ACCELERATED STEEL SOLUTION IN THE HEART OF IRON COUNTRY

VINCENT T GASTONI

KEVIN WESTERN

BIOGRAPHY

Mr. Vincent Gastoni is a Principal Bridge Engineer with Parsons and one of Parsons leading Design-Build and complex bridge Project Managers with over 24 years of structural experience in the design and management of major transportation projects. Mr. Gastoni's signature projects include the New Carquinez Suspension Bridge, Vallejo, CA; I-64 Design Build, St. Louis MO; and the Lafayette Bridge Replacement over the Mississippi River, St. Paul MN, the Hastings Bridge over the Mississippi in Hastings MN and the US 53 Rouchleau Mine Bridge in Virginia, MN. He is currently serving as the CEI Manager to the MN DOT on the new extradosed bridge over the St Croix River between Minnesota and Wisconsin and the Design Manager for the new Cable Stayed Lachine Canal Bridge in Montreal Quebec.

Mr. Kevin Western is MnDOT's Design Manger for the US 53 Project. He has 29 years of experience in bridge design, standards, and construction, and is currently the MnDOT's Major Bridge Projects Design Manager including the St. Croix River Crossing and the US 53 project. He also served as MnDOT's Assistant State Bridge Engineer in charge of the Design Area as well as the Deputy Project Manager for Design on the 35W Bridge Project.

SUMMARY

The new 1,130 foot long steel plate girder bridge will span the Rouchleau mine through the heart of the U.S. Mesabi Iron Range in northern Minnesota with a 480 foot long main span 180 feet above the mine floor. US 53 is a principal route in the region including the Lake Superior Ports of Duluth, Minnesota and Superior, Wisconsin and is being relocated due to encroaching mining operations. Due to critical time constraints required to complete the project by 2017, the Minnesota Department of Transportation (MnDOT) selected the delivery method and utilized steel to accelerate the design and construction

To expedite design and fabrication in parallel with the substructure design and construction MnDOT selected a steel plate girder structure. The steel option allowed MnDOT to advance an early steel contract in concurrence with the project environmental review shortening the construction schedule by several months. Steel was also less sensitive to the extreme weather conditions, allowing for four-season construction. Beginning in late February 2015, the team worked collaboratively to deliver the steel design in 52 days using an integrated fabrication approach.

Leveraging steel and integrating the best industry practices were central to successfully delivering the design for the accelerated construction schedule while mitigating project risks.

Mr. Vincent Gastoni PE, Parsons
Mr. Kevin Western PE, MN Dept. of Transportation

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Overview/Introduction

US Highway 53 traverses the Mesabi Iron Range through the idyllic landscape of Northern Minnesota. Since the late 1800s' this region has been the heart of the United States iron economy. The highway is also a High Priority Corridor on the National Highway System and a critical transportation link serving the Lake Superior Ports of Duluth, Minnesota and Superior, Wisconsin

In the Iron Range city of Virginia, US 53 passes between two open pit iron mines on land leased to the Minnesota Department of Transportation (MnDOT) from the mining companies since 1960. Current taconite mining operations have extended to the highway, and the highway will need to be relocated by the fall of 2017 to continue mining operations per the lease agreement. MnDOT evaluated multiple alignments in and around the mines and City of Virginia ultimately deciding on a three mile alignment crossing the idle, water filled, Rouchleau Mine Pit to the northeast of the existing alignment.

A critical project contraint was the environmental review process which would not be completed with a Record of Decision (ROD) in September 2015 and the need to start construction in November 2015 to meet the lease agreement vacate date of November 2017. In order to meet this challenge, MnDOT decided to advance the design, at risk, ahead of the ROD utilizing the Construction Manager General Contractor (CMGC) project delivery method. This approach allowed MnDOT to select a design consultant to while concurrently having a contractor under contract to participate in the design development, review site constraints and start the construction shortly after the environmental process was completed.

Through this process, MnDOT is constructing a new 1,130 foot, three span steel plate girder bridge, with a 480 ft long main span 180 feet above the floor of the Rouchleau Mine Pit. Project challenges included an accelerated design schedule to accommodate the lease agreement, near vertical rock face walls, mine waste rubble to depths of 120 feet below the pit floor, the need to accommodate future mining operations of the reactivated mine, and a lake in the pit which serves as the drinking water supply for the city of Virginia.

