ACCELERATED BRIDGE CONSTRUCTION – THE MINNESOTA DOT EXPERIENCE

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ABSTRACT
The Minnesota DOT has designed and constructed a wide range of prefabricated bridge components and systems in an effort to reduce on-site construction time, improve long-term durability, and reduce construction work zone impacts on the traveling public. Such systems and components have included a new precast concrete “inverted tee” superstructure, precast concrete abutment and pier cap elements, and full-depth precast post-tensioned concrete deck panels. Larger scale efforts have included the use of self-propelled modular transporters to install a complete superstructure, and the lateral sliding of existing superstructures for use as temporary bypasses during bridge replacement. Ongoing efforts include the development of a decision making tool to determine which bridge sites are best suited for accelerated bridge construction (ABC) techniques and establishment of a policy to consistently and uniformly apply available ABC methods across the state. This paper focuses on the use of available national resource materials and expertise to aid in the design and construction of ABC systems, and highlights the lessons learned and perspective gained from implementing an accelerated bridge construction program.

Keywords: accelerated bridge construction, full-depth deck panels, inverted tee, decision making tool

Introduction

Over the past several years, the Minnesota Department of Transportation (MnDOT) has been implementing various accelerated bridge construction (ABC) techniques and practices in an attempt to lessen construction work zone impacts on the traveling public and to reduce on-site construction time. Implementing any new system or process can often be challenging and time consuming. This paper contrasts the development effort and challenges faced when designing and implementing a new ABC system from "scratch", versus using readily available details, standards, and specifications available from other agencies. It also addresses the need to develop a consistent process, policy, and tools, to select projects most suitable for ABC, and explains how MnDOT is addressing this need.

Starting from Scratch – The Inverted Tee Superstructure

Following a 2004 International Scanning Tour sponsored by the Federal Highway Administration (FHWA) and the American Association of State Highway Transportation Officials (AASHTO)[1], the MnDOT Bridge Office began development of an inverted tee superstructure system, similar to the Poutre Dalle system that was observed by scanning tour members in France. This system consists of shallow, precast, prestressed concrete inverted-tee beams that are placed directly adjacent to each other (Figure 1). The precast beams are connected across a longitudinal joint with 180-degree reinforcement hooks that protrude from the webs of the precast sections (Figure 2). Cast-in-place (CIP) concrete is placed between the beam webs and over the top of the beams to form a solid composite cross section. The inverted tee beams also serve as stay-in-place forms for the CIP bridge deck, eliminating installation of deck formwork in the field. This system also simplifies construction by using prefabricated "drop in" reinforcement cages over the longitudinal joints between the precast sections.

In addition to an overall reduction in on-site construction time, the system provides other advantages including; improved quality control by using certified fabrication facilities, and greater safety and reduced environmental impacts at the project site. MnDOT has used this system for short span bridges (20 to 45 foot spans), a configuration that has previously been served by full-depth, CIP concrete slab span bridges, a common Minnesota bridge superstructure type used where relatively short span, shallow depth structures are desired.[2]

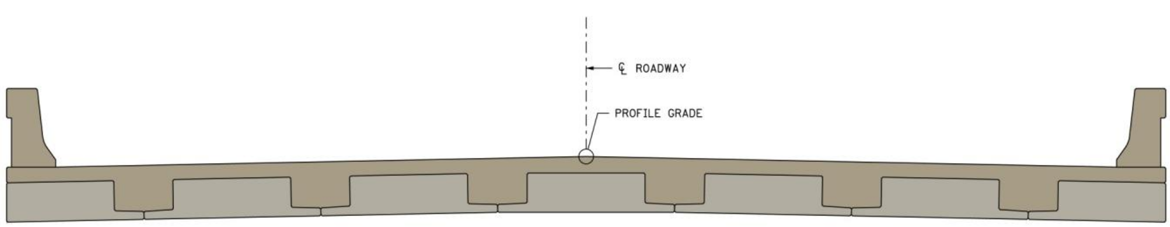

Figure 1
Cross Section Showing Adjacent Inverted Tee Beams Topped with a Cast-In-Place Deck

