HEAVY MOVABLE STRUCTURES, INC.
SEVENTEENTH BIENNIAL SYMPOSIUM

October 22-25, 2018

Minnesota Slip Pedestrian Bridge

John Gimblette, P.E.
Hardesty & Hanover, LLC

MARRIOTT'S RENAISSANCE HOTEL AT SEAWORLD
ORLANDO, FLORIDA

The Minnesota Slip Pedestrian Bridge is an overhead counterweight, double leaf bascule bridge located in the City of Duluth, MN. Its purpose is to provide pedestrians easier access between the City's Canal Park and Convention Center areas while providing on-demand access to the City's Harbor Basin for vessels docked in the adjacent slip. Referred to by locals as the 'the blue bridge', it has suffered innumerable breakdowns, frustrating local pedestrians and politicians for over two decades. This paper will focus on some of the early history of the bridge, resulting problems with the original operating system and the alternate operating system chosen and implemented to address these problems.

Background - 1990 to 1996

In November 1990, final design of the Minnesota Slip Pedestrian Bridge was underway. The City of Duluth had selected a local architectural firm to lead the bridge design effort, who in turn chose to design an aesthetically interesting 'Dutch Style' bascule bridge. Agreeing to an aggressive schedule, the original designer completed their efforts in February 1991 and construction began in April 1991.

FIGURE 1: View of Minnesota Slip Pedestrian Bridge looking Northeast.

In June 1991, the original designer provided a letter to the City describing the parameters to which the bridge was designed and outlined some of the restrictions the bridge would be subject to during its operation. One of the parameters worth highlighting read as follows:

The bridge is designed to be operated in wind speeds up to 50 mph. At wind speeds above 50 mph, the bridge must either be left in the full up position or in the down and locked position. If the bridge is operated in wind speeds exceeding 50 mph, it is possible that the wind pressure will hold a bridge span in the up position. If the operator attempts to lower the bridge in this condition, the cables may go slack and then the bridge will drop when the wind speed decreases. An anemometer located on top of the control building will provide the operator with a wind speed indication and will not allow the bridge to operate when the speed exceeds 50 mph. (K&O Letter, June 6, 1991)

In August 1991, about three weeks after a formal christening ceremony, the bridge suffered its first 'breakdown'. To the original designer's credit, they were able to diagnose the problem and have a faulty drive train component replaced within two weeks.

In September 1991, the original designer provided a follow up letter to the City of Duluth, recapping the aggressive design and construction schedule as well as a few issues/problems realized during the later stages of construction that needed to be remedied. One of the problems worth highlighting read as follows:

Another problem we discovered was that the actual bridge weights were significantly heavier than calculated. This additional weight was primarily due to the wood decking weighing more than we had anticipated. To remedy this problem, it was necessary to add an additional 9600 lbs. counterweight to the lifting arms on each side of the bridge. The counterweight boxes had been designed to accommodate this additional weight in anticipation of this possibility. At this point we also found that with the addition of this counterweight, the bridge would not close by gravity from a fully open position. A spring loaded device was then designed to assist the bridge in overcoming the counterweight forces and push the bridge from an 80 degree open position to 68 degree open position at which point the bridge weight can overcome the counterweight and wind forces which resisted the closing operation. (K&O Letter, September 12, 1991)

To help clarify, the original operating system used hoist drive assemblies mounted to the back end of the counterweight arms and multi-part cabling between the base of the fixed towers and back end of the counterweight arms to operate the bridge. To be effective, the wire rope system required constant tension or for the bridge to act as if it were 'span heavy' throughout its entire operating range.

Based on correspondences shared by the City, over the following year, the bridge did not achieve final acceptance and operations were either restricted or difficult during moderate to high wind conditions.

