HEAVY MOVABLE STRUCTURES, INC.
TWENTIETH BIENNIAL SYMPOSIUM

October 7-10, 2024

Replacement of the North Hero - Grand Isle Drawbridge

Jacek Krysiewicz, P.E.
Paul Jakubicki, P.E.
Khaled Hajjeh, P.E.
HDR

SHERATON HOTEL
NEW ORLEANS, LA

Introduction

Project Location

The North Hero Bridge is located in the Northwest Corner of Vermont. It carries US Rte. 2 over Lake Champlain between the towns of Grand Isle (to the south) and North Hero. Construction activities at the bridge site had to deal with several challenges. The proximity of a marina at the south approach required thoughtful scheduling to ensure that the construction activities at the bridge did not impede water traffic or access. Additionally, the nearby Knight Point State Park is a heavy tourist destination, which meant that construction activities had to be planned to minimize disruption to visitors and to the natural beauty that draws them to the area. Furthermore, the Bernie Sanders summer camp location nearby required that the bridge's design and construction consider the privacy and security of high-profile individuals in the vicinity. Overall, the bridge project had to balance engineering and environmental concerns with the needs and expectations of the local community and its visitors.

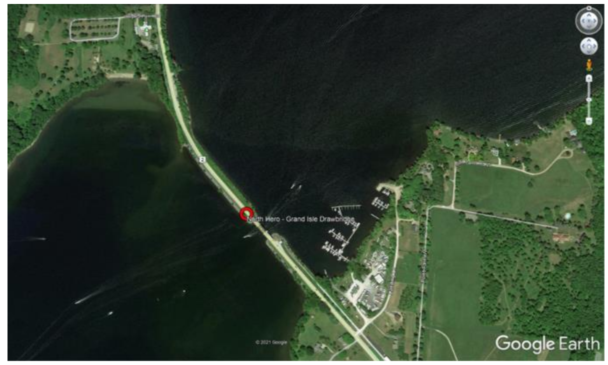

PHOTO 1: Bridge Location Map

Bridge History

The North Hero Bridge, a vital infrastructure asset in Vermont, is owned and operated by The Vermont Agency of Transportation (VTrans). This double-leaf bascule bridge not only facilitates vehicular traffic between North Hero and Grand Isle but also serves as a crucial channel for east-west marine traffic along Lake Champlain with unrestricted vertical clearance. Its strategic importance is underscored by the lengthy detour of approximately seventy miles required, and the harmful impact on public emergency services when it is closed to roadway traffic. Originally constructed in 1953 to replace a fixed timber bridge, the bridge underwent significant rehabilitations in 1996 and 2017, with the latter serving as a temporary measure to extend its service life until replacement plans could be finalized. The decision to replace the bridge followed concerns over its reliability and the increasing maintenance demands. The Vermont Agency for Transportation (VTrans), in collaboration with HDR, began investigating alternatives to replace the bridge.


PHOTO 2: Former North Hero Bridge

Project Goals & Design Considerations

Scoping Report

A scoping report was prepared for VTrans that defined:

Purpose of the project: To enhance the mobility and safety of vehicle, bicycle, and pedestrian traffic traveling across and boat traffic traveling under the bridge.

Need: “The causeway and movable bridge provide the only vehicular connection between North Hero and Grand Isle. The water channel provides one of the most important east-west crossing points for Lake Champlain boat traffic.

Due to increased vehicular and boat traffic, the mobility of both modes of transportation is inhibited by the inefficiency of the movable bridge. The scoping report determined that the increases in the amount of marine traffic result in more frequent and longer open drawbridge periods, thus increasing the delay for vehicular traffic traveling along US Route 2.

Additionally, the following Structural Deficiencies were identified:

- The open steel grid deck developed numerous holes and pits through the main and secondary grating bars.
- Girders and floorbeams in the lift span were in poor condition with significant section loss at the floorbeams connections to the bascule girders.
- The machinery supports and their anchorage to the bascule piers were exhibiting significant section loss in numerous locations.

Furthermore, the following Mechanical Deficiencies were identified:

- The span operating machinery gear sets had excessive backlash and plastic flow on the gear teeth.
- The span lock machinery had excessive clearances resulting in live load being carried throughout the span drive machinery.

Among the Electrical Deficiencies identified were:

- Motor and machinery brakes were at the end of their useful life. Span drive motors had low insulation resistance readings indicating that they are at the end of their useful life. Other electrical conditions included failures in the electrical conduits and support system for the bridge power distribution and control feeders, exposed and improperly terminated conductors throughout the bridge which were a reliability concern.

