

Minnesota Demonstration Project: Accelerated Bridge Construction over Paleface River on TH53 using Prefabricated Elements

**Final Report
June 2013**

HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.



U.S. Department of Transportation
Federal Highway Administration

FOREWORD

The purpose of the Highways for LIFE (HfL) pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. **LIFE** is an acronym for **L**onger-lasting highway infrastructure using **I**nnovations to accomplish the **F**ast construction of **E**fficient and safe highways and bridges.

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. Such “innovations” encompass technologies, materials, tools, equipment, procedures, specifications, methodologies, processes, and practices used to finance, design, or construct highways. HfL is based on the recognition that innovations are available that, if widely and rapidly implemented, would result in significant benefits to road users and highway agencies.

Although innovations themselves are important, HfL is as much about changing the highway community’s culture from one that considers innovation something that only adds to the workload, delays projects, raises costs, or increases risk to one that sees it as an opportunity to provide better highway transportation service. HfL is also an effort to change the way highway community decisionmakers and participants perceive their jobs and the service they provide.

The HfL pilot program, described in Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) Section 1502, includes funding for demonstration construction projects. By providing incentives for projects, HfL promotes improvements in safety, construction-related congestion, and quality that can be achieved through the use of performance goals and innovations. This report documents one such HfL demonstration project.

Additional information on the HfL program is at www.fhwa.dot.gov/hfl.

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| 16. Abstract As part of a national initiative sponsored by the Federal Highway Administration under the Highways for LIFE (HfL) program, the Minnesota Department of Transportation (MnDOT) was awarded a \$150,000 grant to develop plans and specifications, and then construct Bridge 69071 over the Paleface River on TH53 near Cotton, MN. The key innovation included the use of accelerated bridge construction (ABC) techniques by precasting the deck panels off-site in the controlled environment of a fabrication facility, transporting the panels to the project site, and installing the panels onto prefabricated concrete girders. This report documents the entire work effort, including the innovative ABC techniques employed by MnDOT, with specific focus on the connection details including haunches, blockouts, keyway joints, and post-tensioning splices. Removal and replacement of the Paleface River bridge was a great success, and MnDOT was able to meet the HfL program requirement related to the project goals of safety, construction congestion, quality, and user satisfaction. MnDOT and the construction contractor learned some valuable lessons in the process. Since this was the first project of its kind undertaken in Minnesota, MnDOT's goal was to use it as learning and evaluation tool and chose a project site with low traffic volume and minimal anticipated impact to traffic. The overall costs for the construction of this bridge were higher than if the bridge had been constructed using traditional cast-in-place techniques; however, if the bridge had been constructed in a location with shorter haul distances for the precast panels, higher traffic impacts, near urban areas with morning and evening peaks, and longer detours, it could potentially result in cost savings to MnDOT and the traveling public. | | | |
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|--|----------------------------|-----------------------------|-----------------------------|-------------------|
| LENGTH | | | | |
| (none) | mil | 25.4 | micrometers | µm |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| AREA | | | | |
| in ² | square inches | 645.2 | square millimeters | mm ² |
| ft ² | square feet | 0.093 | square meters | m ² |
| yd ² | square yards | 0.836 | square meters | m ² |
| ac | acres | 0.405 | hectares | ha |
| mi ² | square miles | 2.59 | square kilometers | km ² |
| VOLUME | | | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| ft ³ | cubic feet | 0.028 | cubic meters | m ³ |
| yd ³ | cubic yards | 0.765 | cubic meters | m ³ |
| NOTE: volumes greater than 1000 L shall be shown in m ³ | | | | |
| MASS | | | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| TEMPERATURE (exact degrees) | | | | |
| °F | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | °C |
| ILLUMINATION | | | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela per square meter | cd/m ² |
| FORCE and PRESSURE or STRESS | | | | |
| lbf | poundforce | 4.45 | Newtons | N |
| lbf/in ² (psi) | poundforce per square inch | 6.89 | kiloPascals | kPa |
| k/in ² (ksi) | kips per square inch | 6.89 | megaPascals | MPa |
| DENSITY | | | | |
| lb/ft ³ (pcf) | pounds per cubic foot | 16.02 | kilograms per cubic meter | kg/m ³ |

APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|-------------------------------------|-----------------------------|-------------|----------------------------|---------------------------|
| LENGTH | | | | |
| µm | micrometers | 0.039 | mil | (none) |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| AREA | | | | |
| mm ² | square millimeters | 0.0016 | square inches | in ² |
| m ² | square meters | 10.764 | square feet | ft ² |
| m ² | square meters | 1.195 | square yards | yd ² |
| ha | hectares | 2.47 | acres | ac |
| km ² | square kilometers | 0.386 | square miles | mi ² |
| VOLUME | | | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| m ³ | cubic meters | 35.314 | cubic feet | ft ³ |
| m ³ | cubic meters | 1.307 | cubic yards | yd ³ |
| MASS | | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| TEMPERATURE | | | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| ILLUMINATION | | | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/m ² | candela per square meter | 0.2919 | foot-Lamberts | fl |
| FORCE and PRESSURE or STRESS | | | | |
| N | Newtons | 0.225 | poundforce | lbf |
| kPa | kiloPascals | 0.145 | poundforce per square inch | lbf/in ² (psi) |
| MPa | megaPascals | 0.145 | kips per square inch | k/in ² (ksi) |

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ABBREVIATIONS AND SYMBOLS

| | |
|------------|--|
| AADT | Annual Average Daily Traffic |
| ABC | Accelerated Bridge Construction |
| dB(A) | A-weighted decibel |
| DBE | Disadvantaged Business Enterprise |
| FHWA | Federal Highway Administration |
| HfL | Highways for LIFE |
| IRI | International Roughness Index |
| LCCA | Life Cycle Cost Analysis |
| MnDOT | Minnesota Department of Transportation |
| NPV | Net Present Value |
| OBSI | On-board Sound Intensity |
| OSHA | Occupational Safety and Health Administration |
| SAFETEA-LU | Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users |

INTRODUCTION

HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, a Federal Highway Administration (FHWA) initiative to accelerate innovation in the highway community, provides incentive funding for demonstration construction projects. Through these projects, the HfL program promotes and documents improvements in safety, construction-related congestion, and quality that can be achieved by setting performance goals and adopting innovations.

The HfL program—described in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)—may provide incentives to a maximum of 15 demonstration projects a year. The funding amount may total up to 20 percent of the project cost, but not more than \$5 million. Also, the Federal share for an HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

To be considered for HfL funding, a project must involve constructing, reconstructing, or rehabilitating a route or connection on an eligible Federal-aid highway. It must use innovative technologies, manufacturing processes, financing, or contracting methods that improve safety, reduce construction congestion, and enhance quality and user satisfaction. To provide a target for each of these areas, HfL has established demonstration project performance goals.

The performance goals emphasize the needs of highway users and reinforce the importance of addressing safety, congestion, user satisfaction, and quality in every project. The goals define the desired result while encouraging innovative solutions, raising the bar in highway transportation service and safety. User-based performance goals also serve as a new business model for how highway agencies can manage the project delivery process.

HfL project promotion involves showing the highway community and the public how demonstration projects are designed and built and how they perform. Broadly promoting successes encourages more widespread application of performance goals and innovations in the future.

Project Solicitation, Evaluation, and Selection

FHWA issued open solicitations for HfL project applications since fiscal year 2006. State highway agencies submitted applications through FHWA Divisions. The HfL team reviewed each application for completeness and clarity, then contacted applicants to discuss technical issues and obtain commitments on project issues. Documentation of these questions and comments was sent to applicants, who responded in writing.

The project selection panel consisted of representatives of the FHWA offices of Infrastructure, Safety, and Operations; the Resource Center Construction and Project Management team; the Division offices; and the HfL team. After evaluating and rating the applications and

supplemental information, panel members convened to reach a consensus on the projects to recommend for approval. The panel gave priority to projects that accomplish the following:

- Address the HfL performance goals for safety, construction congestion, quality, and user satisfaction.
- Use innovative technologies, manufacturing processes, financing, contracting practices, and performance measures that demonstrate substantial improvements in safety, congestion, quality, and cost-effectiveness. An innovation must be one the applicant State has never or rarely used, even if it is standard practice in other States.
- Include innovations that will change administration of the State's highway program to more quickly build long-lasting, high-quality, cost-effective projects that improve safety and reduce congestion.
- Will be ready for construction within 1 year of approval of the project application. For the HfL program, FHWA considers a project ready for construction when the FHWA Division authorizes it.
- Demonstrate the willingness of the applicant State to participate in technology transfer and information dissemination activities associated with the project.

HfL Project Performance Goals

The HfL performance goals focus on the expressed needs and wants of highway users. They are set at a level that represents the best of what the highway community can do, not just the average of what has been done. States are encouraged to use all applicable goals on a project:

- **Safety**
 - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
 - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported on Occupational Safety and Health Administration (OSHA) Form 300.
 - Facility safety after construction—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.
- **Construction Congestion**
 - Faster construction—Fifty percent reduction in the time highway users are impacted, compared to traditional methods.
 - Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
 - Queue length during construction—A moving queue length of less than 0.5 miles in a rural area or less than 1.5 miles in an urban area (in both cases at a travel speed 20 percent less than the posted speed).
- **Quality**
 - Smoothness—International Roughness Index (IRI) measurement of less than 48 in/mi.
 - Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.

- User satisfaction—An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a measurement of 4 or more on a 7-point Likert scale.

REPORT SCOPE AND ORGANIZATION

This report documents the Minnesota Department of Transportation (MnDOT) HfL demonstration project featuring innovative post-tensioned precast concrete panels for deck construction to replace deteriorated bridge structure on US53. The report presents project details relevant to the HfL program, including bridge replacement and construction highlights, methods and materials, and HfL performance metrics measurement. No technology transfer activities such as seminars, webinars, workshops, showcases, or open houses were performed for this project.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

US53 is a four-lane divided highway that connects the Duluth/Superior Twin Ports with the Iron Range region of northeast Minnesota. The construction project included the replacement of bridge 6603 with 69071 along with resurfacing of 4 miles of bituminous-topped roadway and intersection improvements within the city of Cotton. The portion relevant to the HfL program is the bridge replacement. The bridge, located in St. Louis County, is on southbound US53 and crosses the Paleface River approximately 3 miles north of Cotton. The 2011 two-way average annual daily traffic (AADT) for this section was 8,100 with 15.3 percent commercial traffic.

The key innovation on this project was the use of the accelerated bridge construction (ABC) technique of precast bridge deck panels to improve construction quality, improve worker and work zone safety, reduce construction time, and consequently reduce traffic congestion and delay times. MnDOT developed detailed special provisions and plans for the construction of the bridge. Details included construction and testing of mock-up panels; construction, transportation, and placement of deck panels; post-tensioning; grout properties and testing; and connection and reinforcement details of haunches, blockouts, and keyway joints to ensure composite action between the concrete girders and the bridge deck.

