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Support Machinery Replacement: Modifications vs. In-Kind and Lessons Learned from Two Projects

Stephen A. Mikucki, PE
Mario Palumbo, P Eng
Dave Gerber, PE

Hardesty & Hanover and SLSMC

Purpose

Abstract

This technical paper will outline two case studies, and how the allowable rail closure windows, navigation restrictions, and other construction constraints significantly influenced the design approach to the bridge repair details. The first will summarize Bridge 6 over the Welland Canal, and the complications with replacing the existing tread and tracks for this twin single leaf Scherzer style rolling lift bridge. The railroad users limited rail closers for two 52-hour periods over two separate closures to access the front tread and tracks for replacement. This influenced the design approach to 1) replace in-kind with limited modification since the phase construction requires old and new to operate for durations, and 2) focus on pre-closure fabrication and testing to limit the work required during the outage.

The second project will summarize the modifications and improvements that were made to the Spuyten Duyvil Bridge for Amtrak located in New York. The adjacent 90-day station closure, and temporary bypass of the bridge allowed for the complete removal of the swing span, and replacement of the existing rim bearing tapered roller assembly, with four bogies to support the bridge dead load and live load rail traffic. *(Note: Spuyten Duyvil rehabilitation was presented virtually in 2021 which covered the technical aspects of the total rehabilitation including the operating machinery. Spuyten Duyvil has been combined with Bridge 6 in this technical paper with a different focus on scheduling effects on the design approach for each).*

Introduction

This technical paper will highlight two case studies where the dead load transfer components (elements) or "supporting machinery" required replacement after many years of service, and how the spatial access and allowable work windows influenced the design approach for each restoration project.

Support Machinery (Dead Load Transfer Components): For the twin rolling lift bascule project, the support machinery (dead load transfer components) are the curved treads attached to the bottom flange of the segmental girder, and the flat tracks attached to the top flange of the track girders embedded in concrete on the approach span. *(there is some debate as to whether the tread and track elements are structure or machinery, but for this project and the required alignment tolerances for proper operation this work was considered machinery)* The treads are equipped with pockets, and the tracks are equipped with lugs to guide the leave both longitudinally and transversely through the range of operation. The treads and tracks were replaced "in-kind" with slight modifications to allow for the stage construction outlined to limit the closures. These bascule leaves were tracking properly through operation, so the in-kind replacement was selected.

CAPTION: New rear tread and track (unpainted) installed during adjacent to the old tread and track segments (painted grey). Note the modifications to the new tread pockets and the modifications required to old pockets for temporary operation.

For the swing span, the original system was a hybrid rim bearing and center pivot bearing arrangement that used 64 tapered rollers at a diameter 30 ft supported approximately 80% of the dead load of the span. The remaining 20% of the load was supported by the pivot bearing. This was changed out with a larger center pivot bearing (spherical plain bearing chosen for long term durability) and 4 railroad carriage style bogies that replaced the tapered rollers. The tapered roller arrangement had a history of tracking problems, and maintenance of the tapered roller bearings in the often-flooded zone were problematic.

CAPTION: Spuyten Duyvil with old drum girder in place blocking access to pivot pier.

<u>Innovation</u>: *def – a new idea, method, or device*. For movable structures it is hard to develop a truly innovative idea, but the term seems to be overused in the industry. Maybe because the definition includes a "method", but we rarely see innovative devices being installed due to risk of failure. H&H like to limit this to "innovation with a reason, not just to do something different".

<u>Schedule Constraints</u>: Since each bridge carries rail over a waterway, both projects required addressing the limited detours associated with this type of bridge, versus a typical roadway project. In addition, the Seaway canal introduced equally challenging shipping windows, in particular in the Spring of 2022, when the canal is open for business, and the ships are lining up in Lake Eerie and Ontario. Additionally, these are large cargo ships, that take up the entire width of the adjacent locks, so multiple passing of navigation is not possible.

Bridge 6 East & West over the Welland Canal

History of Bridge 6

Bridge 6 over the Welland Canal is a 90-year-old Scherzer Rolling lift twin single leaf bridge pair with the original tread and track castings. Over the 90 years of service there have been several field repairs that added to the complexity of the replacement including field welding between the track and tread forging joints, as well as being welded to the girder. In addition, the segmental girder was stiffened by welding new radial members to the existing webs.

