CSCE Annual Conference

Growing with youth – Croître avec les jeunes

Laval (Greater Laval)

June 12 – 15, 2019

INNOVATIVE ALUMINUM PEDESTRIAN BRIDGES CASE STUDY

Cusson, B.[1,3] and Toupin, J.-D.[2,4]

[1] WSP, Canada

[2] Proco, Canada

[3] benoit.cusson@wsp.com

[4] jdtoupin@proco.ca

Abstract: In 2017, WSP undertook the challenge of designing two non-conventional aluminum multifunctional walkways for Parks Canada for use at the Lachine Canal National Historic Site. The designer retained the geometry of the early 19st railway bridges to recall the rich heritage of the industrial era that marked the site. Choosing aluminum for the structures emphasizes that Parks Canada's vision is to walk towards the future and to use innovative, maintenance-free materials. The 27 m x 4,5 m pony-truss aluminum structures are completely welded, thus requiring no assembly on site. This is a feat given the constraints of this material. Challenges during the design phase included vibration issues, stability of the top chord on elastic supports, ultimate resistance of welded aluminum and welds calculations. Fabricator Proco's welding procedures and assembly strategy at the factory are discussed. Moreover, this case study explains how the aluminum top chord was bent to reproduce the typical deviation seen in old railway bridges. Details at the foundations such as anchorage rods, bearing devices, and expansion joints are described to demonstrate the impacts of thermal expansion.

1 PROJECT OVERVIEW

In 2017, Parks Canada mandated WSP to first evaluate the structural capacity of two twin pedestrian bridges built in the 1970's over the Lachine Canal National Historic Site in Montreal. The study revealed that they lacked capacity and that it was preferable to replace them than to perform some strengthening works. Over traditional steel walkways solutions, the designer suggested the use of 6061-T6 aluminum for the new structures. The client accepted this innovative approach which would lead to the two first aluminum bridges for Parks Canada in Quebec. The second phase of the mandate was to produce detailed plans and specification for the works delivered by traditional public tender.

Figure 1: Architectural concept of the walkways recalling the geometry of the industrial era

In a kick-off meeting, the client introduced a heritage expert who presented the unique geometry of trusses from the industrial era of the Lachine Canal. WSP then embarked on integrating this spectacular geometry into a compact, completely welded, seamless multifunctional walkway, which was a challenge given the constraints imposed by this material. Parks Canada asked for a fast replacement of the two bridges because of the important number of users on a daily basis (± 5000 cyclists per day). WSP performed the design and the site surveillance. Proco was hired by general contractor Simdev to fabricate the walkways under Englobe's quality control. The two structures were successfully installed in the fall of 2018.

2 DESIGN CHALLENGES

2.1 Bending of the top chord

When trying to achieve the triangular geometry of old railway trusses shown in figure 1, the designer had to plan sufficient resistance in the top chord since this deviation is located directly at the mid span of the structure. It was preferred not to use a bolted connection for aesthetic reasons. Having a welded joint would have been disadvantageous for the resistance because of the particularity of aluminum to weaken after welding. The solution was to bend the central portion of the top chord using three points bending technique.

The specification allowed the bender to perform this maneuver under T4 or T6 condition. T4 condition requires a lesser load to achieve the plastification of the section because of its lower yield limit. On the other hand, the resulting member would have required a thermal treatment to reach the T6 structural capacity required by the specification. Bending in the T6 state requires more load and the radius has to be chosen wisely since this state is less ductile than T4. Moreover, the webs need to be sufficiently thick to avoid bucking during the bending process. In the end, the bending was successfully performed under the T6 state providing the structure with an elegant, seamless and strong top chord.

2.2 Special welded joints for the chords

The second challenge with both the top and bottom chords was to obtain the required 27 m length as most suppliers can only provide sections that are about 15 m long. Joints where inevitable and had to be wisely located for structural reasons. They were placed near the thirds of the span and the orientation of the diagonals was chosen to reduce the compressive load before the joints. The tapered top chord resulting of the architectural concept greatly contributed to have an almost constant compression load along the whole length of the top chord. This way, instead of having a single critical section and the center of the span, the demand over capacity ratio of the top chord is nearly constant for the whole top chord.

