HEAVY MOVABLE STRUCTURES, INC.
TWENTIETH BIENNIAL SYMPOSIUM

October 7-10, 2024

James River Bridge – Main and Auxiliary Wire Rope Replacement

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Background

The James River Bridge (JRB) is a vertical lift bridge located in the Hampton Roads area of Virginia. Vertical lift bridges are a type of movable bridge in which the span rises vertically while remaining parallel with the deck/roadway. The JRB, specifically, is a tower-drive type vertical lift bridge, meaning that all the operating machinery is located at the top of the opposing towers. In these types of bridges, the counterweights are connected to the lift span by means of wire ropes. These wire ropes pass over sheaves at the top of the tower which are rotated with the machinery to operate the span.

Vertical lift bridges are unique types of movable bridges with their ability to offer wide navigational channels. In the case of the James River Bridge, this is an important characteristic given the location of the bridge. The James River is an important navigational channel for the Port of Richmond and other inland stakeholders while also providing a critical vehicular crossing for the Hampton Roads area.

The Hampton Roads area of Virginia has a population of approximately 1.8 million people and is home to the world's largest naval base as well as the Port of Virginia. The convergence of the James, Nansemond, and Elizabeth Rivers into the Chesapeake Bay and Atlantic Ocean poses quite the challenge for the residents in the area. Access between the Southside and the Peninsula is managed by three crossings: the primary crossing: the Hampton-Roads Bridge Tunnel (HRBT), the secondary crossing: the Monitor Merrimac Memorial Bridge Tunnel (MMMBT) and the only bridge only crossing: the JRB. Combined, these crossings serve approximately 178,000 vehicles per day. Figure 1 shows the location of the JRB.

Figure 1: Map of the Hampton Roads Area of Virginia showing the three crossings between the Southside and the Peninsula.

The original James River Bridge was completed in 1928 and provided the first bridge crossing for the area. It remained the only bridge crossing for the area until the opening of the HRBT in 1957. Prior to the JRB, residents used ferries to cross the waterways. The JRB connected Isle of Wight County to Newport News over the James River which has a shore-to-shore distance of approximately 4.5 miles. The original bridge provided only two lanes of traffic (one in either direction). To accommodate the growing area, the original bridge was replaced in 1982 and provided four lanes of traffic (two in either direction). Figure 2 shows the JRB during construction. In addition to increasing the traffic volume, the current JRB provided a wider navigational channel. The current channel is 350 feet wide and has a vertical clearance of 145 feet when the lift span is raised (60 feet when closed). Today's lift span is 415 feet long, weighs approximately 3,360,000 pounds, and operates using 80 wire ropes. Up until this project, the ropes were original to the 1982 construction of the JRB.

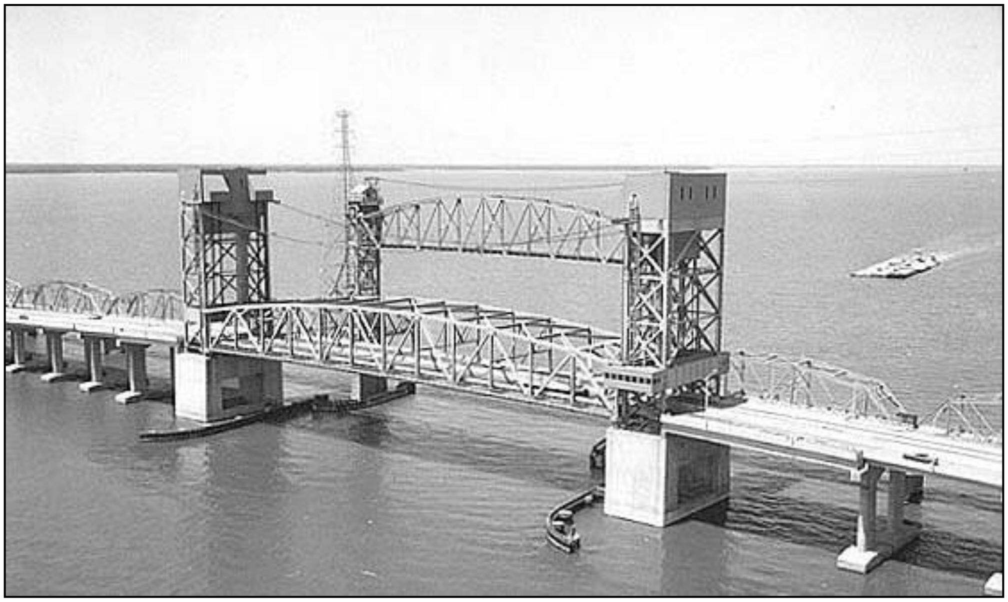

Figure 2: Photo taken in 1982 during construction of the current JRB and prior to removal of the original bridge. Photo Source: The Daily Press.

Project Development

The JRB is currently owned, operated, and maintained by the Virginia Department of Transportation (VDOT). In January 2013, VDOT issued a task order for the performance of an inspection and rehabilitation scoping investigation for the JRB. This investigation was a full mechanical, electrical, structural, and architectural rehabilitation with the goal of maximizing operational availability for the next 25 years. As a results of inspection and scoping investigation multiple recommendations were provided, however one of the most significant findings of this investigation was the condition of the main counterweight wire ropes.

At the time of the investigation, several findings regarding the wire ropes indicated the ropes were nearing the end of their service life. The ropes had been in service for 31 years and while AASHTO does not provide definitive guidance regarding wire rope replacement, OSHA CFR 30 Part 75 does provide wire rope retirement criteria that is commonly used. The OSHA CFR details eight criteria for evaluating wire ropes:

1.) The number of broken wires within a rope lay length, excluding filler wires, exceeds either 5% of the total number of wires or fifteen percent of the total number of wires within any strand.
2.) On a regular lay rope, more than one broken wire in the valley between strands in one rope lay length.
3.) A loss of more than one-third of the original diameter of the outer wires.
4.) Rope deterioration from corrosion.
5.) Distortion of the rope structure.
6.) Heat damage from any source.
7.) Diameter reduction due to wear that exceeds six percent of the baseline diameter measurement.
8.) Loss of more than ten percent of rope strength as determined by nondestructive testing.

Criteria #4 and #7 were found to have been met. Most apparent was criteria #4. As shown in Figure 3, the ropes exhibited a layer of rust and lack of lubrication leading to rope deterioration. Criteria #7 was confirmed in conjunction with field measurements as shown in Figure 4 and the Roebling Wire Rope

Handbook table. As shown in Figure 5, it was estimated that 78% of the outer wires remained. This corresponded to 90% of the rope area remaining intact which exceeds the six percent reduction due to wear of the baseline diameter in criteria #7.

Figure 3: Photo of the condition of the wire ropes from the 2013 investigation.

Figure 4: Measurements taken on the outer wires during the 2013 investigation.