In September 1992, the bridge suffered a cable block connection failure that resulted in one of the bascule leaves being stuck in its lowered position and out of service for four days. Concerned, the City requested assistance from a consultant, whose initial efforts included the following:

- Cursory inspection of bridge mechanical machinery and electrical system
- Review of mechanical machinery design
- Cursory inspection of bridge structural components
- Static stress analysis of cable block connections related to recent failure

With the bridge not meeting the expectations of the City and its operation questioned during windy conditions, the City pushed the original designer to provide details for an alternate operating system.

In September 1993, initial calculations for an alternate operating system were provided to the City. The calculations were then reviewed by the City's consultant and, after some back and forth, final calculations were provided by the original designer in September 1994.

The City planned to procure all recommended equipment making up the alternate operating system and then let for bid a set of contract documents to install the equipment. However, during the procurement effort, the City determined a set of bearings making up part of the system was not available. Seeking guidance from the original designer, the City was apparently offered little support.

To help expedite the effort, the City reached out to their consultant in August 1995 requesting they review the matter and, if possible, offer a substitution. In September 1995, the consultant provided the requested substitution and made its details available to both the City and original designer. In turn, the City followed up with the original designer in December 1995 to confirm they planned to incorporate the substitution details into their final plans. The last related correspondence shared by the City was a follow up letter from the City to the original designer in June 1996 requesting similar. To our knowledge this request was never met, a lawsuit ensued, a settlement eventually reached and the operating system, in use at the time, was made to work for the next 20 years.

Replacement - Justification 20 Years Later

From 1996 through 2016, the bridge's behavior wasn't always predictable, and the City learned to deal with the occasional 'breakdown' event. Typically, an event would result in damage to one of the operating cables, requiring its replacement. Replacement would then require the bridge to be temporarily closed to pedestrians for proper positioning or supporting of the bascule leaf and installation of a new cable. During this effort, the traveling public would be inconvenienced and forced to take a less direct path between the City's Canal Park and Convention Center areas.

The frequency of these events was more than what was considered acceptable and after dealing with them for two decades and receiving pressure from both the public and local businesses, the City committed to improving the bridge's functional reliability.

In June 2016, it was requested of LHB Corporation (LHB) and Hardesty & Hanover, LLP (H&H) to review prior studies performed by other consultants and determine a preferred alternate operating system that could reliably initiate and control movement of the bridge in both the raising and lowering directions. As a subconsultant to LHB, H&H's responsibilities included document review, inspection and design of an alternate operating system.

2016 Design Effort

To begin, we reviewed early correspondence between the original designer and City, original and proposed alternate design plans and calculations and a subsequent study report performed by another consultant in 2005. This effort was invaluable, as it provided insight on the original design and potential improvements for the operating system.

We then performed an inspection of the original operating system, in coordination with LHB's inspection of the bridge structure. This effort allowed us to become familiar with the make-up, condition and limitations of the system. It also allowed us to conceptualize potential alternate operating systems.

With prior studies having been performed, the City encouraged LHB/H&H to use our best judgement to determine an appropriate alternative that would meet the project purpose. As previously mentioned, the City wanted an operating system that could reliably initiate and control movement of the bridge in both the raising and lowering directions. More simply put, the City wanted a multi-directional operating system that would not be limited during typical windy conditions.

Two alternative concepts were discussed, both of which sharing the same general approach of attaching equipment between the base of the fixed towers and back end of the counterweight arms to operate the bridge. The first concept considered the use of hydraulic cylinders, which would allow the counterweight arms to be pulled down or pushed up if oriented properly. The second concept considered the use of rack beams and pinions, which would also allow the counterweight arms to climb down or climb up if oriented properly. Given the owners familiarity with machinery and the fact that much of the second concept had been vetted out between 1993 and 1995, it was recommended the City move forward with the rack beam and pinion design. Final details would include redundant motors, a common parallel shaft speed reducer, floating shaft assemblies, rack beams and pinions and carriage assemblies for each bascule leaf.