Bridge Type & Schedule

After careful review of structure types, site constraints and risks, MnDOT selected a steel

Figure 1: Site overview looking north

plate girder structure as the preferred structure type. Primary reasons for selecting this bridge type were lower cost and reduced schedule risk due to the ability to expedite design and fabrication in parallel with the design and substructure construction.

The steel option also allowed the state to advance the project ahead of the ROD with an early steel contract shortening the construction schedule by several months. Steel erection is also less sensitive to extreme weather conditions than other bridge types, such as segmental concrete, thus reducing the risks of schedule delays by allowing winter construction operations. Parsons Transportation Group (Parsons) was selected by MnDOT to perform the design of the new bridge while Kiewit Construction was selected as the CMGC under a separate MnDOT contract.

The accelerated design schedule included an early steel procurement and fabrication package for the 5,300 ton superstructure within the first 90 days. Key to delivering the design was the integration of the steel industry and a formalized risk management system which focused the project design priorities to ease of fabrication and shipping and minimize schedule risks. Beginning in February 6, 2015, the design team worked collaboratively with MnDOT and the CMGC to validate the structure type and develop delivery strategies to directly address the project risks associated with schedule, the northern Minnesota environment and the unique terrain of the open pit mine. Parsons integrated the best industry practices into the project including Tensor Engineering as a design team member to provide draft shop drawings as part of the bid package to minimize bid risks, facilitate mill orders, and ultimately expedite fabrication. Within 52 days of Notice to Proceed, Parsons delivered the complete plans for the 5,300 ton superstructure and completed the remainder of the project ahead of schedule to allow the construction to start shortly after the ROD was received in September of 2015.

CMGC Process

This CMGC delivery method allowed MnDOT to develop severable design packages with the CMGC contractor serving as their construction manager to develop scope and schedule while managing risks and providing detailed costs estimates for each package. The CMGC also has the opportunity to bid on these packages. Upon review of the CMGC's bid, MnDOT can then award a construction contract to the CMGC, who becomes the General Contractor for the construction of the project or advertise the project publically to solicit bids. In December 2014 MnDOT selected their CMGC, Kiewit Construction, to assist during the preconstruction design development phase.

As a risk management tool the CMGC approach brings the owner-designer-contractor together as a single team. This allowed MnDOT to capture the full spectrum of project risks and mitigate them as

Work Task	START	FINISH	2015	2016	2017
Work Package 1 (Early Steel Package)	6-Feb-15	30-Apr-15			
Work Package 2 (Bridge, Civil & Utilities)	15-Mar-15	7-Oct-15			
Steel Procurement & Fabrication	Jun-15	Aug-16			
Pier & Abut Construction	Nov-15	Sep-16			
Superstructure Erection	Aug-16	Feb-17			
Deck & Finish	Feb-17	Aug-17			
Roadway Construction	Jan-16	Sep-17			

Figure 2: Project Schedule

a team. Ultimately, the process reduces risk by providing the team more certainty and reducing unknowns that can drive both an owner, and a contractor's risk contingencies. A success on the US 53 projects was the team decision to reduce the number of final work packages. This directly reduced the contingencies and indirect costs associated with the uncertainty of the Contractor having to bid on the final third package as a stand-alone bid as well as being able to advance the construction schedule.

In the case of the early steel procurement package, the CMGC process was not as effective. Severable work packages meant the team had to address each package as an individual job limiting the ability to integrate specific means, methods or operational preferences of the contractor. Also, unlike a Design-Build process, under a CMGC approach the Contractor does not enter into agreements with fabricators and erectors during the design phase limiting input on detailing, shipping, and erection resulting in the similar process as MnDOT applies through their industry outreach in a normal design. The accelerated design schedule meant the design team had to make immediate decisions using their experience and industry "best practices" with limited input from the general contractor. However, as a risk mitigation tool, the project benefited from an informed contactor with a complete understanding of the structure and operational opportunities.

Design Approach

In Late January 2015, MnDOT selected Parsons as their designer. Design began in early February as a co-located team of owner-designer-contractor. Weekly task forces were utilized to coordinate design progress, constructability reviews and procurement needs. The pace of design and decision making was blistering with the preliminary plan due in the first 30 days and a fully detailed and sealed set of steel superstructure plans due in the first 90 days.