The southbound roadway was closed to traffic on June 22, 2012, for removal of bridge 6603 and construction of bridge 69071. Many project activities such as mock-up panel construction and testing, construction of prefabricated girders, and construction and curing of the precast deck panels were done at the fabrication facility prior to or concurrent with on-site activities. Following removal of the existing bridge and construction of the abutment walls, the precast concrete girders were set on the abutment walls. The precast deck panels were trucked to the project site and installed on top of the girders over a period of 2 days. This was followed by grouting of the transverse deck joints, installation and tensioning of post-tensioning cables, grouting of the post-tensioning ducts, grouting the haunches and the shear blockouts, closure pours of the end diaphragms and longitudinal joint, pouring the curb and gutters, and planing the bridge deck. The southbound roadway was opened to traffic on August 16, 2012.

DATA COLLECTION

Safety, construction congestion, quality, and user satisfaction data were collected before, during, and after construction to demonstrate that ABC using precast deck panels can be used to achieve the HfL performance goals in these areas.

The HfL performance goals for safety include meeting both worker and motorist safety goals during construction. During the construction of bridge 69071, no workers were injured, so the contractor exceeded the HfL goal for worker safety (incident rate of less than 4.0 based on the OSHA 300 rate). MnDOT did not set a goal for accident rates during construction, and there were no reported workzone accidents.

MnDOT did not set a performance goal for motorist delay because of the rural location and low traffic volume on this roadway. The bridge construction area in the southbound direction was closed to traffic for 55 calendar days. The southbound traffic was detoured to share the two northbound lanes with the northbound traffic. The traffic in both directions were free-flowing at all times, but the decrease in the speed limit from 65 mph to 55 mph resulted in an average delay time of 20 seconds per vehicle.

Producing the full-depth precast concrete deck panels at a climate-controlled fabrication facility outside the project critical path schedule is expected to result in higher quality control and increased durability. In addition, the use of longitudinal post-tensioning to hold the panel joints tight along with an epoxy chip seal applied to the deck surface is expected to provide further deck protection and skid resistance, as well as reduce short- and long-term bridge maintenance. Although the quality of the bridge potentially was improved, the replacement process had no impact on the noise and smoothness of the pavement surface. Because of the short bridge length (50 ft for the existing bridge 6603 and 75 ft for the replacement bridge 69071), noise and smoothness data are not meaningful and were not collected for this project.

Highway user satisfaction surveys were conducted after construction was complete. The survey results showed high levels of satisfaction with this construction. The satisfaction with the bridge and adjacent roadway increased from 4.68 before construction to 5.76 after construction on a Likert scale of 1 to 7 (1 = extremely dissatisfied and 7 = extremely satisfied). Respondents also responded positively to traffic disruptions, with an average score of 5.33 on a Likert scale of 1 to 7 (1 = extreme disruption and 7 = no disruption).

ECONOMIC ANALYSIS

The benefits and costs of this innovative precast deck construction technique were compared with those of a project of similar size and scope with a more traditional cast-in-place construction. MnDOT supplied the cost figures for the as-built project and the cost assumptions for the traditional approach. The economic analysis revealed that the as-constructed bridge resulted in net higher costs of \$204,661.70 over conventional construction practices, after considering the reduced user delay costs.

A life cycle cost analysis (LCCA) was performed to compare the conventionally constructed bridge with the as-constructed bridge. As noted above, producing the full-depth precast concrete deck panels at a climate-controlled facility outside the project critical path schedule is expected to result in higher quality control and increased durability. In addition, the use of longitudinal post-tensioning to hold the panel joints tight along with grouting the joints is expected to reduce bridge maintenance costs over the long term, which is reflected in the LCCA. The LCCA shows that, using a 60-year analysis period and 2.5 percent discount rate, the as-constructed cost is \$168,216.83 more than the conventionally constructed bridge based on net present value (NPV).

MnDOT deliberately chose this project because of the rural location and the low traffic. Since this was the first project of its kind undertaken in Minnesota, MnDOT's goal was to use it as learning and evaluation tool without any substantial impact on motorists, and not necessarily to save costs on this specific project.

A key driver for the higher costs of bridge 69071 was the construction and transportation of the precast panels. They were constructed in the Minneapolis/St. Paul area and transported to the project site on flatbed trucks (two panels per truck) for a distance greater than 150 miles. The engineer's estimate for this item was \$118,156.50, whereas the contractor's bid amount for this item was \$276,210.00, for a cost differential of \$158,053.50. The costs for this item would have been substantially lower had the precast deck been fabricated closer to the project location.

Also, if this project would have been constructed at a location with a substantially higher traffic impact (such as roadways with higher traffic volumes, urban locations with morning and evening peaks resulting in higher traffic delay times, and locations requiring substantial detours resulting in higher traffic delay times and vehicle operating costs), the as-constructed bridge would likely have a lower NPV than the baseline case. MnDOT also believes that since this was the first project of its kind in Minnesota, the bid costs were higher than anticipated, and these costs will likely come down in the future as contractors and the industry gain experience with these technologies.

LESSONS LEARNED

MnDOT learned many valuable lessons through its first ABC project using precast deck panels. These lessons include the following:

- Since this was the first project of its kind in Minnesota, MnDOT did not want to add confounding factors such as construction time to the special provisions. However, when ABC with precast deck panels will be used on a more regular basis, MnDOT could possibly use incentives/disincentives for closure time or require the contractor to rent lanes to reduce closure time to 6 weeks.
- The deck panel size was optimal for the access and location. The crane was close to maxing out. Larger panels would have required a larger crane and thus more expense.
- The shear block out areas need careful coordination with the beam stirrup location. The east fascia beam stirrups had to be slightly bent over to set the panels. The tolerances in shear block out allowed the placement of the deck panel.
- The reinforcement steel could have been detailed differently in the plans at a couple of locations to help with installing the panels. This was particularly true of the steel protruding out of the deck panels to reinforce the longitudinal joint between the two rows of panels. The presence of this reinforcing steel made it difficult to properly align some of the panels into position.
- The haunch forming material, Ceramar®, worked well as compared to the extruded polystyrene.
- The grout and panel placement went well.
- The grout supplier 5 star had important feedback at the end of the project. The grouting material performed well but there are other more economical options that could have performed similarly.
- The post-tensioning ducts were specified to be pressure tested at a pressure of 50 psi prior to grouting. A lower pressure of 15 psi would likely have been better to minimize damage to the ducts/splices.

- The contractor would have preferred additional post-tensioning block out area to get a better splice. The area was small and the splicing was difficult for ductwork.
- The epoxy chip seal is sensitive to temperature and dew point at time of placement in the fall. This is an issue for bridges expected to be completed in the fall rather than spring or summer.
- The chip seal specifications should be changed to require a pre-application pull-off test.

CONCLUSIONS

From the standpoint of speed of construction, motorist and user safety and delay, and quality, this project was an unqualified success and embodied the ideals of the HfL program. MnDOT learned many valuable lessons through the construction of this bridge. Because of the success of this project, MnDOT is expected to use ABC techniques of precast bridge decks on future projects when appropriate. MnDOT believes that it will be beneficial to track the performance of this bridge and noted assumptions for reduced long-term maintenance over time.

PROJECT DETAILS

BACKGROUND

US53 is a four-lane divided highway that connects the Duluth/Superior Twin Ports with the Iron Range region of northeast Minnesota. The construction project includes the replacement of bridge 6603 with 69071 along with resurfacing of 4 miles of bituminous-topped roadway and intersection improvements within the city of Cotton. The portion relevant to the HfL program is the bridge replacement. The bridge, located in St. Louis County, is on southbound US53 and crosses the Paleface River approximately 3 miles north of Cotton.

The 2011 two-way AADT for this section was 8,100 with 15.3 percent commercial traffic. The AADT is projected to increase to 10,600 by 2030. This project is in a rural roadway and does not have any significant morning or evening traffic peaks.

Bridge 6603, a 50.5-ft concrete deck girder type bridge with a 30-ft roadway width was originally constructed in 1953. After more than 50 years after in service, it had a Sufficiency Rating of 53 in 2009. The bridge was designed to be replaced by bridge 69071, a 75.67-ft-long prestressed concrete girder type bridge with a 42-ft roadway width and new construction standards consistent with the southbound roadway. Figures 1 through 4 show the condition of the bridge in June 2007.



Figure 1. Deterioration of bridge 6603 surface and parapet walls.



Figure 2. Deterioration of bridge 6603 surface and parapet walls.



Figure 3. Deterioration of bridge 6603 south abutment wall.



Figure 4. Deterioration of bridge 6603 north abutment wall.

PROJECT DESCRIPTION

The key innovation of the TH53 construction project included using precast, post-tensioned concrete panels for deck construction on bridge 69071 in lieu of a traditional cast-in-place concrete deck. After main span girders are placed, prefabricated deck panels are lowered into position and adjusted for position and fit. After grouting joints, the post-tensioning forces are applied and any necessary closure pours and surface treatments are performed.

In preparation for this project, MnDOT and FHWA held an Accelerated Bridge Construction Seminar that included professionals with experience from other agencies to gather information, share ideas, and discuss anticipated issues and design considerations regarding precast concrete deck construction. Since this was the first project of its kind undertaken in Minnesota, MnDOT's goal was to use it as learning and evaluation tool as part of their efforts to introduce the technology to the overall bridge construction program, so that precast panels can be used on future projects.

For this project, the use of precast panels was expected to reduce construction time by about 3 weeks as compared to cast-in-place decks due to the elimination of falsework construction and the curing of the deck panels at the casting facilities concurrent with other construction activities. The innovation was also expected to result in a reduction in worker injuries and motorist accidents, as well as reduce work zone motorist delays and user costs, as a result of using precast panels.

