure being a culvert, and the stream bottom is undisturbed and maintains a natural bottom. The natural bottom is preferred in streams where there is concern for fish migration or habitat.
Source: Innovative Bridge Construction for Minnesota Local Roads (Minnesota Department of Transportation, 2012)
Existing Experience: MnDOT - Aitkin County - Bridge 01J31
Advantages: Easy to construct, inspection is the same as for all precast box culverts.
Disadvantages: Limitations include that scour-susceptible sites can require a pile foundation, which increases the cost of the structure significantly. The roadway barrier on top of the structure is typically a moment slab, where the railing is anchored into the pavement to prevent the railing from overturning from traffic hits. The three-sided structure is not designed to anchor the barrier railing directly. Costs are usually higher than precast box culverts, so use of a three-sided structure is typically at sites where the open bottom is needed or the arch-like appearance is desired for aesthetics.
Capable Local Companies: Cretex Concrete Products
2046 Samco Road, Suite 2
Rapid City, SD 57702
tel: (605) 718-4111

APPENDIX D: THE CATALOG

#	Category	Structure Alternatives	Profile	Description	Advantages	Disadvantages	Potentially Capable Companies
1	Superstructure	Prefabricated Elements and Systems (PBES)	PDF	PBES are elements and systems that are pre-made before onsite bridge construction.	It leads to a much faster construction due to elimination of falsework. It is more durable than conventional CIP bridge elements and systems.	Might need specialty equipment and personnel for prefabrication and construction.	Cretex Gage Brothers Redi Mix Inc.
2	Superstructure	Jointless Bridge	PDF	In this context, jointless bridges are bridges without expansion joints over the span of the bridge. It can have expansion joints only at the abutments.	Ensure long-term serviceability of the structure, minimal maintenance requirements, economical construction, and improved overall performance of the facility.	Approach slab settlement and approach fill erosion occur on longer spans	Cretex Gage Brothers.
3	Superstructure	Precast Inverted Tee Beam	PDF	The precast inverted tee beam system is based on a similar section that was in use in France (the Poutre Dalle System).	It decreases construction time, and it is easy to construct. It is very durable and does not require frequent inspection and maintenance.	It is expensive in the short run but very cost effective in the long run. Sometimes has a deck cracking issue.	Cretex Concrete Products
4	Superstructure	Precast Prestressed Adjacent Box Beams	PDF	The "adjacent box beam system" is typically more than 21 inches deep and three feet or four feet wide. Some states have used wider sections.	Time saving, durable and long lasting compared to cast in place panels. Massachusetts has used this structure since the 1950's. Recent inspection reports indicate that these local road bridges are doing well even after 50 years of service.	Many states have noted that when these bridges are exposed to heavy truck, there is the tendency for the joints between the beams to leak. In extreme cases, the joints have completely failed.	Cretex Concrete Products Redi Mix Inc.
5	Superstructure	Precast Prestressed Adjacent Deck Slab Beams	PDF	The "slab system" or "deck slab system" is typically less than 21 inches deep. The beams are normally three feet or four feet wide; however, some states have used wider sections.	Time saving, very durable and long lasting compared to cast in place panels. Massachusetts has used this structure since the 1950's. Recent inspection reports indicate that these local road bridges are doing well even after 50 years of service.	Many states have noted that when these bridges are exposed to heavy truck, there is the tendency for the joints between the beams to leak. In extreme cases, the joints have completely failed.	Cretex Concrete Products Gage Brothers Redi Mix Inc.
6	Superstructure	Precast Double-T Beam/The NEXT Beam	PDF	The NEXT beam solves issues purely through its geometry. It is intended for use on medium span bridges with spans ranging from 40 ft to 90 ft. The section resembles that of a standard double tee commonly used for parking structures.	Reduces construction time and cost. Inspections can be done easily because of its geometry.	Might need a specialty load crane to install it in place.	Cretex Gage Brothers.

#	Existing Experience	Installation	Durability	Maintenance4	Other Pertinent Factors	Cost
1	Many state DOTs					
2	TXDOT, NYDOT, CALTRANS etc.					
3	MnDOT - Scott County (Bridge No. 70548) and Chisago county (Bride No. 13521)					
4	MnDOT - Blue Earth County MassDOT					
5	MassDOT					
6	Approved in the following States: Connecticut, Massachusetts, Maine, New Hampshire, New York, Pennsylvania, Rhode Island, and Vermont.					

#	Category	Structure Alternatives	Profile	Description	Advantages	Disadvantages	Potentially Capable Companies
7	Superstructure	Precast Modified Beam-In-Slab Bridge System	PDF	This Precast Modified Beam-In-Slab Bridge (PMBISB) was developed by Iowa State University. The PMBISB system saves Black Hawk County approximately $16,000 or 17% per bridge compared to conventional bridges. The final design of the PMBISB was influenced by strength and serviceability criteria.	This bridge was developed to save construction time, extend available funds by reducing cost, provide year-round work for local forces, and to support superloads. Required deck reinforcement is reduced by about 50%.	Its span is limited to 40 ft.	Cretex Gage Brothers.
8	Superstructure	UHPC Waffle Bridge Deck Panels	PDF	Numerous DOTs and the FHWA have expressed significant interest in using full depth UHPC waffle deck panels. By demonstrating that this system is a viable solution to the problems encountered by design engineers, it is hoped that it will revolutionize the way bridges are designed in North America.	Extremely durable option, fast construction, longer girder spans through the efficient use of materials, reduced weight.	New technology and not widely used	N/A
9	Superstructure	Precast Decked Bulb-T Beam	PDF	Researchers are evaluating the use of prestressed decked bulb T-beams, which have a wider upper flange than I-beams, giving them a T-shaped cross-section. These upper flanges form the deck of the bridge, which allows for faster construction with less traffic disruption, and the T-shaped cross-section provides enough space at the bottom of the bridge for periodic inspection and maintenance.	Researchers predict a decked bulb T-beam bridge will last twice as long as current bridges and require far less maintenance, leading to significant cost-savings for Michigan taxpayers. As a prefabricated bridge system, it will also have the potential for accelerated bridge construction and deconstruction, resulting in minimal traffic disruption. Finally, the use of decked bulb T-beams would eliminate problems associated with inspecting and repairing box-beam structures.	Bridge cost might be high for a start. Not widely practiced yet.	N/A

#	Existing Experience	Installation	Durability	Maintenance4	Other Pertinent Factors	Cost
7	IDOT					
8	UDOT - The Beaver Creek Bridge on US-6.					
9	MDOT					

