# A COLLABORATION IN STEEL ACROSS THE BORDER

## Introduction

The Rainy River defines over 80 miles of the U.S.-Canadian Border between Rainey Lake and Lake of the Woods in remote northern Minnesota and western Ontario. The narrow 1953 Baudette/Rainy River International Bridge over the Rainy River connects the remote fishing villages of Baudette, MN and Rainy River, ON, on MN Highway 72 and Ontario Highway 11. With the next nearest border access over 70 miles away the bridge serves as a vital economic and social link between both the communities and the Countries with over 1,300 border crossings a day. The existing six-span steel truss is located within secured ports of entry and managed cooperatively by the two countries. It is at the end of its useful life and requires replacement.

The relatively modest river crossing connects two rural communities together with over 100 years of mutual history. In addition to the international cooperation necessary to bridge a border between two sovereign counties, to achieve success, mutual collaboration would be necessary to ensure the transportation needs of each Countries infrastructure system was fully respected. Recognizing this challenge, the joint owners of the structure; the Minnesota Department of Transportation (MnDOT) and the Ontario Ministry of Transportation (MTO), cooperatively developed a replacement program focused on satisfying the requirements of each countries transportation system.


**Figure 1:** Project Location

MnDOT was the lead Agency responsible for preparing, advertising and letting the final construction contract. Over the course of the project, the two Agencies acted singularly in the design development, consultant selection, submittal reviews and construction administration of the project to ensure acceptance within their organizations on both sides of the border. This meant that while the design needed to meet U.S. MnDOT/AASHTO LRFD

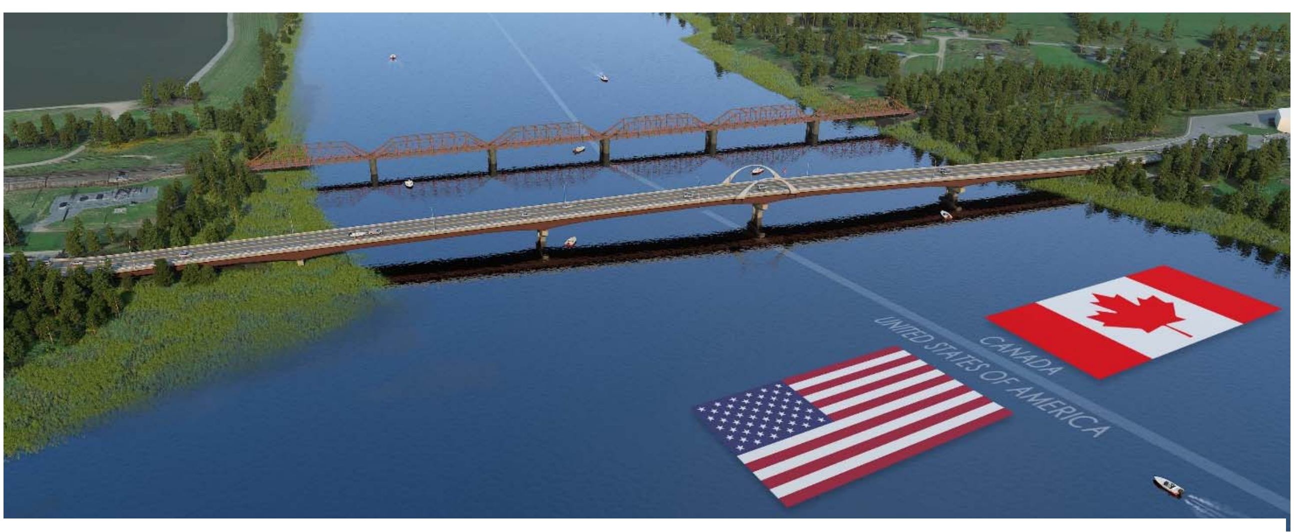



**Figure 2:** Overview Rendering Looking North

requirements it also had to be fully compliant with the CHBDC/CSA S6-14 code. Years prior to initiating the final design, both agencies worked to review their own specifications, preferences, permitting demands, and stakeholder needs. From this they developed a unified project criteria to facilitate the design between the two Countries. The final document would serve as a framework for the design team, but the final compliance of the numerous Articles of Code would remain the responsibility of the final design consultant.

