Town of Souris Swinging Bridge

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ABSTRACT

The original Swinging Bridge located in the town of Souris, Manitoba was built in 1904 by the Late Squire Sowden as a means of transportation across the river. It was billed by officials as Canada's longest historic suspension bridge with a total length of 582 feet and was a landmark and tourist attraction. The spring flood of 2011 had submerged the superstructure requiring the cable anchors to be cut resulting in the bridge being completely destroyed. While the original suspension bridge consisted of nine piers and ten spans, the new bridge needed to be designed without any intermediate piers leading to a single span of just over 600 feet. This length will make the bridge the longest suspension/swinging pedestrian bridge in Canada.

This paper will discuss the design process and challenges, as well as the construction requirements and restraints. The construction of the bridge is proposed to be completed by Summer 2013.

INTRODUCTION

The original Swinging Bridge over the Souris River in the Town of Souris spanned a total of 582 feet. The bridge consisted of ten spans with nine piers with a longest clear span of 242 feet. It was originally built in 1904 by the Late Squire Sowden as a means of transportation across the river. The Swinging Bridge was damaged and replaced twice previously, in 1961 due to a damaged cable and in 1976 due to a flood. It was promoted by officials as Canada’s longest historic suspension bridge. The bridge was well known across the province and served as a tourist attraction in southwest Manitoba. It became the principle attraction in Souris over the years and was one of the best-known long span catwalk style swinging bridges in North America. The original Souris Bridge is shown in Figure 1.

Figure 1: Original Souris Bridge (source Bridgemeister.com)

The Swinging Bridge was completely destroyed during the 2011 spring flood (see Figure 2). The flooding river submerged the superstructure resulting in significant hydraulic pressure on the bridge which was a high risk to the Town since the anchors for the bridge were located under the Town’s dyke. The concern was that forces on the anchors could damage the dykes jeopardizing the protection of the Town. To alleviate the risk, the Town decided to cut the cables, freeing the superstructure of the hydraulic loading and destroying the bridge.

Figure 2: 2011 Flood Damage

Stantec was retained by the Town of Souris to complete the preliminary and detailed designs and contract administration services to replace the bridge. The bridge is being replaced with a new swinging bridge to restore the structure to its pre-flood condition. The bridge consists of concrete abutments and towers founded on driven steel piles, with additional support provided by drilled and tensioned soil anchors.

The superstructure is a 184m long clear span supported by four suspension cables. The timber decking is supported by steel channel stringers connected to HSS floor beams. The two top cables are connected to the floor beams via steel hangers and the two bottom cables are directly connected to the floor beams.

The bridge will be Canada's longest suspension/swinging pedestrian bridge and construction of the bridge is scheduled to be completed Summer 2013

DESIGN CONCEPT

During the conceptual design phase it became clear that it was important to the town to have a bridge that was less susceptible to flood damage and maintain the site as a similar tourist attraction as the original. In order to minimize the risk for future flood damage it was decided to eliminate all piers and to build a single span bridge. This requirement resulted in a bridge length of 184 m, which will make this bridge the longest pedestrian suspension bridge in Canada at the time of design. In order to achieve a similar attraction to tourists it was decided to develop a contemporary design of the abutments and include modern levels of lighting that accentuate the appearance at night and allow for save usage.

Figure 3: Rendering of Design Concept

Another major requirement of the bridge was to provide a minimum 1.7 m freeboard at the lowest point over the 200 year flood level. In order to meet this requirement the bridge requires to be closed during a 200 year flood event which was assumed to occur on the hottest day of the year. Although not likely to occur at the same time, this assumption further reduced the risk of flood damage. Closing of the bridge is necessary since an increase in temperature by 25 degrees increases the bridge sag by approximately 800 mm which in combination with the full live load deflection would require prestressing forces in the suspension cable that are unpractical and difficult to anchor.

Although longer pedestrian bridges have been developed elsewhere in the world, their design usually focuses on minimizing the degree of “swing”. For the Souris Bridge a certain level of swing was a design requirement. There are numerous publications on vertical and horizontal acceleration limits for human comfort, none of which appear to apply to a bridge with a very low frequency and an implicit need for vibrations. In order to investigate the vibration characteristics of the bridge an in-situ vibration test was incorporated into the project which at the time of this paper has not been conducted yet.