#	Category	Structure Alternatives	Profile	Description	Advantages	Disadvantages	Potentially Capable Companies
10	Superstructure	Old Rail Flatcars	PDF	Old railcars are recycled rail cars which are converted to bridges. These recycled rail cars are also called flat cars. TTX Co. of Chicago has the nation's largest pool of railcars. Several counties build bridges with flatcars to save money. Lonoke County has 20 or more railcar bridges on their county roads and they have never had a problem with them. Potlatch Corp. has placed railcar bridges throughout its forestland in south Arkansas.	Old rail cars are much cheaper than conventional concrete and steel bridges. Installations are fast allowing more bridges to be built per year.	It is difficult to rate the load they are capable of handling. Not allowed on state highways.	N/A
11	Superstructure	Wide Flange Steel Girder	PDF	A wide flange steel girder is also known as a W-beam. The web resists shear forces while the flanges resist most of the bending moment experienced by the beam.	The wider the flange, the more bending moment it can resist.	It could be susceptible to corrosion. Bridge decks will have to be manufactured for the girders.	TrueNorth Steel Egger Steel
12	Superstructure	Channel Beams Placed Adjacent To One Another	PDF	One of Alabama's standards for prefabricated bridges on secondary, low-volume roads consist of precast concrete channel beams that are placed side by side between supports eliminating the need for formwork or deck panels. The elements are transversely post-tensioned together using galvanized threaded bolts, however in harsher environments, the use of stainless-steel bolts should be considered.	Fast construction. The bottoms of the beams are open which allows for easier inspection compared to box beams. Alabama also has standards for a precast concrete barrier to be used with this superstructure system that can be bolted onto the fascia of the exterior beam in a similar fashion as how the individual beams are connected together.	Access to the underside of the bridge is required for post-tensioning. No accommodation for skewed bridges. Spalling can occur around bolted connections.	Cretex Concrete Products Gage Brothers Redi Mix Inc.
13	Substructure	Geosynthetic Reinforced Soil (GRS) Abutments	PDF	The GRS system is composed of alternating layers of geosynthetic fabric with backfill in 4-inch to 8-inch layers. The fabric is polypropylene which provides the reinforcement for the system, and together with the soil layers transfers the horizontal load that would exert active pressure on the back face of traditional abutments back beyond the failure plane of the backfill.	Time-savings due to faster construction. Low initial cost and use of common construction materials and techniques. Can be used to strengthen weak soils.	Cannot be used for bridges with potentially high scour.	INF

#	Existing Experience	Installation	Durability	Maintenance4	Other Pertinent Factors	Cost
10	Lonoke County, and Vinton County among others across the United States.					
11	Sevier River Axtell - Utah Wheeler Bridge, Latah Cty Idaho.					
12	Alabama DOT					
13	MnDOT - Rock County - Bridge 67564					

#	Category	Structure Alternatives	Profile	Description	Advantages	Disadvantages	Potentially Capable Companies
17	Material	High-performance/ High-strength Lightweight Concrete	PDF	Lightweight aggregate concrete has been used in the construction of American highway bridges for over 50 years and there are more than 200 concrete and composite bridges containing lightweight aggregates in the United States and Canada. Weight savings of 30 % on the superstructure can be achieved in some cases, with consequent savings of reinforcing and prestressing steel. The size of the piers and foundations can also be reduced.	Results in reduced bridge dead load. Very Durable and long lasting.	Initial costs might be higher than for conventional concrete girders.	Cretex Concrete Products Gage Brothers GCC Ready Mix
18	Material	Self-consolidating Concrete	PDF	The Iowa Department of Transportation combined several accelerated bridge construction methods and innovative materials to replace a rural bridge during a 16-day closure, saving motorists months of travel disruption. Self-consolidating concrete was used to improve consolidation and increase the speed of construction of the abutment piles. Self-consolidating concrete (SCC), sometimes referred to as self-compacting concrete, can effortlessly fill and consolidate in complex structural shapes and around congested steel rebars, eliminating the need for mechanical vibration.	Reduced labor requirements and improved worker safety: workers no longer have need to access unsafe areas to vibrate concrete. Ensures quicker installations: quicker installation process translates to lower project costs. Longer lasting forms.	N/A	Cretex Concrete Products Gage Brothers GCC Ready Mix

#	Existing Experience	Installation	Durability	Maintenance4	Other Pertinent Factors	Cost
17	IDOT					
18	U.S. 6 over Keg Creek in Pottawattamie County – Iowa DOT					

#	Category	Structure Alternatives	Profile	Description	Advantages	Disadvantages	Potentially Capable Companies
19	Material	EPS Geofoam	PDF	Geofoam has the scientific name of expanded polystyrene (EPS). A block of EPS is made from particles of polystyrene through an expanding and melting process in an automatic mold machine by adding steam.	Ultralight weight: (density is only about 1/100 of sand or soil). Efficiency: short construction period, small digging amount, low maintenance cost, and low overall construction cost. Construction is simple and rapid and it can be handled by just manpower; Good self-sustaining character: small Poisson's ratio, high self-sustaining property, it can decrease soil lateral pressure and is suitable as a backfill material for structures such as retaining walls. Superior cushion property: the individual air bubble body has the ability of reducing impact and vibration effects. Good proof ability: the individual air bubble body has the merits of water resistance, non-distortion character.	Should always be treated against insects and fire.	Benchmark Foam Inc.
20	Material	Cellular Confinement System	PDF	Cellular Confinement Systems are widely used in construction for erosion control, soil stabilization on flat ground and steep slopes, channel protection, and structural reinforcement for load support and earth retention. Engineers discovered that sand-confinement systems performed better than conventional crushed stone sections.	It has the advantage of providing abutment face protection against erosion and shallow scour.	Not very useful in high scour areas.	N/A
21	Material	Carbon Fiber Prestressing Strand	PDF	Researchers are evaluating replacing traditional steel prestressing and post-tensioning strands and other reinforcement with corrosion-resistant carbon-fiber-reinforced polymer composite cables, or CFCCs.	It is corrosion resistant.	It is less ductile than steel.	N/A

#	Existing Experience	Installation	Durability	Maintenance4	Other Pertinent Factors	Cost
19	VDOT					
20	TXDOT					
21	MDOT					