- The layout of the electrical equipment was not in compliance with National Electrical Code requirements for access and arc-flash protection.

The scoping report determined this crossing was utilized by increasing numbers of pedestrians and bicycles and provisions should be considered for the safety and mobility of these modes of transportation. The existing open grid deck was identified as the primary cause of bicycle accidents on the bridge.

Selected Design Alternative

After the preliminary alternative analysis and life cost cycle analysis were completed, VTrans decided to proceed with the construction of a new bascule bridge following the existing alignment. This new bridge alternative meets the necessary functional requirements while also minimizing environmental impact. The geometry of the new bridge is typical for a modern bascule bridge. With approach spans on both the south and north sides extending 48 feet, it offers a nice balance of bascule to approach span lengths and contributes to the aesthetic. The centerpiece of this structure is the 160-foot bascule span, The leaves of the bascule, each measuring 80 feet, provide a clear passage when raised.

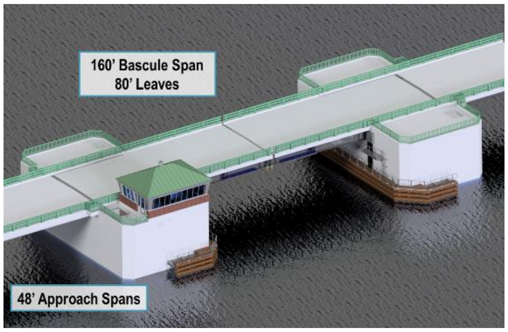

FIGURE 1: Bridge Span Lengths

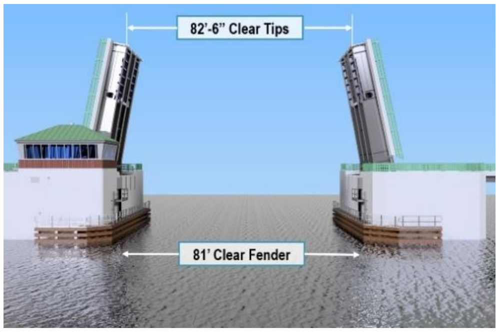

FIGURE 2: Bridge Clearance In Open Position

The new bridge's design provides an 81-foot clearance between fenders and an 82.6-foot clearance between bascule girders tips. This clearance allows for the safe passage of a variety of vessels including tall mast sailing boats, ensuring that maritime and river traffic can flow smoothly.
The new bridge has 17 ft. freeboard above the high-water level when closed allowing for a safe passage of smaller boats.

FIGURE 3: Bridge Clearance In Closed Position

Project Goals

The design criteria for a new bridge that addressed the existing structure's shortcomings, maintained traffic flow during construction and ensured a minimum service life of 75 years were multifaceted. These requirements included:

- Staged Construction utilizing a Temporary Bridge
- State-of-the-art Operator Facilities and Dedicated Equipment Rooms
- Protection of Machinery from the Elements
- Redundant Structural Framing
- Superior Corrosion Protection for Steel and Concrete
- Redundant Mechanical and Electrical System
- Full Machinery Maintenance Access

PHOTO 3: Former Span In The Open Position - Note Counterweight Was Partially Submerged In The Water.

The design had to adhere to the latest AASHTO recommendations, and standards for seismic design, consider site-specific ice loads, comply with environmental regulations, and develop sustainable and resilient infrastructure.

Delivery Method

The Construction Manager/General Contractor (CMGC) method, as utilized by VTrans, allowed for a collaborative project delivery approach. By involving a construction manager early in the design phase, VTrans capitalized on specialized expertise to enhance the project's constructability. This proactive involvement allowed for a dynamic design process where informed decisions could be made with real-time input from the construction manager. Cianbro, selected through a Qualifications-Based Selection process, played a pivotal role in providing critical feedback during design reviews at various project milestones. Their contributions in scheduling, phasing, and constructability were instrumental in shaping a project that was not only more buildable but also cost-effective. The iterative process of quantity and cost reconciliation at key stages—60%, 90%, and 100% design completion—culminated in a Guaranteed Maximum Price (GMP) that aligned closely with the project's budget expectations. VTrans's satisfaction with the resulting GMP and design quality led to the awarding of construction services to Cianbro, marking a successful application of the CMGC method.
The total construction cost was $74M.