Parsons held a kick-off workshop shortly after receiving their Notice-to-Proceed. The goals of the workshop were to review the MnDOT three-span steel plate girder conceptual design, validate the type selection and prioritize key design elements

Figure 3: Bridge rendering looking north-east

with regard to cost and schedule. From this review the team identified span layout and fixity, erection, fabrication, shipping, materials, and deck systems as priorities.

The entire team confirmed the steel plate girder bridge as the preferred type for cost and schedule, and it presented the least risk option to meet the project goals. The final bridge span arrangement of 270'- 480'- 375' was slightly altered from the MnDOT conceptual layout of 250'- 500'- 375' to move the east pier, closer to the water and minimize rock excavation. The west pier location, within the mine waste fill zone, was confirmed by the team and remained unchanged. Fixity conditions were also an early consideration with regard to stabilizing the piers and minimizing the number of joints in the bridge. Due to the height of the piers and overall bridge length, Parsons proposed a tie-back system at the east abutment similar to their Hurricane Deck Bridge over the Lake of the Ozarks in Missouri. For the Rouchleau mine bridge, this system was combined with a semi-integral abutment to eliminate a maintenance prone modular joint and improve long term durability. The west abutment would be a conventional parapet seat type on multi-directional bearings with a modular expansion joint. Piers utilized fixed disk type bearings.

In the week ahead of the workshop, MnDOT and Parsons ran parametric studies of the bridge cross section to evaluate optimal steel weights, web depths, plate thickness and deflections. Seven and eight girder sections were evaluated based on a 174 inch maximum web depth. Web depth was selected as a constraint to facilitate competitive bidding, fabrication, and shipping. This depth was based on MnDOT's experience with the majority of fabricators' shop limitations and would maximize the number of competitive bidders. Secondly, the 174 inch piece was a proven shippable size that would not require significant specialty considerations. Bolted web splices were considered but the additional cost and complications they presented in fabrication and erection versus a shop spliced web were seen as an unnecessary risk where a 174 inch web design solution was achievable.