#	Category	Structure Alternatives	Profile	Description	Advantages	Disadvantages	Potentially Capable Companies
22	Entire Bridge Structure	Precast Large Box Culverts	PDF	Aitkin County replaced an existing bridge with a large precast box culvert structure for Bridge No 01J31, County Road 73 over the Sandy River (Co. Ditch #42) near McGregor, Minnesota. The structure is are 20 feet wide and 8 feet high (20'x8') which exceeds the maximum span of 16 feet covered by the MnDOT standard culvert designs tables. An engineer was retained to design the reinforcing and modify the MnDOT standards, and the culvert was constructed in 2011. A set of twin boxes was not desired at this location, so a large single box structure was chosen with the intent of maintaining the full waterway opening across the entire width of the box.	Easy to construct, inspection is the same as for all precast box culverts.	For some sites, access and placement of larger box sections may be an issue. Shipping weight and size of boxes may be an issue for trucking.	Cretex Concrete Products
23	Entire Bridge Structure	Precast Three-Sided Frame	PDF	Three-sided structures are precast but do not have a bottom slab. The legs bear on a footing that is cast in place on the site. Spans for the three-sided structures can go up to 60 feet, however the common spans are typically 28 to 42 feet	Easy to construct, inspection is the same as for all precast box culverts.	Scour susceptible sites can require a pile foundation, which increases the cost of the structure significantly. The three-sided structure is not designed to anchor the barrier railing directly. Costs are usually higher than precast box culverts, so use of a three-sided structure is typically at sites where the open bottom is needed, or the arch-like appearance is desired for aesthetics.	Cretex Concrete Products

#	Category	Structure Alternatives	Profile	Description	Advantages	Disadvantages	Potentially Capable Companies
24	Entire Bridge Structure	Grant County Bridge Construction		The bridge system used is prefabricated box beams placed on cast-in-place abutments seated on shallow spread footings. Most off-system bridge spans typically average 35 feet in length and range from 24 feet to 40 feet.	The bridges are cost effective due to the cast-in-place abutments and construction time is reduced due to the precast slabs from Cretex Concrete Products.	Not all the materials are tested for quality assurance.	Cretex Concrete Products

#	Existing Experience	Installation	Durability	Maintenance4	Other Pertinent Factors	Cost
22	MnDOT - Aitkin County - Bridge 01J31					
23	MnDOT, Caltrans. NYSDOT					
24	Grant County, SD	A six-inch layer of rock is usually placed under the shallow footings. The railings are open metal. Grant County had not noted any problems with performance to date.	The bend at the stem wall has double the amount of reinforcing to prevent the bend from overstressing due to the impact of flow.	Repairs of off-system bridges to date have only consisted of re-riprapping abutments at three bridges locations.	The footing dimensions are typically eight feet wide by two feet thick. The abutment walls are typically two feet inboard and range from five to 11 feet in height.	$42 per sf

APPENDIX E: SDDOT CONVENTIONAL COSTS TABLES

	Project Number	Total 'ON' Bridge Cost	Mobilization	Traffic Control	Area	Total Cost/SF
Steel Girder Bridges	NH 0235(1)0	$1,323,138.00	$183,333.33	$64,025.38	19602	$80.12
	IM-BRF 90-1(185)30	$3,155,362.00	$376,135.00	$268,254.00	45474	$83.56
	NH-BRF 0012(103)30	$1,702,942.00	$325,000.00	$33,457.50	16464	$125.21
	IM 29-2(52)72	$1,813,860.00	$730,000.00	$37,735.00	17746	$145.47
	IM 90-2(134)	$1,884,335.00	$637,280.00	$333,996.83	17794	$160.48
	BRF 0012(92)248	$1,258,500.00	$90,000.00	$19,349.30	12385	$110.44
	IM 29-3(76)78	$3,483,607.00	$323,835.76	$30,643.96	43886	$87.46
					Mean	$113.25
					Std. Dev.	$31.79
					Mean + Std. Dev.	**$145.04**

	Project Number	Total 'ON' Bridge Cost	Mobilization	Traffic Control	Area	Total Cost/SF
Continuous Concrete Bridges	NH-PH 0085(30)45	$349,559.00	$166,666.67	$26,387.67	6168	$87.97
	P 0010(38)362	$680,894.00	$113,300.00	$14,524.60	6059	$133.47
	BRF 0903(44)167	$1,123,264.00	$253,490.72	$65,782.06	12408	$116.26
	BRF 3134(01)276	$913,187.00	$180,000.00	$5,226.00	7687	$142.89
	P-BRF 0018(126)387	$744,120.00	$95,000.00	$14,748.24	6283	$135.90
	NH-PH 0018(139)87	$501,429.00	$105,000.00	$46,423.00	3555	$183.64
	EM 0018(152)69	$636,655.00	$40,000.00	$6,702.86	6728	$101.57
	P 0034(152)69	$722,630.00	$136,620.06	$16,728.29	9377	$93.42
	EM0385(15)0	$746,777.00	$200,000.00	$16,194.29	5200	$185.19
	NH0018(160)424	$1,216,297.00	$157,800.00	$17,700.00	7381	$188.56
					Mean	$136.89
					Std. Dev.	$38.29
					Mean + Std. Dev.	**$175.18**

	Project Number	Total 'ON' Bridge Cost	Mobilization	Traffic Control	Area	Total Cost/SF
Prestressed Girder Bridges	NH 0235(1)0	$637,076.00	$366,666.66	$128,050.76	11986	$94.43
	P-PH 0011(5)81	$1,583,459.00	$104,000.00	$4,742.40	25346	$66.76
	BRF-P 3052(3)319	$186,880.00	$61,666.67	$6,396.70	3326	$76.65
	BRF 0212(64)36	$421,626.00	$68,700.23	$14,556.58	7124	$70.87
	BRF 0073(20)202	$371,134.00	$62,000.00	$8,801.00	4466	$98.96
	NH 0083(23)191	$283,554.00	$47,562.50	$9,008.34	4214	$80.71
	BRF 3130(6)196	$492,577.00	$110,000.00	$8,052.76	6279	$97.25
	IM 90-6(37)281	$935,307.00	$123,352.00	$29,736.00	14764	$73.72
	BRF 90-2(92)64	$1,039,927.00	$30,000.00	$69,000.00	15233	$74.77
	IM 90-5(39)239	$1,093,907.00	$99,400.00	$19,036.34	11286	$107.42
	NH 0212(107)318	$424,375.00	$85,000.00	$10,155.00	5547	$93.66
	EM 0902(39)61	$2,686,235.00	$465,250.00	$124,524.75	38494	$85.10
	IM 0909(69)390	$721,433.00	$71,140.00	$15,666.29	9472	$85.33
	BRF 3071(5)3	$917,151.00	$190,000.00	$24,742.00	11561	$97.91
	IM-PH 0901(61)49	$1,469,425.00	$383,333.33	$100,704.00	17590	$111.06
	IM 0909(77)390	$893,429.00	$81,622.78	$9,529.11	9472	$103.95
	EM 0018(98)44	$2,188,425.00	$95,567.79	$12,860.91	24283	$94.59
	EM-P 4411(01)	$1,900,925.00	$407,877.00	$13,003.75	20069	$115.69
	IM-EM 0909(68)396	$1,831,151.00	$383,650.00	$26,235.00	24163	$92.75
	NH-PH 0018(139)87	$353,563.00	$105,000.00	$46,423.00	3248	$155.48
	P 0065(04)214	$1,553,250.00	$438,000.00	$24,093.00	13820	$145.83
	P1282(06)	$3,251,778.00	$650,000.00	$142,893.80	29750	$135.96
	P0028(31)281	$1,493,010.00	$297,932.50	$13,761.80	16899	$106.79
	NH-PS0012(145)387	$1,072,152.00	$676,500.00	$22,839.50	9083	$195.03
					Mean	$102.53
					Std. Dev.	$29.95
					Mean + Std. Dev.	**$132.48**