CABLE LAYOUT

The clear horizontal bridge span is 184 m with a vertical elevation difference of 8.4 m. The required stress level in the cables was determined by the geometry required to keep the cable 1.7 m above the 200 year flood level on the hottest day of the year. This can be achieved by fitting a parabola over the required geometry using the two end points and the elevation of the low point as the boundary conditions. Once the lowest geometry has been established the geometry on a normal day can be calculated by reducing the cable length by

$$\Delta b = \alpha_T \cdot \Delta T \cdot b \qquad \textit{Equation 1}$$

where Δb is the change in length of the cable, α_T is the thermal coefficient of steel, ΔT is the temperature change, and b is the length of the cable. The range of temperature for this type of structure that needs to be considered in Souris, Manitoba is +50°C to -43°C. The length of the cable can be established by

$$b = \sqrt{\frac{L^2}{4} + 4 \cdot f_{max}^2} + \frac{L^2}{8 \cdot f_{max}} \cdot ln\left(4 \cdot \frac{f_{max}}{L} + \sqrt{\frac{16 \cdot f_{max}^2}{L^2} + 1}\right) \qquad \textit{Equation 2}$$

where f_{max} is the maximum sag of the cable and L is the horizontal span between the abutments. Alternatively the length of a shallow parabola can be approximated by the length of a circle segment as:

$$b = \frac{L^2 + 4 \cdot f_{max}^2}{4 \cdot f_{max}} \cdot asin\left(\frac{4 \cdot L \cdot f_{max}}{L^2 + 4 \cdot f_{max}^2}\right) \qquad \textit{Equation 3}$$

or simply by (Strasky 2005):

$$b = L + \frac{8 \cdot f_{max}^2}{3 \cdot L} \qquad \textit{Equation 4}$$

Once the geometry has been established the horizontal force, *H*, at the abutments can be estimated using:

$$H = \frac{w \cdot L^2}{8 \cdot f_{max}} \qquad \textit{Equation 5}$$

where *w* is the uniform selfweight of the bridge deck. Once the geometry and the prestressing force is established the bridge geometry can be entered into a non-linear finite element program to establish load levels in the cable and at the supports for the abutment for different loading conditions. The most relevant loading conditions are full live load on the coldest day of the year and on the hottest day of the year. The results for the coldest day of the year give the maximum tension force in the cables while the fully loaded bridge on the hottest day of the year is established to review the cable profile as well as the forces on the deviator at the abutment. The maximum slope of the bridge at the upper end on the hottest day is 15% which was deemed steep but walkable. The slopes of the bridge at 50°C are shown in Figure 4.