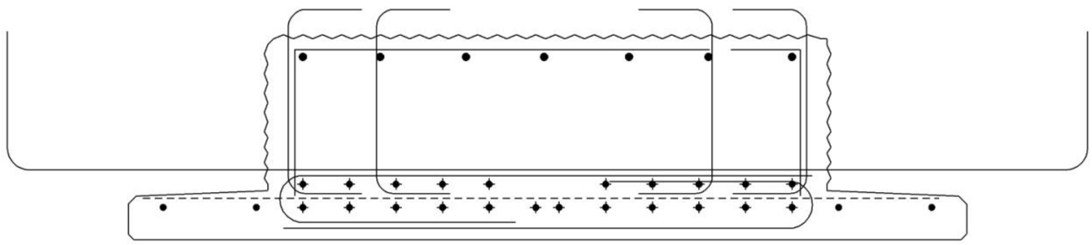

Figure 2
Typical 6’-0” Wide Individual Inverted Tee Beam

The Design and Development Process

Without the benefit of existing drawings or design data, staff from the MnDOT Bridge Office started from “scratch” and developed initial design sketches and concepts for the inverted tee shape based on photos of the Poutre Dalle system. Design staff also met with several local precast beam fabricators to discuss adaptability of their existing forms to produce this new shape, and to get feedback regarding constructability and cost.

After receiving positive feedback from fabricators, the initial design progressed smoothly with the project team methodically addressing specific design issues such as; live load distribution, effectiveness of the composite action between the precast tee section and the CIP deck, thermal gradients, and layout of the reinforcement in the CIP portion of the deck. A more significant work effort was required to address the bending moments that result from restraint induced by time-dependent deformations that occur after adjacent spans are made continuous through the placement of the composite CIP concrete deck (restraint moments).

MnDOT also sponsored a multi-phase research project with the Civil Engineering Department at the University of Minnesota to verify the design assumptions, conduct research on test beams in the university’s laboratory, instrument a pilot bridge, and to conduct follow-up site reviews and deck surveys on several of the first bridges that were built.

Contract drawings and specifications were completed in late 2004, and the first two bridges with inverted tee superstructures were built in 2005 (Figure 3). The fabrication, erection, and placement of the deck and barriers proceeded smoothly and resulted in significant savings in on-site construction time[2].

Over the past 8 years, MnDOT has constructed about a dozen similar bridges, several resulting in road closure times of 4 weeks or less, which is a substantial reduction in on-site construction time compared to conventionally constructed slab span bridges.

Use of the inverted tee superstructure system adds an approximate 10-15 percent cost premium compared to conventional construction. However, more widespread use of inverted tee beams will no doubt improve fabricator and contractor familiarity and expertise, and will likely reduce this cost premium.

Figure 3
Erection of Inverted Tee Sections

Performance

While few noteworthy issues arose during fabrication, erection, and deck placement, inspections of several bridges one year after initial construction indicated varying levels of transverse and longitudinal cracking in the CIP deck. Monitoring of the strain by the University of Minnesota research team indicated that some cracks appear to be the result of thermal gradients[3]. The resultant cracking is not a structural capacity or strength issue. The primary concern is that the cracking could lead to future challenges related to serviceability and long-term maintenance of the bridge deck.

Based on feedback from the research team and field reviews of several of the initially constructed bridges, numerous incremental design modifications have been made in recent years, including:

- The bottom flanges of the tee sections have been made thinner to help improve transverse load distribution.
- Changes have been made to the placement and the amount of mild reinforcement in the tee sections.
- Chamfer sizes on the edges of the beams have been increased to relieve potential areas of stress concentration.
- The spacing between transverse deck reinforcing bars has been reduced.
- Reinforcing bars protruding from the sides of the tee sections have been staggered to allow for simplified installation of the drop-in reinforcement cages.
- Modifications have been made to the placement location of the fixed anchorages between the superstructure and the substructure at the supports, near the centerline of the bridge.

- Flexible foam has been placed around the anchorage dowels to allow a small amount of lateral movement.
- Construction specifications have been updated to require moistening the surface of the precast tee beams prior to placement of the cast-in-place deck.
- Improvements have been made to the bridge deck concrete mix to reduce shrinkage.

