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Rehabilitation and Remote Controlled Operation of a 115 Year Old Swing Span

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Rehabilitation of Norfolk Southern Bridge No. HE-3.77 (Shellpot Bridge) Rehabilitation and Remote Controlled Operation of a 115 Year Old Swing Span

Bridge History and Existing Conditions

The Norfolk Southern Bridge No. HE-3.77, commonly known as the Shellpot Bridge, crosses the Christina River in Wilmington, DE. Built in 1888, the original double track, through truss swing span was powered by steam. In the mid-1930's, the prime movers were converted from steam to electric power, and in 1950 the approach spans were replaced by steel I-beams supported by concrete pier camps on H-piles. Use of the railroad line declined and was reduced to a single track. In 1994, the bridge was removed from service due to approach pier settlement. Since that time, freight trains were routed through downtown Wilmington, DE on Amtrak's Northeast Corridor line. In 1999, the Shellpot Bridge fell under the ownership of Norfolk Southern during the acquisition of Conrail. In order to re-route freight traffic from downtown Wilmington, the Delaware DOT agreed to fund a rehabilitation of the Shellpot Bridge. Upon completion of the rehabilitation, each freight car that crossed the bridge would be electronically counted and, over time, DelDOT would be reimbursed for the costs of construction.

Severe Wear on Open Gearing

Existing End Floorbeam Machinery

An in-depth inspection and rating was performed and in 2002, the existing span drive system consisted of a single electric motor and open gearing to operate two pinions which engaged a curved rack gear fixed to the pivot pier. Severe wear was prevalent in the machinery. The end floorbeam machinery was comprised of wedges, end lift rollers, and rail lifts. All of the end floorbeam machinery was driven by a common shaft, which was operated by a single electric motor at the center of the span. The level of corrosion and wear present in the end floorbeam machinery was unknown prior to disassembly. Despite the severe wear in the existing machinery, the span drive machinery and end floorbeam machinery was still operable.

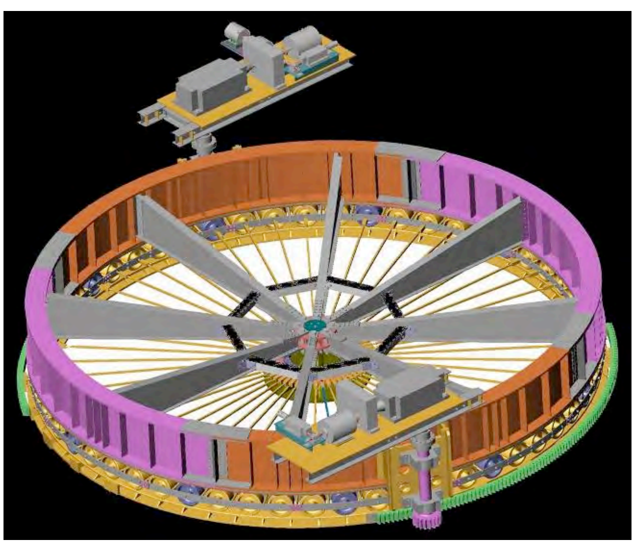

Existing Drum Girder and Rim Bearing Rollers

The span support and turning machinery consisted of 55 conical rollers, with tapered upper and lower tread plates. The rollers supported a circular drum girder which, in turn, supported the swing span trusses. The axles of the rollers were connected to rods which connected to a ring at the center of rotation. The drum girder was supported by eight beams oriented radially from the drum to a center pivot post, which dictated the center of rotation of the span. The drum girder was in poor condition with cracked weld repairs and significant corrosion of the steel. The pivot pier top was at an elevation that was susceptible to flooding, which deteriorated the rollers and lower tread assemblies.

In general, the structure required significant repairs and replacements of key members. Nearly all of the machinery components were un-usable and unable to be rehabilitated. The electrical system was unable to be used for the desired future functionality.