Design Criteria

To start, we first needed to determine the range of load seen by the systems tie rods between the bridges seated and raised positions. To do this, we investigated three load cases as defined below:

- Load Case 1: DL (dead load) only
- Load Case 2: DL + Ice (2.5 psf) + Wind (10 psf acting to push span down)
- Load Case 3: DL + Ice (2.5 psf) + Wind (10 psf acting to push span up)

For Load Case 1, the results showed a maximum tie rod load in the seated position. It also showed that the tie rods remain in tension throughout the bridges full range of motion but with minimal tension in the raised position.

For Load Case 2, the results also showed a maximum tie rod load in the seated position. However, since the wind load was defined as acting against the vertical projection of the bridge, it was more influential as the bridge raised, resulting in similar tie rod loads throughout bridge movement.

For Load Case 3, the results also showed a maximum tie rod load in the seated position. However, since the wind load was now defined as acting to push the span up, the results showed the tie rods could see compression at and near the fully raised position.

In addition to the above, we also considered a holding case, where wind loading was defined as 50 psf acting against the vertical projection of the raised lift span to determine maximum holding loads.

With this portion of the analysis complete, we had defined an ‘operating’ design load at allowable stress and a ‘holding’ design load at 50% allowable overstress.

The next step was to perform a similar analysis using the same load cases but determine the rack/pinion forces. With rack/pinion forces known, we were then able to determine the horsepower required to operate the bridge and begin sizing equipment that would make up the operating machinery. This process was somewhat iterative, in that we first needed to estimate the weight and location of equipment, establish the actual size of equipment and then confirm the accuracy of estimated values. Once the actual values matched the estimated values we had a workable solution.

During this process we had assumed that the existing counterweight might remain as-is. Its value was estimated based on information available during design and a scope item added to the contract documents to confirm its actual weight. If needed an adjustment would be made during construction.

Lastly, the fixed towers and counterweight arms were analyzed by H&H, to ensure the frame structures could handle the two-directional loading imparted by the alternate operating system.

Design Challenges

Integrating the selected alternate operating machinery presented some challenges.

The effort required rough sizing of the rack beam and supports to locate and fit the assembly within the base of the fixed tower and back end of the counterweight arm. It also included manipulating the beams proposed position to maximize its mechanical advantage while confirming clearance throughout its full range of travel. Integrating the rack beams pivot support as well as its carriage support assembly within the constraints of the existing structure added to the complexity of this challenge.

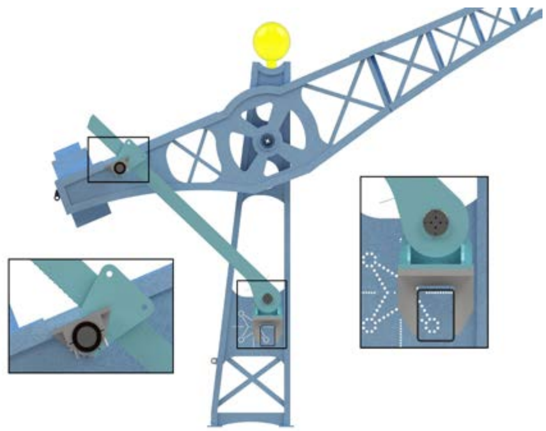

FIGURE 2: Side Elevation of Rack Beam with its Carriage Assembly and Pivot Support highlighted.

Unlike most double leaf bascules that target a 1.5 kip downward reaction at the toe per bascule girder with the leaf fully seated, the Minnesota Slip Pedestrian Bridge would be closer to 6 kips. This heavier seated imbalance was considered acceptable since it would promote positive seating and unintentional movement could be prevented by the operating machinery.

In reviewing the original mid-span support details, it was our understanding that the effectiveness of the original center latch assembly would be highly dependent upon proper mating. Knowing that leaf lengths would vary over the course of an operating season as well as the associated fully seated position, we decided to replace the original assembly with a simpler detail. The new center bearing assembly would utilize a two-piece spherical bearing, that would serve to support the bascule span arch regardless of its actual seated position. From a controls standpoint, this required having the two spans be synchronized for mating.