After completion of the Preliminary Design in early 2017, MnDOT and the MTO selected a design consultant to prepare the final design. The agency's Request For Proposals (RFP) included specific requirements for the AAHSTO LRFD based design combined with an independent certification of compliance to the CSA-S6 code. The RFP also emphasized constructability demands in the remote region and harsh mid-continental climate. The project would also need to be completed under an accelerated design schedule to accommodate the MnDOT funding provided under the Minnesota Legislatures Chapter 152 bridge improvement program for structurally deficient and fracture critical bridges. As such, the final plans needed to be delivered to the agencies by November 1, 2017 to meet a February 2018 Construction Letting.

Parsons Transportation Group Inc. was selected in April 2017 for the final design and leveraged their significant US and Canadian resources, experienced in delivering to both agencies, to develop a team to work seamlessly across the border. This was fully goal realized with the spring 2018 with the start of construction of the 1,348-foot-long 5 span haunched steel plate girder bridge (pans=220'-300'-300'-300'-220' supported on hammer head piers and eight-foot diameter drilled shafts.

## International Design and Construction Criteria

With the majority of Canadian population centers located within 50 miles of the border, the U.S. and Canada are intertwined socially and economically through a network of highways and roads. The practical evolution of this network has created two transportation systems with very similar characteristics allowing for the flow of goods and services between the countries. However, creating a system that appears interchangeable to the user is one thing, the path to each Countries design approach, construction administration and long-term maintenance philosophy can be something different.

Since Codes are uniquely calibrated to their own parameters through specific live load vehicles and load factors for fatigue & strength, mixing codes can be a real "apples and oranges" issue. By selecting