Rehabilitation Design

The design of the rehabilitation involved significant repairs to the truss structure, while retaining the original look of the bridge for historical purposes. The new structure would carry a single track instead of two tracks. Repairs were designed for the floorbeams and new stringers using 315K rail cars. The swing span was to have a new drum girder and double floorbeams at the center panel where the trusses bear on the drum girder. New pier caps were designed for the pivot and rest piers to raise the elevation of the span to lessen the chance of flooding on the pivot pier. New approach bents were designed using prestressed concrete piles and pre-cast bent caps. The existing double-track approach beams were to be removed, cleaned and inspected, and those in the best condition used for the new single-track approach spans.


New Span Drive and Rim Bearing Assembly Model

The span drive machinery arrangement was to be completely replaced with two independent drive trains for redundancy which would load share electrically. The end lift machinery was to be disassembled, inspected, and cleaned, with new components fabricated as needed. The rim bearing rollers were to be cleaned, inspected, and re-used, while new upper and lower tread plates were designed to match the new drum girder and pivot pier cap. A new center post was also designed to center the new drum girder as well as a new rod assembly to keep the rim bearing rollers centered.

The electrical system was to be completely replaced. The requirement for remote operation of the swing span necessitated a PLC driven control system for turnkey operation. The bridge operation would be initiated by the railroad dispatch center in Harrisburg, PA and would have to send feedback in terms of errors or faults to dispatch who would relay the errors to a local maintenance crew. The electrical system would include CCTV cameras, boat detectors, and a PA system to monitor and communicate with the area around the swing span.

Construction

Removing the First Half of the Swing Span Truss

Half of Swing Span Truss on Barge Ready for Shipment to Baltimore, MD

Structure

The first step in construction was to remove the swing span from the pivot pier. The swing span was moved to the closed position and the two arms were separated. Instead of using tidal action to float the spans out of position, the Contractor elected to use a 200 ton crane to pick each arm of the swing span and place them on barges. The barges were then moved, via tugboat, from Wilmington, DE to the Contractor's yard near Baltimore, MD where all of the structural repairs to the swing span trusses were able to be performed.

New Pier Cap on Pivot Pier to Raise Elevation of Swing Span

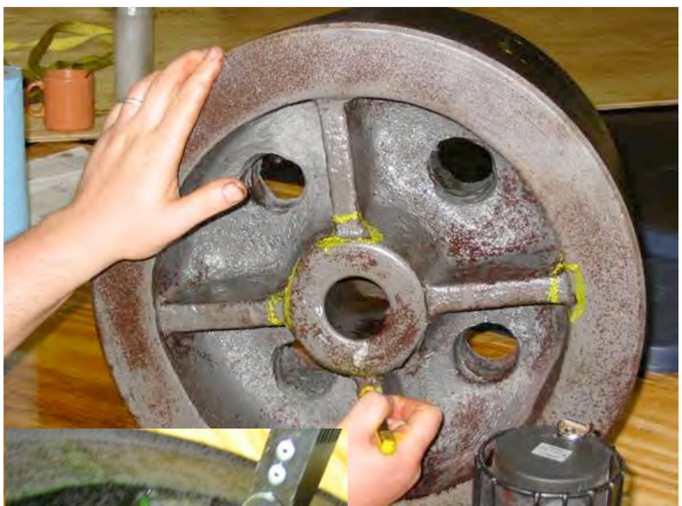
The approach span beams were removed from the approach bents and barged to the Contractor's yard. With the swing span removed, the remaining machinery was removed from the pivot and rest piers, and new pier caps were poured to raise the elevation of the swing span.