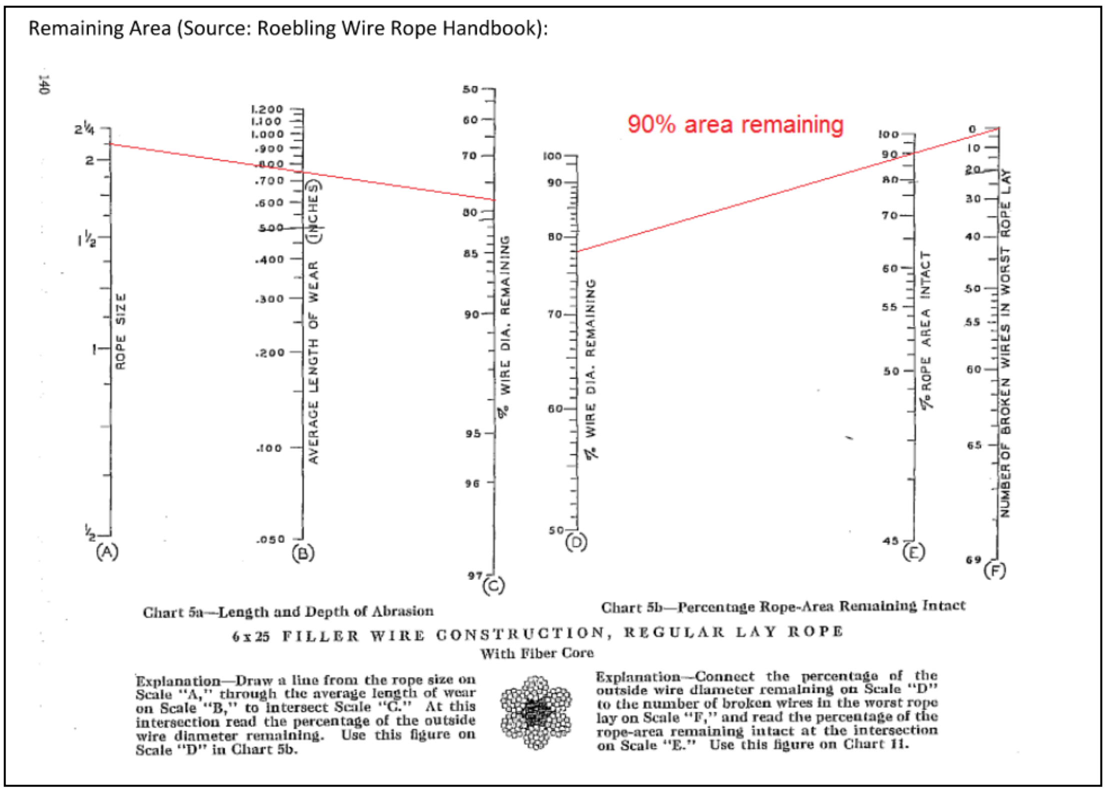

Figure 5: Analysis of the diameter reduction due to wear utilizing the Roebling Wire Rope Handbook

Given these findings, a recommendation for replacement of all 80 ropes was made. However, given that wire ropes for this application are not readily available, it was acknowledged that immediate replacement was not practical and recommended that the ropes be closely monitored while working towards replacement in the next 12-18 months.

Shortly after this scoping investigation was completed in 2014, plan development for a full mechanical and electrical rehabilitation of the JRB's operating equipment began, which included replacement of both the main and auxiliary wire ropes. The plans progressed to the 100% phase, but unfortunately, funding for the project was not approved and the project was shelved in 2016. Over the next 5 years, the condition of the ropes were continually monitored. Monitoring primarily occurred during the biennial AASHTO inspections which took place in 2017, 2019 and 2021. Not long after the 2021 AASHTO inspection, VDOT was able to secure funding for a project to replace the ropes but did not include any other mechanical or electrical systems. With funding secured, the rope replacement portion from the original M&E rehabilitation project was extracted and the project documents revised based on the new scope of work. The new scope for this project included replacing all 80 of the 2-1/8 inch diameter main counterweight wire ropes and associated hardware, and replacing all 8 of the 7/8 inch diameter auxiliary counterweight wire ropes and associated hardware. While the auxiliary counterweight ropes were not in the same severe condition as the main counterweight wire ropes, it is common practice to replace these ropes at the same time. The auxiliary counterweights are essential to the operation of the bridge in maintaining balance throughout the raising and lowering of the lift span. As the main counterweight wire ropes pass over the sheave at the top of the tower, the weight of the ropes is transferred from the lift span side to the counterweight side. The auxiliary counterweights are in place to compensate for this transfer in weight.

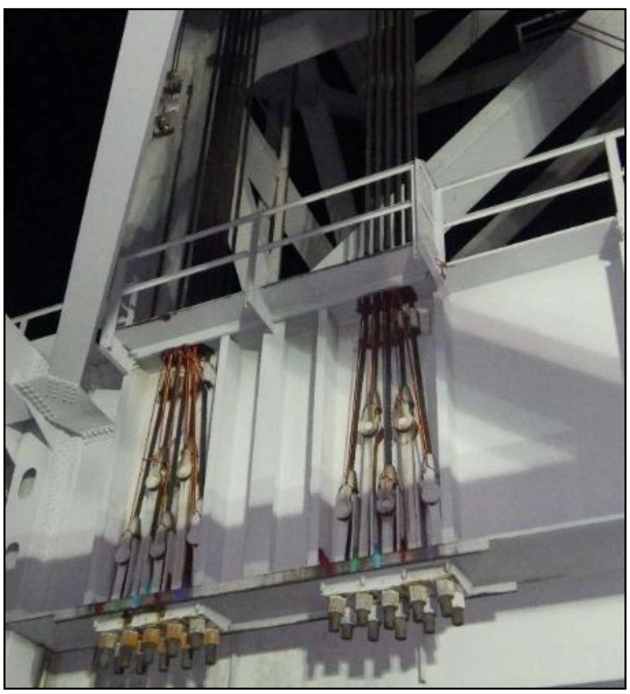

Figure 6: Photo of the main counterweight take-ups connecting the wire ropes at the lifting girder. Note the color coding.

As an added precaution for this particular rope replacement project, VDOT elected to include replacement of half of the main and all of the auxiliary counterweight rope take-ups within the scope of work. The take-ups, for the main counterweight ropes are the portion of the ropes that form the connection to the lifting girder at the lift span end, refer to Figure 6. Apart from making the connection, the take-ups are essential to the configuration of the ropes and provide the ability to adjust the tension within each rope. From past experience, the condition of the take-ups cannot be verified prior to removing the ropes and can pose challenges and costly delays if attempting to restore them and place them back into service in the middle of an outage. Additionally, the pins connecting the rope sockets to the take-ups have been known to seize in place slowing down the rope removal process. To avoid both issues, new take-ups were to be installed during the first outage allowing the pins to be removed and the take-up threads restored in a shop prior to their reinstallation in the subsequent outage.

In the Spring of 2022, to expedite the rope replacement project even further, VDOT chose an alternative delivery option consisting of a procurement contract and a separate construction contract. This allowed VDOT to purchase and begin fabrication of the long lead time materials prior to the construction portion of the project and avoiding the difficulties associated with a delayed notice to proceed (NTP) project. The items that were procured ahead of time included the main counterweight wire rope and the auxiliary counterweight wire rope assemblies. The assemblies included the wire ropes, rope sockets and socket pins, take-ups for half the ropes with washers, nuts, and cap nuts, and the threaded rods, washers and nuts for both connection ends. The wire ropes were fabricated, cut, and tested by Wire Rope Works, refer to Figures 7 and 8.

Figure 7: Photo of the wire rope on the spool prior to cutting at Wire Rope Works.

Figure 8: Photo after the break test of the wire rope at Wire Rope Works.

Another unique characteristic of the James River Bridge is the peregrine falcon nest located at the top of the North Tower. In Virginia, the peregrine falcon is considered a threatened or endangered species and is therefore protected by the Virginia Department of Wildlife Resources (DWR, formally Virginia Department of Game and Inland Fisheries). The protection for the falcon prohibits construction activities which might distrub the nesting habits within 600 feet of the bird's nest. These restrictions, referred to as an enviornmental Time of Year Restriction (TOYR), are in place from February 15 through July 15. This TOYR greatly reduced the window in which the wire ropes replacements could occur. VDOT's goal for this project was to complete the replacement of the ropes prior to the 2024 TOYR. This created a fairly condensed schedule for advertising, selecting, and awarding the contract and further validated VDOT's decision to procure the long lead time items ahead of awarding the construction contract. The complete timeline for this project is shown in Figure 9.