These changes have resulted in simplified construction and a decrease in the level of deck cracking, but the amount of deck cracking continues to be a concern. The use of a thin polymer overlay, applied after the CIP deck has cured, was successfully used as a mitigation measure on one bridge, but since this adds to the construction time and cost, it is undesirable to make this a requirement on an accelerated construction project. In the summer of 2013, MnDOT plans to experiment with the use of synthetic fibers in the concrete deck mixture in an attempt to further reduce cracking.

Lessons Learned

A significant benefit to using the inverted tee system is the reduction in on-site construction time, which has been substantially reduced. Experience has shown the potential to consistently shorten construction time by 20% to 40%. Under the appropriate circumstances, the added cost can easily be justified by the significant construction time savings, since lengthy road closures or extended construction periods are often very costly to area residents and local businesses, especially in northern Minnesota's tourist areas. Experience over the past 8 years has revealed that the system is a practical and economical accelerated construction alternative to slab span bridge construction, but there is still room for improvement and efforts are continuing to further reducing the amount of deck cracking.

Designing and developing a new superstructure system without the benefit of previous design data or plans has certainly been very challenging and time consuming, but it has also been very rewarding. The challenges presented in the design phase enhanced our designer skills, provided an opportunity to innovate, and exposed design staff to topics such as restraint moments and thermal gradients, neither of which have been significant issues for MnDOT in the past. In addition, working closely with our local prestressed beam fabricators has enhanced communication between the parties and led to a stronger partnership.

To aid in technology transfer, in the fall of 2005, MnDOT shared its experience with other bridge designers, contractors, fabricators, and engineers at workshop in Minneapolis. The session had approximately 150 attendees and included sessions on design, fabrication, and construction and included a site visit to one of the first bridges built. By publishing reports[(4)], papers [(2)], and journal articles[(5)], MnDOT continues to share its successes and shortcomings with others and welcomes feedback to make further improvements.

Starting With Standards from Other Agencies – Full-Depth Precast Deck Panels

In contrast to developing a new ABC system from scratch, MnDOT's first use of full-depth precast concrete deck panels relied heavily on the use of details and specifications developed by other agencies. After a brief review of plans and reports available from other organizations, MnDOT focused on design standards and documents available from the Utah

Department of Transportation (UDOT) [6]. UDOT has been a strong leader in the development and use of ABC for many years. They have also continued to monitor their ABC installations and have been very open in sharing their successes and disappointments, including publishing information regarding lessons learned [7].

Site Selection and Design

Careful consideration was given to selecting the appropriate site for the initial installation of full-depth deck panels. MnDOT is ultimately interested in implementing precast deck panels on a wide range of projects, including very high traffic volume routes, so it was essential that the first project be completed successfully. However, since neither the DOT or its fabricators or contractors had any previous experience with this system, it was determined that the initial installation would occur on a lower volume route, where if fabrication or construction issues surfaced, delays would not have a significant impact on the traveling public. All involved agreed that it was more important to take the time to "get it right the first time", than to take unwarranted risks or to compromise long-term durability in order to complete the project early.

With this in mind, MnDOT's first full-depth post-tensioned precast deck panel bridge was constructed on state highway 53 in northern Minnesota. The bridge was designed in the fall of 2010 and constructed in the summer of 2012. The structure is a single span prestressed beam bridge with a length of 76 feet and a width of 45 feet. The design was relatively simple and progressed smoothly using guidance available from the Prestressed Concrete Institute [8] and standard drawings available from UDOT. The process was also aided by two conference calls with staff from the UDOT Bridge Office to clarify details and design methodology.

The deck panels were fabricated using conventionally reinforced concrete and were 9 inches thick, with a maximum length of 9.5 feet in the direction of traffic and post-tensioned longitudinally after installation. To allow for a crown in the roadway, the transverse width of the roadway was split into two separate panels, and a longitudinal joint was included over one of the prestressed concrete beams near the centerline of the bridge (Figure 4).