APPENDIX F: EXISTING INNOVATIVE OFF-SYSTEM BRIDGE COST DATA

Bowman Road Bridge – Defiance County, Ohio

The bridge consists of prestressed concrete box beams supported on GRS abutments without the use of a deep foundation to support the superstructure. The GRS abutments were built on a Reinforced Soil Foundation (RSF) over the clay subsoil. The bridge has no cast-in-place concrete.
The bridge also does not have an approach slab. The intent was to allow the bridge and the adjacent road to settle together, providing a bump free, smooth ride for drivers traveling over the bridge. The cost to construct this bridge was about 20 percent less than the quoted price of a bridge supported on pile-capped abutments with 2:1 slopes. The bridge was instrumented and surveyed to evaluate performance and to refine the "integrated abutment" design concept. To date, the performance of the bridge is excellent, and the angular distortion of the superstructure is well within AASHTO criteria for simple supported bridges. The bridge was built in about six weeks. It is a 79-foot span bridge. The bridge width is 34 feet.

Abutment Type Cost Comparison			
GRS Abutment		Pile Cap Abutment	
GRS Abutment	$95,000	Conventional cap Abutment on piles	$105,000
Beams and Waterproofing (34 ft x 82 ft)	$171,000	Beams and Waterproofing (34 ft x 82 ft)	$233,000
Total	**$266,000**		**$338,000**

Reference:

Adams, M. T., Schlatter, W., Stabile, T. (2007). Geosynthetic Reinforced Soil Integrated Abutments at the Bowman Road Bridge in Defiance County, Ohio.
Geosynthetics in Reinforcement and Hydraulic Applications: pp. 1-10.

Mt. Pleasant Road Bridge – Clearfield County, Pennsylvania.

This bridge is a glulam slab over GRS abutments. The deck is overlain with asphalt and it is currently the only modern GRS bridge in Pennsylvania. It was built in the fall of 2011 by a township crew at a total cost of ~$102,000. This represented a significant cost saving over the standard bridge alternatives. The GRS abutments were constructed in six days and the entire bridge, including paving, was done in 36 days. It is a 26-foot span bridge.

Item	Cost
Permitting	$5,273.75
Excavation Contractor (removal, disposal, excavation, backfilling)	$12,364.00
Timber Superstructure	$28,165.00
Concrete Blocks (including delivery)	$3,696.15
Geotextile	$2,850.00

Aggregate (2RC and AAHSTO 8)	$8,807.40
Aggregate (Rip Rap)	$4,509.00
Miscellaneous (filter bags, filter sock, concrete, coffer dam, tool rental, rebar, lumber, plastic, tools)	$5,282.70
Bituminous Paving	$15,429.84
Guard Rail (contracted out)	$6,290.40
Township Labor	$9,225.67
Total Cost	**$101,893.91**

Comparable Cost

GRS-IBS	PENNDOT Box Culverts and Bridge Beam Projects	Local Project Box Culvert (no paving) – Genesse Township, Potter County	Contracted Design and Construction Box Culverts
~102,000	**$150,000**	**$194,000**	**$500,000+**

Reference:

Albert, G. R. (2011). “Mount Pleasant Road Bridge - Houston Township, Clearfield County.”

Black Hawk County, Iowa

This bridge is a custom precast beam-in-slab (40.75 ft long) superstructure over sheet pile abutments. The bridge is 31 feet wide and has two lanes. This was the first sheet pile abutment bridge demonstration project constructed in Black Hawk County (BHC), Iowa. The site selected was a low volume road bridge crossing Spring Creek (a tributary of the Cedar River) on Bryan Road near La Porte City.

According to the BHC Engineer's Office, the total cost of this project (including labor and materials) was **$151,230**. The BHC Engineer's Office believes that a significant portion of the cost can be attributed to the labor and equipment time involved in developing a new method of construction for this type of bridge and many associated equipment breakdowns. Future projects using a similar design and construction method with comparable site conditions could be performed at a reduced cost.

Reference:

Evans, Ryan Richard, "modified sheet pile abutments for low volume road bridges" (2010). *Graduate Theses and Dissertations*. Paper 11678.

Boone County, Iowa

The second demonstration project was constructed in Boone County (BC), Iowa. This project was undertaken to investigate the feasibility of sheet piling combined with a GRS system for use as the primary abutment foundation element and backfill retaining system. The bridge superstructure is a 30-foot wide, 100-foot long three-span continuous concrete slab with a 30 degree skew. The site selected was a LVR bridge, originally constructed in 1937, crossing Eversoll Creek (a tributary of the Des Moines River) on Owl Avenue near the city of Madrid.

The total cost of the construction of the BC demonstration project was approximately **$591,000**, with a typical 100-foot three-span county road J30C-87 standard bridge (with steel H-pile abutments) expected to cost $397,000. Total construction time was approximately 18 weeks. The bridge had an anchorage system, which was the cause of the high total project cost.

Reference:

Evans, Ryan Richard, "modified sheet pile abutments for low volume road bridges" (2010). *Graduate Theses and Dissertations.* Paper 11678.