Bridge 6 is located along the Welland Canal providing shipping between Lake Erie and Lake Ontario. It crosses the Welland Canal and connects Thorold to St Catharines and has been mainly used by CNR, but the expansion of commuters to Toronto has introduced passenger rail (Go Train in addition to the existing Via Rail and Amtrak). Construction over the canal introduced additional pressures not always seen with movable bridge projects. A typical navigational channel usually allows for larger time windows for construction. Due to being located in the North climate, the work window of approx. Jan 1st though March 24th provides a full canal closure and for this work the railroad agreed to single track operation.

Although the bridge operation was reliable, the issues starting at the bridge included 1) concerns with fatigue crack development at the segmental girders, and 2) seating challenges at the toe joint after an operation, and 3) extensive concrete repairs to the substructure. It was decided during a previous study that in order to provide service through the year 2040, the girders would need fatigue mitigation methods applied, and the tread and tracks required replacement. This was considered a 20-year extended life rehabilitation project.

<u>History of Bridge 6 E&W over the Welland</u>:

- *Original design 1926-27 and constructed circa 1929-1930 by Harrington Howard & Ash Consulting Engineers and Hamilton Bridge Company Ltd.*
- *Two track spans, and approx. 100 ft in length*
- *The original tread and tracks were forged steel (no designation on plans), and in regular service since the commissioning of the bridge. Major repairs included welding the tread to the segmental*

girder flange along the curve, welding in new stiffeners along the segmental arc, and along the track girder, and welding the butt splice joints together, essentially making one continuous track and one continuous tread at each corner. In addition, the original turned bolts were seized.

Rehabilitation Design of Bridge 6

Challenges:

- *Tread and track had been welded to the girder flanges and required removal*
- *Tread to tread butt joint had been welded (no nondestructive and positive method to confirm depth accurately. Ultrasonic Testing results varied, so the team opted to grind the intersection for visual confirmation.*
- *Also, as part of this project, the added radial stiffener welds would be treated for fatigue (Ultrasonic Impact to increase fatigue life) and repaint part of the work*
- *Operating Machinery Replacement – Originally scheduled to be replaced simultaneously with the tread and track work, fabrication delays affected the schedule shift and are to be replaced next winter season*
- *Existing machinery alignment with new tread and track installation, as well as uneven roll for approximately 6 months. The new tread plates were not worn and thicker than the existing castings (nominally 1/8 wear on tread and track for a total of ¼ inch elevation change).*
- *Part new and part old tread and tracks, operation and sequencing – since the new tread and track are thicker, there was a need to ramp the old plate rolling surface to meet the new plate surface for operation.*
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Design Improvements (Innovations):

1. *Engagement of old lug and pocket under temporary operation required field modifications to the old tread and tracks*
2. *Final engagement of old lug and pocket*
3. *Sequencing and alignment criteria had to be established before any shutdown of the bridge was granted and the existing tread and track plates removed from the bridge.*
4. *Aside from all these details for construction and scheduling, it is essentially a replace in kid, so innovation and changes are limited to "methods" versus designing an entirely new device to accomplish the function as you will see in the next case study. But innovations of the methods and accomplishing this retrofit proved to be challenging and require excellent teamwork.*

Schedule Constraints

Three phases spread over two construction years, 2022 and 2023 winter works closures:

- Phase 1: Fall of 2021 and considered pre-winter canal closure initial field work – survey work, removal of welds, removal of bolts and fabrication of new tread and track forgings.
- Phase 2: Winter 2022 canal closure work, bridge open to rail (one track at north side), and removal and replacement of the tread and tracks at the South girder. Coordinate with counterweight repairs and span painting work.
- Phase 3: (June 6-8, 2022) rail closure work, bridge in open position for full navigational passage and for the replacement of the front tread and track on the South girder, both spans.