CSA S157-17 specifies the provisions when it comes to calculate the resistance of a member welded away from its ends. It treats a transverse weld differently than a longitudinal weld (which can reach up to 45 degrees in angle by definition in the Code). Hence, special 40 degrees joints were designed and provided the member with two longitudinal welds and two transverse welds. These two types of welds created higher capacity than transverse welds alone could have done.

2.3 Pros and cons of aluminum’s light density

Aluminum is nearly three times lighter than steel. As it is also more flexible, it requires thicker section walls to reach the same stiffness. The usual rule of thumb that accounts for these materials properties is to consider an aluminum structure’s weight as half of its equivalent in steel. In this project, combining the lightweight of the aluminum truss and the retained wood decking allowed the walkways to be transported by truck as a monolithic unit. The crane could lift the bridges from a farther location. Plus, the bearings' dimensions were modest. Another great advantage resulting from the lightweight was the fact that the dead load transmitted to the footings of the abutment was low. After an optimisation process, the designer was able to avoid piles and specified shallow foundations even if the soil’s capacity was poor. The abutments were fully precast, shipped by truck and installed quickly on site. This was a turning point in reaching the fast replacement criteria of the project.

On the other hand, dealing with a 27 m long single span pedestrian bridge requires a delicate balance between weight and stiffness to overcome vibration issues due to pedestrian crossings. The main idea highlighted in bridge standards is to keep the natural frequency of the structure as far a possible to first (±2 hz) or second harmonic (±4 hz) of the pedestrian crossings. Optimizing the depth of the truss and the section of the chords was a real challenge when trying to keep the weight (cost) as low as possible while also accounting for sufficient stiffness from the transverse U-frames supporting the compressed top chord of this pony type lattice. Moreover, the overall possible height of the structure was limited by the clearance under highway bridges during delivery. After many iterations, the designer chose a combination of parameters that suited all the mentioned constraints without requiring the use of dampers nor ballast.

2.4 Dealing with thermal expansion

Aluminum expands and shrinks twice as much as steel does under thermal variations. Hence, this 27 m long by 4,5 m wide structure was the equivalent of a 54 m x 9 m steel bridge when it came to deal with thermal displacements. Three secondary components had to be custom made with regards to thermal expansion: anchoring system, expansion joints and bearings. The anchoring system fixed the bridge in one of its four corners. Two corners blocked only one direction while the last one had a special oversize hole allowing full displacement in both directions. The difficult challenge here was to properly locate the anchorage rods within the holes in the structures and those drilled on site in the precast abutment. The implication of the designer was mandatory for this critical step.

Elastomeric bearings were selected to allow the bridge to move and bend freely under regular loads. A sliding PTFE plate was included to allow the ± 50 mm total longitudinal thermal displacement possible at the free end. Thirdly, the expansions joints specified for this project were redefined to suit the needs for displacement, cyclist comfort and snow removal operations. Tapered bolts through slotted holes in the expansion joint plate connected the structure to an embedded steel angle in the concrete abutment. Final adjustment of these plates was planned and executed on site. For all these components, the key to success was to plan realistic tolerances during the design phase to avoid arguments with the erection team on site.

Figure 2: From left to right: anchorage rods, expansion joint and sliding bearing devices

3 FABRICATION CHALLENGES

3.1 Welding design and procedures

The assembly design period enabled to create a list of the different welded joint types required depending on the various forces and node geometry. A total of 68 full penetration welds and numerous multipass fillet welds up to 23mm in size were designed. After taking into account all of the project's parameters, the GMAW conventional welding parameters in pulsed spray mode was retained. The corresponding welding procedures were subsequently developed, tested and finally certified by the CWB. Considering the magnitude of the welds to be performed, it was essential to control the deformation of parts subjected to heat gains. Particular importance was therefore given to the sequencing of the different welding steps. Also, the GMAW pulse spray mode proved to be particularly effective in reducing heat gains. The result demonstrates that it is possible to effectively control the deformations no matter the magnitude and asymmetry of the welding to be performed on the members.