Buchanan County Bridge, Iowa

A bridge built in Buchanan County had railroad flatcars (RRFC) as the superstructure system supported by reinforced concrete cap beams with backwalls with each cap beam supported by five HP 10x42 steel piling. Longitudinal flatcar connections consisting of reinforced concrete beams with transverse threaded rods spaced 24 inches on center were installed between the flatcars for distributing live loads efficiently among the three RRFCs. To ensure that the longitudinal connections supported their own self weight, midspan shoring was used during construction of the connections, which reduced the dead load being distributed to the steel structural members

The use of RRFCs on low-volume bridges is obviously subject to the availability of decommissioned flatcars. Flatcars are removed from service because new designs make them obsolete or because their net worth has depreciated to essentially zero. However, it is recommended that flatcars be selected that have been removed from service because of obsolescence. In addition, if possible, select a type of RRFC that is abundantly available so bridges may be constructed repetitively and not require new designs.

Using these five criteria and a simplified grillage analysis to evaluate each type of RRFC, it was determined that the 56-foot v-deck style RRFC and the 89-foot style RRFC were the best flatcars for the Buchanan County Bridge (BCB) and the Winnebago County Bridge (WCB), respectively.

Each 56-foot RRFC cost **$6,500**, and this price included shipping to the bridge site. If the labor and equipment costs are disregarded for each bridge, the price of the BCB was approximately **$20** per square foot. If the actual costs for the county labor and equipment are included, the price of the BCB would be **$39** per square foot. The county's alternative to the RRFC bridge was to contract for a concrete slab bridge costing approximately $65 per square foot.

Reference:

Doornink, J. D., Wipf, T. J., Klaiber, F. W. (2003). "Railroad Flatcar Bridges for Economical Bridge Replacement Systems." *Proceedings of the 2003 Mid-Continent Transportation Research Symposium*, Ames, Iowa.

Winnebago County Bridge, Iowa

The Winnebago County Bridge (WCB) demonstration bridge is a three-span structure because preliminary calculations determined that the 89-foot RRFCs would be inadequate for a single span. Therefore, the 89-foot (27.1-m) flatcars were supported by steel-capped piers and abutments at the RRFCs' bolsters and ends, resulting in a 66-foot (20.1 m) main span with two 10-foot (3.0 m) end spans. The use of RRFCs on low-volume bridges is obviously subject to the availability of decommissioned flatcars. Flatcars are removed from service because new designs make them obsolete or their net worth has depreciated to essentially zero. However, it is recommended that flatcars be selected that have been removed from service because of obsolescence. In addition, if possible, select a type of RRFC abundantly available so bridges may be constructed repetitively and not require new designs.

Each 89-foot RRFC cost $9,700, and prices included shipping to the bridge site. If the labor and equipment costs are disregarded for each bridge, the price of the WCB RRFC bridge was approximately $26 per square foot. If the actual costs for the county labor and equipment are included, the price of the WCB RRFC bridge would be $37 per square foot. The county's alternative to the RRFC bridge was to contract for a concrete slab bridge at a cost of approximately $65 per square foot.

Demonstration Bridge		
ITEM	**COST**	**NOTES**
Initial Costs	$498,017	Actual Recorded Cost of Construction (Provided by Wapello County)
Annual Maintenance	$250 / Year	Estimated Yearly General Maintenance (Provided by Wapello County)
Inspections (Required Every Two Years)	$175	Estimated Inspection Cost (Provided by Wapello County)
Five Year Increment Scheduled Maintenance Crack Repair, Patching, Joint Sealant (Inspect / Repair / Replace)	$250 / Occurance	This item is Not Needed on UHPC Bridge
25 Year Scheduled Maintenance Surface Grinding and Overlay	$0	This item is Not Needed on UHPC Bridge
50 Year Scheduled Maintenance Redeck Bridge	$0	This item is Not Needed on UHPC Bridge
75 Year Scheduled Maintenance Surface Grinding and Overlay	$0	This item is Not Needed on UHPC Bridge
100 Year CIP Design Life Reached Demolish and Rebuild CIP Bridge	$0	This item is Not Needed on UHPC Bridge
120 Year UHPC Design Life Reached End of Useful Life - No Residual Value	$0	Assume girder life is extended by 20 years due to fewer deck rehabilitation and less damage from corrosion due to poor deck conditions.
User Costs Associated with Construction and Maintenance Consist of Driver Delay Costs, Vehicle Operating Costs, and Accident Costs	$168,702	(Calculated from data provided by IDOT)
TOTAL LIFE CYCLE COST $680,270		

Estimated Cost of a Similiar Bridge with CIP deck		
ITEM	**COST**	**NOTES**
Initial Costs	$375,642	Estimated Cost of Construction with Typical CIP Desk Design (Provided by Wapello County / IDOT)
Annual Maintenance	$250 / Year	Estimated Yearly General Maintenance (Assume slightly more than UHPC) (Provided by Wapello County)
Inspections (Required Every Two Years)	$200 / Occurance	Estimated Inspection Cost (Assume slightly less than UHPC) (Provided by Wapello County)
Five Year Increment Scheduled Maintenance Crack Repair, Patching, Joint Sealant (Inspect / Repair / Replace)	$1,000 / Occurance	
25 Year Scheduled Maintenance Surface Grinding and Overlay	$25,000	(Provided by IDOT)
50 Year Scheduled Maintenance Redeck Bridge	$45,000	(Provided by IDOT)
75 Year Scheduled Maintenance Surface Grinding and Overlay	$25,000	(Provided by IDOT)
100 Year CIP Design Life Reached Demolish and Rebuild CIP Bridge	$375,642	Assumed Typical Service Life of CIP Bridge is 100 Years
120 Year UHPC Design Life Reached	$0	Not Applicable to the CIP Bridge
120 Year Residual Value of CIP Bridge	$297,313	Credit for 80 years of useful life remaining in the structure (Calculate from construction cost - future maintenance costs)
User Costs Associated with Construction and Maintenance Consist of Driver Delay Costs, Vehicle Operating Costs, and Accident Costs	$233,842	(Calculated from data provided by IDOT)
TOTAL LIFE CYCLE COST $662,756		

Ultra-high-performance Concrete (UHPC) Waffle Bridge Deck – Wapello County, Iowa

The demonstration bridge in Wapello County is 33 feet and 2 inches wide by 60 feet long, consisting of 14 UHPC panels supported on five Iowa "B" beam precast/prestressed concrete girders spaced at 7 feet 4 inches, with overhangs measuring 1 foot 11 inches. The panels are jointed with UHPC at the crown longitudinally, the transverse panel-to-panel joints, and the shear pockets over the girders.

Leflore County, Mississippi

CO RD 523 over PECAN BAYOU is a bridge constructed in 2010 with precast channel beams as the superstructure. It is 24.6 ft wide and 95.1 ft long. ADT for 2012 is 60. The estimated cost of work is $57,000.