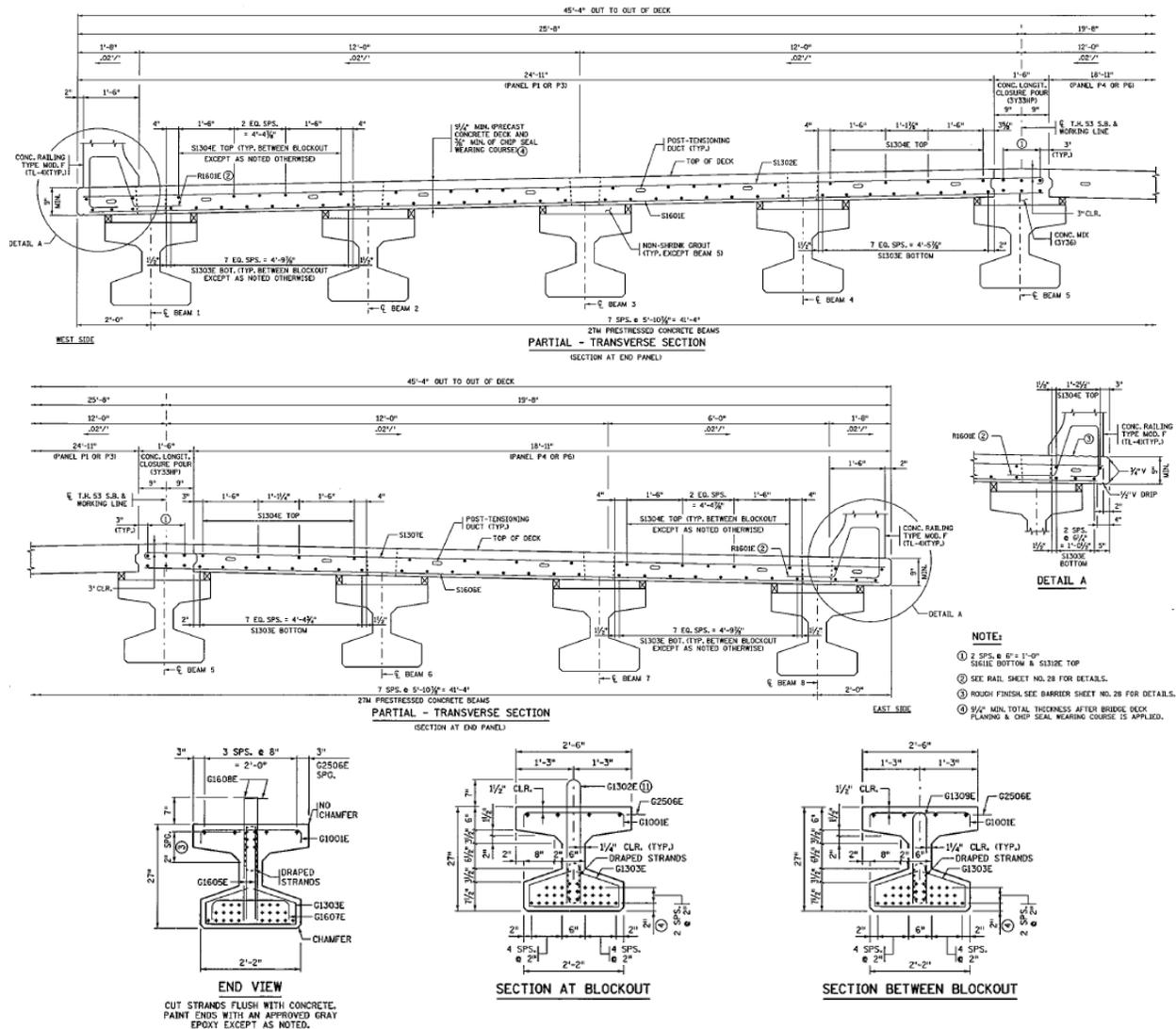


Figure 6. Diagram. Superstructure details and reinforcement for bridge 69071.

Figure 7 shows that the panels contain three to four rows of shear blockouts (depending on the size of the panel), with each row contain three to four shear blockouts (depending on the size of the panel). Four steel reinforcement bars (bundled in two pairs) extend from the girder into the shear blockouts. Figure 8 shows that each shear blockout measures 10 inches by 10 inches at the top of the panel and 9 inches by 9 inches at the bottom of the panel. The deck panels are separated from the girders by the temporary haunch forming material. Composite action between the concrete girders and the deck is achieved by pouring structural non-shrink grout in the shear blockouts and girder haunches contiguously.

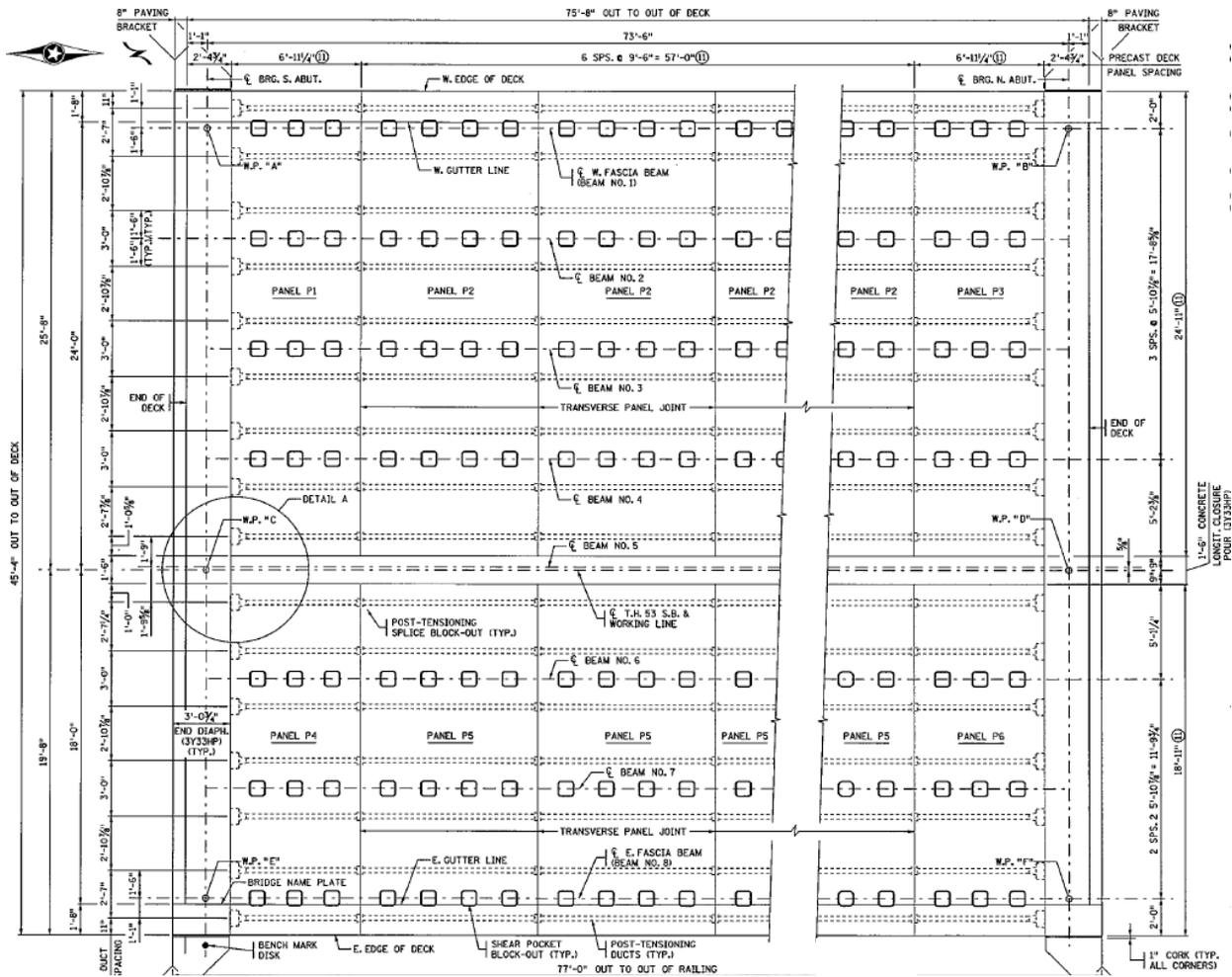


Figure 7. Diagram. Bridge 69071 superstructure details.

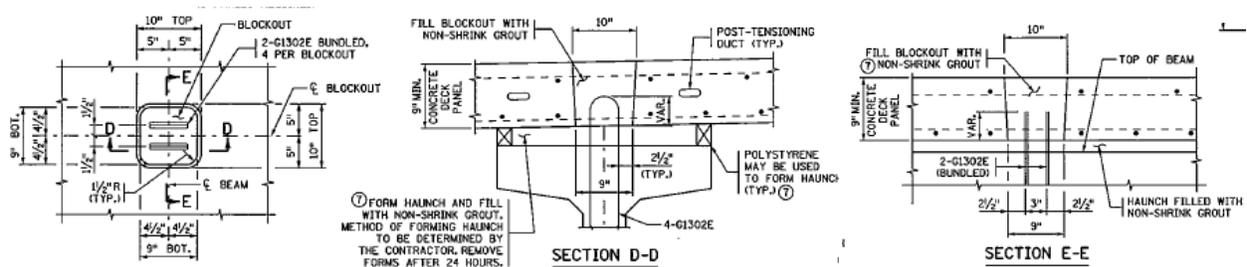


Figure 8. Diagram. Bridge 69071 shear pocket blockouts and haunches.

The post-tensioning system for the deck panels consists of seven to nine longitudinal post-tensioning ducts per panel (depending on the panel size). Figure 9 shows the duct splices are connected and sealed at the deck panel joints. The post-tensioning duct splice blockouts for connecting the ducts measure 6 inches by 8 inches to a depth of 7 inches. Figure 10 shows that the deck panels are reinforced transversely, and the end deck panels are also reinforced longitudinally. The transverse and longitudinal reinforcement extends into the centerline longitudinal joint and the end diaphragms, respectively. The 18-inch-wide centerline longitudinal

joint opening between the panels consists of steel reinforcement tied to the transverse steel reinforcement from the panels on both sides of the centerline. The 36-inch end diaphragm openings consist of steel reinforcement tied to the longitudinal steel reinforcement from the end panels. Structural concrete mix 3Y33HP is used for the closure pours of the centerline longitudinal joint and the end diaphragms. Figure 11 shows how the prestressing strands are passed through the ducts, post-tensioned, and anchored to the end panels. The post-tensioning ducts and the end anchor blockouts are then filled with non-shrink grout.

The deck panel transverse joints consist of shear keys designed for an opening of 1.5 inches at the top 2 inches of the joint, flaring to a 2.5-inch opening for the middle 3.5 inches of the joint and closing down to 0.75 inches for at least the bottom 2 inches of the joint. A foam backer rod extends the full transverse length of the deck joint between panels and the openings along with the post-tensioning duct splice blockouts are filled with non-shrink grout.

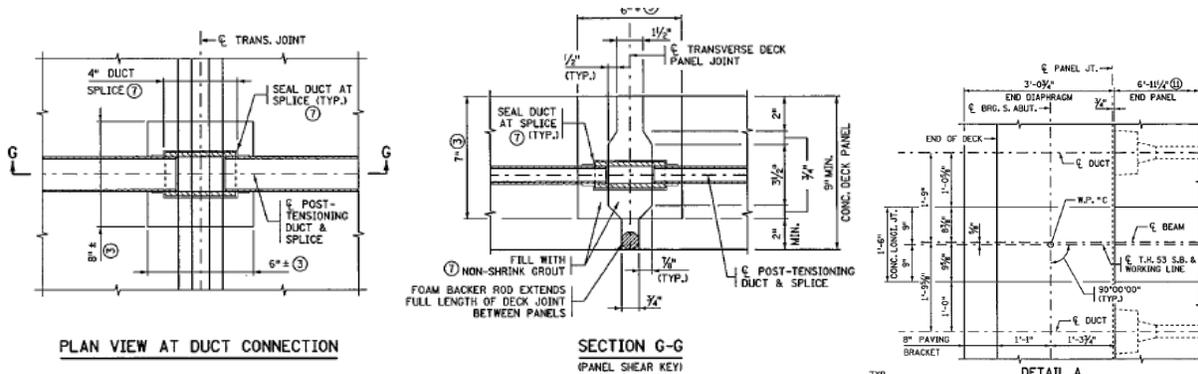


Figure 9. Diagram. Post-tensioning duct and deck panel connections for bridge 69071.