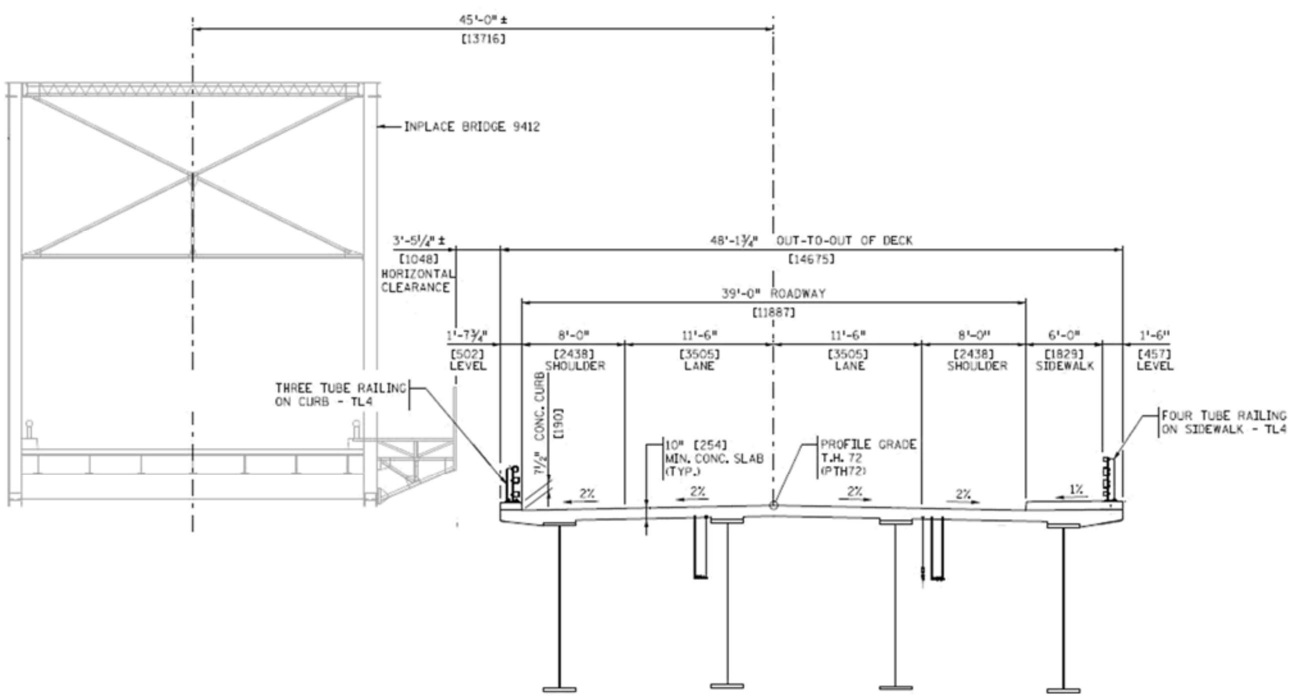



**Figure 3:** Typical Section (Looking North)

| Item | MnDOT | MTO | Project Criteria |
|---|---|---|---|
| Currency | U.S. Dollar | Canadian Dollar | U.S. Dollar |
| Units | U.S. Customary | Metric (SI) | U.S. Customary w/ Metric Subscript |
| Permitting | U.S. Agency | Canadian Agency | Respective Agencies |
| Design Specifications | AASHTO LRFD, $7^{th}$ Ed. | CHBDC/CSA S6-14 | AASHTO LRFD, $7^{th}$ Ed. w/ S6 Compliance |
| Traffic Barriers | MnDOT | MTO | MTO w/ FHWA Approval |
| Frost Level | 4'-6" (1.372 m) | 7'-3" (2.200 m) | 7'-3" (2.200 m) |
| Structural Steel | ASTM A 709 / A 588 Grade 50W | CAN/CSA G40.21-04 Grade 350AT | ASTM A 709 / A 588 Grade 50W |
| High Strength Bolts | ASTM A325 | ASTM A325 | ASTM A325 |
| Deck Design | Approximate Elastic | Empirical Method | Empirical Method |
| Reinforcing | Epoxy Coated | Black w/ Add'l Cover | Black w/ Add'l Cover |
| Reinforcing-Deck | Epoxy Coated | Black w/ Add'l Cover | Stainless Steel |
| Bearings | MnDOT/AASHTO | MTO/CSA S6 | MnDOT/AASHTO |
| Joints | MnDOT | MTO | Respective Agency |

**Figure 4:** Project Specific Criteria

one Agencies' code to lead the project and requiring independent certification to the other Agency's code MnDOT and MTO ensured a consistent design and process that would identify and address differences for full compliance. Ahead of the final design phase, the agencies reviewed each other's respective design and construction standards, identified variances and then prepared a project specific standard for the entire project team to follow. Key provisions of this document are listed in Figure 4.

The design team then incorporated these requirements into the project workplan which were then formally documented in the contract plans through the "General Notes" for current and future generations. During the design phase, these requirements were continuously reviewed by both the agencies personnel to ensure the final project and subsequent field construction would meet the unique requirements of an international crossing.

## Accelerated Schedule

One of the primary challenges faced by the project team was the need to complete the design and produce the approved contract documents by November 1, 2017 in order to assure the project funding. On receiving the Notice-To-Proceed (NTP) on April 3, 2017 this left the team 212 calendar days to evaluate, optimize, submit, review, resolve and coordinate a design between two sovereign agencies and multiple stakeholders local, regional and national stakeholders.

Key to successfully delivering the accelerated project was the groundwork both Agencies had spent years developing ahead of the final design phase. The project design criteria provided direction to the design team and monthly Project Development Team (PDT) meetings and Design Technical Meetings (DTM) allowed the Agencies to manage the technical groups through progress reviews and proactively resolve issues ahead of scheduled submittals. Critical to effective PDT and DTM meetings was for the design team providing information and issues ahead of the meetings.

To facilitate this communication, the design team also held biweekly team teleconferences to informally discuss the design progress, proactively address Agency comments and provide "Over-The-Shoulder" status prints for technical and interdisciplinary coordination. This process allowed the team to focus in on more significant issues and develop strategies for resolution head of the monthly meetings. Ultimately, the project schedule was met as planned by the entire team.

## Design Approach, Challenges & Unique Features

The MnDOT system of project development includes Scoping, Preliminary and Final Design phases. The goal of the preliminary design phase is to produce approved roadway design layouts and identify bridge type, size and location configurations so the final design team can proceed with little risk of changes in the base concept. This process also assures that the Municipal Consent of the design, required by law from local MN Stakeholders early in the project, is met in the final contract documents. MnDOT developed the 5-span, 1,340 foot-long preliminary bridge design plans in conjunction with the MTO and their preliminary design consultant Stantect. Parsons final design scope was to take this prepare the complete detail design and final contract plans and specifications.

Based on experience using both the AASHTO and CHBDC codes, Parsons prioritized known areas where the CSA-S6 can control the design over LRFD code in order to minimize risk of late-schedule changes during the S6 compliance review. These areas were reviewed early and compliance issues documented and resolved ahead of the subsequent submittal. Specific items included live-load distribution, Primary plate sizing for flanges and webs, fatigue, splice design and composite deck design.