Simpson County, Mississippi

DAN KEYES ROAD over ROCKY CREEK is a bridge built in 2009 with precast channel beams as the superstructure. It is 24.6 ft wide and 57.1 ft long. ADT for 2012 is 20. The estimated cost of work is $38,000.

Neshoba County, Mississippi

COUNTY ROAD 123 over LUNELUAH BRANCH is a bridge built in 2009 with precast channel beams as the superstructure. It is 24.6 ft wide and 30.8 ft long. ADT for 2011 is 100. The estimated cost of work is $180,000. Wearing surface is gravel.

Adams County, Mississippi

PALESTINE RD over TURKEY CREEK was built in 1979 with precast channel beams as the superstructure. It is 107 ft long and 28.2 ft wide (deck width edge to edge) ADT for 2008 was 50. The estimated cost of the project was $230,000. Wearing surface is monolithic concrete.
DEERFIELD ROAD over PRETTY CREEK was built in 1970 with precast channel beams as the superstructure. It is 68.9 ft long and 28.2 ft wide. ADT for 2013 was 100. The estimated cost of the project was $230,000. Wearing surface is monolithic concrete.

Item	Price
Prestressed Concrete Slab Beam	$85 per lf
Prestressed Concrete T Beam	$125 per lf
Rolled Steel Beam (Sections Smaller Than 30 in.)	$0.35 per lb
Rolled Steel Beam (Sections 30 in. or Larger)	$0.5 per lb
Steel Plate Girders	$0.70 per lb

Reference
Amanda M. Bergeron, Karl H. Frank, Liang Yu, Michael E. Kreger. (2005). "Economical and Rapid Construction Solutions for Replacement of Off System Bridges."

Item	Price
Bulb Tee Girders	\$0.37 lf/in^2 of area
Voided Slabs	\$0.35 lf/in^2 of area
Prestressed Box Beam	\$0.43 lf/in^2 of area
MSE Wall	\$45 per sf

Reference

Idaho DOT. ( ). “Chapter16: Cost Estimating.” Bridge Manual.

Permanent MSE Walls

= \$34 per sf (July 2006)
= \$27 per sf (January 2009)
Steel Sheet Piling Walls (cost per square foot):
Permanent Cantilever Wall = \$27 Anchored = \$36 (July 2006)
Permanent Cantilever Wall = \$27 Anchored = \$36 (January 2009)

New Construction (2005 Cost per Square Foot)		
Bridge Type	Low	High
Precast Concrete Slab Simple Span	\$125	\$175
Concrete Deck/ Steel Girder – Simple Span	\$95	\$125
Concrete Deck/ Steel Girder – Continuous Span	\$105	\$170
Concrete Deck/ Pre-stressed Girder – Simple Span	\$85	\$125
Concrete Deck/ Pre-stressed Girder – Continuous Span	\$95	\$135

New Construction (2007 Cost per Square Foot)		
Bridge Type	Low	High
Precast Concrete Slab Simple Span	\$115	\$200
Concrete Deck/ Steel Girder – Simple Span	\$125	\$135
Concrete Deck/ Steel Girder – Continuous Span	\$135	\$170
Concrete Deck/ Pre-stressed Girder – Simple Span	\$85	\$155
Concrete Deck/ Pre-stressed Girder – Continuous Span	\$115	\$211

Reference

FDOT. (2006a). “Chapter 6: Bridge Development Report Cost Estimating.” Structures Design Guidelines.
FDOT. (2006b). “Chapter 9: Bridge Development Report Cost Estimating.” Structures Design Guidelines.

2009 Year End Structure Costs – Stream Crossing Structure

Structure Type	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Superstructure Only Cost per Square Foot	Cost per Square Foot
Prestressed Concrete Girders	27	225,572	23,546,996	54.77	104.39
Reinforced Concrete Slabs (All but A5)	39	108,422	11,214,819	46.46	103.44
Reinforced Concrete Slabs (A5 Abuts)	32	58,049	6,312,845	51.00	108.75

Retaining Walls	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Cost per Square Foot
MSE Walls	26	103,486	5,460,180	52.76

2010 Year End Structure Costs – Stream Crossing Structure

Structure Type	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Superstructure Only Cost per Square Foot	Cost per Square Foot
Prestressed Concrete Girders	20	255,157	23,302,014	58.02	91.32
Reinforced Concrete Slabs (All but A5)	24	60,992	6,851,861	61.34	112.34
Reinforced Concrete Slabs (A5 Abuts)	25	54,354	6,988,519	70.10	128.57

Retaining Walls	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Cost per Square Foot
MSE Walls	74	448,972	26,243,005	58.45

2011 Year End Structure Costs – Stream Crossing Structure

Structure Type	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Superstructure Only Cost per Square Foot	Cost per Square Foot
Prestressed Concrete Girders	36	218,311	18,719,353	50.45	85.75
Reinforced Concrete Slabs (All but A5)	22	63,846	7,135,430	52.90	111.76
Reinforced Concrete Slabs (A5 Abuts)	14	21,005	2,470,129	53.00	117.60

Retaining Walls	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Cost per Square Foot
MSE Block Walls	6	7,893	494,274	62.62
MSE Panel Walls	19	87,000	6,679,782	76.78

2012 Year End Structure Costs – Stream Crossing Structure

Structure Type	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Superstructure Only Cost per Square Foot	Cost per Square Foot
Prestressed Concrete Girders	18	115,512	11,610,435	53.88	100.50
Reinforced Concrete Slabs (All but A5)	22	80,797	8,269,942	53.04	102.35
Reinforced Concrete Slabs (A5 Abuts)	3	6,438	739,983	53.24	114.95

Retaining Walls	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Cost per Square Foot
MSE Block Walls	17	30,536	1,604,280	52.54
MSE Panel Walls	25	111,365	7,215,980	64.80

2013 Year End Structure Costs – Stream Crossing Structure

Structure Type	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Superstructure Only Cost per Square Foot	Cost per Square Foot
Prestressed Concrete Girders	17	120,700	12,295,720	49.75	101.87
Reinforced Concrete Slabs (All but A5)	12	26,361	2,244,395	48.26	85.14
Reinforced Concrete Slabs (A5 Abuts)	5	8,899	992,966	49.28	111.58

Retaining Walls	No. of Bridges	Total Area (Sq. Ft.)	Total Costs	Cost per Square Foot
MSE Block Walls	8	13,351	447,017	33.48
MSE Panel Walls	55	255,817	23,968,072	93.69