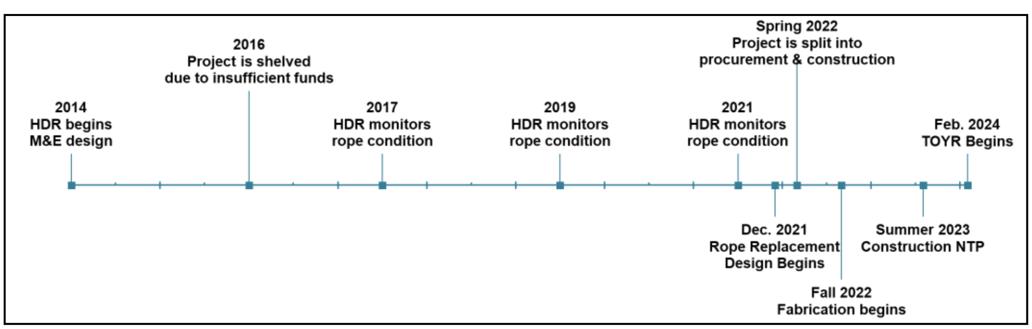

Figure 9: Timeline of the project starting with design including fabrication and going through construction

Design Considerations

Wire Rope Selection

The original wire ropes on the JRB were 2-1/8 inch diameter, 6x25 Filler Wire, Fiber Core (FC), refer to Figure 10. This type of wire rope was fairly standard in the industry at the time of construction, however since then, wire ropes and the fabrication process have improved. The new general industry standard are independent wire rope core (IWRC) wire ropes which provide a greater minimum breaking strength and stretch less both at initial installation and over the life of the ropes, refer to Figure 11. The original, fiber core ropes had a minimum breaking load (MBL) of 358,000 lbs and provided a safety factor of less than 8 given the anticipated average and maximum tensions. IWRC ropes in both Improved Plow Steel (IPS) and Extra Improved Plow Steel (EIPS) were evaluated. IWRC IPS ropes were found to have a factor of safety of just over the minimum AASHTO requirements at the lower limits. For the replacement of the ropes, a 2-1/8 inch diameter, 6x25 Extra Improved Plow Steel (EIPS), IWRC rope was selected. This change provided a significant strength increase with a MBL of 442,000 lbs. When the rope samples were tested by the manufacturer (Wire Rope Works), they were found to break at nearly 500,000 lbs. Figure 8 shows the condition of the wire rope following the break test.

Rope Type	Nominal Strength	Factor of Safety (Assumed Tension = 45 kips)
Fiber Core (IPS)	179 tons (358 kips)	7.95 (min. 7.55/max.8.35)
IWRC (IPS)	192 tons (384 kips)	8.53 (min. 8.10/max.8.96)
IWRC (EIPS)	221 (442 kips)	9.82 (min. 9.33/max.10.31)

Table 1: Wire Rope Type Comparison

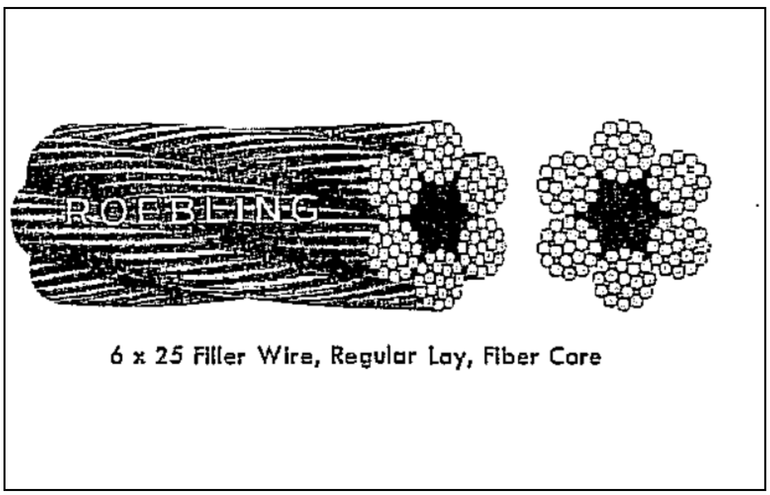

Figure 10: 6x25 Filler Wire, FC Wire Rope

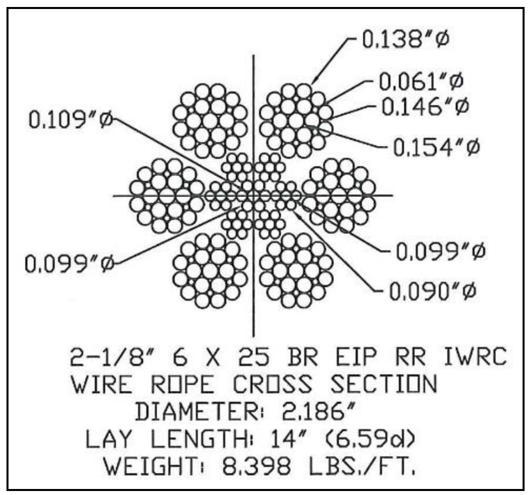

Figure 11: 6x25 EIPS, IWRC Wire Rope

As alluded to above, the existing ropes were anticipated to have stretched from their original fabrication/installation length. This was a primary factor when determining the construction sequencing and will be discussed later with the risks associated with the proposed construction options.

Bridge Jacking Analysis

To facilitate the replacement of the ropes, the lift span needed to be raised by the means of hydraulic jacks. Given the weight of the movable span of 3,360,000 pounds, the jacking system was required to have a minimum of two jacks per corner capable of jacking and holding a minimum of 4,800,000 pounds. Consideration for the placement of these jacks was factored into the construction plans developed for the project. The historical as-built drawings for the JRB indicated that the jacking points were located where the air buffers are currently mounted on the end floorbeams, refer to Figures 12 and 13. Jacking at these locations would require the contractor to remove and reinstall the buffers, refer to Figure 14, leading to potential delays during the outages. It would also temporarily eliminate one of the bridge's safety features. However, after performing a structural analysis of the end floorbeams, it was determined that, without significant strengthening modifications, jacking at the locations of the existing buffers was the only viable option.