**Live Load Distribution:** AASHTO and CHBDC utilize different methodologies for live load distribution to each girder which fundamentally impacts the girder design. With spans at 300 feet long, AASHTO simplified live load distribution equations were not applicable and refined analysis was required to develop project specific values. The preliminary design used the CHBDC code to develop the typical section and the design team was required to evaluate and optimize the girder spacing to ensure compliance to both codes.

Parsons developed 3-D finite element models to evaluate Dead Load (DL) and Live Load (LL) distribution of the preliminary design utilizing AASHTO methodology. The girder spacing was then optimized with a goal of balancing the interior and exterior girder DL+LL load over the 48'-1 3/8" wide typical section. Based on the Strength I results, Parsons increased the four girder section increasing from increasing from 12'-1" to 13'-0" and subsequent reduction in overhangs from 5'-11 3/8" to 4'-6 7/8". The CSA-S6 compliance team created an independent FEM model to develop Live Load Distribution factors (LLDF's) per the CHDDC methodology. Prior to applying the CHBDC methods they ran the AASHTO methodology through their model to compare with the AASHTO results and validate model functionality. Once validated, the CSA-S6 team developed their own LLDF's per CHBDC requirements for use in their compliance checking.

| Submittal Level | NTP | 30% | 60% | 95% | 100% |
|---|---|---|---|---|---|
| **Days From NTP** | - | 29 | 130 | 179 | 212 |
| **Design Plans & Spec's** | 4/3/17 | 5/2/17 | 8/11/17 | 9/29/17 | 11/1/17 |
| **CSA S6 Independent Certification** | | - | Report | Memo | ✓ |

**Figure 5:** Project Schedule

The final girder spacing produced a well-balanced design that was compliant to each code respectively. Under AASHTO methods, the exterior girder takes a greater LL while the interior takes a greater DL but the total Interior and Exterior DL+LL effects for each girder are similar. The Canadian CHBDC method applied to the same typical section also resulted in a more efficient S6 design with the exterior girder still governing under Ultimate Limit States (ULS) with the interior and exterior girder force effects being almost identical under the Serviceability Limit States (SLS). Per Figure 6, the comparison results were generally consistent between the two codes using their respective methodologies. After MnDOT/MTO review and acceptance, the final distribution factors were then developed under each code and applied only to the respective codes to ensure compatibility and final compliance.

| LOC. | AASHTO (STR I) | | CHBDC (ULS) | |
|---|---|---|---|---|
| M (+) | Ext. | Int. | Ext. | Int. |
| Span 1 | 1.09 | 0.94 | 1.07 | 0.89 |
| Span 2 | 1.07 | 0.90 | 1.05 | 0.87 |
| Span 3 | 1.10 | 0.94 | 1.05 | 0.87 |
| Span 4 | 1.07 | 0.91 | 1.05 | 0.87 |
| Span 5 | 1.09 | 0.96 | 1.07 | 0.89 |
| M (-) | Ext. | Int. | Ext. | Int. |
| Pier 1 | 0.92 | 0.80 | 1.06 | 0.87 |
| Pier 2 | 0.92 | 0.78 | 1.05 | 0.85 |
| Pier 3 | 0.92 | 0.78 | 1.05 | 0.85 |
| Pier 4 | 0.91 | 0.80 | 1.06 | 0.87 |
| Shear | Ext. | Int. | Ext. | Int. |
| Pier 1 | 1 .19 | 1.26 | 1.20 | 1.15 |
| Pier 2 | 1.19 | 1.23 | 1.20 | 1.15 |
| Pier 3 | 1.19 | 1.23 | 1.20 | 1.15 |
| Pier 4 | 1.17 | 1.22 | 1.20 | 1.15 |

**Figure 6:** Live Load Distribution Comparison

**Plate Sizing:** With AASHTO as the basis of design there was concern early in the project that the CSA-S6 compliance check may require increased plate thickness and widths over the U.S code. If discovered late in the design process this could lead to design revisions that would negatively impact the schedule. To manage this risk, the CSA-S6 compliance team ran their independent design checks concurrently with the U.S. AASHTO based design via bi-weekly updates of the framing plans. Through this process a few isolated instances were identified where the CSA-S6 code provisions requiring slightly wider or thicker plates. These were quickly addressed through updates in the AASHTO design. By the 60% design submittal, the independent compliance checker was able to certify that all primary plate sizes of the AASHTO based framing plan were complaint to the CSA-S6 code for both strength and fatigue.