The typical section was confirmed and approved

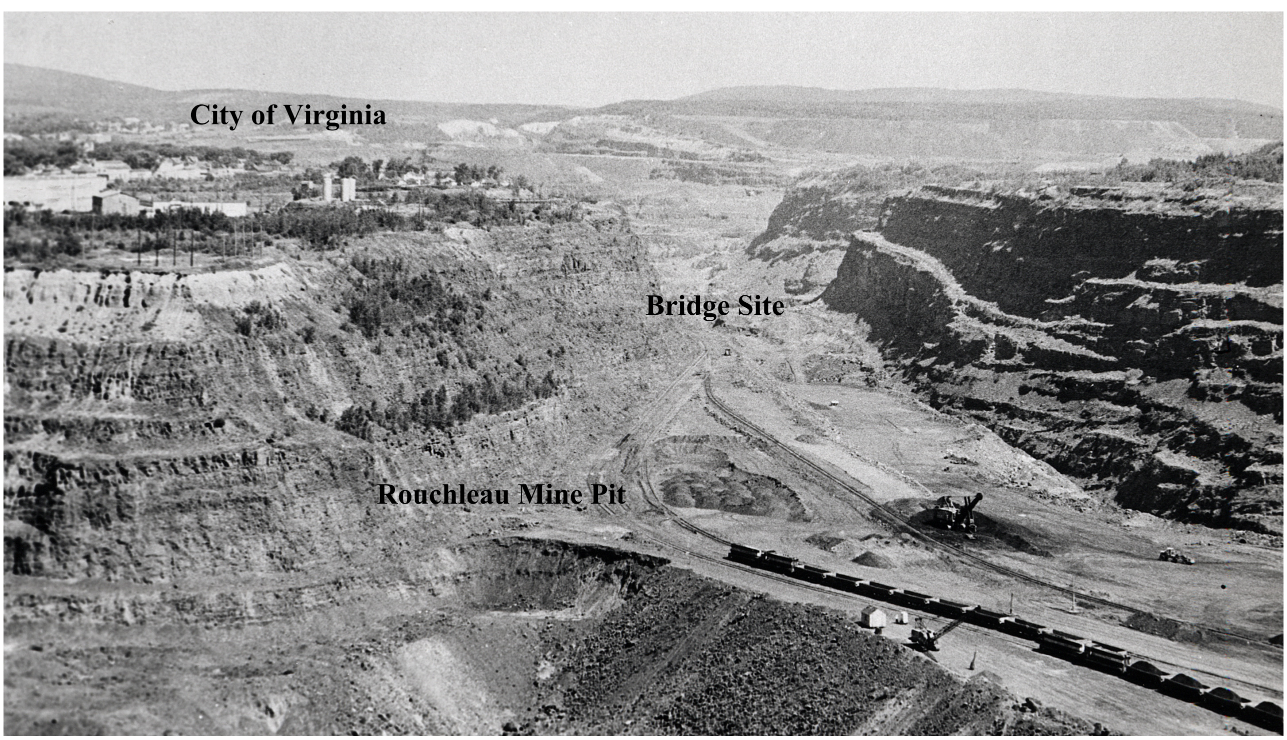

Figure 4: Historic photo of active Rouchleau pit at bridge site

in the project kick-off work shop. From this preliminary evaluation, an eight line configuration was selected. A seven line design required 4-inch thick flanges over the pier supports with no initial reserve and was only marginally meeting the deflection criteria. The eight-line solution offered more flexibility in final design, reduces design schedule risk should loads increase or deflections control the design. Even though the seven line arrangement was about 5% less steel, eight-lines ensured the preferred maximum web depths would be achievable combined with a lower cost deck due to reduced stainless steel reinforcing demands for the closer spaced girder. The final web configuration consisted of 174 inch deep webs over the piers, a 93 inch deep web in Span 1 and 112 inch deep web in Span's 2 and 3. Per MnDOT standard practice, all steel would be GR50W weathering steel specified for cold weather climate (Zone 3 Charpy). Use of high strength steel would be reviewed as part of the final design process.

A substringer cross section configuration was considered and rejected early in the preliminary design process. While it represented a savings in steel weight, it increased project risks which offset the material costs. Risks identified included the increased level of design effort and duration, higher fabrication demands impacting the overall schedule, and increased web depth at the piers complicating shipping. Erection would also be negatively impacted due to the increased piece weight and complexity associated with the substringer framing fit up and bolting demands. Availability of rolled section materials meeting the Charpy T3 requirements also presented a materials risk for procurement and fabrication.

Erection was a significant consideration in the design process and the CMGC method allowed direct access to the contractor's operational capabilities and experience. As noted previously however, the CMGC requirement to maintain severable work packages meant that the contractor could only act as an industry advisor and their specific means, methods and capabilities could not be integrated into the design. Through the initial kick-off workshop, various erection schemes were reviewed including strand jack lifting of the main span and launching. The terrain of the mine pit challenged the team with a 212 feet tall shear rock face at the east pier and water depths of 132 ft. Construction of span 3 could be conventional due to the exposed floor of the mine in the waste fill area; however, it still presented the need to work over 190 feet in the air.

In order to advance the design toward the schedule completion date, the team agreed to the baseline schematic erection approach of erecting the back span conventionally and installing the main span from the water in a single lift utilizing strand jacks and strong backs. Fabrication camber was then based on a traditional no-load configuration

Figure 5: View from east abutment looking west during field boring program

without the need for specialty considerations ahead of the contractor's actual means and methods. Launching was rejected due to the curved approach alignment at the east abutment precluding practical launching without more extensive rock excavation. The contractor also prepared conceptual erection plans and worked with the design team to adjust splice locations and piece weights to accepted practices. Ultimately, the CMGC process, the contractor decided to build a full width rock causeway across the water and erect the entire structure conventionally.

With the deck design occurring after the early steel package, it was critical to develop a baseline deck concept so that plate sizes and cambers would not change and design could progress on the early steel design package. A cast-in-place CIP deck was selected since it would not prelude the use of the alternate deck systems. To facilitate the schedule, MnDOT elected a single stage, nine inch thick cast-in-place deck and epoxy overlay utilizing stainless steel reinforcement. The team evaluated alternative deck systems for schedule, cost and long term durability opportunities. Only full deck precast concrete deck panels utilizing ultra high performance concrete (UHPC) were ultimately considered since partial depth concrete panel have a poor performance record in Minnesota. Eventually, the UHPC system was determined to be too expensive and too risky to schedule without any significant cost savings and not incorporated due to the potential for cold weather placement combined with the limited historical use of UHPC nationwide. However, if the CMGC contractor was interested in using the UHPC system and MnDOT was open to a value engineering proposal during construction based on actual schedule and construction progress. The final deck system utilizes the stay-in-place (SIP) metal form system which provided the best compromise of schedule and performance since it could be installed with the girders.