Reference

Wisconsin DOT. (2014). "Chapter 5 – Economics and Costs." *WisDOT Bridge Manual.*

FHWA Presentation

	GRS Abutment	
Built by	Height (ft)	Cost (ft^2)
County	20	$25
	14	$21
	9	$28
Contractor	16	$33

Reference

FHWA Presentation.
http://webcache.googleusercontent.com/search?q=cache:KpVrjdxo0k4J:https://www.fhwa.dot.gov/everydaycounts/pdfs/summits/GRS-IBS_full_presentation.pdf+&cd=1&hl=en&ct=clnk&gl=us

Caltrans, 2012 (for highways)

FHWA Average Cost: Precast Prestressed Bulb T Girder = $170 per sf Florida State Structures design guidelines Manual - Chapter 11
Precast Double Tee Average = $218 per lf

APPENDIX G: INNOVATIVE OFF-SYSTEM BRIDGE COST ANALYSES FOR CALIBRATING WEIGHTING FACTORS

GRS Abutment

1. Bowman Road Bridge – Defiance County, Ohio

Cost of GRS Abutment = Cost of abutment – cost of labor ($7,000 assumed)

= $95,000 – $7,000

Cost of GRS Abutment = $\frac{\$88,000}{79 \text{ ft x } 34 \text{ ft}}$ = **$33 per sf**

2. Mt. Pleasant Road Bridge – Clearfield County, Pennsylvania

Cost of GRS Abutment = Total Cost – Cost of timber structure – Bituminous paving – Guard rail – Permitting – Riprap – Aggregate – cost of labor – 0.5(Miscellaneous)

= $101,900 – $28,200 - $15,400 – $6,300 - $5,300 - $ 4,500 – $9,200 – 0.5($5,300)

= $30,400

From its pictures, assuming it is a two lane road with a width of 30 ft,

Cost of GRS Abutment = $\frac{\$30,400}{26 \text{ ft x } 30 \text{ ft}}$ = **$39 per sf**

3. Boone county, Iowa

Cost of GRS Abutment = Total cost – Cost of sheet piling – Cost of deadman – cost of superstructure – cost of labor

= $591,000 – ($30/sf x 30ft x 100ft) - $70,000 – ($120/sf x 30 ft x 100 ft) – 10,000

Cost of GRS Abutment = $\frac{\$61,000}{100 \text{ ft x } 30 \text{ ft}}$ = **$20 per sf**

4. FHWA Presentation

	Abutment	
Built by	Height (ft)	Cost (ft^2)
County	20	**$25**
	14	**$21**
	9	**$28**
Contractor	16	**$33**

5. GRS Abutment Cost Range = $21 - $45

Average = $\frac{\$33+\$39+\$20+\$25+\$21+\$28+\$33}{7}$ = **<u>$28 per sf</u>**

Grant County's Bridge Construction

1. Cost of Construction = Cost of Bridge – Labor – Riprap – Railings - Transportation

= 60,000 - $7,000 - $3000 - $4000 - $2000

= $44,000

Average Cost = $\frac{\$44,000}{35\text{ft x } 30\text{ft}}$ = **<u>$42 per sf</u>**

Prestressed Concrete Box Beams

1. Bowman Road Bridge – Defiance County, Ohio

Cost of Beams = Cost of beams and waterproofing – cost of labor ($15,000 assumed)
= $171,000 - $15,000
= $156,000

Cost of Beams = $\frac{\$156{,}000}{82\text{ft x }34\text{ft}}$ = **$56 per sf**

2. PENNDOT Bridge Beam Projects

Cost of Beams = Total Cost – Permitting – Cost of abutment (60% of total cost assumed) – Cost of guard rail – Riprap – Cost of Labor
= $150,000 - $5,300 – 0.6($150,000) – $6,300 – $4,500 - $10,000
= $33,900

Cost of Beams = $\frac{\$33{,}900}{26\text{ft x }30\text{ft}}$ = **$43 per sf**

3. Texas DOT

Average total cost = cost per sf x average sf = $104 per sf x (26,469sf/14) = $196,600
Cost of beams = average total cost – permitting – abutment – railing – riprap – labor - miscellaneous
= $196,600 - $5,000 – (0.5 x $196,600) - $6,000 - $3,000 - $10,000 - $5000
= $69,000

Cost of Beams = $\frac{\$69{,}000}{26{,}469\text{sf}/14}$ = **$36 per sf**

4. Average = $\frac{\$56+\$43+\$36}{3}$ = **<u>$45 per sf</u>**

MSE Walls

1. Idaho DOT

Cost of MSE Wall = $45 per sf

2. Wisconsin DOT

Cost of MSE Wall = $\frac{\$53 + \$58 + \$63 + \$77 + \$53 + \$65 + \$33 + \$94}{8}$ = **$62 per sf**

3. Florida DOT

Cost of MSE Wall = $27 per sf

4. Average = $\frac{\$45+\$62+\$27}{3}$ = **<u>$45 per sf</u>**

Precast Modified Beam-in-slab Bridge System

1. Cost of Superstructure = Total Cost – Sheet pile abutment – Transportation – Riprap – Labor – Pile caps – Bituminous paving
= $151,200 – (0.4 x $151,200) - $2,000 - $3,000 - $10,000 - $2000 – $15,000
= $58,700

Cost of Beams = $\frac{\$58,700}{41\text{ft x }31\text{ft}}$ = **$46 per sf**

Railroad Flatcar

1. Buchanan County Bridge, Iowa

   Cost of superstructure = Cost of railcars + miscellaneous
   = (3 x $6,500) + $5,000
   = $24,500

Cost of Railcars = $\frac{\$24,500}{56\text{ft x }30\text{ft}}$ = **$15 per sf**

2. Winnebago County Bridge, Iowa

   Cost of superstructure = Cost of railcars + miscellaneous

   = (3 x $9,700) + $6,000
   = $32,100

Cost of Railcars = $\frac{\$32,100}{89\text{ft x }27\text{ft}}$ = **$15 per sf**

3. Average = $\frac{\$15+\$15}{2}$ = **<u>$15 per sf</u>**

Channel Beams

1. Leflore County, Mississippi
   Cost of Superstructure = Total cost – Substructure – Labor
   = $57,000 – (0.5 x $57,000) - $7000
   = $21,500

   Cost = $\frac{\$21,500}{95\text{ft x }25\text{ft}}$ = **$9 per sf**
2. Simpson County, Mississippi
   Cost of Superstructure = Total cost – Substructure – Labor
   = $38,000 – (0.5 x $38,000) - $5000
   = $14,000