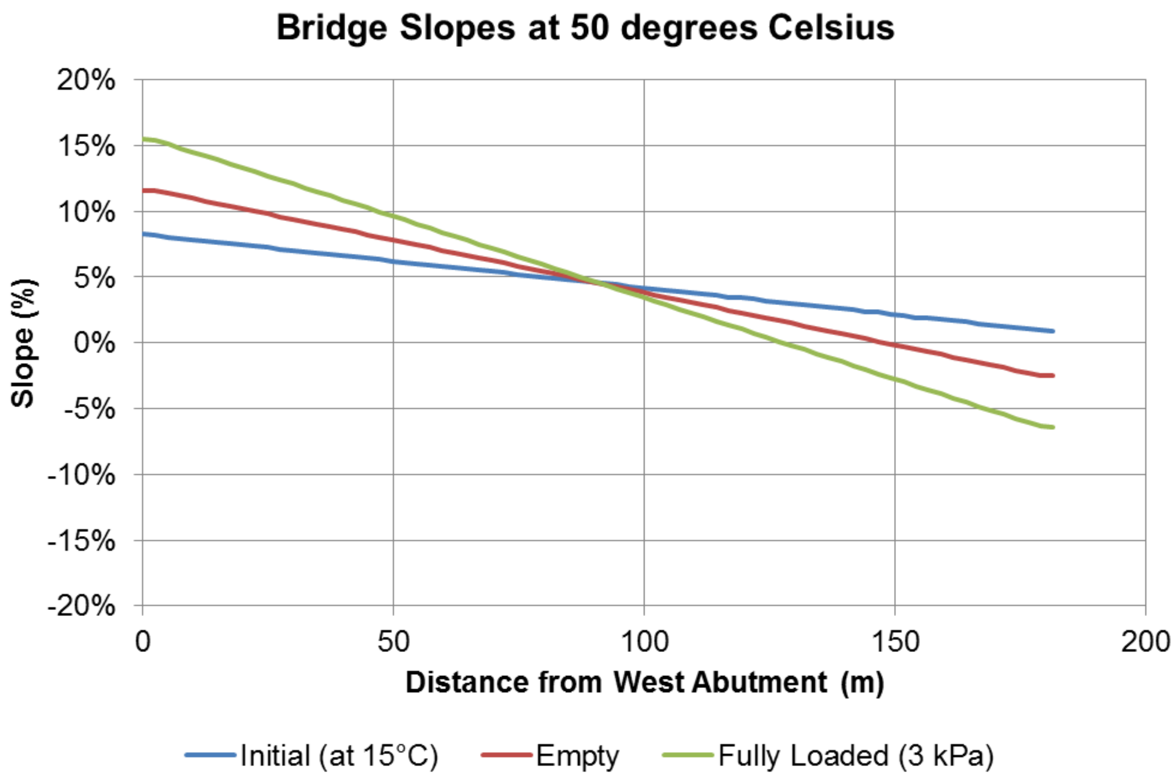

Figure 4: Bridge slopes over the length at 50°C

The live load that needs to be considered for this bridge is 1.6 kPa in accordance with S6-06. This live load was generally used in design but a load of 3.0 kPa was assumed to be the extreme load for days like the grand opening and other events.

CROSS SECTION DESIGN

One of the most important criterion in the design of the bridge cross-section is the requirement of having both handrails reachable by a pedestrian at the same time in order to feel safe while crossing the bridge due to the anticipated bridge vibrations. This needed to be combined with the ability for two people to pass each other which is essential on a long bridge with bi-directional pedestrian movement. It was therefore decided to have a 1.5 m wide walkway with a handrail spacing of 1.5 m. The bridge cross section is shown in Figure 4.