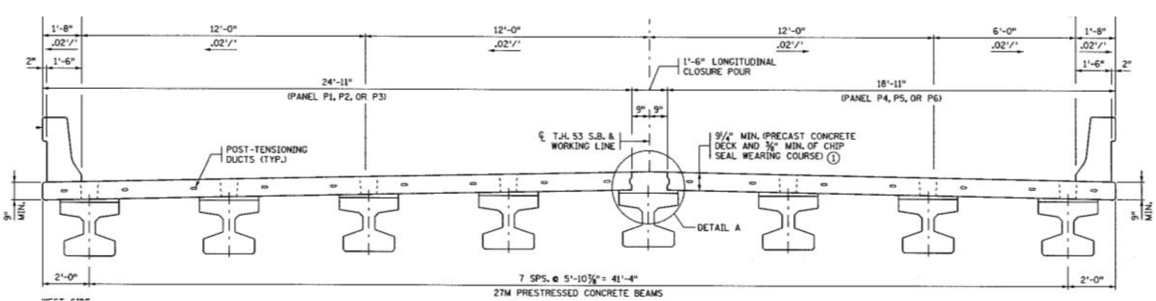

Figure 4
Bridge Cross Section Showing Longitudinal Deck Joint

The panels included "shear pocket" openings along each beam line to allow shear stirrups from the underlying beams to protrude into and engage the deck panel. These shear pockets were grouted along with the haunch between the underside of the panels and the top of the beams to form a composite system for resisting live load (Figure 5).

Communication

Upon award of the construction contract, several meetings and conference calls were held with staff from MnDOT, the deck panel and beam fabricator, grout supplier, and bridge contractor. This interaction was very helpful in addressing the concerns of each party, allowing each to communicate their viewpoints and concerns, and to attend to issues that needed to be resolved. Another very important and beneficial interaction was a series of conference calls with the aforementioned parties, and contractors and staff that had previously completed successful full-depth deck panel projects in Utah. The insight and suggestions from those involved in previous projects was invaluable in helping the contractor and fabricator to finalize their details, shop drawings, and construction procedures.

In particular, discussions with experienced contractors regarding the process and materials used to form and grout the haunch between the top of the beam and the bottom of the deck panel (Figure 5) was particularly helpful. This portion of the work was of significant concern to both MnDOT and the contractor since the bridge was located over a stream and grout leakage could lead to environmental issues. Owing to this concern, project provisions required the contractor to erect a "mock-up" of the interface between the prestressed beam and the deck panels to confirm the contractor's proposed method of setting and leveling the deck panels and grouting the haunches.

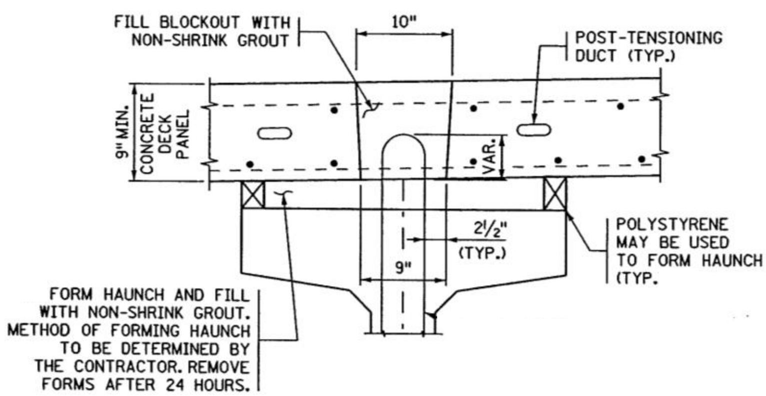

Figure 5
Connection between Deck Panel and Bridge Beam

Installation and Grouting

Following successful completion of the mock-up and submission and approval of shop drawings, the first full-size deck panels were fabricated. Meanwhile, the contractor removed the existing bridge, constructed the new bridge abutments, erected the prestressed beams, and installed compressible foam on the top flanges of the beams, upon which the deck panels would rest. Panel installation started slowly, but placement times decreased rapidly after a few panels were set. Setting time for the first two panels was approximately 60 minutes each. Setting times for the last panels was approximately 15 minutes each (Figure 6).

Over the next several days the transverse panel joints were grouted, the panels were post-tensioned longitudinally and the post-tensioning ducts were grouted. Minor grout leakage was evident at a few of the of the post-tensioning duct couplers between the panels, but was not a significant problem. The shear pockets and haunches were then successfully grouted. The design and construction changes that were implemented following the discussions with the contractor and DOT staff from Utah, along with lessons learned from the mock-up, proved to be very helpful and forming and grouting of the haunches and shear pockets proceeded smoothly.