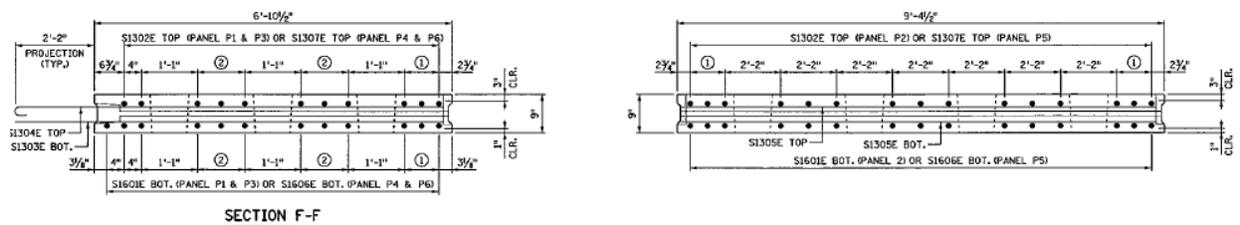


Figure 10. Diagram. Cross section showing deck panel reinforcement details for bridge 69071.

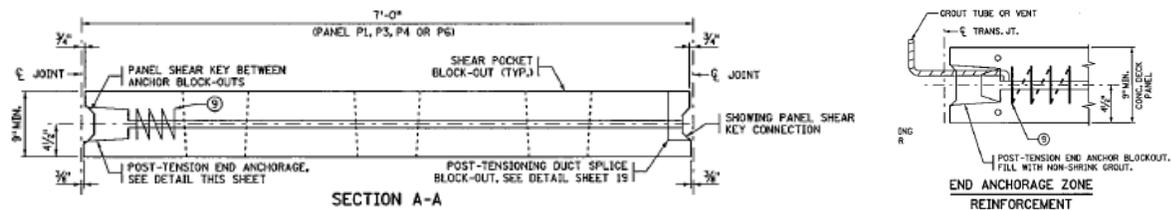


Figure 11. Diagram. End panel section and anchorage detail for bridge 69071.

The specific details with regards to devices for lifting the precast deck panels into place and the corresponding design and details was left to the contractor. Table 1 shows deck panel tolerances for bridge 69071. The lifting hardware cast into the panel during fabrication was specified to be

Special Provisions and Submittals

The special provisions developed for this project included a section detailing specifics regarding the bridge construction activities, due to the investigative and research nature of this project. The special provisions also summarized the overall scope and coordination necessary that would be unique to this project as follows:

Bridge No. 69071 utilizes full depth precast concrete deck panels to facilitate the development of Accelerated Bridge Construction (ABC) in the State of Minnesota. The full depth precast concrete panels are placed on prestressed beams, posttensioned longitudinally with grout-filled haunches and shear pockets to achieve composite beam/deck behavior. The bridge deck is finished with a chip seal overlay. The integral abutments are founded on steel HP piles.

Bidders are advised that significant coordination and cooperation will be required between the Contractor, Subcontractors, MnDOT and other associated parties during the execution of this Project. In addition to typical project coordination, the Contractor will be required to coordinate his/her activities closely with the work of the prestressed concrete beam manufacturer, the precast concrete deck panel manufacturer, the post-tensioning operators, MnDOT and other situations that may arise during the course of the Project.

The special provisions contain many items related to the bridge construction activities. Some of the key items are summarized below:

- Safety – The contractor was to submit a plan, at the preconstruction conference, for providing all safety equipment as required by the Occupational Safety and Health Administration (OSHA), such as safety nets, static lines, and false decks, for all work areas with a working surface 6 ft or more above the ground, water, or other surfaces. All safety equipment, in accordance with the plan, was specified to be in place and operable in adequate time to allow MnDOT personnel to perform their required inspection duties at the appropriate time. No concrete was to be placed in any areas affected by such required inspection until the inspection had been completed.
- Bridge abutment construction – Construction of each abutment could not be started until after the approach fill at that abutment has been constructed to the full height and cross section. The approach fill construction was to extend a distance of at least 50 ft behind the abutment as measured along the centerline of the roadway.
- Planing of precast deck panels – Special care was to be taken in finishing roadway surfaces in the vicinity of joints to ensure a smooth riding surface. Before the application of the chip seal overlay, a surface smoothness check would be made on the bridge surfaces and approach panel surfaces. The final surface was to meet the specified tolerance requirements. Surface areas not meeting the specified tolerances was to be corrected by removal and replacement or by grinding the high spots to the extent directed by the Engineer.

- Slurry residue – All concrete residue and water (slurry) resulting from concrete texture planing was to be continuously vacuumed from the surface, captured, and containerized for further handling or processing. The slurry was not to flow across lanes occupied by traffic, into drainage facilities, or discharged anywhere within the highway right-of-way. The contractor was to submit a slurry disposal or reuse plan at the preconstruction conference for approval by the engineer.
- Mock-up panel –The contractor was required to construct a mock-up panel to demonstrate the ability to handle, place, finish, and cure the precast concrete deck panel concrete and the structural non-shrink grout to the tolerances. Details for construction of the mock-up panels were included in the project plans. The contractor was to submit shop drawings of mock-up panel to the engineer for review before any work was started.
- Precast concrete deck panel – The special provisions included details on the precast concrete deck panel furnishing, erecting, grouting, and installing. The contractor was to fabricate the deck panels in a precast/prestressed concrete fabrication plant that had been granted certification by the Precast/Prestressed Concrete Institute, or by an organization approved by the materials engineer. The precast concrete deck panels was to be installed and transported in a manner that would provide safety to the workers, inspectors, and the public at all times, as well as reasonable assurance against damage to the panels. The precast panels was specified to be temporarily anchored, braced, and stabilized as they were transported and erected so as to preclude sliding, tipping, buckling, or other movement that may otherwise occur. Struts, bracing, tie cables, and other devices used for temporary restraint was to be of a size and strength that would ensure their adequacy. The concrete for the precast panels was specified to be MnDOT mix 3Y36. Structural non-shrink grout was to be used for haunches, shear pocket blockouts, transverse keyway, and duct splice blockouts shown on the plans. The contractor was to submit test results of the grout mixture verifying compliance with the specified requirements. The grout could be neat or extended using 3/8-inch pea gravel aggregate. The aggregate composite was not to exceed 50 percent by weight. The specified requirements for the grout included:
 - 1- and 7- or 28-day compressive strength.
 - 1- and 7- or 28-day splitting tensile strength.
 - 28-day shrinkage.
 - 28-day sulfate resistance.
 - Freeze-thaw resistance at 300 cycles.
 - Scaling resistance at 25 cycles.
 - Flow.
- Chip seal wearing course – The chip seal wearing course was specified to consist of two layers of a two-component polymer system with a minimum total thickness of 3/8 inches. The special provisions included a list of prequalified polymer liquid binders and the supplier information.

The special provisions also included details on construction of the precast panels, installation of the precast panels onto the girders, longitudinal post-tensioning, and quality assurance as described in the construction section of this report. The contractor was also required to provide several bridge-related submittals as detailed in the special provisions. These include:

- Plan to provide OSHA required safety equipment.
- Plan and specifications for sheeting and shoring if required.
- Precast concrete deck panel shop drawings.
- Precast concrete deck panel erection plan.
- Test data and certified test results.
- Repair procedures.
- Product data sheets, specifications, certified test reports, installation procedures and drip seal wearing course.
- Post-tensioning system drawing and calculations.
- Post tensioning system product data sheets, specifications, and stressing records, duct pressure field tests, certified test reports, and installation procedures.
- Slurry disposal.
- Mock-up panel shop drawings and cores.

Construction

Figure 13 shows the preconstruction schedule developed for the construction of bridge 69071. Many key activities, such as concrete girders and deck panel fabrication and curing (done at the fabrication facility), were done prior to or concurrent with on-site activities such as removal of the existing bridge, excavation, piling and concrete placement for the abutments, and placement of the concrete girders. As a result, field construction time and lane closure time were reduced (as compared to conventional cast-in-place construction), which consequently reduced the impact on traffic and improved safety.

Since this was the first project of its kind in Minnesota, the plans and special provisions specified the construction of mock-up panels. Payment for the mock-up panel was on a lump sum basis and included all costs of manufacturing, testing and disposal. The work consisted of constructing reinforced concrete mock-up deck panels, including all necessary materials, equipment and testing to complete the work, as shown in the plans (figure 14). The contractor was specified to furnish, install, place, finish, cure, demonstrate and test the mock-up panel using the same personnel, methods, equipment and material that the contractor intended to use on bridge 69071. This included using the same forms, concrete mix, panel thickness, reinforcement, pocket dimensions, transverse panel joint, lifting assemblies, post-tensioning ducts, leveling assemblies, and non-shrink grout. The support surface for the mock-up panels was to be roughened to simulate the tops of the prestressed concrete beams.

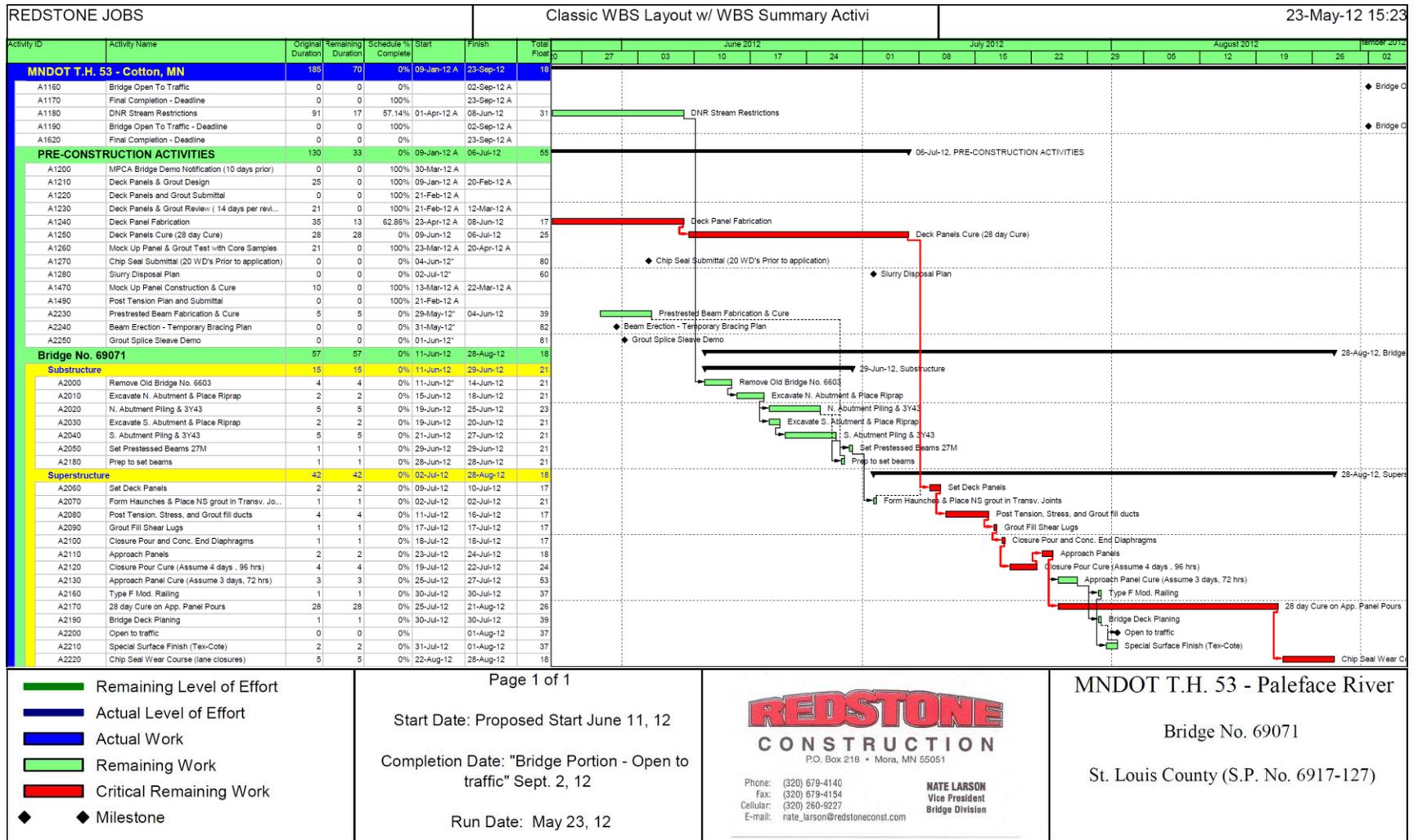


Figure 13. Graph. Preconstruction schedule for bridge 69071.