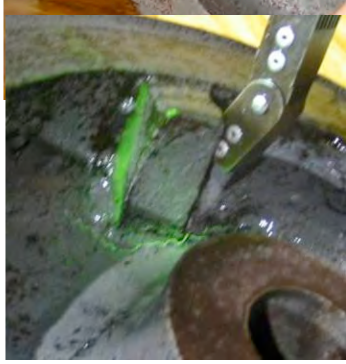
New Approach Bents Built Among Existing Piles

New approach bents were built by driving prestressed concrete piles and placing pre-cast concrete caps on the piles. The pre-cast caps were fabricated with holes to fit over the tops of the piles, which were filled with concrete once the caps were placed on the piles. A challenge when driving the new piles was interference from the old timber piles from the original timber approaches (which were replaced in 1950).

The existing approach span beams were cleaned and inspected. Since the new approaches would carry a single track instead of two, only half of the approach beams would be re-used, so the best of the beams were selected for use in the new approach spans.

Machinery





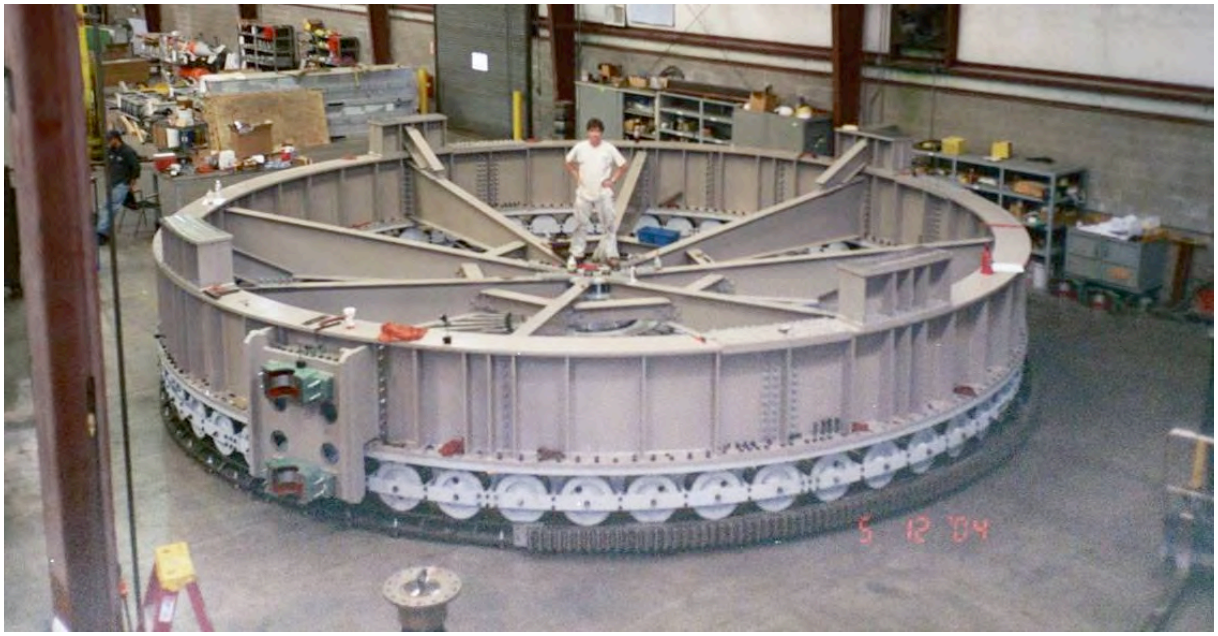
Cracks Identified in Existing Rim Bearing Rollers (above)

Close View of Crack in Web near Stiffener (left)

The rim bearing rollers were sent to the machinery fabricator for cleaning and inspection. Mag-particle tests discovered cracks at the junction of the web stiffeners and the hub as well as the wheel rim were widespread among the rollers. It was decided to scrap all 55 of the existing rim bearing rollers and fabricate new rollers. The design for the new rollers was created and sent to the fabricator. The new rollers were cut from a solid cylindrical forging and machined to the final dimensions. To ensure even distribution of the live load and dead load of the span across the rim bearing rollers, the pitch diameter of the conical rollers was held to ±0.002”.