**Splice Design:** Another area of concerns between the two codes was the design of the splices, literally down to the nuts and bolts. Similar to the plate sizing concern, having to revise the AASHTO design for a minor change to bolt spacing or count late in the design process was undesirable. It was understood that the underlying theory for splice design in the Canadian S6-14 design code was generally consistent with AASHTO 7th Edition approach in that the web splice is designed to resist a moment in proportion to the stiffness of the web versus the overall cross section plus eccentric shear. It was expected that the two codes would yield similar results, but unknown which code would govern the final number of bolts. Adding to the concern was the then upcoming change in the AASHTO LFRD 8th Edition which utilized a direct shear approach for the web splice and differed from the S6-14 code approach.

| Location | Code | Web Bolts | | Top Flange Bolts | | Bottom Flange Bolts | |
|---|---|---|---|---|---|---|---|
| | | LRFD | S6 D/C | LRFD | S6 D/C | LRFD | S6 D/C |
| FS-2/11 | AASHTO 7th | 69 | 0.76 | 28 | 0.84 | 34 | 0.85 |
| | AASHTO 8th | 34 | **1.32** | 24 | 0.98 | 36 | 0.80 |
| FS-4/9 | AASHTO 7th | 48 | 0.93 | 15 | 0.63 | 27 | 0.54 |
| | AASHTO 8th | 28 | **1.55** | 15 | 0.61 | 24 | 0.61 |

**Figure 7:** Girder Splice Bolt Comparison

To study the potential impacts, Parsons performed a study of two splices at representative locations; one of low Demand to Capacity (D/C) ratio of the web splice (FS 2/11) and one for a low D/C ratios of the flange splices (FS 4/9). From this analysis it was clear that the AASHTO 7th Edition would govern splice design. However, while flange splices designed under AASHTO 8th Edition may still remain compliant under the CSA-S6 code, the web splices would not (Figure 7). Based on this evaluation it was concluded that the AASHTO LRFD 8th Edition splice design criteria will not be compatible with the CSA-S6-14 criteria and mixing of codes between web and flange splice designs was not recommended. As such, the AASHTO 7th Edition remained the primary design criteria used for the splice design.

**Composite Deck Design:** From the parallel compliance review it was clear that there were fundamental differences in codes for crack control provisions in concrete decks over intermediate supports and allowable fatigue resistance of shear studs. In both cases the CSA-S6 code applied more stringent criteria that would control the design. While neither issue presented a significant design or schedule risk, resolution on both side of the border was required to allow for the final design submittal and compliance certification.

Based on the AASHTO provisions, the required amount of longitudinal reinforcing in the concrete deck for crack control yielded marginally larger crack widths than allowed by CSA-S6 code (0.27mm to 0.25 mm respectively). However, simply increasing reinforcing to meet the CSA-S6 requirements added significant quantity to the higher cost stainless steel reinforcement (Figure 8). The Agency's determined the CSA-S6 crack control was appropriate for a project located in the harsh northern environment and the ASHTO design would need to comply to the Canadian requirements. Parsons evaluated the impact of the additional steel over the piers and was able to offset the net increase in quantity through more efficient detailing using non-traditional bar size transitions at midspans allowable under the LRFD code provisions.

| Over Piers | LRFD | CSA-S6 | % Chg |
|---|---|---|---|
| Top Mat | #6's @ 5.5" | #6's @ 4" | 38% |
| Bott. Mat | #5's @ 6 | #5's @ 5" | 20% |

**Figure 8:** Deck Reinforcement

Shear stud design was another area where the two codes diverged. While the AASHTO based design conformed to the CSA-S6-14 strength and service requirements, the CSA code required significantly more shear studs in the positive moment regions for the composite deck. In researching this finding, it was determined the root of the difference was in a combination of the larger fatigue stress range and lower fatigue resistance required under the CSA-0S6-14 code compared to the AASHTO code. For example, the AASHTO design results in about 113