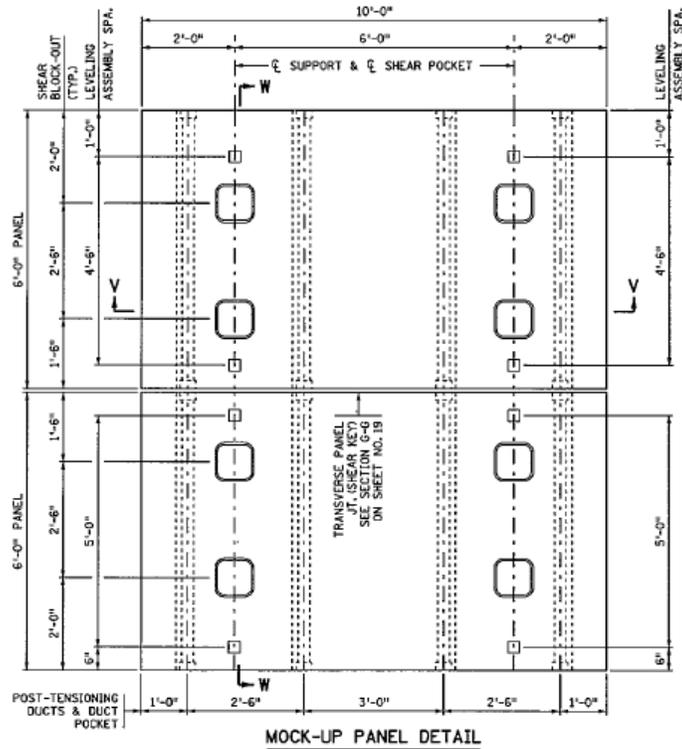


Figure 14. Diagram. Mock-up panel plans for bridge 69071.

The goal of constructing the mock-up panels was to demonstrate the ability to handle, place, finish and cure the precast concrete deck panel concrete and the structural non-shrink grout all to the tolerances shown in the plan. Specifically, the contractor was to demonstrate the ability of the:

- Proposed haunch forming material and its ability to prevent leaking of the non-shrink grout.
- Proposed foam backer rod in the transverse deck panel joint to prevent leakage of the non-shrink grout.
- Vertical adjustment assemblies to distribute loads uniformly to the mock-up beams and the ability to adjust the panels to required grade and tolerances as required by the plans and the special provisions.
- Structural non-shrink grout and placement method to fill the spaces in the haunches, transverse panel joint, shear pocket blockouts, and post-tensioning duct splice blockouts without the formation of any voids.

One week after placement of the mock-up panels, 6-inch-diameter full depth cores (extending from the top of the precast panel to the bottom of the haunch or bottom of the precast panel depending on the location) were taken. The cores were examined to determine uniformity, consolidation, and the extent of voids in the concrete and non-shrink grout. Acceptance of the mock-up panel was contingent upon demonstrating that the requirements of the specifications were satisfied for placement, consolidation, finishing, curing, performance, and testing. If unsatisfactory results were obtained, the contractor was to submit a written procedure identifying corrective actions for non-conforming results.

Following the construction and evaluation of the mock-up panel's materials, methods, and calculations, including non-shrink grout test results to MnDOT's satisfaction, the contractor began the prefabrication of the deck panels at the fabrication facility. Concurrently, the on-site activities such as demolition and removal of the existing bridge, piling and forming for the abutments, and placement of concrete for the abutments were conducted.

Table 2 shows the schedule for the actual on-site construction activities. The table also shows that the actual on-site construction (and correspondingly closures) would have likely be completed about 2 weeks earlier, had it not been for delays related to concrete girder delivery and the post-tensioning subcontractor. The concurrent on-site activities listed between June 22 and July 13, 2012, including placing the concrete beam girders on the concrete abutments, are not unique to this construction and would have to be done even if the bridge deck was cast-in-place.

Figures 15 through 17 show photographs of the construction process. Following placement of all the girders onto the elastomeric bearing pads placed on top of the abutments, the girders were prepared for the placement of the prefabricated decks. The top of the girders were cleaned to remove all dirt, oil, grease, or other loose material. The haunch-forming material (3-in wide Ceramar® flexible foam expansion joint filler) was placed at the edges of the girder. Note the steel reinforcement cast at the top of the girder. This steel reinforces the shear blockouts in the deck which will be filled with grout to provide composite action between the concrete girder and the deck. The top and bottom of the haunch-forming material was coated with a spray adhesive (3M Scotch-Weld™) to bond with the girder and the prefabricated deck. Steel leveling plates measuring 6 inches by 6 inches by 0.25 inches are placed on top of the girder. These leveling plates along with the leveling screw and the leveling bolt and sleeve cast into the deck panel are used to level the deck panels following placement. Figures 18 and 19 show the girders ready for placement of the deck panels. The girders were fully braced in preparation for placement of the deck panels.

The deck panels were cast at the fabrication facility with a minimum curing of 28 days prior to on-site placement. The concrete was placed in the forms only after MnDOT had inspected the placement of all materials in the deck panels. A light broom finish was used for the top surfaces and all joint surfaces of the panels, and a smooth finish was used for the bottom surface of the panels. The deck panels were wet cured by covering all exposed surfaces with wet burlap and plastic sheets for 14 consecutive days beginning immediately after performing the final finish. Forms could only be stripped after the precast panels had obtained a minimum compressive strength of 4000 psi. Immediately after completion of wet cure, a membrane curing compound was applied homogeneously to the top surface of the panels.

Table 2. On-site construction details for brige 69071.

| Working Days | Date | Description |
|---------------------|-------------|---|
| 1 | 6/22/2012 | Remove bridge |
| 2 | 6/25/2012 | Excavated for north abutment |
| 3 | 6/26/2012 | North abutment piling and forming |
| 4 | 6/27/2012 | North abutment forming and rebar |
| 5 | 6/27/2012 | North abutment forming and rebar |
| 6 | 6/28/2012 | Pour north abutment |
| 7 | 6/29/2012 | Excavated for south abutment |
| 8 | 7/2/2012 | South abutment piling |
| 9 | 7/3/2012 | South abutment forming |
| | 7/4/2012 | Holiday - no work |
| 10 | 7/5/2012 | South abutment forming and rebar |
| | 7/6/2012 | No work - could have poured south abutment on 7/5/12 but beam delivery was delayed |
| 11 | 7/9/2012 | Pour south abutment |
| | 7/10/2012 | Waiting for beams |
| | 7/11/2012 | Waiting for beams |
| | 7/12/2012 | Waiting for beams |
| 12 | 7/13/2012 | Beams delivered and set |
| 13 | 7/16/2012 | Prep for deck panels |
| 14 | 7/17/2012 | Set south half of deck panels |
| 15 | 7/18/2012 | Set north half of deck panels |
| 16 | 7/19/2012 | Prep for transverse deck joint pours |
| 17 | 7/20/2012 | Pour all transverse deck joints |
| | 7/23/2012 | No work - could have done post-tensioning but subcontractor didn't come |
| | 7/24/2012 | No work - could have done post-tensioning but subcontractor didn't come |
| | 7/25/2012 | No work - could have done post-tensioning but subcontractor didn't come |
| | 7/26/2012 | No work - could have done post-tensioning but subcontractor didn't come |
| | 7/27/2012 | No work - could have done post-tensioning but subcontractor didn't come |
| | 7/30/2012 | No work - could have done post-tensioning but subcontractor didn't come |
| 18 | 7/31/2012 | Installed all post-tensioning cables |
| 19 | 8/1/2012 | Tensioned all cables |
| 20 | 8/2/2012 | Grouted post-tensioning ducts |
| 21 | 8/3/2012 | Grouted post-tensioning ducts and shear lug pockets, formed and reinforced end diaphragms |
| 22 | 8/6/2012 | Cleanup and remove end diaphragm forms |
| 23 | 8/7/2012 | Pour remaining deck shear pockets and from north approach panel |
| 24 | 8/8/2012 | Form approach panels and bridge rail |
| 25 | 8/9/2012 | Poured approach panels and curb and gutter |
| 26 | 8/10/2012 | Cure |
| | 8/13/2012 | No work |
| 27 | 8/14/2012 | Poured bride rail and panel curbs. Special surface finish |
| | 8/15/2012 | No work |
| 28 | 8/16/2012 | Planed bridge deck and open to traffic |



Figure 15. Haunch forming material for bridge 69071.



Figure 16. Placement of the haunch-forming material at the edges of the concrete girders.



Figure 17. Placement of the leveling plates on top of the concrete girders.



Figure 18. End girder placed on top of the abutment wall for bridge 69071.



Figure 19. Girders for bridge 69071 prepared for placement of deck panels.

For quality assurance purposes, each precast panel was permanently marked in the fresh concrete with the date of casting and supplier identification. Panel elements that sustained damage or surface defects during fabrication, handling, storage, hauling, or erection were subject to review and rejection. Cracks that extended to the nearest reinforcement plane and fine surface cracks that did not extend to the nearest reinforcement plane but were numerous or extensive were subject to review and rejection. Full-depth cracking and breakage greater than 9 inches long were specified as cause for rejection. Cracks wider than 0.007 inches were to be repaired. In the case of damage, the contractor had to submit proposed repair procedures and obtain approval from MnDOT before performing repairs. The repair work would only be approved if it reestablished the element's structural integrity, durability, and aesthetics to MnDOT's satisfaction.

Figures 20 and 21 show transportation of the deck panels from the fabrication facility to the bridge site on flatbed trucks. Figures 22 and 23 show the panels being lifted off the flatbed truck for placement onto the girders using a crane and lifting hardware. The contractor performed the design and details of the lifting hardware using the *PCI Design Handbook, Precast and Prestressed Concrete, Fifth Edition*, approved by MnDOT. Once a panel was lifted off the flat bed truck, the leveling bolts were passed through the cast sleeve and screwed through the cast nut to protrude from the bottom of the slab to provide the clearance between the girder and the panel to form the haunches (see figures 24 and 25). Figures 26 through 37 show the sequence of placing the deck panels and aligning them on top of the girders.