New Rim Bearing Rollers

The entire span supporting assembly was assembled in the fabricator’s shop to check fit of the components and concentricity of the rack gear with respect to the center of rotation of the drum girder. The backlash between the rack and pinion gearing was also verified and maintained in the proper range of 0.090” to 0.120”.



Rim Bearing and Drum Girder Assembly Shop Test

The end floorbeam machinery was disassembled cleaned. Upon inspection, severe wear was discovered on a majority of the parts. The heavily loaded end lift and wedge pivot pins and shoulder bolts had large steps and grooves. It became obvious that nearly all of the end lift machinery would need to be replaced.

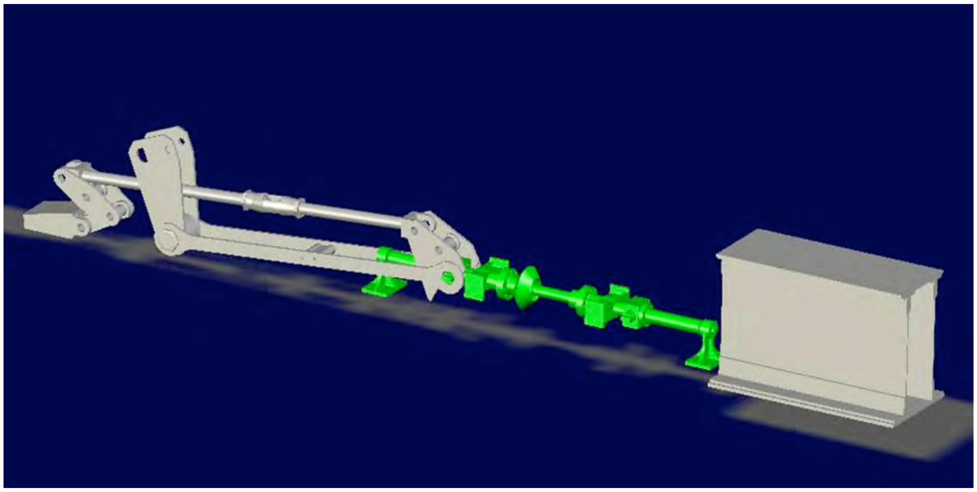

End Floorbeam Machinery Components with Severe Wear

To avoid delaying the construction schedule, it was decided to design new components to replace the existing machinery in-kind rather than design a new machinery arrangement. Newer methods of accomplishing the machinery movements desired would have been simpler, but would have taken more time to design. Therefore, the machinery design from 1888 was re-created with new components.

The end floorbeam machinery arrangement is a complex system of power screws, cams, and linkages. With only one input shaft, the machinery accomplishes three tasks:

- End lift rollers swing to lift the end of the swing span and then lower it back down after the wedges have driven/retracted
- End wedges drive or retract
- Rail lift beam raises or lowers the rails

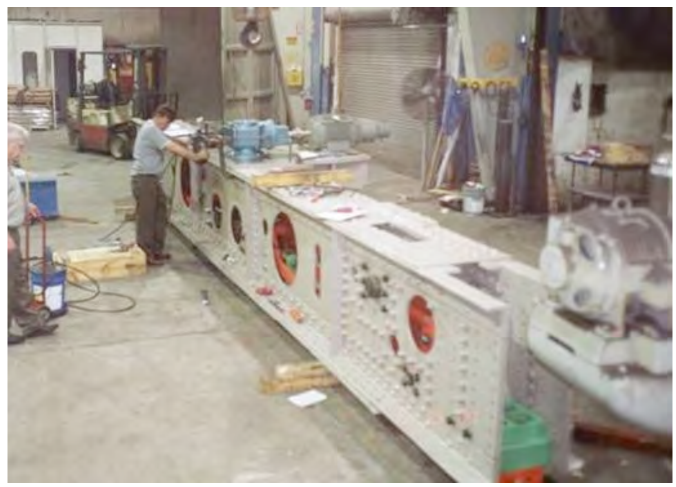
These tasks must be timed appropriately so that the wedges drive or retract while the end of the span is lifted.