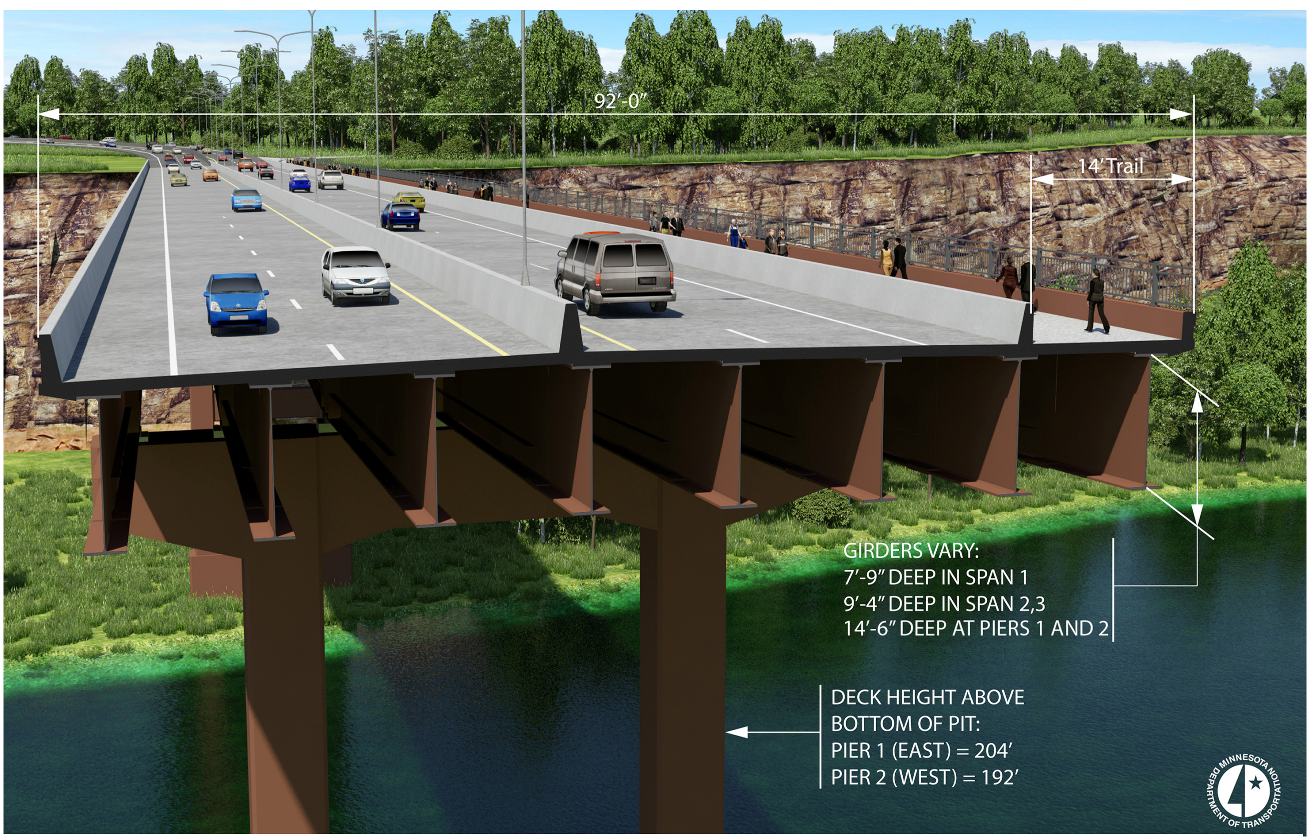

Figure 6: Bridge section looking west

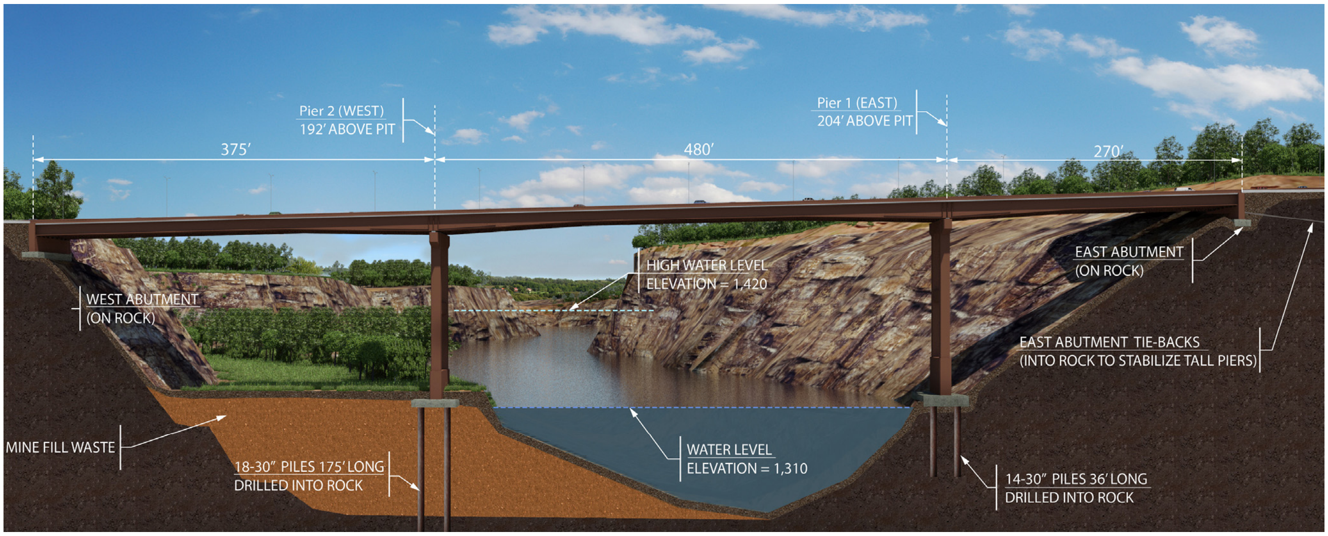

Figure 7: Cross section of bridge site

Analysis and Design

The design is based on MnDOT standards, 2014 AASHTO LRFD Bridge Design Specifications for the HL-93 load, MnDOT permitting vehicles and an importance factor of 1.0. Parsons, design utilized a line girder analysis with unique live load distribution factors determined through a detailed 3D LARSA model due to the long span (Table 1). Methodology for live distribution followed AASHTO code development methodology utilizing only the concrete deck and girders without consideration for the cross frames and lateral bracing.

	Exterior Girder		Interior Girder	
	Design	Fatigue	Design	Fatigue
Moment LLDF, Positive Moment Region				
Span 1	0.782	0.587	0.639	0.360
Span 2	0.770	0.575	0.627	0.368
Span 3	0.776	0.549	0.628	0.342
Moment LLDF, Negative Moment Region				
Pier 1	0.852	0.553	0.695	0.329
Pier 2	0.857	0.573	0.689	0.330
Shear LLDF				
Pier 1	0.917	0.704	1.038	0.593
Pier 2	0.933	0.704	1.022	0.580

Table 1-Live Load Distribution Factors (LLDF) from 3D LARSA Analysis

Correlation to AASHTO was generally as expected proving the methodology used. Table 2 shows AASHTO live load distribution factors for reference. These values have been determined per LRFD Article 4.6.2 using the actual span lengths.

	Exterior Girder		Interior Girder	
	Design	Fatigue	Design	Fatigue
Moment LLDF, Positive Moment Region				
Span 1	0.788	0.792	0.755	0.389
Span 2	0.737	0.792	0.705	0.347
Span 3	0.787	0.792	0.754	0.378
Moment LLDF, Negative Moment Region				
Pier 1	0.875	0.792	0.837	0.418
Pier 2	0.861	0.792	0.824	0.407
Shear LLDF				
Piers	0.918	0.7917	1.082	0.700

Table-2 Live Load Distribution Factors (LLDF) from AASHTO LRFD (for reference)

Live load deflection was checked using line-girder analysis with the following project specific deflection limits and live load distribution factors:

Limit	LLDF	Case
L/800	0.6375	6 lanes/8 girders x 0.85 MPF
L/1000	0.5313	5 lanes/8 girders x 0.85 MPF
L/1000	0.5688	7 lanes/8 girders x 0.65 MPF

Table-3 Live Load Distribution Factors from

Framing Plan Optimization

The use of high strength steel was evaluated early in the design process to reduce steel weight and costs related to shipping and erection. Parsons, evaluation of GR70W steel in the flange plates indicated a total savings of about 125T (about 2%) representing a net cost saving to the GR50W of about $80,000. This represented about a 0.5% cost saving of the estimated total steel cost of $14.9M. Based on this analysis, Parsons recommend proceeding with the GR50W steel only. The resulting weight reduction related to high performance steel for shipping and erection and small cost benefit was not significant enough to mitigate the potential supply risk still associated with GR70 steels over 2-1/2 inch thick.

Web plate thickness optimization focused on web stiffening and fabrication costs. In the haunched regions Parsons investigated the web stiffeners against a thickened web section. A baseline design of a stiffened web design offered about 94 lb/ft of weight saving over an unstiffened web but at a higher fabrication cost due to the intersecting plates of the vertical and longitudinal stiffeners plus the increased fabrication duration. Eliminating all intermediate stiffeners increased the average total steel weight about 617,000 lbs. This equated to an average weight increase of 2,300 lbs for each stiffener removed with MnDOT guidelines recommending an intermediate stiffener where a 1,000 lb weight reduction can be achieved. Based on this evaluation, Parsons optimized the web by utilizing an unstiffened web in the shallower haunched sections, thus eliminating the horizontal web stiffeners as well in these sections, and a stiffened web elsewhere.

Due to the need for lateral wind bracing, Parsons selected the horizontal cross bracing spaced tighter than MnDOT typically uses in their traditional designs. This approach results in steeper lateral bracing angles to reduce the bracing member loads and connection demands. To evaluate this approach Parsons investigated cross frame spacing in the 18 ft. and 22 ft. range. The tighter lateral bracing spacing was shown to actually reduce overall steel weight by reducing the forces and member sizes in lateral bracing. This also had the added benefit of improving constructability performance for deck placement due to closer spaced cross frames.

Max Cross Frame Spacing	18'	22.5'
Cross Frame + Angle Lateral Brace (lb.)	339,600	381,600
Cross Frame + WT Lateral Brace (lb)	303,300	326,100

Table 4-Cross Frame Optimization Results

While WTs further reduced the lateral bracing weight, feedback from suppliers was mixed regarding the extra cost for splitting and straightening WT's. Angles were used in the base design with the option for the fabricator to utilize WT's. The final shop drawings utilized angles as designed.

In order provide a fully integrated, industry team approach to the project, Parsons included Tensor Engineering on the design team to facilitate steel detail reviews and advise the design team. As part of Parsons' innovative approach, Tensor also developed the preliminary shop drawings as part of the design contract. The preliminary shop drawing included the preparation of calculation plans, web camber diagrams, flange cutting diagrams, cross frames, and diaphragm layouts to facilitate material ordering and expedite final shop drawings of the successful fabricator. This approach worked extremely well with the shop drawing development and review occurring without issue and with no delay to the project schedule.