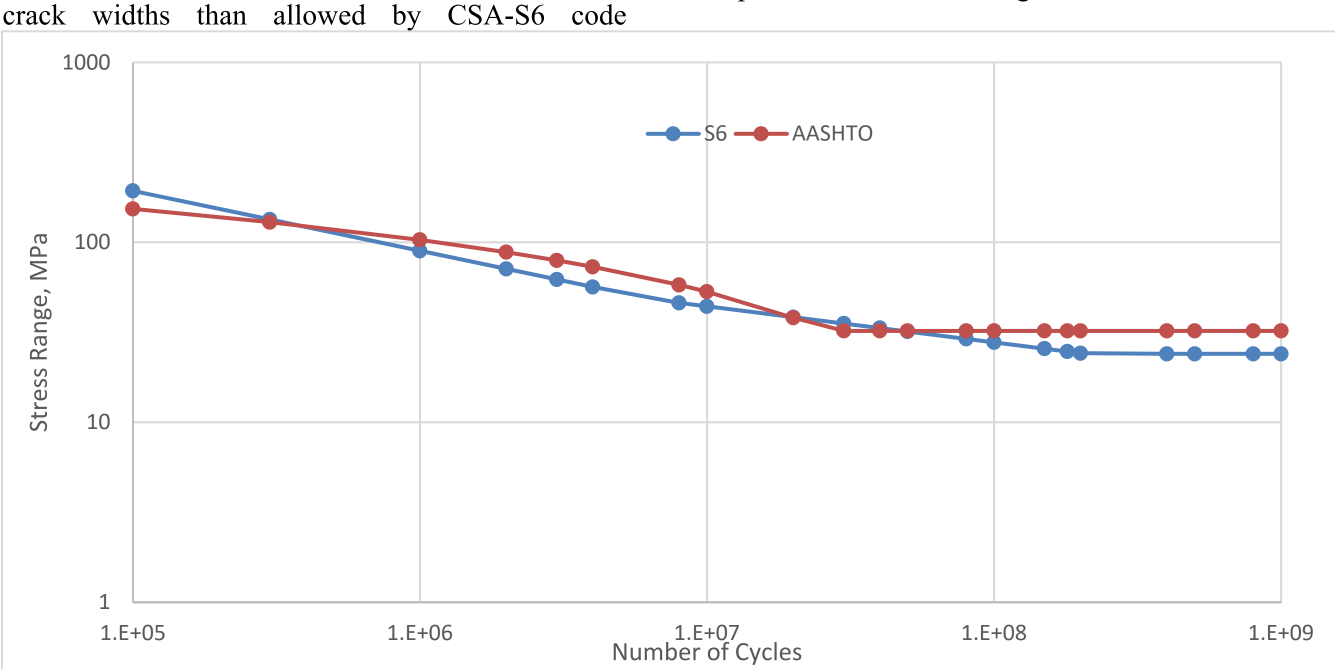



**Figure 9:** Shear Stud fatigue Curve Comparison

kips (504 kN) shear range in Span 1 at the abutments compared to 189 kips (841 kN) per the CSA-S6-14 design. When combined with about a 30% reduction in fatigue shear resistance between AASHTO and CSA-S6-14 infinite life range (cycles) the 12-inch spacing required by AASHTO is reduced to 7" under CSA (42% reduction). The total difference would more than double the shear studs from 13,648 to 22,272.

| Stress Range (Cycles) | AASHTO LRFD | S6-14 |
|---|---|---|
| 1,000,000 To 10,000,000 | 75.8 | 61.6 |
| 100,000,000 To Infinite | 32.2 | 24.8 |

**Figure 10:** Stud Fatigue Resistance (Avg. Fsr)

In recognition of the code differences and acceptable performance of U.S. structures under the AASHTO provisions, the MTO accepted a criteria adjustment for shear stud fatigue from Class A highway (Infinite life) to Class B highway (ADT = 1,100, 75 Yr Life). This revised the S6 fatigue shear stress limit in the studs to a similar to that permitted in the AASHTO LFRD design code. The resulting shear stud design was completed per the S6 Class B parameters and is complaint to both codes.

| Spacing | AASHTO (Infinite) | S6-14 (Class A) | S6-14 (Class B) |
|---|---|---|---|
| 12" (M+) | 12" | 7" | 11" |
| 18" (M+) | 18" | 9.5" | 1'-2" |
| 24" (M-) | 24" | 24" | 24" |
| Total (EA) | 13,648 | 22,272 | 17,218 |

**Figure 11:** Shear Stud Spacing

## CSA-S6 Compliance

Under the accelerated schedule, CSA-S6 compliance of the AASHTO LRFD design was critical to successfully delivering an "on-time" design to MnDOT and the MTO. To manage this risk, the design team performed the Canadian based independent CSA compliance review in parallel with the AASHTO design development. An internal milestone schedule of critical activities was developed to identify and resolve differences ahead of project submittals. Critical items included design criteria, dead loads, independent FEM model performance and live load distribution analysis.