This would be repeated on the North side of bridge for the replacement of tread and tracks in 2023

Challenges

Phase 1 challenges: pre-winter closure preparation work included the removal of the existing bolts with temporary bolts in order to accurately locate the bolt holes prior to fabrication. Field conditions reported that the bolts were seized in the holes, and the contractor proposed method was to remove the bolts with the tread and track elements (ie. Cut the nut end of the bolt off, and jack the entire track segment vertical, with the bolt body seized in the hole). This offered time saving advantages, but eliminated the possibility of locating the holes accurately, and assessing the holes prior to the winter shutdown. Summary of the method change includes:

- Disadvantages included not being able to remove the bolt and measure the hole for fabrication of the new plates.
- Disadvantage was the curved tread and radial placement of the bolts does not allow for this type of one-piece removal, as the bolt body would bind in the different angled holes.
- Welds along edge of old tread and track to track and segmental girders needed removal. Contractor set up test samples to show that air arch gouging would not damage the existing steel to remain. Also, additional stiffeners had been welded in place and limited the access to the bolt nuts for tightening.
- The welded butt joints were not easily removed (deep weld), and installation of the new plate end required precise alignment adjacent to the old plate.

In addition to these technical challenges, there were general COVID and supply delays with the operating machinery replacement. This portion of the project was ultimately delayed to the winter of 2023.

CAPTION: Top photo show excavation of the added weld at the tread joints. Second photo shows joint after one tread section is removed, showing the depth of the added weld.

Phase 2 challenges: The contract documents specified the replacement of the rear tread and track plates first during the 3-month winter works closure period. This allows the contractor a 3-month window to remove and replace the treads and “iron out” any specific challenges and refine their methods prior to the 52-hour closure. There was concern about working from the rear to the front (channel) side could affect the alignment at the toe end of the span after all work was complete. As a result, and to avoid this occurrence, it was agreed that the ‘first’ lug of the second track, and ‘first’ pocket of the second tread being the critical locations. As long as those points were held, in phase 3 the front plates would align so that the bridge will seat in same location after replacement.

Phase 3 challenges: The Contractor mobilized two crews for the 52-hour rail closure, one crew on each leaf. The West leaf was removed, installed and tested staggered ahead of the East leaf. During the time period between April and May 31st, the existing bolts were ultimately removed by lancing the center and temporary bolts were installed until the closure for operation. The rail joints aligned perfectly at the toe end of the West leaf approximately 18 hours before the closure ended.

The removal, installation and alignment of the tread and track at the East leaf had staggered after the West leaf. Due to some interference issues (adjacent concrete work), it delayed testing to verify the fully seated positions, further taking away critical time. With approximately 6 hours before the end of the closure, the leaf was first tested.

Upon the first test seating of the East leaf, it had shifted to the North at the toe end alignment. After some discussion, it was determined that the South side (old tread and track) were too sloppy and allowed for the bridge to be slightly steered by the North tread and track “first lug and pocket”. This was temporarily corrected by welding ¼ thick plate at the North lug to push the leaf straight to the rest pier. This was within the limits of thermal expansion extremes for the 100 ft leaf.

CAPTION: Temporary alignment fix included the addition of ¼ inch plate welded to the old lug to properly align the span at the toe end.

Lessons Learned

The fortunate detail about this project is that the team gets to perform this work again on the North side in 2023. This schedule resulted in some real improvements for consideration as we move into the next construction year:

1. Identify the depth of weld repairs at the butt joint locations, and extent using mandatory exploration grinding, and confirm this splice joint with the length of the newly fabricated forgings.
2. Lock in the position of the first lug and pocket for each span and match the lug and pocket pair installed this previous year. We will only have the adjustment of the undersized bolts in the holes for tweaking the North tread and track forgings.
3. After the tread and track positions are locked in, rehabilitate the centering device.
4. Remove bolts to assess actual hole integrity and establish the oversized bolts for replacement - it is noted that the bolts at the segmental girder required removal base on the curvature, and the radial alignment of the bolts causing interference when removed with the tread plate.
5. Ideally replace the front tread and track plate and align the lug and pocket in the exact same point along the segmental girder and track girder **this is being proposed and discussed moving into the next season of construction.**

6. Install reference points (monuments) for each lug and pocket location, transverse and longitudinal alignment with respect to the girders. This will avoid looking for points in survey world when the toe is not lined up. Note that once the old plates are removed, the lug and pocket locations are lost except for the survey data. Reference points provide a sanity check when everyone is scrambling to fix the misalignment.

