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Norfolk Southern Bridge N 6.66 Rolling Bascule Track Replacement

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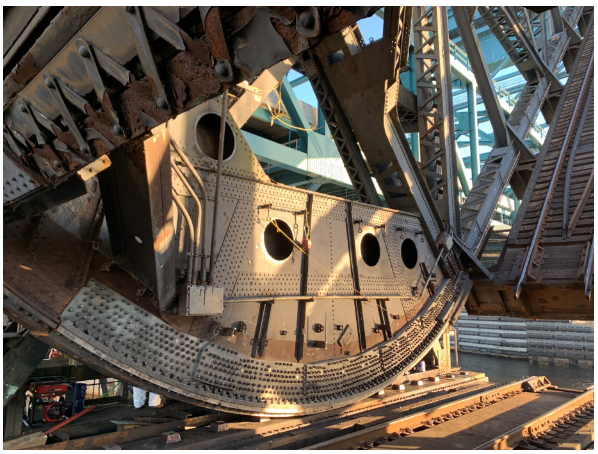
Project Overview

Norfolk Southern Bridge N 6.66, locally referred to as Bridge 7, is a railroad Scherzer Rolling Bascule Bridge. The bridge spans 143 feet east to west over the Southern Branch of the Elizabeth River in Norfolk, Virginia. According to the latest accessible as-built plans, the bridge was constructed in 1908 by the Bethlehem Steel Company. Since 1908, the bridge has undergone several rehabilitations to the tracks and treads.

The most recent rehabilitation prior to the 2021-2022 track and curved tread replacement occurred in 2008. During the 2008 rehabilitation, the curved treads were set with a gap between the tops of the treads and the bottom of the curved webs, which were uneven due to flame cutting during a previous rehabilitation.

Due to time constraints, the gap was filled with liquid zinc, which was intended to cure and provide even bearing between the tops of the treads and bottom of the curved webs. The curved treads installed in 2008 were fabricated from a combination of existing curved tread pieces and new steel welded together. The treads were also fabricated with offset pintle pockets to accommodate the near 2” lateral movement of the movable span which had occurred over the life of the bridge.



CAPTION: North rolling tread and track

After the rehabilitation, the cured zinc began to deform due to the bridge’s immense rolling load, and the bearing load path transitioned into the flange angles which hold the curved tread in place. The new load path caused the welds on the rehabilitated curved treads to crack. Norfolk Southern performed various weld repairs throughout the years, but the welds continued to crack.

In 2017, Norfolk Southern initiated the design for the replacement of the tracks and curved treads. The material order was placed in 2020 and construction began in 2021.

Design Challenges

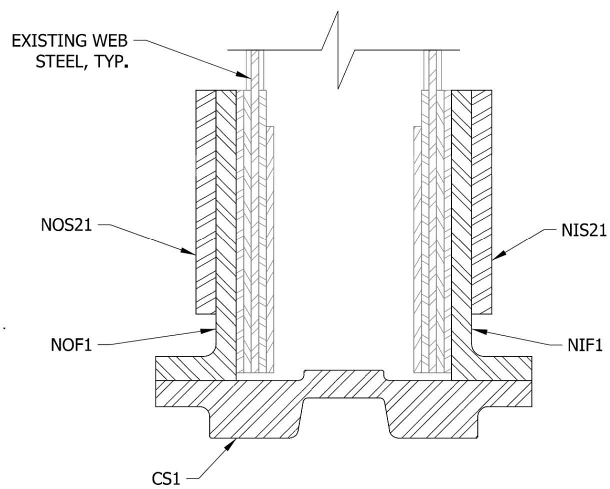
Uneven Roll Radius

Historical data indicates, prior to the 2008 rehabilitation, the bottom of the built-up web girder was flame-cut. The inconsistency of the flame-cut edge created an uneven roll radius and uneven bearing surface on the bottom of the built-up web girder. After 2008, the bridge settled to a lesser roll radius due to the insufficient compressive strength of the zinc used to fill the gap between the bottom of the web girder and top of the curved tread. In a typical Scherzer design, the bottom of the web girder bears flush against the top of the curved treads, creating a smooth and even roll radius.