   Cost = $\frac{\$14,000}{57\text{ft x }25\text{ft}}$ = **$10 per sf**
3. Neshoba County, Mississippi
   Cost of Superstructure = Total cost – Substructure – Labor
   = $180,000 – (0.5 x $180,000) - $10,000
   = $80,000

   Cost = $\frac{\$80,000}{31\text{ft x }25\text{ft}}$ = **$103 per s**
4. Adams County, Mississippi
   Cost of Superstructure = Total cost – Substructure – Labor

= \$230,000 – (0.5 x \$230,000) - \$10,000
= \$105,000

Cost = $\frac{\$105{,}000}{107\text{ft x }28\text{ft}}$ = **\$35 per sf**

5. Adams County, Mississippi
   Cost of Superstructure = Total cost – Substructure – Labor
   = \$230,000 – (0.5 x \$230,000) - \$10,000
   = \$105,000

   Cost = $\frac{\$105{,}000}{70\text{ft x }28\text{ft}}$ = **\$54 per sf**

6. Average = $\frac{\$9+\$10+\$103+\$35+\$54}{5}$ = **<u>\$42 per sf</u>**

Wide Flange Steel Girder – Steel Plate Girder (200 lb/ft assumed)

1. Cost = $\frac{\left[(\$0.70\text{ per lb})\left(200\frac{\text{lb}}{\text{ft}}\right)(65\text{ft})(4)\right]}{65ft\ x\ 30ft}$ = **<u>\$19 per sf</u>**

Wide Flange Steel Girder – Rolled Steel Beam (200 lb/ft assumed)

1. Cost = $\frac{(\$0.35\text{ per lb})(\$0.50\text{ per lb})}{2}$ = \$0.425 per lb

   Cost = $\frac{\left[(\$0.425\text{ per lb})\left(200\frac{\text{lb}}{\text{ft}}\right)(65\text{ft})(4)\right]}{65ft\ x\ 30ft}$ = **<u>\$12 per sf</u>**

Waffle Bridge Decks

1. Cost = Total Cost – Cost substructure – Bituminous paving – Guard rail – Permitting – Riprap – cost of labor – Miscellaneous - Design

= \$498,000 – (0.5 x \$498,000) - \$15,000 - \$8000 - \$5000 - \$4000 - \$20,000 - \$5000 - \$15000

= \$177,000

Cost = $\frac{\$177{,}000}{60\text{ft x }33\text{ft}}$ = **\$89 per sf**

Sheet Pile Abutment – Anchored

1. Cost = 0.4(Total Cost) = 0.4 x \$151,200
   = \$75,600

Cost = $\frac{\$60{,}500}{41\text{ft x }31\text{ft}}$ = **\$47 per sf**

2. Florida DOT

Cost **= \$36 per sf**

3. Average = $\frac{\$47+\$36}{2}$ = **<u>\$42 per sf</u>**

Sheet Pile Abutment

1. Cost = 0.4(Total Cost) = 0.4 x $151,200
   = $75,600

Cost = $\frac{\$60{,}500}{41\text{ft x }31\text{ft}}$ = **$47 per sf**

2. Florida DOT

Cost **= $27 per sf**

3. Average = $\frac{\$47+\$27}{2}$ = **<u>$37 per sf</u>**

Large Precast Box Culverts

1. PENNDOT Box Culverts and Bridge Beam Projects

Cost of Beams = Total Cost – Permitting – Cost of guard rail – Riprap – Cost of Labor
= $150,000 - $5,300 – $6,300 – $4,500 - $15,000
= $118,900

Cost of Beams = $\frac{\$118{,}900}{26\text{ft x }30\text{ft}}$ = **$152 per sf**

2. Local Project Box Culvert (no paving) – Genesse Township, Potter County

Cost of Beams = Total Cost – Permitting – Cost of guard rail – Riprap – Cost of Labor
= $194,000 - $5,300 – $6,300 – $4,500 - $15,000
= $162,900

Cost of Beams = $\frac{\$162{,}900}{26\text{ft x }30\text{ft}}$ = **$209 per sf**

3. Average = $\frac{\$152+\$209}{2}$ = **<u>$181 per sf</u>**

Precast Prestressed Deck Slab Beams

1. Florida DOT

Average = $\frac{\$125+\$115}{2}$ = $120 per sf

Cost of Typical Off-system bridge = $120 x 60ft x 30ft = $234,000

Cost of slabs = Total cost – labor – abutment – permitting – riprap – guard rail – bituminous paving
= $234,000 - $15,000 – (0.5 x 216,000) - $5,000 - $3000 - $5000 - $15,000
= $74,000

Cost of slabs = $\frac{\$74{,}000}{65\text{ft x }30\text{ft}}$ = **$38 per sf**

2. Wisconsin DOT

Average = $\frac{\$103+\$109+\$112+\$129+\$112+\$118+\$102+\$115+\$85+\$112}{10}$ = $110 per sf

Cost of Typical Off-system bridge = $110 x 65ft x 30ft = $214,000

Cost of slabs = Total cost – labor – abutment – permitting – riprap – guard rail – bituminous paving
= $214,000 - $15,000 – (0.5 x 216,000) - $5,000 - $3000 - $5000 - $15,000

= $64,000

Cost of slabs = $\frac{\$64,000}{65\text{ft x }30\text{ft}}$ = **$33 per sf**

3. Average = $\frac{\$38+\$33}{2}$ = **$36 per sf**

Precast Prestressed Bulb T Girder

1. Caltrans, 2012 (for highways)
   FHWA Average Cost:
   Precast Prestressed Bulb T Girder = $170 per sf
   Total Project Cost = $170 x 65 ft x 30 ft = $331,500
   Cost of Bulb T girders only = Total cost – labor - abutment - permitting - riprap – guard rail – bituminous paving
   = $331,500 - $15,000 – (0.5 x $331,500) - $5,000 - $3,000 - $5,000 - $20,000
   = $117,750

Cost of slabs = $\frac{\$117,750}{65\text{ft x }30\text{ft}}$ = **$60 per sf**

Precast Double Tee

1. Florida State Structures Manual
   Average = $218 per lf
   Cost of a typical girder = $218 per lf x 65 ft = $14,170
   Assuming the bridge is about 30 ft wide and each girder is about 4 feet wide,
   Cost of girders = $14,170 x (30/4) ft = $106,275
   Cost of entire superstructure = cost of girders + miscellaneous = $106,275 + $10,000 = $116,275

Cost of superstructure = $\frac{\$116,275}{65\text{ft x }30\text{ft}}$ = **$60 per sf**