**Figure 12:** Girder Erection, Summer 2019

Only after agreement on these critical items was reached could the CSA-S6 design review of the superstructure and substructure confidently proceed based solely on AASHTO based progress plans. For the August 2017, 60% submittal, the team determined the conformance of all primary laod carrying elements with the focus on steel girder and foundation design. As such, the interior and exterior girders were fully checked for ULS (Strength) and SLS (Service) as well as primary fatigue stress range, stiffeners, and deflections. The 60% review also included review of a representative splice design in order to evaluate the potential risk of code non-conformances in the post 60% final design. From this 60% review, only the deck cracking and shear stud spacing was identified as non-conforming to the S6 code for further review.

**Figure 13:** Girder Erection to Pier 3, Looking East

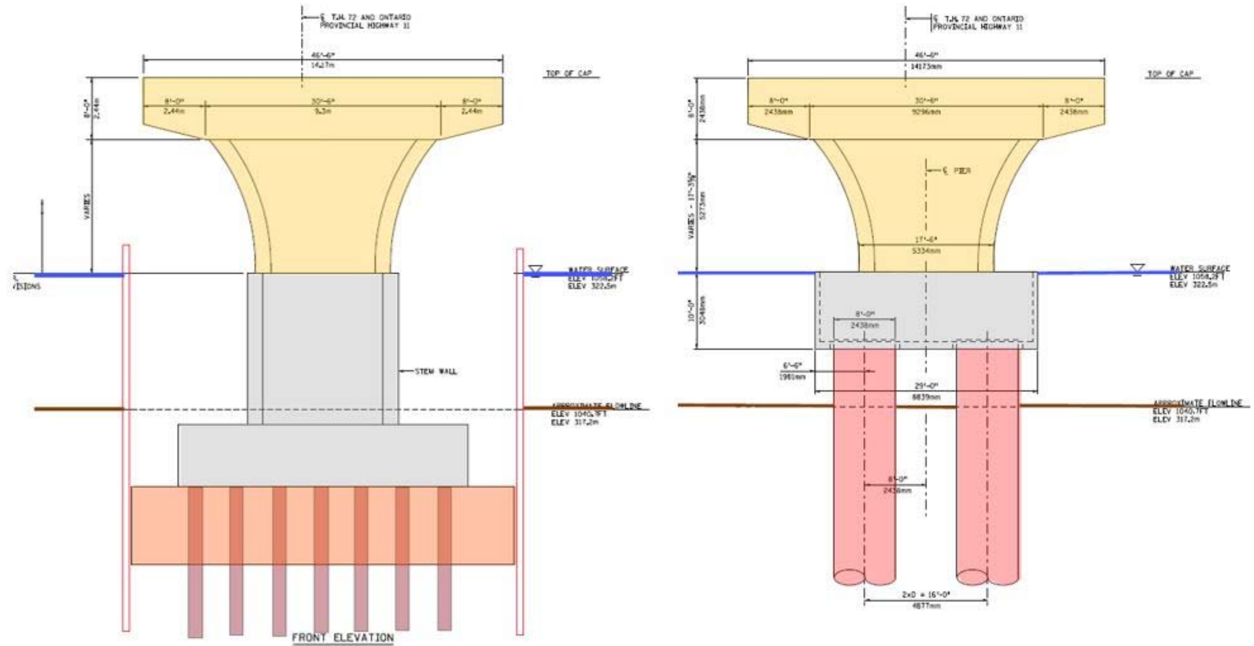
As the team moved forward toward the September 95% submittal these issues were resolved as the CSA-S6 team updated their models and analysis for any AASHTO design updates coming from the final checking of the U.S. design. The final plans were submitted to MnDOT/MTO on November 1, 2017 with the Certificate of Compliance issued by the Parsons CSA-S6 review team on November 15, 2017.

## Substructure Overview

The constructability of the four-river piers supporting the Baudette/Rainy River Bridge were a significantly challenging design element on the project. The dense glacial till underlying the soft riverbed are comprised of granular soils contain gravel, cobbles, and boulders. The preliminary design and foundation recommendations identified traditional pile supported footings located deep under the under the stream bed below the 100-year scour elevation. Early in the final design phase, Parsons geotechnical advisor, Dan Brown & Associates, identified constructability issues related to coffer cell construction and pile driving due to the underlying dense soil conditions. Recognizing this as a project risk, the design team submitted a value engineering proposal to MnDOT and MTO for the use of waterline precast cap supported on two large diameter drilled shafts.