In this project, certain linear weld assemblies seemed to favor the use of friction stir welding (FSW). Thus, the procedures were developed and the tests were carried out at the UQAC facilities in collaboration with the CMQ. The first tests were not conclusive since some challenges were encountered regarding the alignment of the extrusion welds. Due to the delivery schedule, the additional tests that would have been required for the qualification of the procedure were suspended and we were not able to rely on this method.

3.2 Quality and inspection

In addition to ensuring the structural integrity of the frame, specific precautions were taken to control the final aesthetic aspect of the walkways. The cuts, the preparation, the assembly and the welding of the frame were performed in a plant that also produces steel frames. To prevent aluminium contamination, steel work was thus temporarily suspended. In addition, a specialized firm performed in-depth cleaning of the locations, the equipment and the work tables before manufacturing began. All work was carried out in compliance with the additional requirements relative to the "fracture-critical members" of the CSA S6-14 standard. Then, since certain members of the project were anodized, it was necessary to locally remove the anodizing to ensure high quality welds.

All full penetration welds were inspected by ultrasound, whereas 50% of the welds were inspected by liquid penetrant. In total, nearly 2,000 linear meters of fillet welds were performed. From this batch, two repairs were required to correct a slight lack of penetration and five repairs were required to correct a lack of fusion. The most important factors in achieving these high-quality results are the procedures, the equipment, the working environment and the quality of the welders. The members were polished to remove any surface imperfections from manufacturing and to ensure a uniform appearance on the aluminum before delivery.

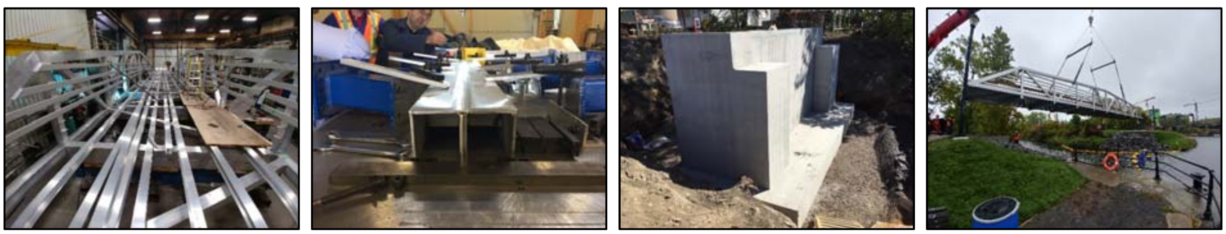

Figure 3: From left to right: assembly in factory, FSW trials, precast concrete abutments and crane lift

4 CONCLUSION

4.1 Innovation

Many of the topics mentioned in this case study prove the innovative nature of this project. The bent top chord, the seamless welded light aluminum structure and the special top and bottom chord joints created a stunning patrimonial geometry. The overcoming of the thermal expansion, vibration and welding issues associated to aluminum is also noteworthy. The great project planning lead to a narrow three weeks closing of the cyclist access. Thus, this project reflects Parks Canada's determination to modernize the usage of the materials selected for the maintenance of the historical canals.

4.2 Lessons Learned

Engineers interested in the design of aluminum bridges should be aware of the limited availability of large structural sections. It is important to make sufficient research with suppliers in the early stages of the project. Welding calculations and execution require an important amount of work and should not be neglected especially for isostatic structures like these footbridges. In the end, all participants to this project are proud of the result of their work.

Acknowledgements

The authors would like to express their gratitude to Parks Canada for the opportunity of leading this project from the preliminary studies to completion. Englobe, Groupe Conseil en Soudage 2012 (GCES) and the Quebec Center for Aluminum Research and Development (CQRDA) of are thanked for their collaboration in solving the material challenges of the project. CEAL from Alu-Québec is acknowledge for its help to get in contact with key aluminum technical resources.