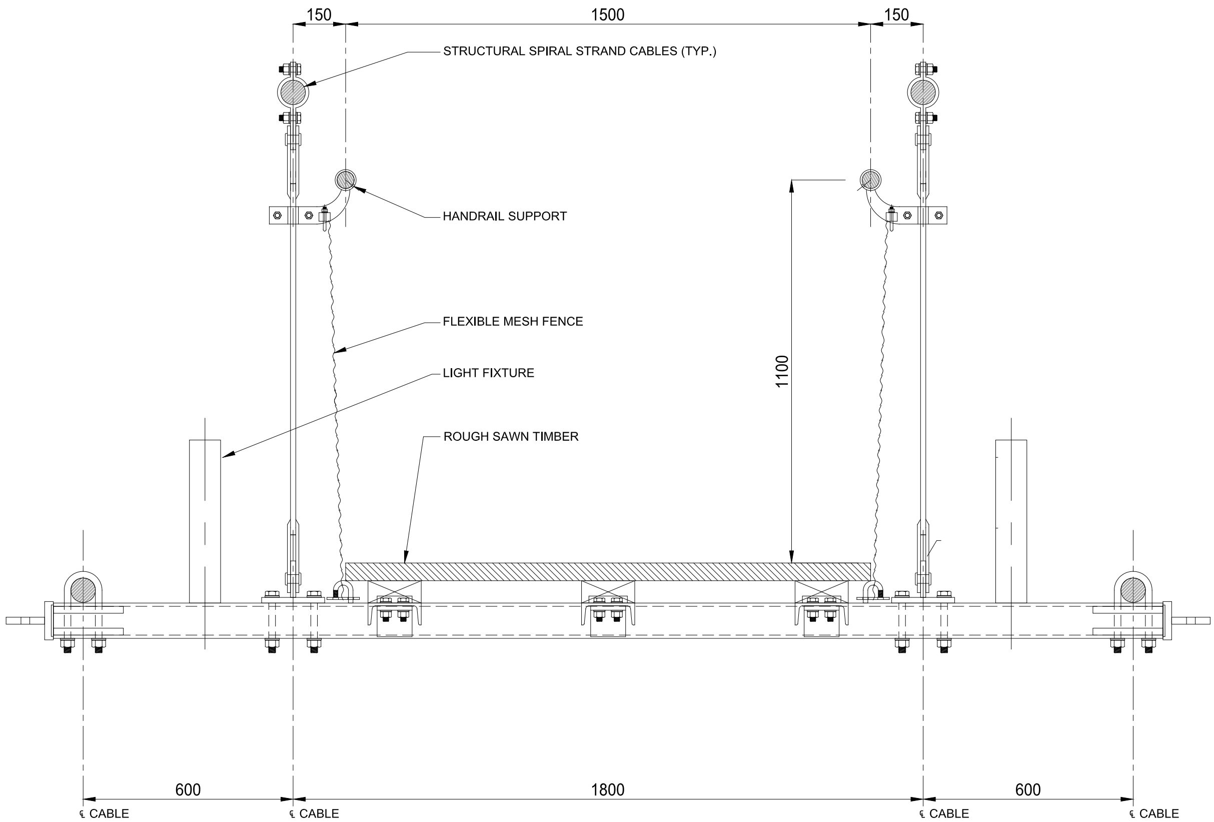

Figure 5: Cross-Section

The four suspension cables were positioned to accomplish two things, prevent overturning of the entire bridge and to increase the pedestrians' safety in terms of falling over the railing while maintaining reasonable site liner. It was therefore decided to have the top of the upper suspension cable approximately 1.4 m above the walking surface which is similar to the handrail height on a cyclist bridge. The two bottom cables were moved 0.6 m further apart on either side. This additional distance increases the stability of the bridge against overturning significantly. The movement of the top and the bottom cables were linked through stiff hanger elements to reduce the risk of wind induced cable vibrations.

The walkway construction consists of a steel frame with wood decking. All connections of the steel frame to the cables were designed to allow for simple installation after the cables have been stressed. The clamps between the frame and the cable have a neoprene interlayer to prevent kinking of the cable and slippage of the connection. The handrail itself consists of a hemp rope which is clamped to the steel frame every 2.5 m. A rope was used to allow for the temperature and live load movements of the bridge without creating loads in the handrail and its connections. A stainless steel mesh is installed between the top cable and the walkway.

ABUTMENT DESIGN

The abutment was designed as two foundation blocks. The front block (tower block) supports the forces created by the deviation of the cable while the back block (anchor block) functions as an anchor block for the tension forces. The foundation of the tower block is supported by 10 driven steel H-piles, five of which are battered at a 5:1 slope towards the outside of the bridge. The force that needs to be resisted by the tower block is the resultant force of the cable slope towards the anchor block and the suspension cable (see Figure 5)