Model of End Floorbeam Machinery Assembly

The end floorbeam machinery was treated as a design-build to save time on the schedule. Shop drawings were developed and delivered to the machinery fabricator who made the parts and assembled the end floorbeams in the shop. The assemblies were operated in the shop in a no-load condition to verify operability and check for any clearance issues or binding.

After shop testing was complete, the span support assembly was match-marked, disassembled, and shipped to the bridge site for re-assembly. The end floorbeams were shipped to the Contractor's yard in Baltimore for further work attaching the floorbeams to the swing span.



End Floorbeam Machinery Assembled in Shop

Installation of the span support machinery on the pivot pier began with the center post. Accurately setting the position and elevation of the center post was crucial to proper alignment of the tracks where the swing span met the approaches. Once the location was finalized, the center post was leveled and anchored to the center of the pivot pier.

Center Post Assembly Set and Leveled on Center of Pivot Pier

Measuring Jig Installed on Center Post

With the center post installed, a measuring jig was placed over the machined portion of the post. This jig, basically an over-sized compass, served to measure the radius and runout of the lower tread plate. Dial indicators on the end of the jig were able to measure changes in radius and elevation of the lower tread plate by swinging the jig around the center post. During the installation of the tread plates, the concentricity of the upper and lower tapered tread plates was held at 0.060" T.I.R. with respect to the center of rotation of the span, and the elevation of the lower track was to be held to ±0.010". This precision was an attempt to ensure contact between all rollers and the upper and lower tread plates at all opening positions of the swing span.

Drum Girder being Placed on Rim Bearing Rollers, Previously Installed on Pivot Pier

While the lower tread plate was aligned on the pivot pier, the drum girder was assembled on the adjacent pivot pier fender system. When the lower tread alignment was complete, the 55 new rim bearing rollers were placed on the tread plate and attached to the central ring on the center post support. The drum girder was then placed on the rollers.

Checking the contact between the rollers and the upper and lower tread plates was a lengthy process which involved checking for clearance with feeler gauges at every wheel for several rotational positions of the drum girder. Once measurements were taken, the rollers could be individually adjusted radially in or out as needed. After adjustments were completed, the majority of the rollers had good contact through the 90° rotation that the swing span would operate within. During operation, some rollers would stop rotating and start again, indicating variations in either the elevation or radius of the lower tread plate that were large enough to create a space between the roller and the tread plate. However, since no single roller consistently lost contact, no further adjustment to the radial position of the rollers could be made.

Span Installation

The next crucial step was to place the rehabilitated truss spans onto the new drum girder and approach piers. Since there is a navigable channel on both sides of the pivot pier, placing the first half of the swing span would not close the marine traffic. However, setting the second half of the span would require a marine traffic closure approved by the Coast Guard.

South End Floorbeam Placed on Rest Pier Awaiting Swing Span truss Placement

The two halves of the swing span superstructure and the end floorbeams were barged from the Contractor’s yard to the bridge site. First, the south end floorbeam was placed on the south rest pier and wedges were used to hold the floorbeam in the proper position. Bolsters were bolted to the top of the drum girder and the south truss of the swing span was placed in position on the drum girder and the end floorbeam and held there by crane until the attachments were completed. The end floorbeams attach to the end panel of the swing span truss with pins, which were driven once the span was in position. The end floorbeam machinery was operated manually to drive the wedges so that the dead load of the span could bear on the rest pier properly. With the end floorbeam truss pins in place, the stringers were installed in the end panel of the truss.