Structural Design

Staged Construction utilizing a Temporary Bridge

The decision-making process for infrastructure projects often involves complex considerations, as exemplified by the situation with this drawbridge serving as a vital connection between islands and the Vermont mainland. The economic impact study conducted at the 60% design stage was a critical step in understanding the "user costs" that arise from potential detours and stage construction-related delays. In this case, the analysis revealed that the financial implications of a temporary movable bridge and the staged construction to the public were comparable. Consequently, VTrans's choice to proceed with an off-line aligned temporary bridge designed by a contractor reflected a strategic approach to minimize disruption and maintain essential connectivity during the construction phase. This decision underscores the importance of thorough planning and economic analysis in ensuring that infrastructure projects are conducted efficiently while considering the public's needs and resources.

PHOTO 4: Temporary Bridge In The Open Position

ACROW was the supplier of the temporary bascule span, the back span, machinery, and the control house. The movable span was 60 ft. long and the back span was 70 ft long. The bridge was 30 ft wide to accommodate two traffic lanes and included a walkway to access the control house. Temporary piers consisted of pipe piles and steel cap beams. The temporary approach spans featured simply supported stringers with timber deck and asphalt overlay. The temporary bridge was in service from the spring of 2019 till 2022. The cost of the temporary bridge was approximately $13M.

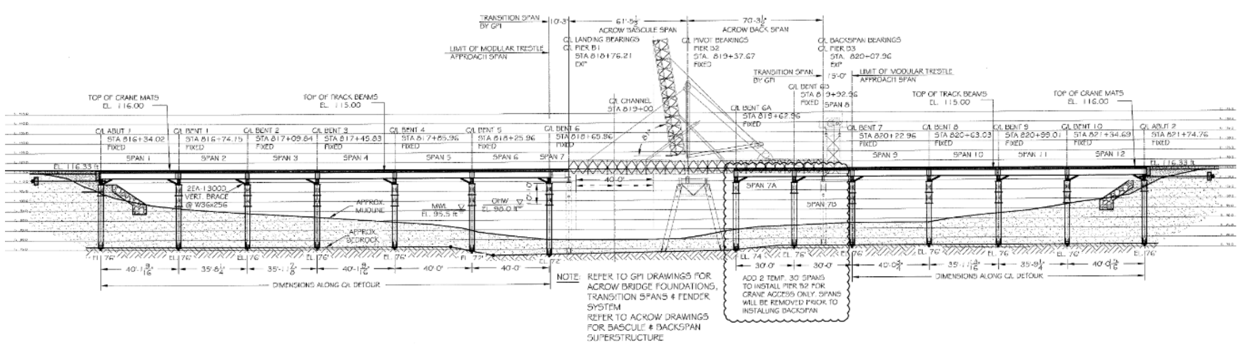

FIGURE 4: Elevation View Of The Temporary Bridge

Improved Operator's Facilities and Bascule Pier Functionality

The modernization of the bascule pier and control house design marks a significant improvement over previous structures. The spacious new control house comfortably accommodates large crews, ensuring a collaborative and efficient work environment. Accessibility has been greatly enhanced with the main entrance at street level, complemented by an internal staircase that allows for effortless movement to lower levels. This thoughtful design ensures that maintenance personnel can easily reach vital mechanical and electrical equipment. Additionally, the inclusion of essential amenities such as bathroom and kitchen facilities addresses the daily needs of the operators, promoting a more comfortable and sustainable workspace. These upgrades not only improve operational efficiency but also contribute to the well-being of the staff. The strategic placement of multiple windows in a control house provides a clear line of sight in all necessary directions for the operators. Bascule piers are critical components of movable bridges that keep the counterweights dray and house all electrical and mechanical components of the bridge. The design of bascule piers for the North Hero - Grand Isle Drawbridge includes enclosed spaces for mechanical and electrical systems, ensuring that sensitive equipment remains operational regardless of external weather conditions. Air conditioning within these rooms is essential for both equipment longevity and personnel comfort. Safety is paramount in these structures, and the provision of dual egress methods using enclosed stairs and ladders ensures that individuals can exit safely in case of an emergency. Furthermore, the inclusion of maintenance hatches directly from the roadway level allows for efficient replacement or repair of machinery and electrical components, minimizing downtime and disruption to traffic flow. Storage rooms at the lowest level of a structure are a common feature, providing space for equipment and materials necessary for the operation and maintenance of the bridge. Additionally, the inclusion of redundant sumps in pits at each bascule pier is a critical design element. These sumps are part of a system designed to collect and remove excess water, thereby preventing flooding and water damage to the bridge mechanisms. Oil/water separators are also a vital component, as they ensure that any oil or grease from the machinery does not contaminate the waterways.