Figure 20. Transportation of precast deck panels on flatbed trucks to bridge site.



Figure 21. Precast deck panels tied to flatbed trucks on wooden supports for transportation to bridge site.



Figure 22. Lifting the deck panels from the flatbed truck using crane and lifting hardware.



Figure 23. Close-up of the lifting hardware.



Figure 24. Passing the leveling bolt through the cast sleeve and screwing through the cast nut.



Figure 25. Protusion of the leveling bolt at the bottom of the deck panel to lift the deck panel above the surface of the girder and form the haunches.



Figure 26. Placement of the deck panel onto the concrete girder (horizontal cable shown is the safety harness for crew on top of the girder).



Figure 27. Placing the deck panel onto the haunch forming material.

The steel cast in the girders pass through the shear blockout to reinforce the grout in the haunch and the blockout and help provide composite action between the girder and the deck.



Figure 28. Shear breakout to be filled with grout to provide composite action between the girder and the deck (to the right is a leveling bolt).

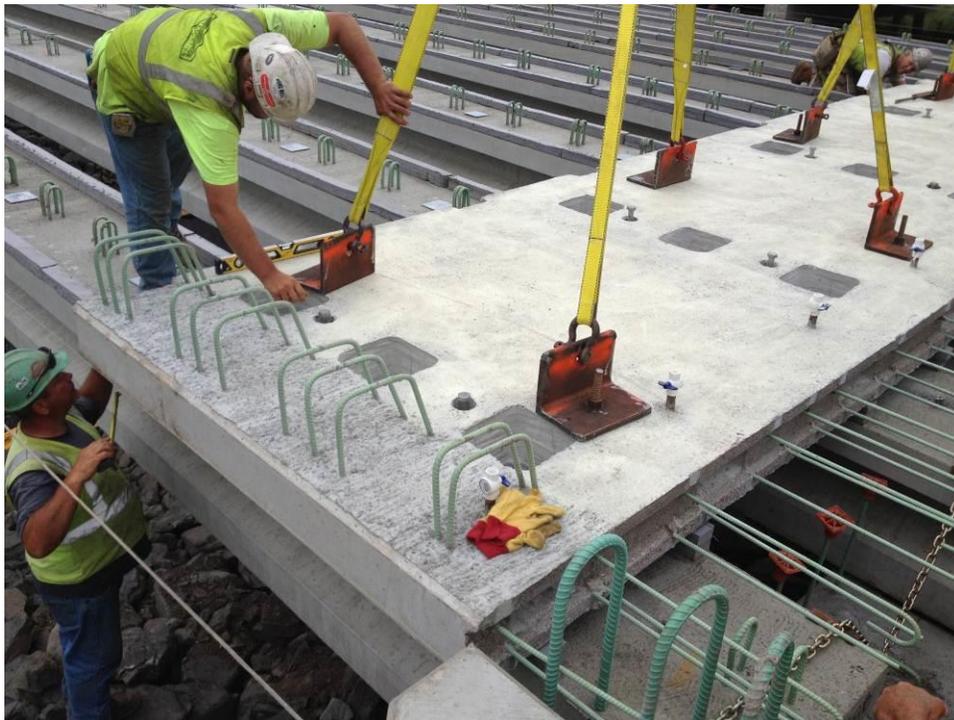


Figure 29. Aligning the deck panel.



Figure 30. Aligning the deck panel and ensuring proper horizontal placement.

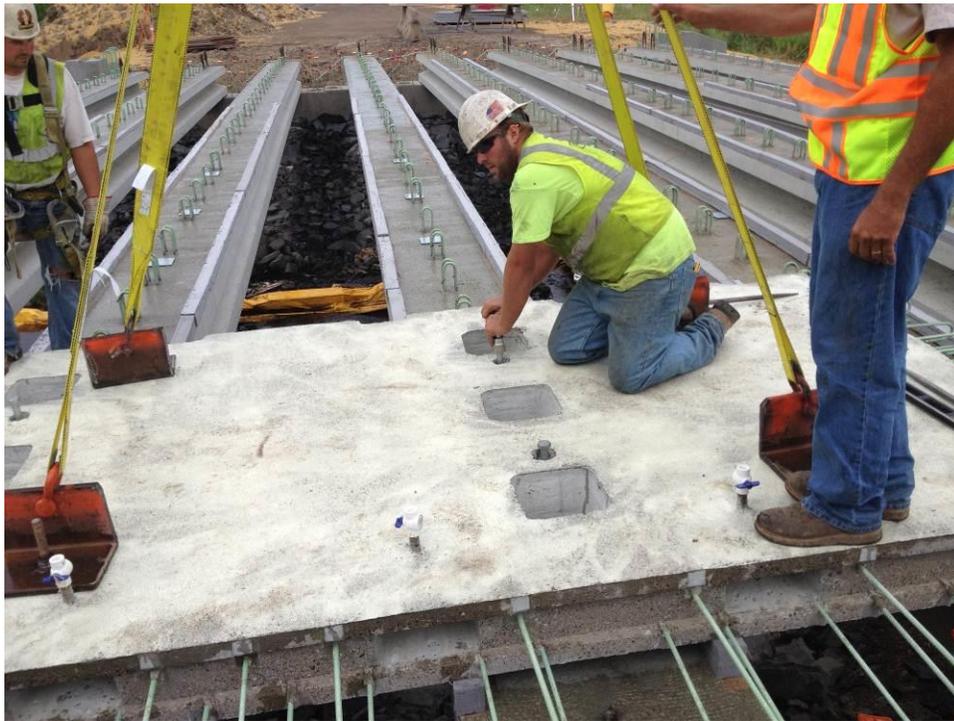


Figure 31. Aligning the leveling bolts to achieve the proper grade.



Figure 32. Close-up of torquing the leveling bolts to achieve the proper grade.

Leveling bolts on each panel were torqued to within 15 percent of each other to ensure proper distribution of panel weight to the underlying girders.



Figure 33. Leveling bolt resting on the steel plate on top of the girder.

All bolts were in contact with the steel plate before the panels were released from the crane. The deck is lifted and lowered onto the steel plate and the girder by screwing the leveling bolt clockwise and counterclockwise, respectively.



Figure 34. Placement of the second deck panel to align with the first deck panel.



Figure 35. Positioning deck panels into place using the placed deck panels.



Figure 36. Alignment of deck panels.



Figure 37. View of bridge deck following placement of all deck panels.

Figures 38 through 45 show activities related to forming the joints and reinforcing duct connections between deck panels.



Figure 38. Spraying the bottom of the panel joint with adhesive to install the backer rod.



Figure 39. Installation of backer rod to form the joints between the panels.



Figure 40. Side view of backer rod in place. The panels were placed such that they were in tight contact with the backer rod separating them.



Figure 41. View of the backer rods from beneath the deck panels.



Figure 42. View of the backer rod from the top of the deck panels. The backer rod prevents the grout poured into the transverse joint keyway from escaping.



Figure 43. Corrugated plastic ducts that hold the post-tensioning cables.

These ducts were connected and covered with a heat shrink sleeve. The duct splices were attached to the ducts protruding out of the panels before the successive panels were erected.



Figure 44. Heat shrink sleeve tightly covering each connection of the corrugated plastic ducts. It prevents post-tensioning grout from escaping at the connections.



Figure 45. Reinforcing steel protruding at the 18-inch longitudinal joint.

The steel was longer than detailed in the plans and had to be bent to ensure proper alignment of the individual panels. These were later shortened and straightened back into the joint prior to the closure pour.

Figures 46 through 57 show the preparation and pouring the extended concrete grout for the keyway and the post-tensioning duct splice blockouts between the transverse joints.



Figure 46. Cleaning the keyway joints and post-tensioning duct splice blockouts in preparation for pouring concrete.



Figure 47. Aggregate used for extending the grout for the keyway joints and post-tensioning duct splice blockouts.



Figure 48. Mixing the grout for the keyway joints and post-tensioning duct splice blockouts.



Figure 49. Testing the grout for slump.



Figure 50. Placing the grout into the keyway joint and post-tensioning duct splice blockouts between the transverse deck panels.



Figure 51. Vibrating the grout into the transverse keyway joints and post-tensioning duct splice blockouts.



Figure 52. Forms at the edge of the transverse keyway joint between the deck panels to contain the grout.



Figure 53. Forms at the edge of the transverse keyway joint between the deck panels to contain the grout.



Figure 54. Floating the placed grout to remove excess material.



Figure 55. Applying curing compound to the grout to control shrinkage cracks.

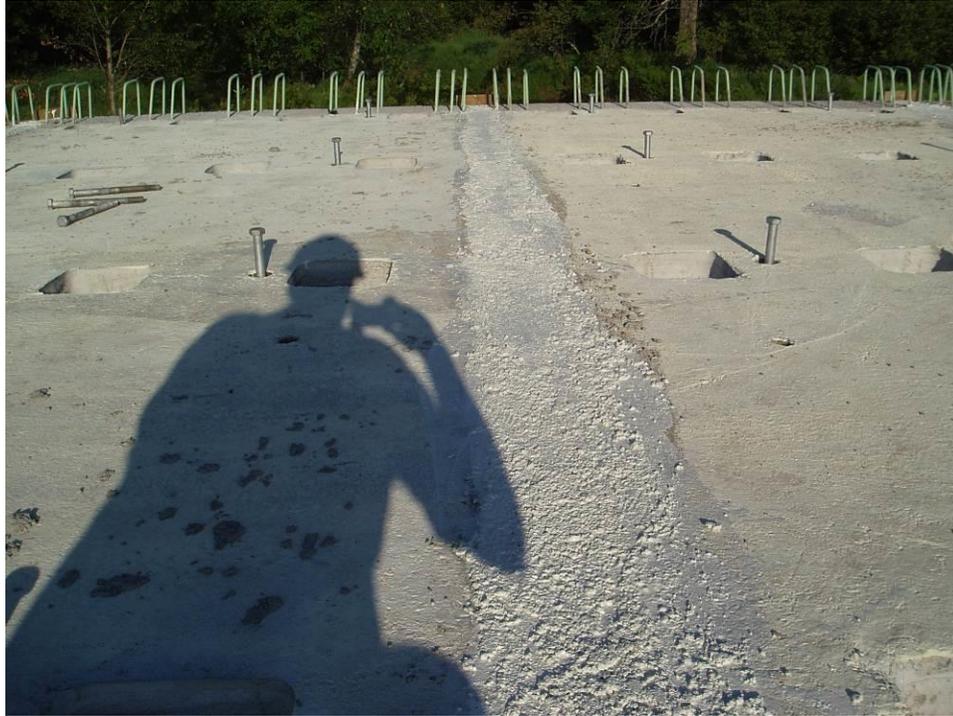


Figure 56. Transverse deck panel joint after placement of grout.



Figure 57. Bridge 69071 after placement of grout in the transverse deck panel keyway joints and post-tensioning duct splice blockouts.

Figures 58 through 66 show the post-tensioning activities, including installing the cables, post-tensioning, and grouting the post-tensioning ducts.