The 2017 curved tread and connection angle design eliminates the problem by suspending the bridge through a slip-critical connection between the web girders and connection angles. The new connection angles are taller than the original to encompass a larger bolting area, which is needed to achieve the slip-critical joint requirements. The angles are also thicker to meet the stiffness and bearing requirements created by the eccentric load from the weight of the bridge through the bolted connection. The bottoms of the flanges were shop machined to the radius required to set the curved treads back to the original roll radius of the bridge. Shims were added between the bottom of the curved web and the top of Curved Segment 1 to provide a direct load path between the two and to supplement the slip-critical connection under live load from rail traffic.

Deformed Web Girders and Bolt Locations

The earliest drawings of the bridge provide dimensions of the curved girders and the locations of all rivets in the built-up web girders. However, it was noted during bridge inspections that the web girders were warped in various directions, leading to discrepancies between the as-built drawings and field conditions. The 2017 design used over 2,000 bolts in the connection angles on each girder, over 4,000 bolts total. Given the thickness of the new connection angles and the limited available outage time for construction, it was not feasible to field drill all the bolt holes. Therefore, it was necessary to determine the approximate location of all bolt holes and pre-drill the connection angles.

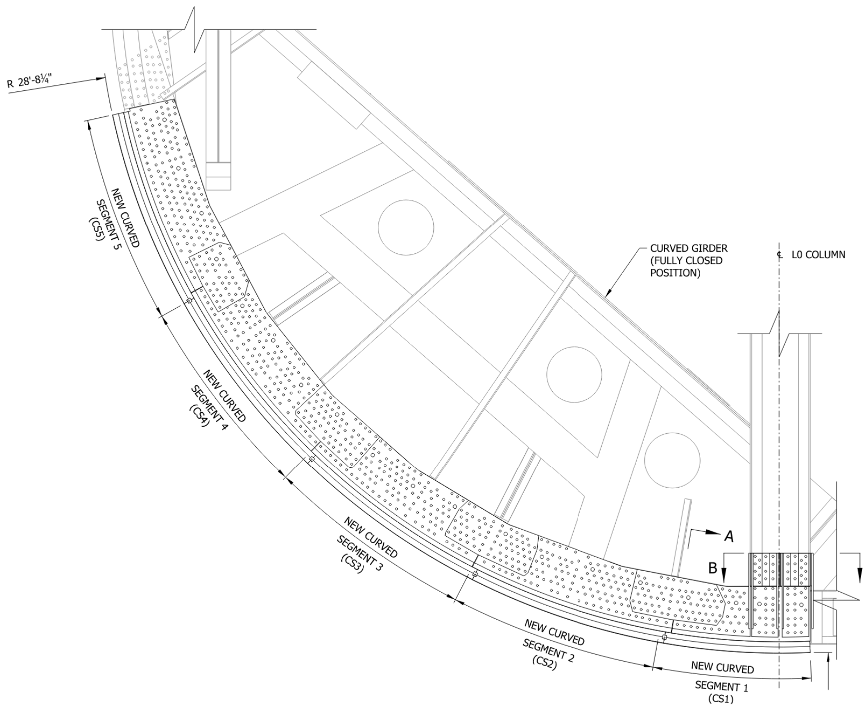


CAPTION: Cross-section of new flange angles and curved tread, existing web

A LiDAR survey of each side of the curved girders was performed to create a three-dimensional point cloud of the girders and bolts. The centers of the bolt holes were then located on the point clouds and translated to two dimensional planes, which could be overlayed on the connection angles. The LiDAR survey was also used to determine the center of roll and bridge orientation in the seated position, so the bolt hole locations could be properly overlayed on the connection angles. During analysis of the point cloud data, it was noted that the web spacing of each girder varied by up to 1" due to warping. Additional diaphragms were added between the webs of each girder using the existing internal radial stiffeners. The additional diaphragms help prevent further warping of the webs and resist the moment in the webs created by the eccentricity between the bridge load and the bearing location on the bottom of the connection angles.