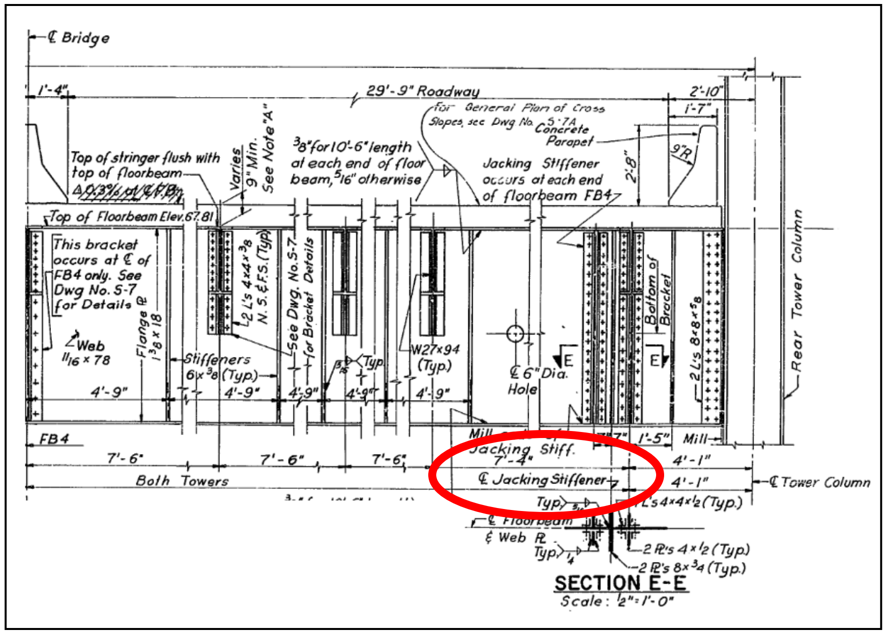

Figure 12: End view of the floor beam from the historical as-builts

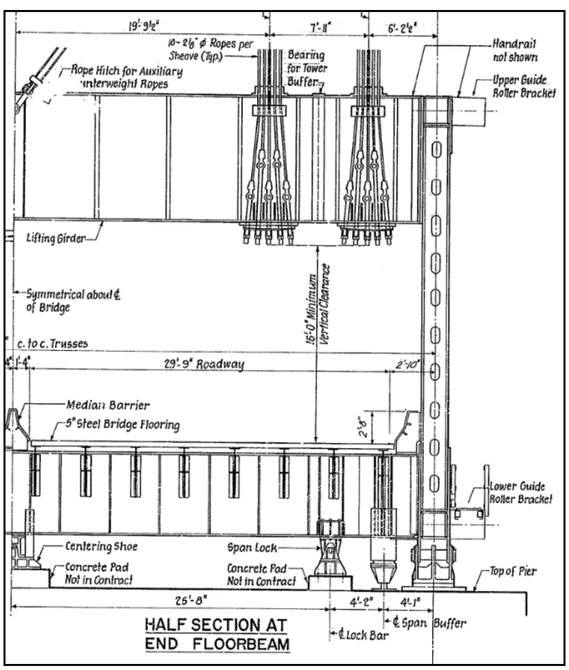

Figure 13: End view of the lift span

Figure 14: Photo of existing air buffer

Constructability Assessment

One of the major considerations for VDOT was the number and duration of the outage(s) that would be needed to complete this project. Because the JRB provides an essential crossing in the Hampton Roads area, one of the focuses was on reducing the amount of time the bridge would be closed to vehicular traffic. Refer to Figure 15 showing the detour route for a vehicular closure of the JRB. At the same time, the James River is a major shipping channel that provides access to the Port of Richmond and has multiple stakeholders when it came to impacts of the navigational channel. Two of the primary stakeholders were the Virginia Maritime Association (VMA) and the United States Coast Guard (USCG). Taking a proactive approach, VDOT engaged both the VMA and USCG early in the design process to inform and discuss with them the options VDOT was considering, durations that would be accepted by the industry, as well as the critical nature of the project.

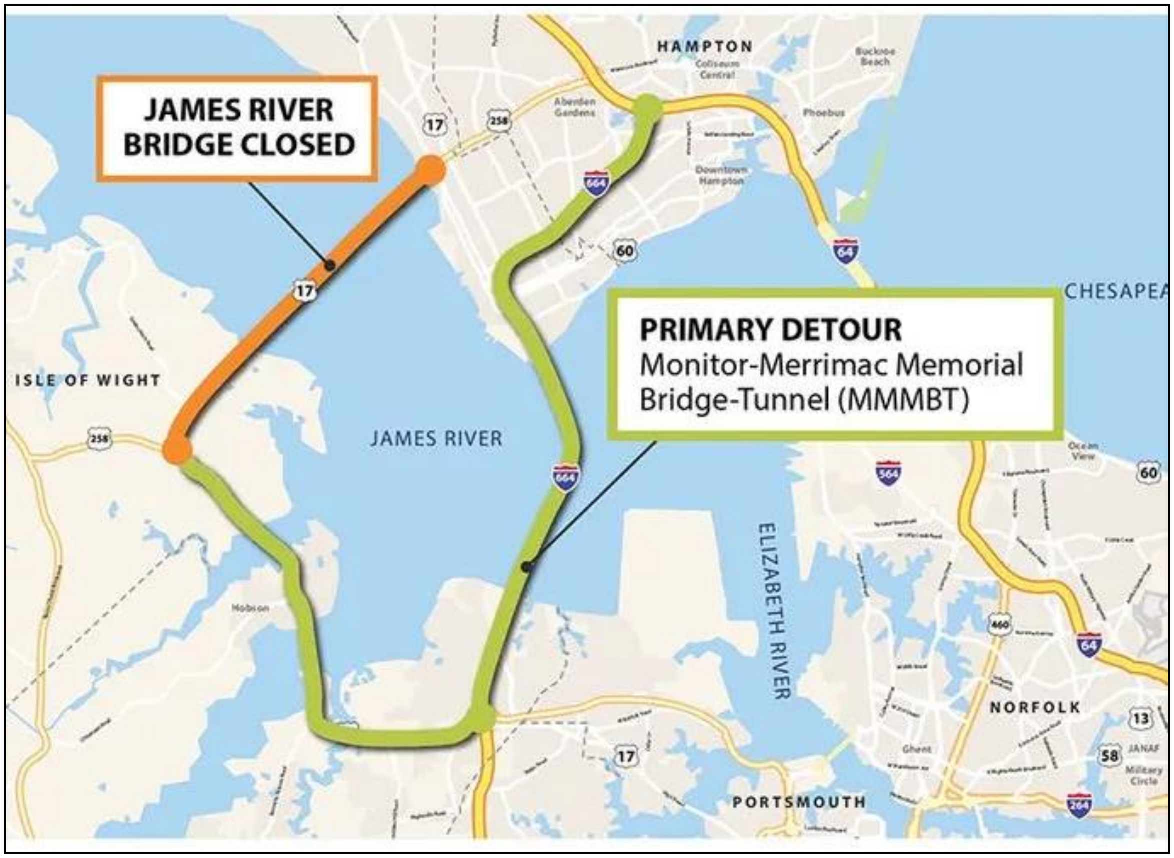

Figure 15: Detour plan for vehicular closure of the JRB

During this phase of the project, a considerable amount of time was spent identifying and developing various sequences of construction for VDOT to choose from prior to listing the project for advertisement. While these sequences did not dictate the means and methods in which the contractor would be allowed to replace the wire ropes, they did compare the number of outages, length of outages, crew requirements, equipment requirements and risks associated with each option. In total, eight options were developed for VDOT's consideration for completing this project. These options ranged from a single, extended outage during which all 80 ropes would be replaced to four, shorter outages where only corner (20 ropes) were replaced. Each option had pros and cons associated with them.

To help VDOT assess all the options, a risk matrix was compiled, refer to Figure 16, identifying the risk for not only VDOT, but the Contractor as well. This allowed VDOT as well as the stakeholders to determine the appropriate durations for the project while still managing the risk. This matrix did not compare the costs associated with each option as the estimated cost variance between them was approximately +/- 10% and was not the primary focus of this task.

Rope Replacement Outage Option Assessment Matrix

Option (Ref memo)	Anticipated Number of Outages (A)	Anticipated Number of Crews per Shift (per day) (B)	Anticipated Outage (Days)		Anticipated Number of Equipment	Resource Comparison (1)			Risk (3)		
									Construction Risk		Bid Risk
			Marine (C)	Vehicular		Crew Days (AxBxC)	Equip. Weeks (2)	Total Resource Days	VDOT	Contractor	
1	1	4 (8)	6	6	2	48	2	62	1	2	2
2	2	4 (8)	4	4	2	64	8	120	1	2	3
3	2	2 (4)	6	6	1	48	4	76	1	1	1
4	2	2 (4)	6	2	1	48	4	76	2	4	3
5A	4	2 (4)	3	3	1	48	8	104	4	5	4
5B	4	2 (4)	3	3	1	48	8	104	3	4	4
6A	4	2 (4)	3	3	1	48	8	104	5	5	5
6B	4	2 (4)	3	3	1	48	8	104	4	5	4

1. "Total Resource Days" is only meant to show a comparison of resources based on anticipated outages, crews and equipment. It is not meant to provide a cost for each option.
2. "Equipment Weeks" are determined assuming that the speciality equipment will be rented from the start of the project to the end of the project and assuming outages will occur every two weeks.
3. Risk Assessments do not include likelihood of anticipated outage durations being accepted by VDOT, USCG, DOD and all other stake holders. Risk assessment also does not include possible conflicts with HRBT construction.