Figure 6
Deck Panel Installation

Following installation of the slipformed concrete barrier, the deck was longitudinally surface planed to ensure a smooth ride, and to prepare the surface for a thin bonded polymer overlay. Due to low ambient temperatures in the fall of 2012, placement of the polymer overlay was delayed until the spring of 2013.

Excluding placement of the polymer overlay, the total road closure time was approximately 1 week less than would be expected to build a similar bridge with a cast-in-place deck. It is anticipated that more extensive use of deck panels will increase contractor familiarity with the fabrication and installation process, resulting in more substantial reductions in on-site construction time.

The cost of the deck panels for this initial project was substantially higher than a conventional cast-in-place concrete deck. This was to be expected due to the start-up costs for the deck panel fabricator, and bridge contractors not being familiar with all of the risks and effort required to install the panels. Experience in the state of Utah has indicated that over time the cost of building bridges with deck panels will decrease and become comparable to the cost of conventional bridge construction.

Lessons Learned

As expected, the effort required to implement full-depth precast deck panels was substantially less than that required to design and develop the inverted tee system. The availability of vast amounts of information, including; design details, construction photos, reports, and UDOT expertise and lessons learned regarding ABC, made this undertaking very straight forward and fairly simple to implement.

It should also be noted that the FHWA has scheduled many excellent workshops and showcases around the nation to help educate owners and contractors regarding ABC technologies. MnDOT was fortunate to host an FHWA sponsored workshop exclusive to full-depth deck panels that was attended by fabricators, contractors, and agency/owners, which was very instructive. Owners are strongly encouraged to host or participate in similar events to become better informed and to help them overcome initial fear or apprehension regarding the use of precast elements or ABC techniques.

The importance of establishing effective communication cannot be overstated. Bi-weekly conference calls with representatives of the owner, fabricator, grout supplier, and bridge contractor proved to be extremely beneficial in addressing issues in a timely matter and in keeping the project submittals and progress on track. Additional discussion with owners and contractors who have successfully constructed similar projects was also exceptionally valuable and reassuring to all involved.

Due to the satisfaction experienced on this initial project, MnDOT is moving forward with a project that will use full-depth precast deck panels to re-deck of an existing steel girder bridge over an interstate highway near downtown Minneapolis in 2014.

ABC Project Selection

In addition to the full-depth deck panel and inverted tee installations mentioned above, MnDOT has also used precast concrete abutment and pier cap elements on several projects to reduce on-site construction time. Other larger scale ABC efforts have included the use of self-propelled modular transporters to install a complete superstructure, and lateral sliding techniques have been used to shift the horizontal alignment of an existing bridge, allowing it to serve as a temporary bypass while a new bridge was constructed on the original alignment.

Having successfully implemented a wide range of ABC systems and techniques, the next significant challenge is to determine how to select project sites that are best suited to use these techniques. Specifically, a methodology is needed to provide a consistent, objective, and defensible method of selecting appropriate ABC projects.
Fortunately, several such resources are readily available, including a recently published document by the FHWA(9) and software developed as part of a pooled fund study led by the Oregon DOT, that includes a set of decision-making tools designed to help determine if ABC

is potentially more effective than traditional construction for a given bridge replacement or rehabilitation project[10].

Several state DOT's, including; Utah, Iowa, and Wisconsin, have also developed selection tools, which were very helpful in the development of MnDOT's draft selection methodology. In particular, the 2-stage approach used by the Iowa DOT was found to be very appealing and aligned well with MnDOT's project development process.

Iowa DOT ABC Project Selection[11]

The Iowa DOT uses a 2-stage selection and screening process. The initial stage includes a Decision Making Tool (DMT) and flowchart that can be applied across the entire system of state owned bridges to screen for potential candidate bridges, with limited requirements for subjective user input. The result of this first stage is a numerical score from 0 to 100 that indicates the viability of a particular bridge benefitting from the use of ABC concepts. The higher the score the better suited a project is for ABC.