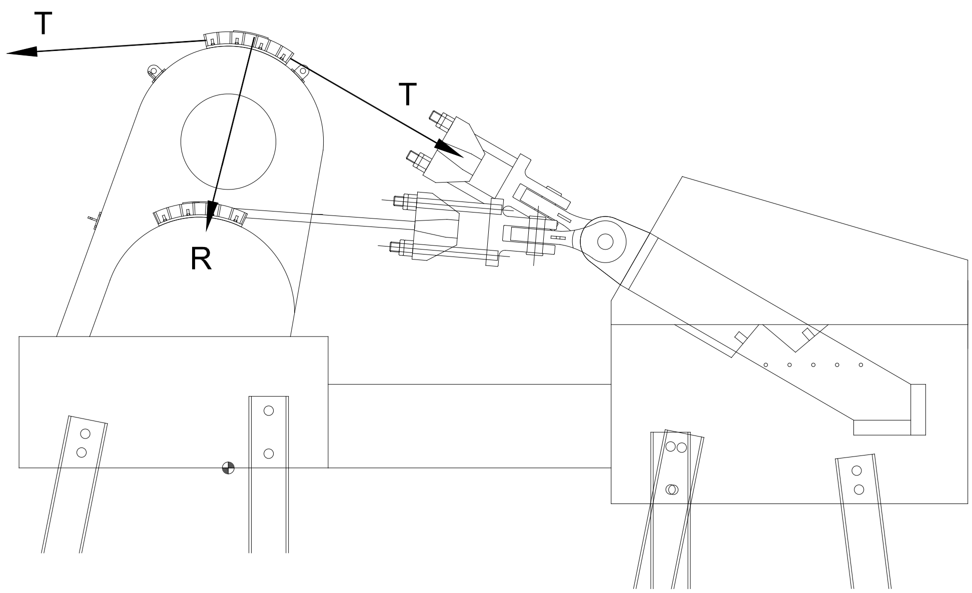

Figure 6: Tower Block resultant force

The anchor block foundation consists of 16 driven steel H-piles with 22 soil anchors. The outside H-piles are battered at a 5:1 slope. The soil anchors are inclined horizontally between 5 to 20 degrees and vertically between 5 to 20 degrees in the plane of the cross section and 40 to 50 degrees longitudinally. The provided inclinations maximize the amount of soil that is engaged in the bonded zone of the soil anchors. The anchor layout is shown in Figure 7.

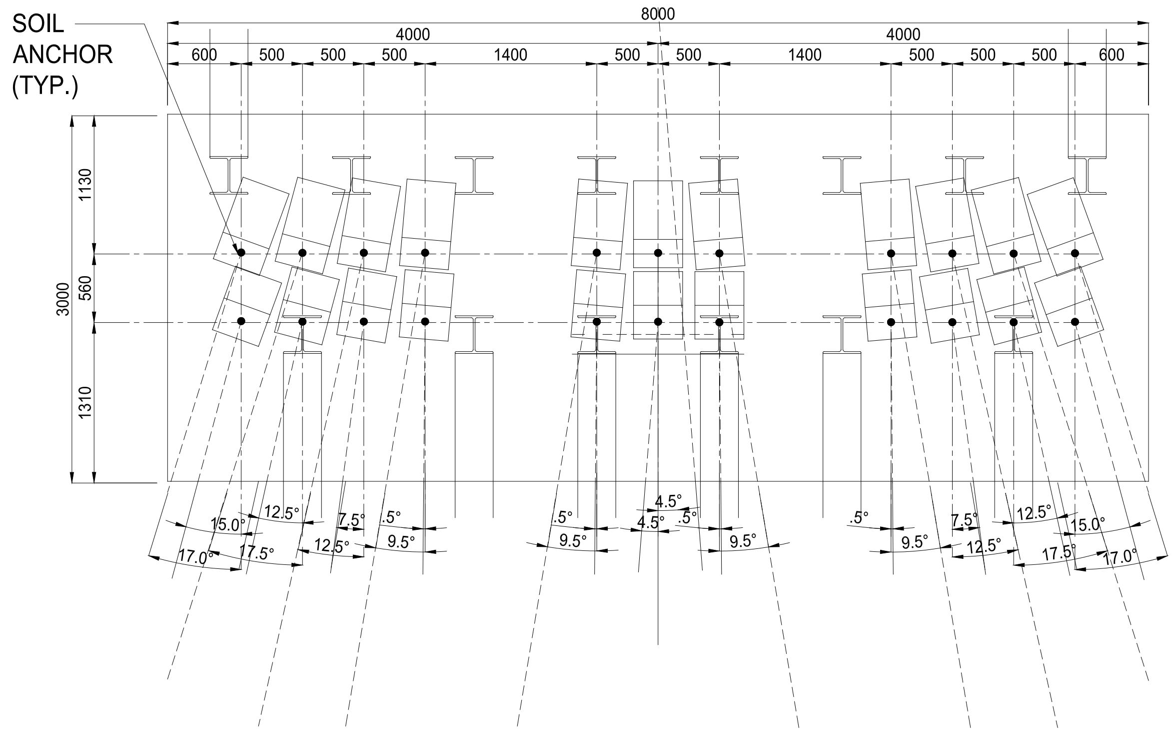

Figure 7: Layout of soil anchors and piles in the anchor block

The two foundation blocks are connected through a connector beam in order to allow sharing of the horizontal anchor forces. This connection is mainly needed for the stressing of the soil anchors prior to the installation of the suspension cables.   Once the cables are installed the horizontal force in the cables can be resisted in full by the soil anchors.