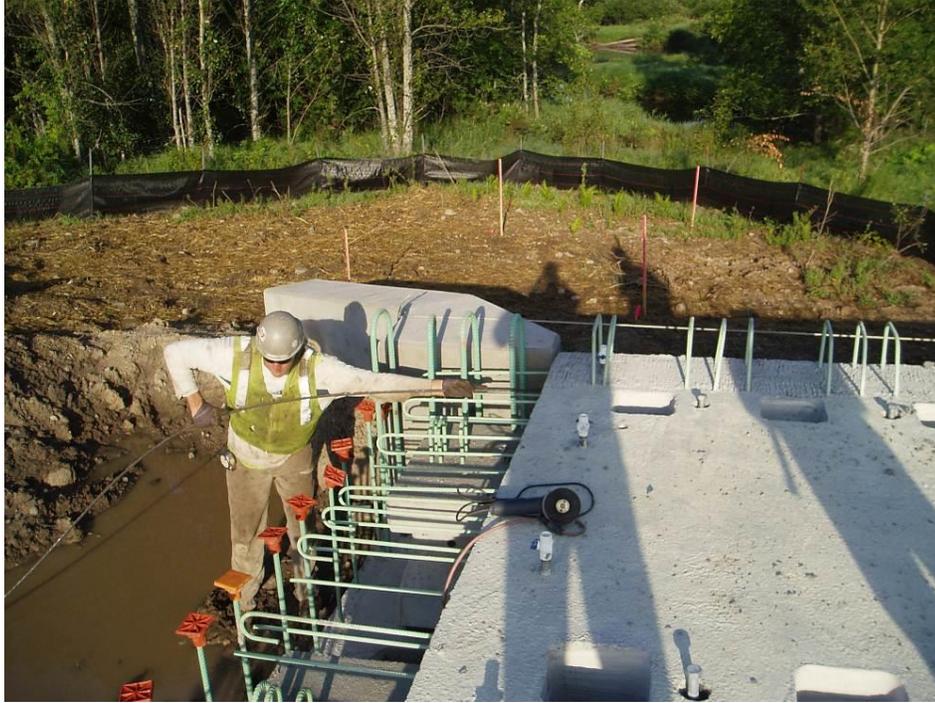


Figure 58. Installing the post-tensioning strands.



Figure 59. Four post-tensioning steel strands were installed through each duct.



Figure 60. Anchoring the post-tensioning strands.

The grout in the transverse keyway joints had to attain a minimum compressive strength of 6,000 psi before any post-tensioning could be performed.



Figure 61. Post-tensioning the steel strands.

After losses due to friction, anchorage set, and elastic shortening, the force per strand was 26 kips. Deck panels were specified to be allowed to slide on girders during post-tensioning. Stressing began at center of the panels without allowing more than 12.5 percent eccentricity of the prestressing force at any time.



Figure 62. Testing and clearing the corrugated post-tensioning ducts prior to grouting.



Figure 63. Equipment for mixing and pumping post-tensioning duct grout.

The duct grout consists of measuring devices for water, high-speed shear colloidal mixer, storage hopper (holding reservoir) and pump with all the necessary connecting hoses, valves, and pressure gauge. Pumping equipment had sufficient capacity to ensure that the post-tensioning ducts were filled with grout and vented without interruption at the required rate of injection within 30 minutes.



Figure 64. Measuring fluidity of grout using flow cone to meet manufacturer's specifications.



Figure 65. Pumping neat grout into the corrugated post-tensioning ducts.

Grout was pumped at a rate of 16 to 50 feet of duct per minute at a pressure range of 10 to 50 psi measured at the grout inlet. Grout was pumped such as to ensure complete filling of the ducts and complete encasement of the steel.



Figure 66. Grout pumped and continuously discharged at the anchorage and grout cap outlets.

The pumping and discharging was done until all free water and air were discharged and the consistency of the grout was equivalent to that of the grout being pumped into the inlet. Grout cap outlets were closed after a minimum discharge of 2 gallons of grout.

Figures 67 through 69 show the grouting of the haunches and the shear blockouts.



Figure 67. Mixing the grout for the haunches and the shear pocket blockouts.



Figure 68. Grouting the haunches and the shear pocket blockouts by pumping extended grout through the shear pocket blockouts.

Also shown are the end diaphragm and longitudinal joint reinforcement steel prepared for closure pours.



Figure 69. Close-up of grouting the haunches and the shear pocket blockouts by pumping extended grout through the shear pocket blockouts.

Construction traffic was not allowed onto the bridge deck until the concrete in the haunches, blockouts, and keyway joint had attained a minimum compressive strength of 6,000 psi.

The construction activities concluded with capping and sealing the post-tensioning end anchorages, placing concrete mix 3Y33HP in the end diaphragm and longitudinal joint closures, removing leveling bolts and filling holes with grout mix, planing the bridge deck, placing the barrier rails, sealing all deck and joint cracks with sealant, and paving the approach and leave ends of the bridge. Figures 70 and 71 show the completed bridge.

Although the bridge deck was planned to be surfaced with epoxy chip seal wearing course, due to weather/temperature limitations, that activity will not be performed until spring/summer of 2013, when the ambient and bridge deck surface temperatures are warmer to meet the specifications of the epoxy chip seal.



Figure 70. Overview of bridge 69071 after completion.



Figure 71. Close-up view of bridge 69071 deck surface after completion.

DATA ACQUISITION AND ANALYSIS

Data collection on the MnDOT HfL project consisted of acquiring and comparing data on safety, construction congestion, quality, and user satisfaction before, during, and after construction. The primary objective of acquiring these types of data was to provide HfL with sufficient performance information to support the feasibility of the proposed innovations and to demonstrate that ABC using precast deck panels can be used to do the following:

- Achieve a safer environment for the traveling public and workers.
- Reduce construction time and minimize traffic interruptions.
- Deliver better quality.
- Produce greater user satisfaction.

This section discusses how well the MnDOT project met the HfL performance goals in these areas.

SAFETY

The HfL performance goals for safety include meeting both worker and motorist safety goals during construction. The MnDOT project did not establish performance goals for work zone crash rate or incident rate for worker injuries.

The innovative deck construction method was anticipated to improve safety to both the project construction workers and motorists traveling US53 through the project work zone. Two factors were expected to result in the improved safety on this project as compared to cast-in-place bridge decks:

- 50 percent average reduction in expected worker injuries due to the lack of typical falsework construction, deck reinforcement steel hand placement and tying, and concrete pouring and finishing, associated with cast-in-place bridge deck.
- 38 percent average reduction in risk of motorist injuries and fatalities due to an expected 3+ week reduction in time required for deck construction resulting from the elimination of falsework construction and curing time associated with cast-in-place deck.

No workers were injured during the construction of the TH53 bridge 69071 project, so the contractor exceeded the HfL goal for worker safety (an incident rate of less than 4.0 based on the rate reported on OSHA form 300).

To address the safety of the traveling public, MnDOT's foremost solution was to minimize traffic disruption and interaction with construction activities and workers. This was done by completely closing the southbound roadway between June 22 and August 16, 2012, for removal of the old bridge and construction of the new one. All southbound traffic was diverted to the two-lane northbound direction, as shown in figures 72 through 75. For motorist safety, the speed limit was reduced from 65 mph to 55 mph with an advisory speed limit of 45 mph for the tapers and the bypasses.



Figure 72. Closed Southbound Lanes.



Figure 73. Traffic diverted to the northbound lanes from southbound lanes.



Figure 74. Taper and north bypass due to closure of the southbound lanes.



Figure 75. Taper and south bypass due to closure of the southbound lanes.

Due to the low traffic volume on this two-lane divided roadway, and because the original bridge was only 50 feet long (replaced by the 75-ft-long new bridge), historical accident rates for the short span are not meaningful. In the 5 years before construction began (2007–2011), only one accident was recorded near the vicinity of the bridge. The property damage only crash happened

in inclement (snowy) weather and was not attributed to any specific characteristics of the bridge. However, the widening of the bridge (from a 30-ft roadway width to a 42-ft roadway width) provided extra distance between the lane stripe and the bridge barriers, which is expected to enhance motorist safety (see figures 76 and 77).



Figure 76. Small shoulders on the old bridge resulted in an increased chance of crashes and structural damage due to errant vehicles.



Figure 77. Both inside and outside shoulders of the new bridge are wider, resulting in improved motorist safety.

CONSTRUCTION CONGESTION

As noted previously, the southbound roadway was completely closed for removal of the old bridge and construction of the new one, and all southbound traffic was diverted to the two-lane northbound direction. Based on visual observations and discussions with the MnDOT project manager, the diverted traffic was free flowing at all times. The low traffic volume (two-directional AADT of 8,100) on the roadway without any significant morning or evening peaks allowed for this diversion without any major traffic impact.

The traffic diversion was approximately 2 miles (barrels start at the 0.0 mark, one lane traffic starts at 0.2, transition to northbound direction at 0.9, transition back to southbound direction at 1.5, one lane traffic at 1.8, and barrels end at 2.0). Based on the difference in posted speed limits, the delay time per vehicle for the 2-mile diversion is calculated to be:

$$(2 \text{ miles}/55 \text{ miles per hour} - 2 \text{ miles}/65 \text{ miles per hour}) \times 3,600 \text{ seconds per hour} = 20 \text{ seconds}$$

The 20-second delay time would be the same regardless of whether the bridge was constructed with precast deck panels or was cast-in-place. However, the accelerated construction of the precast bridge as compared to a cast-in-place bridge (estimated reduction in time of 3 weeks) resulted in a reduction in cumulative delay time of 945 vehicle-hours:

$$3 \text{ weeks} \times 7 \text{ days per week} \times 8,100 \text{ vehicles per day} \times 20 \text{ seconds per vehicle} \div 3,600 \text{ seconds per hour} = 945 \text{ vehicle-hours}$$

An even greater reduction in construction time can be expected in locations with greater traffic volumes and construction congestion.

QUALITY

Producing the full-depth precast concrete deck panels at a climate-controlled fabrication facility outside the project critical path schedule is expected to result in higher quality control and increased durability. In addition, the use of longitudinal post-tensioning to hold the panel joints tight along with an epoxy chip seal applied to the deck surface is expected to provide further deck protection and skid resistance, as well as reduce short and long-term bridge maintenance.

Although the quality of the bridge potentially was improved, the replacement process had no impact on the noise and smoothness of the pavement surface. Because of the short bridge length, noise and smoothness data are not meaningful and were not collected for this project.

USER SATISFACTION

Following completion of all construction activities and opening to traffic, a user satisfaction survey was conducted. The objectives of the survey were to (a) identify how satisfied users were with the new facility as compared to its previous condition, (b) identify users' experience and tolerance of traffic disruption during construction, and (c) understand if users had knowledge of this construction project's innovations.

The survey included Constant Contact members and MnDOT Online Community members. Constant Contact members are travelers who request MnDOT’s email updates for particular construction projects. The MnDOT Online Community is a recruited, representative sample of Minnesota residents, based on the 2012 census data. Constant Contacts were surveyed between September 11 and September 25, 2012. A reminder was sent halfway through the survey period. The Online Community was surveyed between September 14 and September 28, 2012.