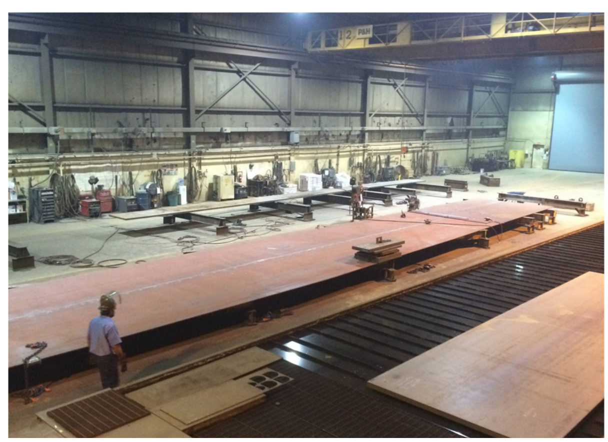

Figure 8: Steel fabrication begins Oct. 2015

Substructure Design

With the fabrication package delivered on schedule, the design team could fully focus on the remaining elements of the bridge. Preliminary design of the substructure took place during the superstructure design process in order to evaluate and validate the overall system stability and performance. Critical factors included the stability of the piers under construction and final wind loads, as well as stability due to pier heights of 182 ft. at Pier 1 and 165 ft. at Pier 2. Multiple pier sections from traditional columns to solid and hollow piers were evaluated. Ultimately, a two column, solid concrete, configuration was selected after thorough review by the CMGC contractor with regard to forms, lift configurations, and schedule. Hollow columns were considered to minimize the mass concrete pours on the project, but MnDOT's extensive experience with controlling heat of hydration in mass concrete through mix design was sufficient to not warrant cooling tubes or complex hollow section.

Due to the height of the piers, an intermediate brace was required. The team evaluated various configurations including a steel cross frame and steel beam strut with a traditional CIP concrete strut being selected. To facilitate the forming system of the pier columns during construction, the pier was designed to be constructed such that the strut could be added after the completion of the columns and top cap beam. By allowing a construction joint at this location the forming system could simply continue vertically past the strut region without any delay in column construction. Reinforcement layout was based on traditional best practices and was detailed as bundled #10 bars with lap splices. The CMGC was consulted on preference of fewer, larger reinforcing bars utilizing couplers as well as the use of 75ksi reinforcement, but due the speed of the design process, no definitive recommendation could be made and the #10 bars remained as the baseline design. After award of the final construction package, the CMGC contractor elected to submit an RFI for a no cost change order to fewer #11, 75 ksi reinforcing bars utilizing couplers.

Foundation Design

MnDOT had performed a pile test program in the winter of 2014-2015 to evaluate pile installation and load capacities in the mine waste fill area near Pier 2 (west). 16 and 24 inch rotary drilled test piles using ½ inch thick steel shells were installed through the 135 feet of boulders, cobbles and fill to the iron formation bedrock below. Casing was seated into the bedrock at various depths with rock sockets extending further below. The entire system was tremie filled with high strength grout and concrete. The piles were all successfully installed and tested with results exceeding minimum required capacities. The information from the program allowed MnDOT to minimize the rock socket length in the final design. Dan Brown and Associates served as the project Geotechnical Engineer of Record for the project under contract to Parsons.

Through the CMGC process, a 30 inch pile alternative was identified as a viable alternative during the design process. Evaluation of the 30 inch pile showed it would reduce the number of piles to be installed and improve production schedule as well as reduce the size of the footing.

Figure 9: 30" Rotary drilled pile installation, December 2015

However, since the 30 inch piles were not the tested system, 24 inch piles were utilized as the baseline design with the 30 inch included in the plans as an alternative. Ultimately the 30 inch piles with a ϕRn of 3,000 kips filled with 7 ksi grout and concrete were selected by the contractor and installed into the permanent work. To facilitate the installation schedule, MnDOT procured the majority of the 30 inch casing at risk ahead of the final CMGC work package.

Instrumentation

MnDOT will instrument the bridge and site with the goal to provide a monitoring system to measure changes in the rock slopes and bridge. This monitoring will allow MnDOT to both confirm the design and provide early indication of changing conditions so that repairs or mitigation can be performed before and damage occurs. Primary site instrumentation includes multi-phased global arrays in the mine waste fill area and fixed survey targets on the rock faces and bridge elements. Geocomp designed the instrumentation and monitoring plan system under contract to Parsons.

Summary

When faced with a daunting time constraint and a unique, challenging environment, the Minnesota Department of Transportation teamed with industry leaders and turned to a steel solution to achieve their goals. Steel allowed the state to advance the construction schedule several months through an early procurement contract while reducing the risk of delays from extreme weather conditions with a four-season material. Under a CMGC delivery process and accelerated design schedule MnDOT delivered the 5,300 ton bridge on schedule, well on their way to the project goal of completing construction by November 2017. Leveraging steel and integrating the best industry practices were central to successfully delivering the design for the accelerated construction schedule while mitigating project risks. In a win-win approach, the steel solution offered least risk option to the Department while providing the residents of the Iron State of Minnesota the best value, lowest cost solution.

Figure 10: January 2016-Site looking east with rock causeway in place to cross the channel