South Arm of Swing Span Truss placed in Position

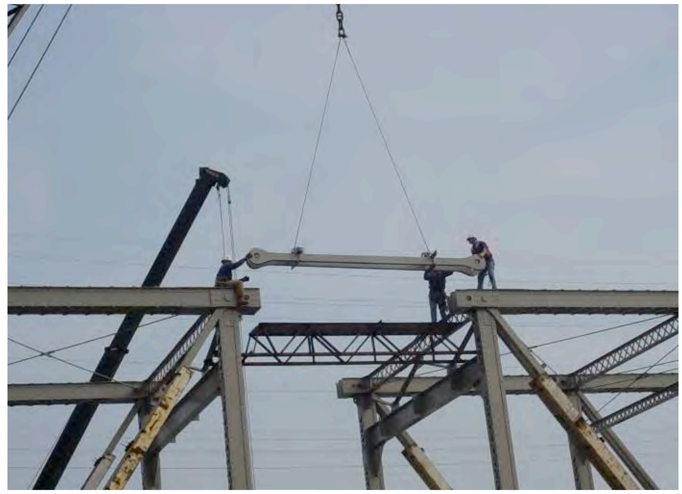
The north truss of the swing span was moved into position on a Tuesday morning. The span was placed on the drum girder and the end floorbeam as was performed for the south truss. By the end of the day on Tuesday, the lower chord splices between the two truss halves were bolted and torqued, and the truss pins at the north end floorbeam were installed.

Over the next two days, the eyebars which connect the upper chords of the two arms were installed. Four eyebars make up the connection at each upper chord. To install the truss pin through the truss joint and all four eyebars, the end of the one of the swing span arms was jacked to align the pin holes, and the pins were installed

Installing End Floorbeam Truss Pin

with mauls and hydraulic jacks. At the end of the day Thursday, the swing span was pushed into the open position with a small tugboat.

Due to the low friction in the rim bearing roller arrangement, the swing span turned easily and slowly coasted to a stop when the tugboat stopped pushing at the end. The end floorbeams were fastened to the fender system to temporarily hold the span in the open position at the end of each work day. The majority of the remaining work could then be accomplished with the swing span in the open position.



Installing Eyebars at Truss Upper Chords

New Operator's House being Placed into Position

While the swing span trusses were being rehabilitated, a new operator's house was built near the north abutment of the bridge. The house and support platform were constructed on a lifting frame of steel beams. Once the two arms of the swing span were installed and rotated to the open position, the operator's house was lifted into position on the truss and bolted to the upper lateral bracing at the center panel of the swing span truss. With the house in place, the installation of the electrical drive and control equipment could begin, all of which would be contained in the operator's house.

The span drive machinery installation began with the main pinions which are integral with their shafts. Since the swing span would only rotate in one direction, two rack gear segments, each spanning an arc of 90°, were bolted to the lower tread plate support. The pinions were aligned with the rack gear segments and the pinion bearings were bolted to the drum girder with undersized bolts. Alignment was initially checked by measuring the backlash between the pinions and racks, however cleaning the gear teeth and applying blue layout dye was the most direct method to observe the contact pattern.

Blue Layout Dye on Rack Gear Teeth to Check Contact pattern

Span Drive Machinery, Shop Aligned on a Common Bedplate, Installed on Span

Once the pinions/shafts were located in the correct positions, the span drive machinery was positioned above the pinion shaft. The span drive machinery was previously installed on a common bed plate and aligned at the shop. A short vertical floating shaft served to connect the span drive machinery to the pinion shaft.