Marine and Rail Traffic Limitations

Bridge N 6.66 is one of Norfolk Southern's highly trafficked bridges. In addition to Amtrak crossings twice a day, every freight train which enters and exits Norfolk Southern's Lambert's Point crosses over Bridge N 6.66. Over 20 trains pass over the bridge on an average day. Bridge N 6.66 is also located on the Southern Branch of the Elizabeth River adjacent to the Gilmerton Lift Bridge. Due to the low clearance of the bridge, most marine traffic entering and exiting the Southern Branch of the Elizabeth River requires the bridge to be opened. The Southern Branch of the Elizabeth River is a critical artery along the intracoastal waterway with the only alternate being the Atlantic Ocean around the Outer Banks, a dangerous stretch of open water.



CAPTION: Profile View of New Curved Tread and Flange Angles

To limit the effect on marine traffic, the construction outages were scheduled between the peak marine season. Similarly, to limit the effect on rail traffic the construction was staged to perform the work on one girder at a time utilizing a single-track outage, closing the track adjacent to the work and operating trains on the opposite track with reduced speed. The exception to the single rail outages was the rail outage for Curved Segment 1 replacement, which required the bridge to remain in the open position, and the rail outage for bridge jacking, which required the rails to be re-aligned.

Construction Outage Lengths

The marine and rail traffic outages were limited in length during construction in order minimize the construction's effect on normal business operations. The bridge needed to be returned to a fully operable condition between each outage. The outage limitations were a major constraint on constructability of the new design and significantly impacted the design.

The 2017 connection angles for the new curved treads were split into 5 distinct sections so that each curved tread and its connection angles could be installed during a separate outage. The holes for the connection angles were pre-drilled based on the LiDAR survey data to limit the amount of field drilling, which is one of the most time-consuming tasks during construction. Temporary splice plates were included to supplement the new curved tread and connection angles, allowing the load to transition between old and new segments so that the bridge could return to full operation in between short-term closures.

Scope of Work

The scope of work for this project included:

1. Demolition and removal of existing curved tread and flat track
2. Installing new flat track, curved tread, and curved tread connection angles
3. Re-shimming of rack drive machinery to accommodate new radius of bridge
4. Coating of new structural steel components
5. Horizontal shift of the entire bridge approximately 2” to return the bridge to its original location

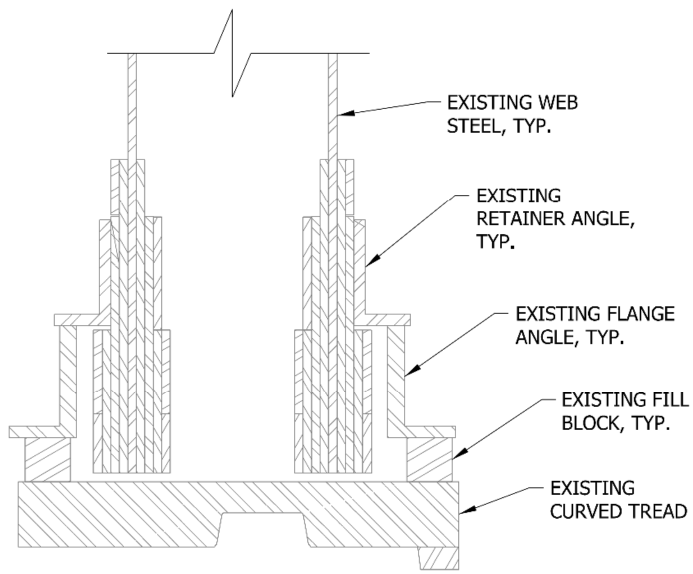
To accommodate the 2” horizontal shift of the bridge and the change in pintle shape from circular to square, the design accommodated for three completes sets of removable pintles on the flat track. The pintles were initially installed with a 2” offset to allow for the initial lateral mis-alignment of the bridge and with a circular shape to match the existing curve tread. As each curved segment was installed, the pintles mating with that segment were replaced with 2” offset square pintles. Finally, during a full bridge outage, the bridge was shifted horizontally to remove the misalignment, while simultaneously swapping to the last set of square pintles without an offset.

Construction Challenges

Closure/Outage Windows

The work was completed throughout 12 closures, varying from single track coupled with marine closures to double track closures.

The flat track work was the least difficult scope. The work was split into two 12-hour marine closures, one for the 5 flat track segments on the right, and one for the 5 flat track segments on the left.