The primary concern with sheet piling and driven piles was the risk of practical refusal due to the dense soils and boulders prior to required embedment depth. As part of this study, the design team also evaluated rotary drilled piles as well as drilled shafts. While the rotary drilled pipe piles were feasible, the sheet piling installation required for the cofferdam still presented a significant risk constructability risk. The drilled shafts also represented constructability challenges related to the 8-foot diameter permanent casing through soft riverbed soils and water. This was further complicated by the cobbles and boulders present in the underlying dense soils of the 7-6” socket.

Economically, the traditional pile footing constructed via cofferdam and waterline cap supported by drilled shafts were statistically even. However, the shafts presented a schedule reduction of approximately 35 working days per pier as well as reduced environmental impact and lower risk of construction vibrations near the existing structure. Based on this analysis, MnDOT and MTO elected to proceed with the drilled shaft footing and waterline cap. The design included a precast stay-in-place concrete shell that fit over the top of the shafts so the cap could be constructed in the dry without any




Preliminary Design                    Final Design

**Figure 14:** Foundation Value Engineering

temporary works in the river.

## Aesthetics

Recognizing the primary requirements on the new bridge are security and safety, MnDOT and MTO identified aesthetic options within the context of the site. Through the Project Advisory Committee (PAC) and Technical Advisory Committee (TAC) input, the Consultant team of Stantec developed the aesthetic vision for the proposed bridge in the Preliminary Design phase of the project. Community input revealed that the existing truss bridge had become iconic to the communities.

Since the new bridge was to be a girder type structure and not iconic in itself, the project team sought a way to express the community history of the existing bridge for the traveler experience crossing the new one. As a result of this exercise, it was determined to include a significant aesthetic feature for travelers on the bridge at the international border. After much review an arch-type monument feature composed aluminum was selected. The 76'-4" long by 23'-0" tall arches would be located on each side of the structure outside the roadside barriers.

In the final design Parsons developed the detail design for the arches. The design consisted of a plate box section of variable width and thickness and detailed for shipping in two pieces. A 1" plate thickness was selected for the arch plates with a 2" thick base plate. 3D FEM analysis was used to develop the stress envelopes based on the primary wind loads. Aluminum was specified as ASTM B209, 6061-T6 and fabricated per AWS D1.2.

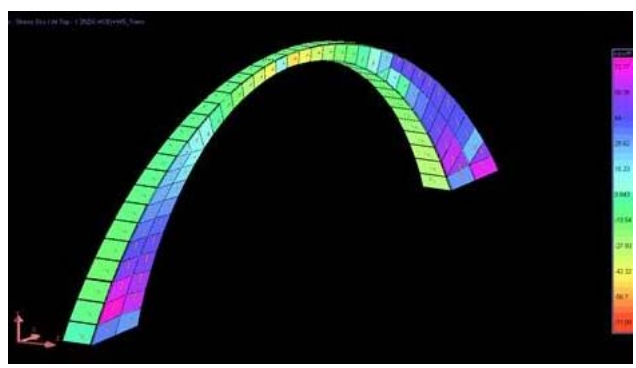


**Figure 15:** Arch FEM Stress results

## Project Status

The final steel superstructure design included 4,045,550 pounds of uncoated GR 50 weathering steel resulting in a steel weight per foot value of 62.4 lbs/sq-ft. Welding and fabrication requirements were

**Figure 16:** Arch Elements At International Border

also a consideration for this international project. While AASHTO and CSA-S6 specify different welding codes for each country, the welding and fabrication practices between the countries were commercially similar enough due to the history of cross border commerce to specify US requirements without any significant risk to bidding, schedule or quality.

The project was successfully Let and Awarded in on schedule and on budget. As of December 2019, the steel girders were fully fabricated, substructure complete, and steel erected from the west (U.S.) abutment out to Pier 3. Erection will be completed in the spring after ice-out. Deck placement will follow over the summer with the bridge opening scheduled for the fall of 2020. Both agencies continue their seamless cooperation across the border through the administration of the construction contract. As a testament to the years of groundwork and team building between the two Agencies, the project has progressed without any significant delays or bureaucratic challenges within the Ports of Entry between the two Countries.