DYNAMIC BEHAVIOUR

The dynamic behavior of the bridge was evaluated using SAP 2000 on a full-scale non-linear model. The natural frequencies for the bridge were calculated to be 0.43 Hz, 0.49 Hz, and 0.63 Hz for the horizontal, vertical, and torsional mode shapes, respectively. These frequencies apply to an unloaded bridge. Typical critical frequencies for a pedestrian bridge are 1.65-2.35 Hz for vertical excitation and 0.85-1.20 Hz for horizontal excitation (Bachmann 1995). The values are derived from normal walking speeds and can be higher for running pedestrians. From these numbers it can be concluded that the natural frequencies of the bridge are well below the walking step frequencies of pedestrians. The natural frequencies for the bridge loaded with approximately 150 people drops to 0.35, 0.43, and 0.61 Hz for the horizontal, vertical, and torsional mode shapes, respectively.

The low frequency of the bridge structure in combination with its small selfweight makes traditional methods of evaluating the human comfort level using maximum acceleration limits very difficult. It was therefore decided to assess the actual swinging characteristics on the finished bridge. In order to mitigate possible vibration issues the bridge design has included numerous locations were possible dampers can be installed. The vibration mitigation strategies being considered, if required, are increasing the stiffness of the structural system using tie-backs, increased damping, and/or vibration absorbers in form of mass-dampers. The vibration load test is anticipated to take place in the summer of 2013.

CONSTRUCTION CONSIDERATIONS

Through the design phase several potential construction issues were considered. The construction site is located in the heart of the residential area of the Town of Souris. The site is surrounded by houses, a museum, and a daycare. In addition to the residences and structures surrounding the bridge site, significant underground and overhead utilities exist.

The bridge site at the abutments is very limited in space due the proximity to the structures which surround they site. During the design, construction methodologies and equipment were considered to mitigate construction conflicts or issues prior to engaging a contractor. One of soil anchors is one example which can be installed using small equipment. The site has limited area for laydown of equipment or materials. Therefore it was important to be able to pre-fabricate most of the deck section and to allow for simple installation using bolts. The limited space available for construction and the methodologies to be utilized were reviewed with the Contractor, and the Contract Administration and Design teams are working closely together during the construction progresses.

A survey of the buildings within approximately 31 m of the construction areas at each abutment was conducted prior to construction commenced to ensure any potential damage due to construction could be mitigated and noted. Cooperation of the Town, the residences, and business' in the local vicinity of the construction is crucial to the successful construction of the bridge. An open house was held near the start of the design to obtain comments and concerns of the stakeholders as well as meetings with specific stakeholders during the design and construction phases. Through this collaborative effort with the stakeholders as well as the Contractor, the concerns and impacts to the Town were noted and mitigated as reasonably as possible.

To address the potential issues associated with the underground utilities an onsite locate of the underground utilities including the Town of Souris was conducted. Based on this locate process, several watermains and a fire hydrant were abandoned or relocated in the fall of 2012, ahead of the construction works.

In consideration of the electrical and telecommunication overhead utilities within the construction limits, the organizations responsible were contacted and a mitigation plan was developed. The utilities were temporarily diverted, but the electrical power diversion was potentially complicated. The overhead power lines at the west side of the site were determined to be most likely to be in direct conflict with the anticipated construction equipment. As such, the overhead line was temporarily removed thus resulting in the power for such items as the water treatment plant and the hospital being solely provided from the east side. As the power had to be rerouted through the overhead lines adjacent to the east limits of the site, construction activities were closely and well-coordinated to mitigate and limit any potential disruption to the supply of electricity to vital buildings within the Town.

As the original structure was destroyed due to flooding of the Souris River, consideration was given to elevated water levels for the design of the structure, as noted previously, but also for during construction. Both abutments were placed such they are at the top of each embankment reducing the effect of the potential effect of the proposed bridge on the diking system of the Town as compared to the original structure. This will allow for the construction of the bridge to continue even if elevated water levels are realized during the construction period. The temporary works such as the hi-line, to be used to bring the bridge cables across the river, and the work bucket, which will hang by rollers from the bridge cables when installed to facilitate the construction of the superstructure, have been designed to accommodate elevated water levels. These items have been thoughtfully designed to help limit the effect of potential flooding on the construction of the bridge.

CONCLUSIONS

The presented paper gives an overview of the design considerations and limitations for the new construction of the Sours Swinging Bridge. Implemented solutions are presented and discussed for design static and dynamic design considerations. The bridge is currently under construction and is anticipated to open in the summer of 2013.

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