Risk Factors	
1	Low
2	Low-Moderate
3	Moderate
4	Moderate-High
5	High

Figure 16: Rope Replacement Outage Option Assessment Matrix

The first option was a single, extended outage where all 80 ropes would be replaced. Due to the low construction risk for VDOT, this was assumed to be one of the preferred options. However, at the time of advertisement, it was questionable if there were contractors that would be able to provide the experienced crews needed to staff this type of work. Therefore, it was a concern as to whether contractors would even consider bidding on the project and VDOT did not want to run the risk of having to readvertise the project, missing the targeted construction window. This option also posed the greatest risk of overcrowding on the bridge, creating unsafe working conditions and potentially slowing down progress. Additionally, this was undesirable to the navigational channel stakeholders as the extended duration of the outage would be more impactful to them than multiple shorter outages.

Options 2 through 4 all required two outages and would replace the ropes on one tower at a time. The significant difference between them were the duration of the vehicular closures. Option 2 was similar to Option 1 in regard to the amount of resources that the contractor would need to provide but by splitting up the outage, it was anticipated that it may actually increase the likelihood that a contractor would have the flexibility to provide the number of experienced crews necessary to hit achieve the deadlines.

Option 3 was considered to be the most desirable option for successfully completing this project. While the navigational and vehicular outages were longer than Option 2, it seemed to be the most likely option to receive competitive bids. Confidence in the success of this option was high as it was most similar to another VDOT vertical lift bridge rope replacement project that had been recently completed.

Option 4 was the final two outage option that was developed. The key difference with this option was that it was a shortened/partial vehicular outage. The concept behind this partial vehicular outage was that the contractor would be able to work one corner of the bridge at a time. Because the JRB has four lanes of traffic (two in each direction), two lanes of traffic could remain open while the contractor was working on the other side of the barrier wall, refer to Figure 17. Once one corner (20 ropes) had been replaced, traffic could be switched, and the contractor could replace the opposite corner on the same tower. This option significantly increased the amount of risk for the contractor as they would be working adjacent to live traffic and would require additional safety measures. It also meant that there would be two-way traffic across the entire 4.5-mile-long bridge and would potentially require ramps to allow vehicular traffic onto the jacked bridge all of which was not preferrable for the danger associated with the traveling public.

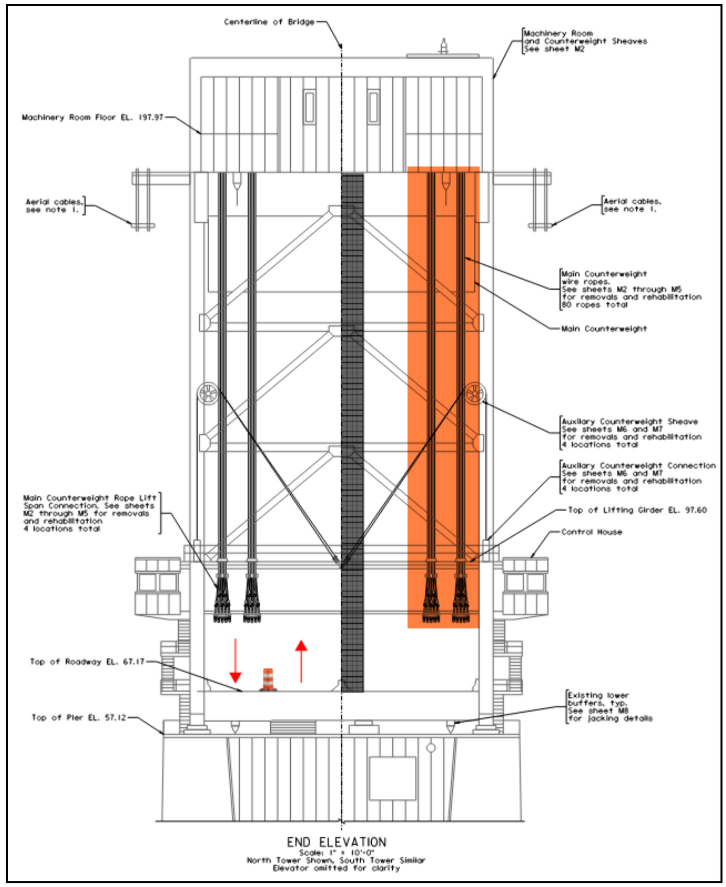

Figure 17: Construction phasing for Options 4, 6A, and 6B with vehicular traffic adjacent to rope replacement.

Options 5A, 5B, 6A, and 6B all required four total outages. From a constructability standpoint, these all presented the most risk. Options 5A and 5B were most similar to Option 3 with full vehicular outages but split into only replacing one quarter of the ropes per outage. Options 6A and 6B were most similar to Option 4 with partial vehicular outages, but again split into only replacing one quarter of the ropes per outage.

The key differences between these A and B options had to do with the length of ropes that would be fabricated. The A options used the original fabricated rope lengths whereas the B options required laser measurements of the existing ropes to determine the current rope lengths. Over the course of the 40+ year service life, the existing wire rope had seen stretch due to elastic and constructional stretch. Refer to Figures 18 and Table 2 regarding the stretch analysis. The stretch over time was estimated as being upwards of 4 inches.

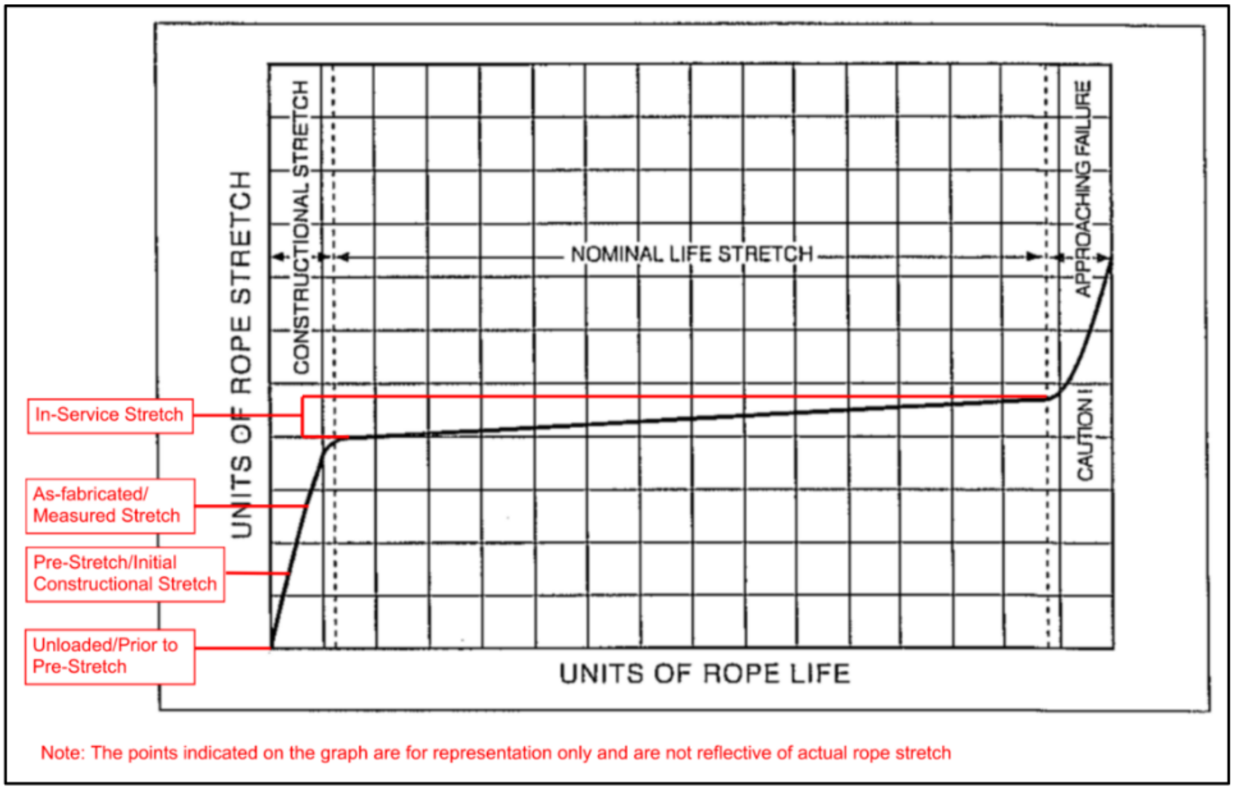

Figure 18: Graph showing typical stretch rope stretch over the life of a wire rope