The first stage ABC rating score is categorized into two ranges:

- Bridges with a score of 50 or more are further evaluated in stage 2 for consideration of ABC techniques.
- Bridges with a score of less than 50 are only evaluated in stage 2 if requested by the District, who may be aware of unique circumstances, such as a critical environmental issue, that may make the project suitable for ABC.

The second stage of the selection process incorporates use of Analytical Hierarchy Process (AHP) decision making software that was developed at Oregon State University[10]. This software allows for qualitative analysis of various construction alternatives based upon user-selected criteria, which allows ABC concepts to be compared against traditional construction approaches.

Successful use of the AHP software tool necessitates the user having very specific knowledge of the bridge and the surrounding site, which may require input from multiple disciplines (environmental, hydraulics, roadway design, bridge design, construction, geotechnical, etc.) and other interested parties. In some cases, gathering the required information and expertise can be challenging and time consuming.

MNDOT ABC Project Selection

MnDOT's first draft of its 2 stage ABC selection process is modeled after methodology developed by the Iowa DOT, with several significant modifications;

- Similar to tools developed by Wisconsin[12] and Utah[13], MnDOT added stage 1 selection criteria regarding bridges over navigable water.
- MnDOT's second stage of the selection process uses subjective criteria gleaned from several states and agencies in lieu of using the AHP software.
- Consideration of alternative contracting methods was incorporated into the second stage review process.

Stage 1
MnDOT's stage one ABC rating score is based on a set of measures which includes;

- User costs (in the form of daily vehicle operating costs)
- Average annual daily traffic
- Heavy commercial average annual daily traffic
- Detour length (assuming complete closure of the bridge)
- Railroad impacts
- Work over navigable water

The stage one process can be completely automated and does not require any subjective user input. The data for each bridge is retrieved from the MnDOT Bridge Management System and used to populate a spreadsheet. Each of the above characteristics is assigned a score based on a set of criteria (Figure 7) in the spreadsheet. The individual score for each characteristic is multiplied by a weight factor to account for the relative importance. The weighted scores are then summed to form an overall weighted score, which can have a maximum value of 165. The overall weighted score is then normalized to a 100-point scale to become the ABC rating score. The higher the score the better suited a project is for ABC.

The 1st stage rating score will eventually be added as a data field to MnDOT's "Structure Inventory Sheet", a one page listing of information generated by MnDOT's Bridge Management System that includes specific data about a particular bridge, including length, width, structure and foundation type, site conditions, and a general summary of its present condition. The stage 1 score will also be added to MnDOT's Bridge Replacement and Improvement Management (BRIM) tool. BRIM is a spreadsheet tool that has been developed to identify and prioritize bridges suitable for improvement or replacement based on present condition. Data from the BRIM tool provides very valuable input for determining which bridges are ultimately programed for future work.

Stage 2
The second stage of the ABC selection process allows the district to consider issues that are much more subjective than those identified in stage 1, and may require input from several specialty disciplines.

MnDOT has not yet confirmed the final content or format (i.e. spreadsheet or flowchart) of its stage 2 process, but the current draft addresses the issues shown below. Each of the issues is quantified in terms of being a minor, moderate, or major concern, and whether or not ABC will aid in addressing the concern.

Stage 2 - Issues considered at each proposed bridge site (in no particular order);

- Safety of the Traveling Public and Workers
  - Consider the duration and number of traffic shifts
- Economy of Scale/Geometry/Complexity
  - Consider number of spans, repeatability, geometry, site conditions
- Impact to the Critical Path of the Project

Selection of Accelerated Bridge Construction Projects
Draft MnDOT Decision Making Tool (DMT) V6 05/03/2013

Stage 1 - Score computed using Bridge Management Data:

30% Wt. Daily Vehicle Operating Costs - Dependent on Bridge Length

"On Bridge" AADT and HCAADT Only

Score	Criteria	Bridge Length Factor:
0	No user costs	
1	Less than $10,000	*Total Length from 10'-100' = 1.0*
2	$10,000 to $50,000	*Total Length from 100'-300' = 1.2*
4	$50,000 to $75,000	*Total Length from 300'-500' = 1.6*
6	$75,000 to $100,000	*Total Length greater than 500' = 2.0*
8	More than $100,000	

User Cost Formula = (AADT x $0.31/mile + HCAADT x $0.64/mile) x Detour Length x Br Length Factor