CAPTION: Cut-section of Existing Curved Tread

After the flat track work was completed, replacing the curved tread segments was initiated. The originally planned sequence, duration, and impact of the closures is summarized below. Two closures were planned each week. Segment 5 is bearing in the full open position, and Segment 1 is bearing at full closed.

Closure Sequence	Segment	Duration	Outage Impact
Curved Tread Closure #1	Segment 5 Left	25 hours	Single Track, full marine
Curved Tread Closure #2	Segment 4 Left	25 hours	Single Track, full marine
Curved Tread Closure #3	Segment 3 Left	25 hours	Single Track, full marine
Curved Tread Closure #4	Segment 2 Left	25 hours	Single Track, full marine
Curved Tread Closure #5	Segment 5 Right	25 hours	Single Track, full marine
Curved Tread Closure #6	Segment 4 Right	25 hours	Single Track, full marine
Curved Tread Closure #7	Segment 3 Right	25 hours	Single Track, full marine
Curved Tread Closure #8	Segment 2 Right	25 hours	Single Track, full marine
Curved Tread Closure #9	Segment 1 Left & Right	12 hours	Both Tracks

The first 25-hour closure took 96 hours to complete the work due to various challenges. After the initial closure, the plan was re-evaluated by the team, changes were made to the means and methods, equipment, tooling, and access. Through many discussions with the US Coast Guard and the local maritime community a revised closure duration of 64 hours was ultimately agreed on for the remaining segments. The remaining segments were completed well within the planned closure windows.

Curved Tread closure #1-8 were completed utilizing single track closures, so one of the two tracks were closed to train traffic while the other track operated trains at a reduced speed. The main work area for people, tools, and equipment was the closed track. Work was performed with 12-15 people working immediately adjacent to a live track.

CAPTION: Drilling misaligned holes in flange angle

Impacts of 2008 Repair

One of the larger construction challenges was anticipating the impact of the 2008 molten zinc repair. Molten zinc was poured in between the web girders in order to provide bearing in the gap between the bottom of the web girder and the flat track. This repair was successful for a number of years, but eventually created many construction challenges for this project.

Several attempts were made to remove portions of the zinc. To remove the zinc, a person would need to get in between the web girders, which was a challenge in itself, with the 24” width and many internal diaphragms. Once inside, the properties of the zinc made it hard to remove. When trying to chip it, the zinc was soft enough that a chisel would penetrate it, but not break it off entirely. Trying to torch or melt the zinc was also considered, but being in between the girders, there was nowhere for the zinc to flow once melted. The heat and fumes required confined space and exposure safety considerations. Ultimately, it was determined that removal of the zinc was not feasible.

CAPTION: Segment 5 Flange Angles Exposed

The level of the zinc varied since it was poured as liquid, but in most cases, the top level of the zinc covered between two to four of the four vertical levels of bolts in the existing curved tread flange angles. This created challenges removing the bolts in the flange angles during the closure. Since the head of the bolt was on the inside, with the nut on the outside of the web, the nut could be turned from the outside. However, due to the softness of the zinc, the head would roll and the nut couldn’t be removed. Even if the nut could be removed, the bolt would remain because of the zinc behind it.

Another unexpected impact of the zinc during demo was that the zinc fused the materials together in the web. It was anticipated that once all the fasteners holding the curved tread in place were removed, the curved tread would fall from selfweight, since it was just a flat surface with the zinc pour up against it. After disassembling the curved tread, it was found that two 100-ton jacks could not provide enough force to remove the existing segment. Ultimately, a hoe-ram was needed to break the curved tread free. This worked well after the first couple iterations, but was not anticipated during the first closure.

Field Drilling/Reaming of Flange Angles


CAPTION: Segment 5 Installed

Although the LiDAR scan and pre-drilling of the flange angles was necessary due to the volume of bolts (500-600 per closure), it was not perfect. One cause was that it was scanning the head of a rivet to represent the centerline of a bolt, while the rivet head doesn't necessarily correspond to the center of the rivet shank. Another issue was that all of the rivets/bolts were not visible, some were concealed by additional supports added to the flange angles over the years.