The number of respondents from both surveyed groups was extremely small, and it is recognized that the results represent the opinions of those travelers who responded, not the general population of the area. Of those surveyed, 21 had driven over the Paleface River bridge before and after construction, compared to 37 who had only driven the route before construction. The comparison of “before” and “after” satisfaction with the bridge and adjacent roadway indicates a higher level of satisfaction post-construction as shown in tables 3 and 04.

Table 3. Respondent satisfaction before construction.

| How satisfied were you with the Paleface Bridge and adjacent roadways before the recent construction improvements? | |
|---|------------------------------------|
| | Number of Responses |
| 7 = Very satisfied | 4 |
| 6 = Satisfied | 10 |
| 5 = Somewhat satisfied | 10 |
| 4 = No Responses | 3 |
| 3 = Somewhat dissatisfied | 5 |
| 2 = Dissatisfied | 3 |
| 1 = Very dissatisfied | 2 |
| Total | 37 (Weighted Average Score = 4.68) |

Table 4. Respondent satisfaction after construction.

| How satisfied are you with the Paleface Bridge and adjacent roadways since the construction has been completed? | |
|--|------------------------------------|
| | Number of Responses |
| 7 = Very satisfied | 9 |
| 6 = Satisfied | 9 |
| 5 = Somewhat satisfied | 0 |
| 4 = No Responses | 0 |
| 3 = Somewhat dissatisfied | 0 |
| 2 = Dissatisfied | 1 |
| 1 = Very dissatisfied | 2 |
| Total | 21 (Weighted Average Score = 5.76) |

Respondents also rated the amount of traffic disruption they experienced during construction. The scale ranged from “No disruption” (1) to “Extreme disruption” (7). Table 5 shows that most respondents rated the traffic disruption as low. Respondents were also asked their level of

tolerance or acceptability to the amount of traffic disruption they experienced. Table 6 shows these responses.

Table 5. Respondent rating for traffic disruption.

| How much traffic disruption, if any, did this construction project cause for you? | |
|--|------------------------------------|
| | Number of Responses |
| 1=Extreme disruption | 2 |
| 2 | 0 |
| 3 | 4 |
| 4 | 2 |
| 5 | 8 |
| 6 | 10 |
| 7= No disruption | 10 |
| Total | 36 (Weighted Average Score = 5.33) |

Table 6. Respondent acceptability of traffic disruption.

| How acceptable was this level of disruption during the construction project? | |
|---|------------------------------------|
| | Number of Responses |
| 1= Completely unacceptable | 0 |
| 2 | 0 |
| 3 | 2 |
| 4 | 5 |
| 5 | 4 |
| 6 | 5 |
| 7= Completely acceptable | 18 |
| Total | 34 (Weighted Average Score = 5.94) |

Overall, respondents from both surveys felt that the disruption was acceptable and to be expected during a construction project, although several respondents who experienced extreme disruption did not see this as acceptable. One respondent from the Online Community commented, “There is always traffic during construction, that’s to be expected; and I didn’t feel it was too bad at all.”

All survey respondents were asked if they had heard anything about the new innovation associated with the bridge construction. Over half of Constant Contact respondents and at least three-quarters of Online Community respondents stated that they did not hear of the innovations as summarized in table 7. One respondent recalled hearing about an innovation: “It was the first bridge in Minnesota that used pre-formed concrete sections. I think the State of Minnesota should keep using these pre-formed concrete sections so they can complete the job faster and safer.”

Table 7. Respondent awareness of innovation.

| Did you see or hear anything about a new innovation associated with the bridge construction? | |
|---|---------------------|
| | Number of Responses |
| Yes | 7 |
| No | 34 |
| Not sure | 10 |
| Total | 51 |

ECONOMIC ANALYSIS

A key aspect of HfL demonstration projects is quantifying, as much as possible, the value of the innovations deployed. This entails comparing the benefits and costs associated with the innovative project delivery approach adopted on an HfL project with those from a more traditional delivery approach on a project of similar size and scope. The latter type of project is referred to as a baseline case and is an important component of the economic analysis.

For this economic analysis, MnDOT supplied the cost figures for the as-built project. The baseline case costs were obtained from MnDOT for a comparable bridge (bridge 69049) constructed through traditional cast-in-place construction in a nearby county 5 years ago.

CONSTRUCTION TIME

The total actual closure and traffic detour time for bridge 69071 was 55 days. This was greater than anticipated; MnDOT estimates that it should have been 45 days. As shown in the actual construction schedule (table 2), approximately 10 days of delays were the result of waiting for delivery of the girders and the post-tensioning subcontractor. Based on the comparison with the road closure time on Bridge 69049, MnDOT's estimated savings in closure and traffic detour time for this project would have been 21 days.

DETOUR

As described earlier, the traffic detour for the construction of bridge 69071 was limited to diverting the southbound traffic to the northbound lanes. Because of the low traffic volumes and the rural location, the traffic was free-flowing at all times. As a result, the average delay time is estimated as 20 seconds per vehicle. Had this not been a four-lane divided roadway, the detours (and correspondingly, the delay times) would have been much more significant. Higher traffic volumes and urban locations with morning and evening peaks also would have resulted in a substantially higher overall impact on traffic.

CONSTRUCTION COSTS

The engineer's estimate for the construction of bridge 69071 was \$489,981.40. However, the winning bid was \$686,076.70. The bridge construction was part of a larger construction project which primarily included paving north and south of the bridge. The engineer's estimate for the entire project was \$3,007,751.25, while the lowest bid for the entire project was \$3,449,277.71. The lowest bid tab amount for just the construction of the bridge was \$682,771.40.

Bridge 69049, with similar traffic and dimensions, but with traditional cast-in-place construction, was constructed in District 1, 5 years prior in 2007. The cost of that bridge in 2007 was \$327,369.70. Using a 2.5 percent discount rate, that translates to \$370,388.77 in 2012 dollars. Although bridge 69049 is approximately 22 ft longer than bridge 69071, it is 6 ft narrower, thus making them approximately similar with regards to structural, material, and mobilization considerations. Two key differences are that bridge 69049 did not have an epoxy chip seal or

require mock-up panel construction, whereas bridge 69071 does have an epoxy chip seal and required construction of mock-up panels for evaluating the construction process. The epoxy chip seal cost was \$37,649.50, and the mock-up panel cost was \$57,000. Not including the costs of the epoxy chip seal or the mock-up panel, bridge 69071 cost \$221,038.43 more than bridge 69049 in 2012 dollars. The price for the mock-up panels is excluded from the costs because once the technique for construction and transportation of precast deck panels becomes a MnDOT standard, mock-up panels would not be required.

USER COSTS

Generally, three categories of user costs are used in LCCA: vehicle operating costs, delay costs, and crash- and safety-related costs. The cost differential in delay costs was included in this analysis to identify the differences in costs between the baseline and as-built alternatives. Since no detours resulting in increased mileage were included in this project, vehicle operating costs are not applicable for this analysis.

The following baseline information was available for bridge 69071:

- Based on the data provided by MnDOT, the AADT was 8,100 with 1,240 commercial traffic.
- The average delay time on this project was 20 seconds.
- MnDOT estimates delay costs of \$15.60 per hour for automobiles and \$26.90 per hour for commercial trucks.

Assuming that traditional construction would have impacted traffic for an additional 21 days, this results in a user delay cost differential of \$16,376.73, as calculated below:

$[6,860 \text{ passenger cars/day} \times 15.60 \text{ delay cost/hour} + 1,240 \text{ commercial trucks/day} \times 26.90 \text{ delay costs/hour}] \times 20/3600 \text{ hours delay} \times 21 \text{ days} = \$16,376.73$

The safety standards for the bridge would be the same whether the bridge was constructed using traditional or innovative methods. As such, the crash- and safety-related costs between the as-constructed case and baseline cases are expected to be identical.

INITIAL COST SUMMARY

Traditional construction methods using cast-in-place decks would have cost MnDOT about \$221,038.43 less than ABC using precast decks. However, ABC techniques saved \$16,376.73 in user costs related to traffic delays, for a net cost differential of \$204,661.70.

LIFE CYCLE COST ANALYSIS

To quantify the benefits of the improved performance and service life of the as-constructed bridge versus the baseline bridge, LCCA was performed using a deterministic approach (i.e., no variability in costs, ages, etc. was considered). Life cycle costs differentials were computed in the form of NPV, which is defined as follows:

where:

$$NPV = Initial\ Cost + \sum Future\ Cost * \left[\frac{1}{(1+i)^n} \right]$$

NPV = net present value, \$.
i = discount rate, percent.
n = time of future cost, years.

Figure 78. Equation. Calculation of NPV.

Table 8 summarizes the various costs and the applicable timeline. A discount rate of 2.5 percent was used based on information provided by MnDOT (http://www.dot.state.mn.us/planning/program/appendix_a.html accessed December 2012).

Table 8. Summary of life cycle cost differentials in 2012 dollars (60-year analysis period).

| Cost Category | Age (yrs) | Baseline Bridge | As-Constructed Bridge |
|--|-----------|----------------------|---------------------------|
| Preliminary Design and Engineering, Construction, Construction Engineering | | \$370,388.77 | \$686,076.70 |
| Delay-Related User Cost Differential | 0 | \$ 0.00 | -\$ 16,376.73 |
| Epoxy Chip Seal Differential | | \$ 0.00 | -\$ 37,649.50 |
| Mock-Up Panel Differential | | \$ 0.00 | -\$ 57,000.00 |
| Annualized Maintenance Differential | Yrs 21-40 | \$ 0.00 | -\$ 3,000/yr ¹ |
| Annualized Maintenance Differential | Yrs 41-60 | \$ 0.00 | -\$ 5,000/yr ¹ |
| NPV of All Cost Differentials | | \$ 370,388.77 | \$538,605.60 |

The life cycle cost differential analysis shows that the baseline project would cost MnDOT and the users of the roadway \$370,388.77 in terms of 2012 NPV based on a 60-year analysis period. By comparison, the as-constructed project will cost \$538,605.60 in terms of NPV, for a total excess cost of \$168,216.83. It is worth noting again here that MnDOT deliberately chose this project because of the rural location and the low traffic. The goal was to use it as learning and evaluation tool without any substantial impact on motorists and not necessarily to save costs on this specific project.

A key driver for the higher costs of bridge 69071 was the construction and transportation of the precast panels. They were constructed in the Minneapolis/St. Paul area and transported to the project site on flatbed trucks (two panels per truck) for a distance greater than 150 miles. The engineer’s estimate for this item was \$118,156.50, whereas the contractor’s bid amount for this

¹ Based on the cost estimates provided by Mn/DOT Bridge Office

item was \$276,210.00, for a cost differential of \$158,053.50. The costs for this item would have been substantially lower had the precast deck been fabricated closer to the project location.

Also, if this project would have been constructed at a location with substantially higher traffic impact (such as roadways with higher traffic volumes, urban locations with morning and evening peaks resulting in higher traffic delay times, locations requiring substantial detours resulting in higher traffic delay times and vehicle operating costs), the as-constructed bridge would likely have a lower NPV than the baseline case. MnDOT also believes that costs for this type of project would come down as contractors and industry gain experience with ABC methods.