Acknowledgements

- H&H – Designer
- Client – St Lawrence Seaway Management Corp
- User – CNR

Authors for Bridge 6: Stephen A. Mikucki, & Mario Palumbo

Spuyten Duyvil Swing Bridge over the Harlem River

History of Spuyten Duyvil

Spuyten Duyvil Swing Bridge was originally constructed in 1900 and is a rim bearing / pivot bearing hybrid swing bridge that has a low profile to the water and is periodically flooded at the center pier. The bridge machinery has been flooded several times during its service life, and the pivot pier area is equipped with drainage scuppers to purge any tidal overflow. Spuyten Duyvil is located at the northern tip of Manhattan Island, and spans across the Harlem River connecting rail to the Bronx and destinations northward.

The project was initiated due to the SS sandy damages and high-water damage to the machinery. Therefore, the overall project goal was to raise susceptible components in elevation. The secondary goals included improving the access for maintenance, limiting the components at the pivot pier to reduce maintenance and to correct some of the operating alignment issues with the rotation of the span.

This project was a result of damages caused by Superstorm Sandy and the flooding of the machinery components that were located low on the swing span. The original swing span as supported by a center pivot bearing and a tapered roller assembly and was a 20/80 split to support the dead load. The current system at the start of this project had been replaced in the late 1980s and had a history of misalignment issues at the pivot point.

History of Spuyten Duyvil Swing over the Harlem River:

- The name is Dutch for Spite of the Devil, due to rough tidal currents at the interface of the Harlem River and the Hudson
- Swing Span length is 291 ft long carrying one track across the Harlem River, width is designed for two tracks.
  Original pivot bearing and rollers replaced in the 1980s with extensive steel repairs due to the harsh environment
- Flooding of the pivot pier occurs and corrosion of the machinery systems was accelerated. The bushings within the tapered rollers were replaced with ceramic materials in an effort to slow this process.

Design Challenges for Spuyten Duyvil

In order to achieve the client's goals for improvement, and work within the allowable construction windows the following goals are summarized as follows:

- Provide new machinery resilient to the flooding experienced at this bridge – eliminate as many machinery components from the flood areas as possible
- Eliminate the tapered roller system and replace with a center pivot bearing assembly and limited machinery
- Reconfigure the support structure from the new bearing to the truss in the same elevation constraints
- Realign the swing span pivot point to reduce wear at the drive machinery

Design Improvements for Spuyten Duyvil

- Replaced the 64 tapered rollers and tension rods with four rail style bogie supports
- Structural modifications to transfer the portion of the dead load from the 30 ft diameter rim to the center pivot after the elimination of the original distribution and drum girders.
- Providing load carrying bogies in addition to the center pivot bearing would mimic the existing load distribution and avoided significant modifications to the pivot pier.

Schedule Constraints for Spuyten Duyvil

- During the design phase, uninterrupted rail passage over the Harlem River was the requirement which was later extended due to 90 days due to adjacent work.
- Occupation of the south channel was permitted for Contractor equipment, and only short durations of the north channel and were required to clear completely as necessary to allow for marine vessels.

These two conditions led the design effort for the bridge to be left in place for the duration of the project. The structure and machinery bogies were designed in segments to allow for installation with the spatial constraints.

After the design was complete, the 90-day rail closure was granted due to adjacent work to the south. A temporary bypass of the bridge allowed for the complete removal of the swing span, and replacement of the existing rim bearing tapered roller assembly, with four bogies to support the bridge dead load and live load rail traffic.

This bridge was rehabilitated in (2018) and presented as part of the virtual HMS in 2020 and has been summarized to focus on the innovative changes to the dead load distribution components, and discuss some lessons learned from this project for consideration in the conversion of other swing bridges.

CAPTION: Original drum girder in position blocking off all access to the center pivot pier for routine maintenance.

CAPTION: Bogie design allows for access between the four bogies by eliminating the continuous drum girder.