Rope Designation	As-Fabricated Length1	Elastic Stretch	Constructional Stretch2		Theoretical Rope Stretch over Time3,4
			Min	Max	
Existing Long Rope	149’9.125” +/- ¼ per 100’	4.418”	8.986”	13.478”	4.492”
Existing Short Rope	147’0.125” +/- ¼” per 100’	4.337”	8.821”	13.231”	4.410”
New Long Rope	149’9” +/- 3/8”	3.136”	4.493”	8.985”	-
New Short Rope	147’0” +/- 3/8”	3.078”	4.410”	8.820”	-

Table 2: Estimated stretch for the JRB wire ropes

Due to this significant difference from the original fabrication length, there was concern that additional problems during construction could be introduced by using the original fabrication lengths and Option 5A or 6A were not recommended. Because these options replaced only half the ropes in one tower at a time with ropes that were shorter than the existing ropes, there was potential for the counterweight to transversely skew becoming stuck between the guide rails, refer to Figures 19 and 20. When assessing this situation, it was determined that this could occur with only approximately 3 inches of difference between the rope lengths. Because of this concern, Option 5A and 6A were not considered in the final determinations.

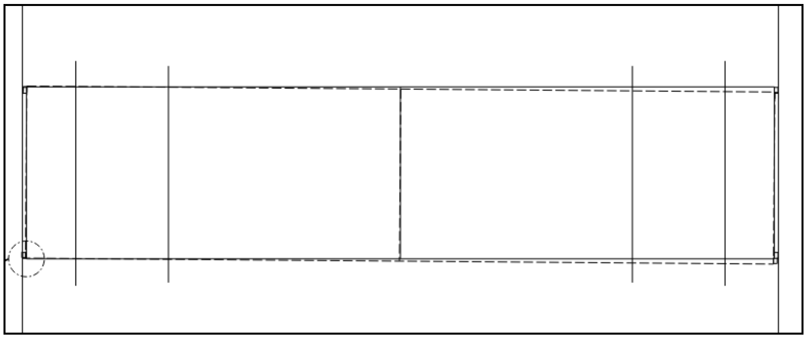

Figure 19: Theoretical counterweight skew

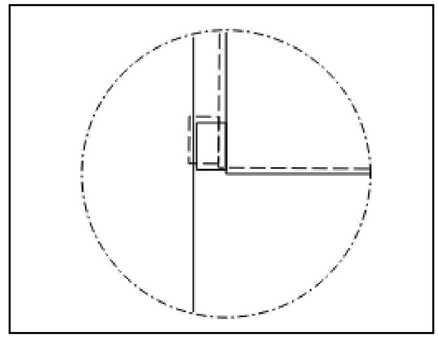

Figure 20: Detail of interference at guide rails

During the design phase of the project, a laser survey of the existing ropes was performed.The survey results found the actual rope stretch to be between 5 and 6 inches, further confirming options 5A and 6A to be non-viable options.

Option 6B was not pursued for the same reasons that Option 4 was not considered; the partial vehicular outage which required the contractor to work adjacent to live traffic with two-way traffic on the same side of the bridge caused too many safety concerns for the traveling public.

Ultimately, VDOT selected a two-outage option which was a hybrid of Option 2 and Option 3; the contractor would be allowed to shut down the JRB to vehicular traffic for 100 hours and to navigational traffic for 124 hours. Recognizing the risks to all the stakeholders and as well as the importance of on time delivery, VDOT included incentives for early completion, disincentives for failure to open the bridge to vehicular traffic, as well as made any penalties levied by the USCG the responsibility of the Contractor. VDOT's intent was to incentive on time or early completion.

Construction

Pre-Outage Work

PCL was awarded the construction contract and given notice to proceed late in the Summer of 2023. This provided approximately 6 months to develop plans and coordinate resources before the TOYR took place on February 15, 2024. To assist in this challenge, Wiss, Janney, Elstner Associates, Inc. (WJE) was brought on as the Contractor's Engineer and provided essential work plans of which included: Main Wire Rope Installation, Auxiliary Wire Rope Installation, Rope Tensioning Procedure and Span Jacking and Pinning Procedure.

A very proactive approach was taken for this project, performing as much work outside of the closures as possible while still maintaining the safety of the traveling public and limiting disruptions to bridge operations. Proactive activities included test jacking of the span, loosening of the counterweight hangers, removal of take-up cap nuts, installing removal devices on the counterweight pins, color coding rope locations in accordance with the reeving diagram and replacing the auxiliary counterweight ropes under lane closures. Thorough work plans for all work activities including air buffer removal, span jacking and pinning, wire rope removal and installation and rope tensioning were prepared well in advance.

To ensure the large jacking assembly functioned as anticipated, a short duration stoppage was performed where the jacks were pressurized and used to test lift the span. With the counterweight unpinned, only the imbalance of the movable span was lifted though all the jacks. This test confirmed the hydraulic power unit

(HPU) and lifting points were adequate for jacking. From previous experience, the counterweight hanger can become seized on the upper pins making it impossible to move the hangers towards the counterweight support until they are freed. The spacers were temporarily removed, the hangers freed and pushed in towards the counterweight support. Once verified, the pins were lubricated, and the hangers were separated out again until the outage began. The removal plan for the counterweight pins required nuts to be welded to the outboard side of the pins and coil rods threaded in. This was done at every pin pre-outage so that just the jack and jacking chair had to be moved. With every minute during the outage counting, even small, time saving tasks were done pre-outage including removal of the take-up cap nuts and color coding the lifting girder rope locations, counterweight support wire rope locations and placing laminated and color-coded reeving diagrams at both locations. This allowed for the installing contractor, the Engineers and VDOT to confirm the placing of all the ropes in the correct locations.

In order to focus on the main rope replacement during the outage, VDOT agreed to replacing the auxiliary counterweight ropes under single lane closures, with short duration gate stoppages and marine traffic call ahead in lieu of doing the replacement at the same time as the main counterweight ropes. This pre-work eliminated roughly three work shifts, kept the opposing side of the span clear and allowed additional crews to focus on the main rope replacement. VDOT also allowed for the lower buffers to be removed ahead of the outage and reinstalled directly following the outage. As noted in the Design Considerations section, the location of the buffers provided the only viable jacking location and removal prior to the outage to allow the jacking systems to be setup and ready for use going into the closures.

Bridge Jacking and Counterweight Pinning

At the start of the outage, the bridge was formally closed to navigational traffic and the roadway was closed and traffic detoured. The bridge was then jacked until the hanger pins aligned with the top hole of the counterweight hangers. Once pinned, the span continued to be jacked to a height where the existing ropes were slacked, and the new ropes could be installed without resetting the jacks. This height totaled approximately 18 inches. Jacking was achieved utilizing four, 400-ton hydraulic jacks and two, 50-ton hydraulic jacks, refer to Figures 21 and 22. Due to the sequencing of the replacement, larger jacks were used for supporting the dead load of the span on the tower where ropes were being replaced and smaller jacks were used to support the imbalance of the opposite tower.