During the closure, preparations were made to ream holes if needed. In the first closure, 40-60% of the holes needed to be drilled or reamed throughout the segment, corresponding to about 250 holes of various alignment conditions between light reaming, to holes in the flange angle with no hole in the web girder at all.

The original approach was to use typical bridge reamers to clean out any holes necessary, reaming through the outer flange plate and removing material from the inner plies (web girder). The web girder was 7" thick, so even minor misalignment required a significant amount of reaming.

CAPTION: Installing curved segment

A significant number of holes were too misaligned to ream and needed to be drilled, requiring the web girder to be drilled 7" deep.

In subsequent closures, the approach was changed to speed up the process. In total, closure #1 required 40 consecutive hours of drilling/reaming. At the end of the first 8 closures, this was cut to less than 10 hours.

There were two main changes made to the drilling and reaming process, a detailed identification/tracking was setup, and a different approach with tooling was taken.

Regarding the process changes, detailed tracking sheets were created to track each hole and the progress being made. Once the flange angles were installed and inspected for alignment, the field engineer and superintendent would go through each hole and determine 1) if a bolt would fit, 2) if it was close enough to be reamed, or 3) if it was the best to drill the hole. Physical marks were made on the steel to let crews know which approach was appropriate at each location. The tracking sheet was updated and progress checked off both on the steel and on the tracking sheet as holes were drilled/reamed. It was important not to install random bolts that could fit, as it interfered with the mounting surface of the mag drills.

CAPTION: Inboard Scaffold

With respect to tooling, it was initially planned to use traditional bridge reamers to relieve any misalignment of holes. Due to the quantity of holes to be adjusted, magnitude of the misalignment, and thickness of the existing steel, it was quickly apparent that a different approach would be needed. After closure #1, extensive testing was performed on test pieces, as well as working with the Engineer to come up with the quickest option while maintaining the required slip-critical connection. The options considered were various types of reamers, end mills, annular cutters, twist-bits, and even briefly an electro arc metal disintegrator. Another factor considered was whether the existing steel, the new steel, or a combination of both should be used to relieve the misalignment. The existing steel web girders were 7” thick and the metal was much harder than the new steel flange angles. When reaming or cutting the existing steel, the rate of removal was much lower, and the steel would chip away rather than produce continuous steel shavings. It was determined that the best method from an engineering standpoint, and the quickest solution, was to drill the new outer flange angles. When misalignment was encountered greater than minor reaming, the hole was drilled in the outer 2” ply with an annular cutter. The center of annular cutter was carefully lined up with the hole in the inner/existing plies of steel, elongating the hole. Once the hole was elongated, a plate washer was used to compensate for the elongated hole.

CAPTION: Outboard scaffold

The engineering required a minimum of 95% of the 500-600 bolts per closure to be installed and tensioned. Once the alignment issues were encountered, the design criteria was re-evaluated and the short-duration minimum bolt requirements was reduced to 85% to allow for areas that were difficult to drill. These holes were drilled between closures during normal work windows.

Access to Work

The additional drilling and reaming required substantially more work to be performed on the flange angles. Due to the variation, a different access plan was needed to increase the time where work could be performed efficiently.