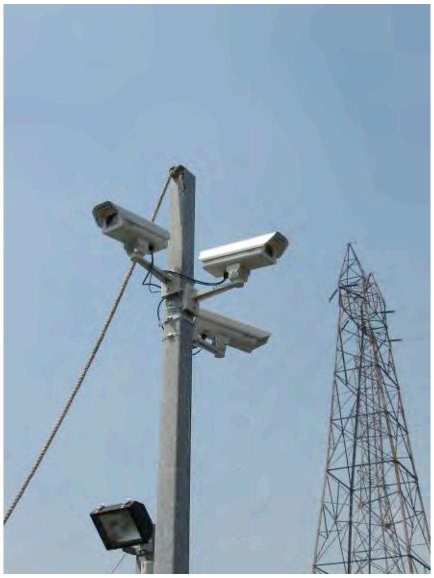
Electrical

After the span drive machinery was positioned in its final location, the electrical power and control wiring installation was completed. For redundancy, utility power was run from either end of the bridge to the pivot pier via submarine cables. The submarine cables emerged through the fender system adjacent to the pivot pier to terminal cabinets anchored to the fender. Power and controls were transferred to the swing span using a festoon cable system. The festoon cable trucks ride on a curved beam attached to the swing span. When the span is open, all the trucks are gathered close to each other. When the span closes, the cable pays out by pulling the trucks farther apart.

Festoon Cable with Span in Open Position

The PLC based control system was installed in the operator's house, along with the two motor drives and the main control console. Since the span would be operated remotely, the operator's house would normally be unmanned. The span would remain open to marine traffic until an approaching train would require the span to move to the closed position. The operation would be controlled from the dispatch station approximately 100 miles away in Harrisburg, PA. In order for maintenance personnel to access the swing span, a small control console was installed in a cabinet on the south rest pier. Control from this console was limited to span operations using the main drive motors or the auxiliary drive motor. Any system faults that would require safety bypasses to be engaged had to be performed from the main control console inside the operator's house.

Control Console in Operator's House



CCTV Cameras for Remote Monitoring of Channel and Bridge Area

For safe remote operation of the swing span, CCTV cameras and a PA system were installed so that the railroad dispatch could monitor the bridge site and communicate with someone near the bridge. Boat detectors (infrared transmitters and receivers) were installed on the fenders which would halt the current operation of the span and move the span back to the open position if an object moved into the channel during a bridge operation. A normal remote-controlled operation process starts by the dispatcher initiating an operation 10 minutes prior to the operation. An audible warning sounds and an automated recording states that the bridge will be opening in 10 minutes. There are similar audible warnings for 5 minutes and 1 minute. The span swings to the closed position and the end floorbeam machinery activated to drive the wedges and lower the rails. When this occurs, the dispatcher receives a signal that the bridge is closed and safe for train passage. An opening operation uses similar audible warnings before the bridge swings open.

Fender-Mounted Boat Detectors to Ensure the Navigational Channels are Clear during Bridge Operations

With the installation of the electrical system complete, the construction process moved into final testing. Electrical interlocking controls were tested to ensure the operation would cancel if the proper sequence was not completed or an operation process failed. All components of the span drive and end floorbeam machinery were operated under normal power and auxiliary/manual power several times to ensure repeatable, reliable operation.

Conclusion

The Shellpot bridge is a good example of bringing an old structure up to date with modern machinery and electronics, while maintaining the historical significance inherent in a century-old bridge. Integral portions of the original design were re-used with modern materials to produce a smooth operating mechanical system. And the original structure, while designed for two tracks, was modified to carry a single track with 315K rail cars.

Span in Closed Position, Open to Rail Traffic

The Shellpot bridge is also a good example of cooperative efforts of public and private entities working together towards a common goal. The streets of downtown Wilmington, DE no longer have freight trains passing through, which also creates a railroad path to bypass the busy city of Wilmington, and each rail car that passes over the bridge slowly repays the bridge rehabilitation loan to the state of Delaware.

Span in Open Position, Open to Marine Traffic

Acknowledgements

Owner: Norfolk Southern Corporation

Contractor:

- -Prime: Merco, Inc.
- -Structural/Mechanical Sub: McLean Contracting Co.
- -Machinery Fabricator: Magna Machine Co.
- -Electrical Sub: Furness Electric
- -Electrical Controls Fabricator: Link Control Systems, Inc.

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