Figure 21: 400-ton jacks under the floorbeam on the rope replacement end of the lift span.

Figure 22: 50-ton jacks under the floorbeam of the opposite end of the rope replacement.

Existing Main Counterweight Wire Rope Removal

Figure 23: Hydraulic jack and jacking chair used for removing pins at the counterweight.

Upon completion of jacking and pinning operations, the wire ropes were secured at the counterweight, cut just above the lifting girder and jacking chairs and hydraulic jacks were utilized to remove the existing pins from counterweight rope connection billets, refer to Figures 23 and 24. Tight fits, between the pins, sockets and billets coupled with corrosion and misalignment slowed the process of removing the pins. However, crews quickly adapted to issues and sped up removal production.

After pin removals on two of the four sheaves were completed, winch lines connected to the air winches located on the approach span were run up to the sheave rooms where they were attached to individual wire ropes. Utilizing two air winches, ropes at two of the four sheaves were lowered to the deck as crews on the counterweight continued to remove pins. This process was continued until all counterweight pins and ropes were removed. Rope removal production rate was estimated at one hour per rope with removals at two sheaves occurring simultaneously. Actual removal production rate met or exceeded the estimated rate during both outages.

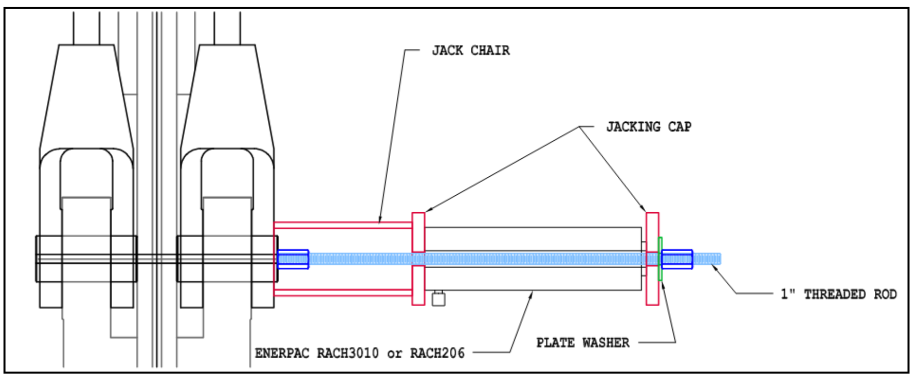

Figure 24: Drawing of hydraulic jack and jacking chair configuration.

Upon completion of all rope removals, all the pin holes in the billet and the sheave grooves were then cleaned and lubricated and pins test fit to the billet to prepare for installation, refer to Figures 25 and 26. Also at this time, crews on the deck used a combination of the air winches and lifting equipment to remove the existing take-ups from the lifting girder, place them onto pallets for delivery off site to be refurbished. During the first outage the existing take-ups were saved for reuse on the opposite tower. During the second outage, the take-ups were cut out of the lifting girder adding to the efficiency of the work.

Figure 25: Condition of the wire rope sheaves prior to cleaning.

Figure 26: Condition of the wire rope sheaves following cleaning.

New Main Counterweight Wire Rope Installation

With cleaning and lubrication complete, installation of the new ropes began. Four ropes at a time were pulled off the reel trailer and laid on top of plywood mats placed on the deck. The short take-ups were then installed with the long ropes and the long take-ups installed on the short ropes. The air winch lines were routed through a snatch block over the sheaves and down to the deck of movable span where they were connected to individual wire ropes. The ropes were then hoisted into the sheave room and down to the counterweight, placed in accordance with the approved reeving diagram. Refer to Figure 27.

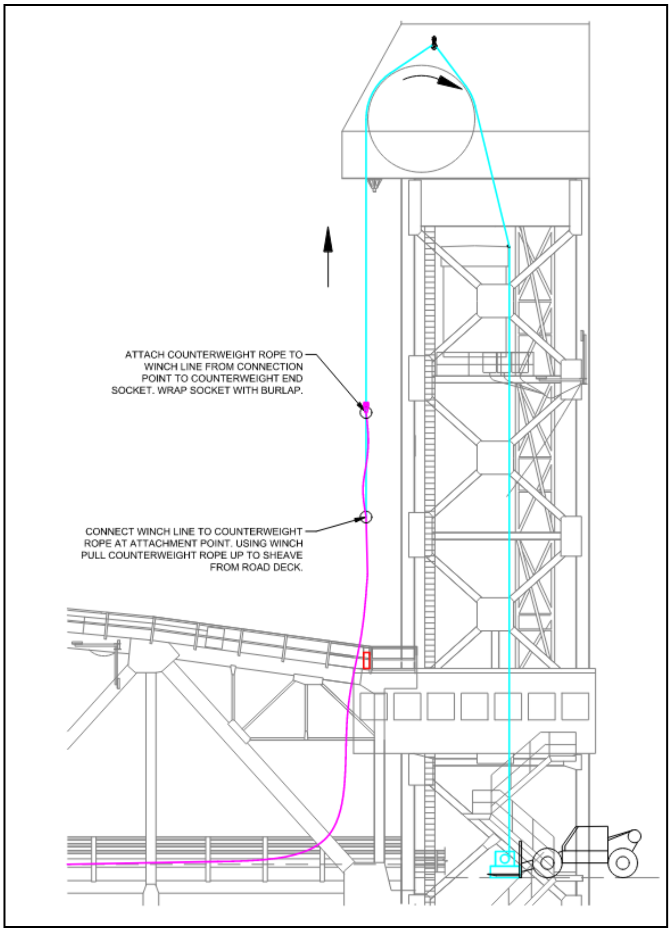

Figure 27: Wire rope installation setup.

The take-ups were left to hang freely outside of the lifting girder until all of the ropes were connected to the counterweight. Once installed, the location of the white stripes in at least three points per rope were checked and recorded. One at a time each rope and take-up was hoisted and placed through the top flange into the bottom flange and take-up billet. The take-ups were rotated in accordance with previously recorded values to ensure the white stripes remained in line for the full length of the rope.

In an effort to obtain even tension across all the ropes upon installation, the main take-ups nuts were set such that a nominal 6 inches of thread protruded from the bottom of the take-up nut and were aligned such that the keeper plates could be installed. With the ropes aligned and the take-ups installed the span was ready to be de-jacked and the ropes loaded. The span was de-jacked until the counterweight hanger pins came loose, and could be removed. With the pins removed the ropes were fully loaded and the span was de-jacked to the fully seated position. Tension testing was performed, and the ropes were adjusted until they were within +/- 20% of the group average, the maximum deviation allowed for temporary operation. Upon completion of the outage, the ropes were final tensioned to +/- 5% of the group average.

With the bridge ready for test lifts, the control desk was turned on to realize the skew and height were too far out to allow operation, refer to Figure 28. The team however was prepared for this, and VDOT bridge maintenance staff was requested to be on site and be prepared to adjust the electrical equipment. Adjustments were made until the skew and height were zeroed out. The bridge was successfully operated through full height lifts fives times with no issues and no further adjustments to the electrical equipment were required.

Figure 28: Control desk indicating height and skew error.

Preparation and Efficiency

In an effort to limit down time and ensure the successful and on-time completion of each outage, all opportunities to create efficiencies were investigated and implemented where appropriate. Backup equipment for the backup equipment was on site and ready for use in the event of failures. The wire rope lifting and removal plans required the use of two air winches, whereas five air winches were on site, as shown in Figure 29. When a failure of one of the air winches did occur, it was immediately replaced, and the on-site mechanic repaired the broken winch. The jacking procedure only required a single HPU for the large jacks however, three HPU's were readily available on the pier caps throughout the jacking and de-jacking process. Due to equipment failures, all three HPU's were utilized during the outage. Multiple backup generators were in place, several of which were used during the outages. Appropriately sized crews were tasked with specific jobs allowing them to focus on the tasks they were prepared to accomplish in lieu of shuffling crews and overloading resources. Detailed plans were successfully created and executed for each task in line with the proposed schedule. As dedicated crews worked through each task, they were able to overcome the learning curves and expedite production. For example, lifting operations at the start of the first outage were right around one and half hours per rope. While this was on plan with the hour-by-hour schedule, the production rate was able to be increased to around 45 minutes per rope near the end of the second outage.