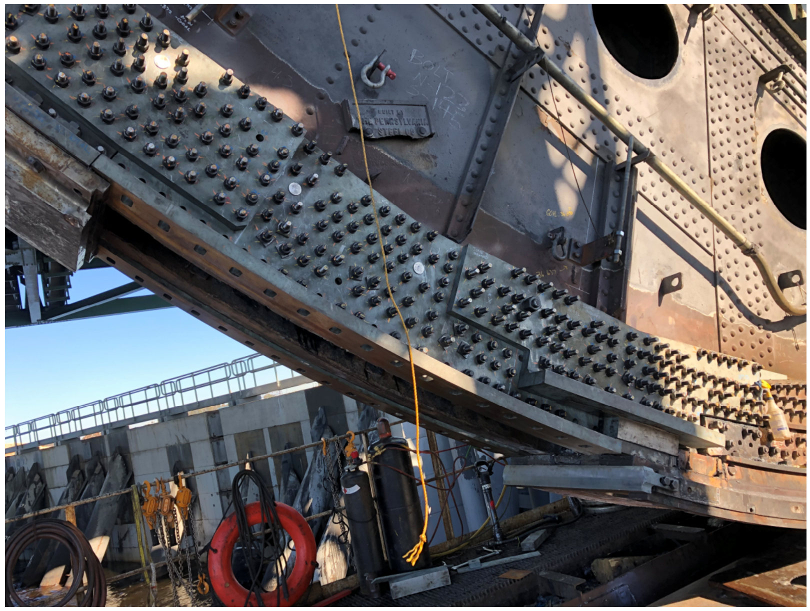
The original plan was to raise the bridge to access the flange angles at Segments 4 and 5, which were around 25' and 15' in the air when the bridge was in the full closed position, respectively. The bridge would be lowered to allow trains to pass, then raised again to continue work. To keep 4 people drilling at all times, a scaffold system was utilized. On the outside, a combination of suspended and ground supported scaffold was used to work around the tower bracing, stairs and electrical components. The scaffold had to be designed and installed in a manner that the bridge was still able to operate. On the interior of the bridge, the scaffold conflicted with the train clearance window, and could not be pre-installed prior to the single-track closure beginning. A scaffold installed on the inside of the web girders would also prevent access for equipment to remove the existing tread and install the new tread. To overcome this obstacle and not significantly increase the duration of the closure, a 3-tiered rolling scaffold was used. The scaffold was stored on its side horizontally in the right-of-way before the closure. Once the closure began, the scaffold was moved to rail carts using a forklift, rolled to the work area, and tripped vertically with a mini-excavator. The scaffold was also on wheels to allow it to be rolled in and out of the work area to allow access for equipment as needed.

Pre-Closure Demo

CAPTION: Pre-demo with come-alongs attached to existing tread

With all of the improvements mentioned above, the team was still concerned with completing the work within the planned closure window. To reduce the duration of work, the team worked closely with the engineer to develop a "pre-demo" sequence that would allow some of the demolition work to be completed immediately prior to the closure.

In a previous repair, an external flange angle had been installed in attempt to prevent the curve tread from


CAPTION: Bolt-up of Flange Angles

further compressing towards the web girder. This included an angle with bolts through the web, and a 2" thick fill block the connected the flange angle to the tread plate. This angle and fill block prevented the bottom row of existing rivets from being seen or removed. These rivets were also not captured by LiDAR since they were not visible with the flange angle and fill block installed, therefore they had a large degree of misalignment. In addition, these rivets were unable to be removed using a rivet buster. Due to the number of plies, and stress in the area, every single rivet needed to be drilled through.

With the current state of the structure, it was no longer believed that the flange angles were providing any capacity to support the bearing load of the tread, and that the flange angles were only holding the tread in place and preventing it from falling.

The team developed a plan to sequentially remove the flange angle and fill block, while supporting the tread with come-alongs attached to hanger plates welded to the tread and supports above the flange angle. This allowed the rivets to be exposed and removed prior to the closure which significantly reduced the time required for demolition during the closure.

Conclusion

Despite the initial challenges on the first tread plate replacement, the team came together to overcome the challenges and deliver a successful project. The bridge in its initial condition had track and treads that were at the end of their life span and needed replacement to prevent impact to train traffic and/or marine traffic at this critical intersection. With this repair, the bridge should operate reliably for decades to come.

Key takeaways:

1. Although the molten zinc repair had fairly good initial results, it made the replacement of the curved treads significantly more difficult. This should be considered when evaluating a similar repair in the future.
2. Engage the US Coast Guard early and often to understand the constraints for closure duration and any time of year considerations.

3. LiDAR, survey, and 3D scans are continuing to change and improve at a rapid pace. Technologies and processes now exist that were not available at the start of this project. Continue to use the best technology available to aid fabrication. Note that despite much misalignment, it was still the right choice for this project to pre-drill. Also, consider bringing in a contractor in a preconstruction capacity to aid in survey efforts and removing or relocating any conflicts present, providing good access for survey, etc.
4. Estimate closure durations as accurately as possible based on experience and production history. Include time contingencies for unknown durations or contemplated issues. Clearly understand the point of no return and the decision process for crossing this point.