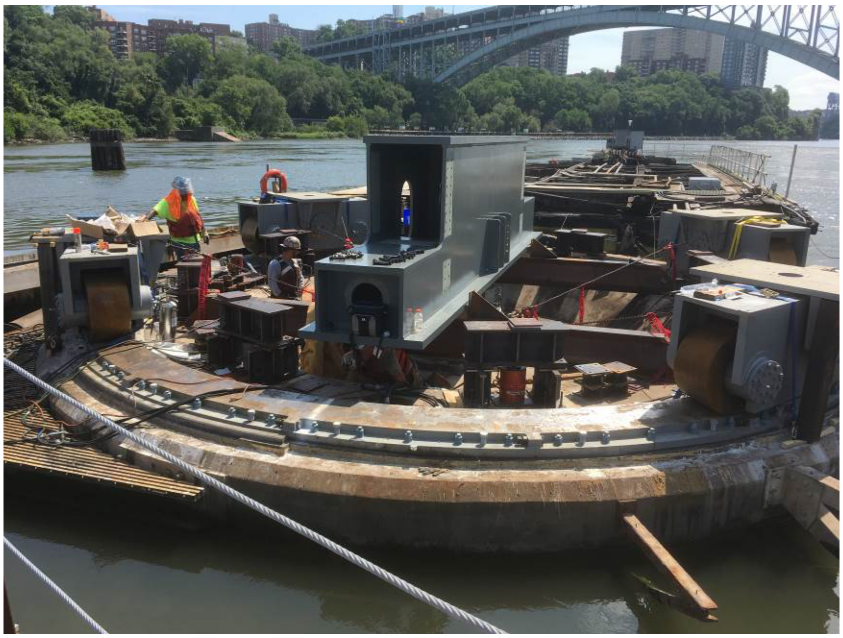
Design Process

Design Configuration: Since we wanted to avoid replacing in kind with the tapered rollers, the concept developed included detailing 4 railroad carriage systems that would take approximately 80% of the dead load from the swing span, but also able to transfer the LL traffic to the rail, instead of having a LL passive balance wheel system. Alignment during construction would be simplified to align 4 bogies rather than 64 rollers. The bogies would be located at the distribution girder, so would be an improvement from the old system, where we see the rollers do not take the LL evenly and will wear flat spots over time.

Construction Details for Spuyten Duyvil

American Bridge was the successful bidder and had included in their proposal the use of the West Coast Lifter crane to lift the span off of the pivot pier and relocate the swing span for the construction.

These two changes in circumstances allowed for much improved access to the pivot pier and increased the durations for construction. The swing span was removed from the center pier at the beginning of the summer of 2018 and was replaced by September of that year within that 90-day rail detour. The bridge has been in service with no reported operating issues, and we are still on the site replacing the electrical systems and festoon cable equipment.



CAPTION: Swing span temporarily removed from the pivot pier shows the layout of the new pivot girder and four bogie arrangement. New structure was installed to transfer the load from the swing span truss to the pivot girder and four bogies, similar to the original system by greatly reducing the number of elements to maintain.

Lessons Learned from Spuyten Duyvil:

- A rim bearing swing bridge can be converted to a center pivot swing bridge simplifying the installation and with some structural modification
- The rail style bogies transfer the live load to the piers effectively and allowed for a simpler installation method replacing the 64 tapered rollers.
- If it were known that the swing span was to be removed during construction, H&H would have detailed the new structural framing differently. It was designed in sections for installation with spliced connections in order to install the elements with the bridge above and all the spatial constraints associated.
- CMGC process versus Design Bid Build – selecting the contractor at the preliminary design phase could have worked through these options and detailed different and more efficient

components for installation. This is a great example of Contractor input regarding installation having a positive influence on the design.

Comparing the Two Projects

At first glance at the title a "replace in-kind" does not seem very innovative, but a better understanding of the definition shows that all challenging movable bridge jobs are unique in some way, and require innovations in methodology in addition to the cooperation between the owners, designers and Contractors.

A second observation is the positive feedback from the Contractor during the design phase could influence the design by expanding the understanding of access during construction by their intended methods. Both projects show the significance of planned removal and installation even between in-kind installation methods to the very different modification made at Spuyten Duyvil.

Thirdly, the allowable rail restrictions and navigational limitations windows greatly influence the direction of design, and can open the project to design innovations that improve the efficiency of the design.

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- American Bridge – General Contractor
- H&H – Designer
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