The original control system utilized a relay logic control system and Rockwell 700 series inverter drives running in open loop. To keep the construction budget reasonable, as much of the existing electrical cabling as possible was maintained, especially the cabling in the underwater duct system. The span motors and drives were not provided with encoders because there were no twisted single pair (TSP) available in the existing cabling. It was decided to replace the relay logic system with a programmable logic controller (PLC) based control system and provide redundant inclinometers on each span. Ethernet cards were added to the existing drives, allowing the PLC to control motor speed precisely. The two leaves were kept in synchronization, similar to maintaining skew in a tower lift bridge. Proper mating is detected by means of a proximity switch at the center bearings and is checked by confirming the direction of applied motor torque has changed from providing counter torque to just beginning to apply lowering torque.

In addition, but only partially related to the selected alternative, it was determined that the fixed towers and counterweight arms would need to be strengthened. With limited time remaining in the design schedule, it was decided to include a miscellaneous structure repair item as part of the contract documents to cover strengthening work. It was also noted this work would need to be completed prior to installing the new operating machinery. This approach allowed the City to issue an invitation to bid per the established schedule and provided H&H a few months to design the necessary strengthening details within an established construction budget.

Fabrication and Construction Schedule

To meet the City's requested schedule of having the bridge rehabilitation work completed by June 2017, the operating machinery reducers needed to be pre-ordered and the contract documents completed by October 2016.

For the reducers, an invitation to bid was posted in mid-October 2016 with a defined bid opening date of November 7, 2016. The invitation clearly noted that the reducers would need to be manufactured, tested and delivered, installation ready, to specified City of Duluth address within twenty-two (22) weeks of award. This was considered an aggressive but reasonable timeframe to deliver the reducers, leaving only a few weeks before the units would need to be placed into service.

For the contract documents, an invitation to bid was posted in early November 2016 with a defined bid opening date of December 1, 2016. Per the published bid tabulation, there were four (4) vendors whose total bids ranged from $2.7 million to $3.3 million. The City of Duluth contracted with the low bidder.

Post Retrofit Operations

During the 2017 operating season, the rehabilitated bridge was operated nearly 3000 times. Considering the operations occurred between June and October or over a five (5) month period, that's an average of twenty (20) times per day. During this period there were two reported disruptions to service. The first related to a failed drive resistor that lasted a day and the second related to a faulty wire bunch that lasted a day and a half. It could be stated that both issues were outside of the project control, but they happened. Had these issues not occurred, it would have been the bridges first year without a disruption.

Conclusion

As of June 2018, the Minnesota Slip Pedestrian Bridge has also been repainted, from its original 'azure' blue that was the basis of its nickname, to a new 'teal' blue. The change in operating behavior with the new operating system was immediate. The new system is reported as operating smoother than the original system and has eliminated the potential for nuisance breakdowns in moderate to high wind conditions. Lastly, the new mid-span support and revised seating features now allow the arch span to consistently mate upon seating. Proper mating has eliminated excessive bouncing, which was previously initiated by pedestrians jumping on the toe of the bascule leaf, creating a diving board affect.

As recently suggested by a local columnist, it is the hope of locals and visitors that the new 'hue' will further shed the bridge from its problematic past. (Duluth News Tribune Article, February 28, 2018)

Acknowledgements

Bridge Owner and Operator:
City of Duluth – Department of Public Works and Utilities Engineering Department

General Contractor:
Lakehead Constructors Inc., Superior, WI

Specialty Sub-Contractors:
Benson Electric Company, Superior, WI
Panatrol Corp., Burr Ridge, IL

Reducer Manufacturer:
Overton Chicago Gear, Addison, IL

Machinery Fabricator:
Lemke Industrial Machine, LLC, Marathon, WI

Design Engineers:
LHB Inc., Duluth, MN
Hardesty & Hanover, LLC, New York, NY