Figure 29: Back-up air winches.

Even the best plans are not immune to challenges or obstacles. When challenges did occur, the best plan was a pre-approved backup plan. This meant all tools and equipment were already in place to allow crews to shift course and maintain schedule. When the first counterweight pin refused to move, the clevis ears were flame cut and freed from the pin allowing the pin to be removed without the hollow hydraulic ram, refer to Figure 30. The crew then returned to the original plan removing the remaining pins utilizing the hollow hydraulic rams and prybars.

Figure 30: Flame cutting the first main counterweight pin.

Unexpected Challenges

With the removal of the existing take-ups intended to be reused, it was realized that moisture retained within the take-up billet had corroded upper sections of the threads, refer to Figures 31 and 32. This raised a concern that the take-ups would not be viable for reinstallation and had the potential of delaying the project while new take-ups were fabricated. At the time of discovery, VDOT did have four spare take-ups, fabricated as a part of the procurement, at their disposal. The spares consisted of two long take-ups and two short take-ups. The contract documents required the take-ups to be cleaned and re-painted prior to installation. Therefore, to understand the full depth of the degradation, the take-ups were completely stripped of paint, mill scale and corrosion. With the take-ups fully cleaned, they were all thoroughly inspected, and four take-ups were rejected for installation. The remaining take-ups along with the four spares were approved for installation. Prior to inspection, calculations were performed to determine how much of the thread engagement would be required to develop the full safety factor of the ropes and prevent stripping. Calculations determined that the full height of the main take-up nut was not required to prevent stripping and meet the safety factor requirements of the ropes in direct tension. Inspection determined that in the worst cases degradation of the threads began with the nut set at 5.5 inches of thread protrusion from the nut, however in most cases it was much less. Based on the required engagement of the nut and the location of the deterioration, the recommendation was made to set all main take-up nuts in the second outage to a 5 inches nominal thread protrusion. This adjustment would allow the ropes to be set, tension adjustments to be made and still provide room for future adjustments.

Figure 31: Condition of the existing take-ups removed during the first outage.

Figure 32: Condition of the existing take-ups following shop cleaning.

Just prior to the second outage an additional four long and three short take-ups were sourced from the procurement fabricator which had been machined as "test pieces" during equipment setup. These additional take-ups, while not necessary, were utilized to replace seven additional existing take-ups, refer to Figures 33 and 34. The additional replacements provided more buffer room for future adjustments as the take-ups with extending furthest down the threads were selected for replacement.

Figure 33: Rejected take-ups.

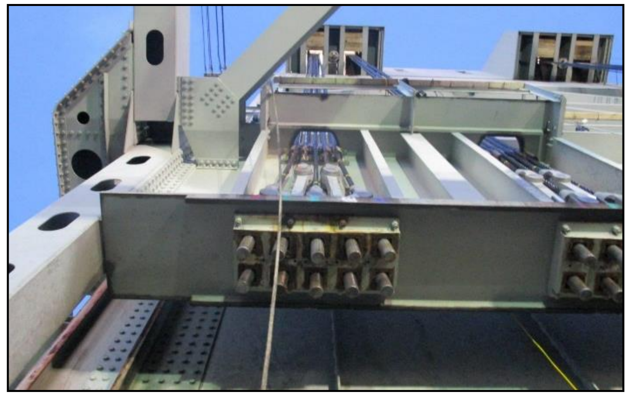

Figure 34: New take-ups installed in the lifting girder.

Successful Results

With the extensive planning, the right crews, redundancy built into every task and proper execution, both outages were completed opening to both vehicular and marine traffic ahead of schedule. The first outage was completed in 88 hours and the second outage completed in 71 hours. For successful completion of both outages ahead of the allotted outage time, VDOT paid hourly incentive bonus' totaling $480k. This project was huge success for the entire team, all the stakeholders and the traveling public and is a great example of the steps VDOT is taking to ensure the reliability of their assets and to keep Virginia moving.

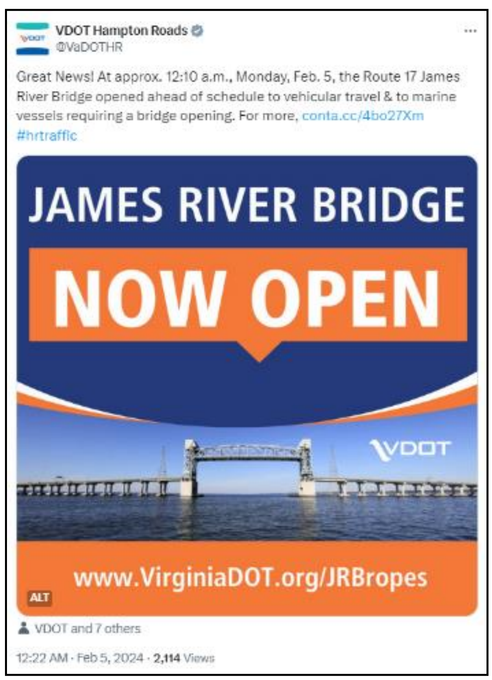

Figure 35: Social media post by VDOT following the second outage.

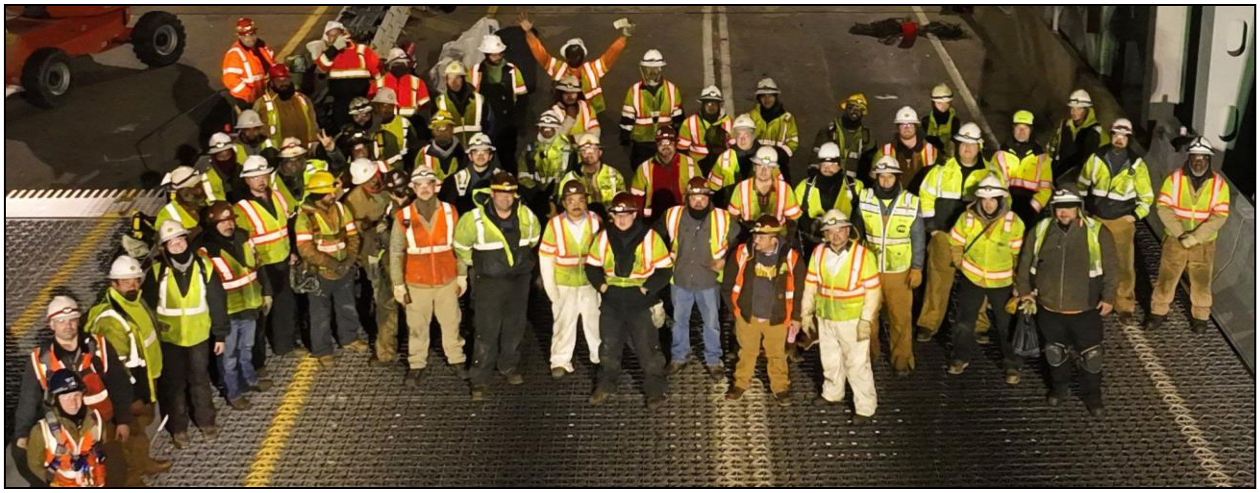

Figure 36: Photo of the PCL, HDR and VDOT team following the second outage.

Acknowledgements

The authors would like to acknowledge the contributions of the Virginia Department of Transportation Hampton Roads District.