20% Wt. Average Annual Daily Traffic (AADT)

Combined "On and Under" Bridge

Score	Criteria
0	Less than 5,000
1	5,000 to 10,000
2	10,000 to 15,000
3	15,000 to 25,000
4	25,000 to 35,000
5	35,000 to 55,000
6	55,000 to 105,000
8	More than 105,000

10% Wt. Heavy Commercial Average Annual Daily Traffic (HCAADT)

Combined "On and Under" Bridge

Score	Criteria
0	Less than 400
1	401 to 800
2	801 to 1,200
3	1,201 to 1,600
4	1,601 to 2,300
5	2,301 to 3,300
6	3,301 to 5,000
8	More than 5,000

20% Wt. Detour Length

Detour Length on Similar Functional Class Rdwy

Score	Criteria
0	No Detour
2	Less than 3 miles
4	3-10 miles
6	10-20 miles
8	20 miles or more

10% Wt. Railroad Impacts

Railroad on/under Bridge

Score	Criteria
0	No railroad track on or under bridge
1	Minor railroad track (Class 2 or 3) under bridge
3	Major railroad track(s) (Class 1) under bridge
6	Minor railroad track (Class 2 or 3) on bridge
8	Major railroad track (Class 1) on bridge

10% Wt. Work Over Navigable Water

Over Nav Channel that must remain open?

Score	Criteria
0	No navigation channel that needs to remain open
8	Navigation channel that needs to remain open

Figure 7
Draft Stage 1 ABC Project Selection Tool

- Local Business Impacts
- Availability of Work Windows/Environmental Impact/Permitting Agencies
  - Does ABC relieve these concerns?
- Risk Mitigation through use of ABC
- Critical Route/Other Considerations
  - Emergency services, historic, transit, local input
- Alternative Detours

In addition to the issues listed above, the second stage review process also considers alternative contracting methods that may help accelerate construction or reduce work zone impacts, including:

- A+B
- Lane Rental
- No Excuse Bonuses
- Incentive/Disincentive
- Design Build
- Construction Manager General Contractor (CMGC)

Final Selection

As mentioned previously, the BRIM tool is the primary driver in MnDOT's process of selecting bridge projects for inclusion in a future construction program. By including the stage one ABC rating score in the BRIM tool, planners can quickly identify which structures are good ABC candidates early in the project development phase. Early identification is critical, as it allows those involved with the project to complete the second stage ABC review and begin to identify potential ABC techniques and solutions.

Following a thorough review of the second stage criteria and alternative contracting methods mentioned above, a final decision on whether to use ABC techniques at a particular site is determined by the district in consultation with the Bridge Office. The second stage analysis also identifies which specific ABC techniques and/or alternative contracting methods should be used.

Final Summary and Conclusion

Implementing ABC concepts and techniques within a transportation agency has never been easier. Workshops, seminars, and showcases allow attendees to confer with national and local experts, discuss lessons learned, review best practices, and often allow attendees to witness ABC techniques first hand.

Additional information is available at an excellent FHWA website(14) that includes many presentations, case studies, manuals, and a wealth of other information related to ABC. The Florida International University website(15) also has many very helpful documents and links including an archive of past ABC webinars and a schedule of upcoming webinars and other events.

Also, many state DOT's have developed details and specifications that are available on their websites and can be incorporated directly in to plans with little modification. FHWA Division Bridge Engineers and Resource Center staff are also a superb source of information regarding ABC and have access to an extensive network of engineers, fabricators, material suppliers, and contractors willing to share their experience and expertise. This assistance is available during the development and construction phase of a project.

One of the key elements of establishing a successful ABC program is early identification of appropriate project sites. Several states have developed ABC project selection tools that can be used on a statewide basis or on individual project sites to determine the suitability of ABC. Most can easily be customized and are available for free.

Being willing to innovate with new techniques and concepts, as well as sharing successes and shortcomings with others helps to expand the ABC knowledge base and leads to refinements and improvements that can simplify construction and reduce project cost. Using tools and resources that are readily available, it is not difficult to provide durable, long lasting structures with limited on-site construction time and reduced work zone impacts, which provide a win-win for the owner and the traveling public.

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