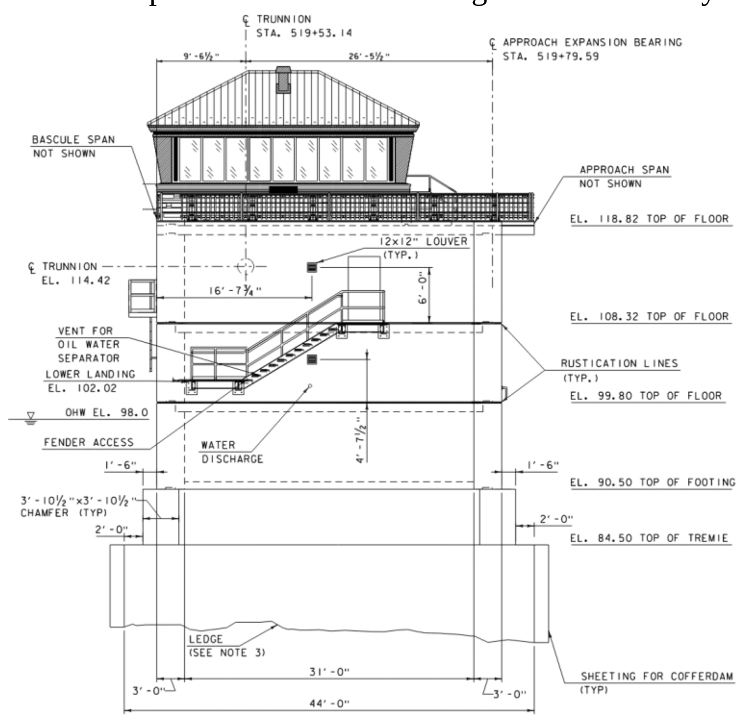

FIGURE 5: Bascule Pier 2 South Elevation

Redundant Framing System

The design of the North Hero - Grand Isle Drawbridge superstructure reflects a robust approach to structural engineering, prioritizing redundancy to ensure safety and reliability. The redundant superstructure provides backup support in the event that one part of the structure fails, which is critical in bridge design. The use of four parallel steel girders for both the bascule and approach spans not only distributes the load evenly but also adds to the structural integrity and allowing for smooth operation. This bascule bridge features four hydraulic cylinders that are essential for the operation but only two are

PHOTO 5: Bascule Leaf Framing View

needed to open the span to allow boat traffic to pass.
The live load shoes play a pivotal role in transferring the moving vehicle forces down to piers, while the shear locks secure the bascule girders in place, preventing differential movement between the leaves when the bridge is down. Each bascule girder is equipped with a shear lock but only two are required to be operational at the same time.

Roadway Deck

The North Hero - Grand Isle Drawbridge has half-filled steel grid decks which offers significant advantages over the older open grid steel deck. The solid deck enhances the durability of the bridge by providing better protection for critical machinery and steel superstructure against environmental elements and corrosive road salts. Additionally, the use of lightweight concrete in construction not only provides structural benefits but also contributes to the overall reduction in dead load, which is essential for movable bridges like bascules. The other advantage of the concrete deck is that it provides an improved and safer riding surface for vehicles and cyclists and reduces ride noise. The absence of flower box joints over the trunnions simplifies the design and reduces maintenance needs. Moreover, the incorporation of drainage troughs and compression seals at the joints is a

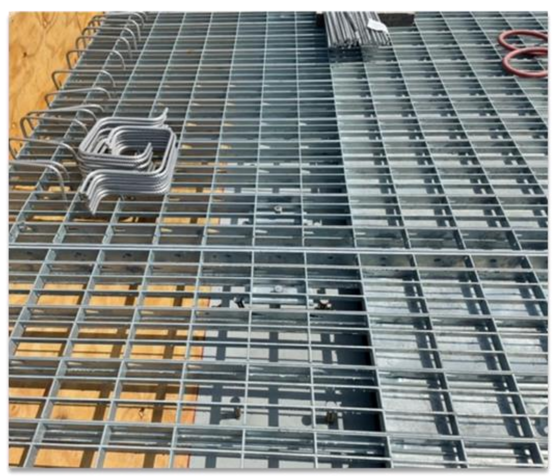

PHOTO 6: Bridge Construction Included Galvanized Grid Deck, Solid Stainless Deck And Curb Reinforcing Bars.

thoughtful design choice that effectively minimizes water penetration, thereby prolonging the lifespan of the bridge components and ensuring smoother operation.

Trunnion Support Framing

In the operations of bascule bridges, trunnions play a crucial role in opening and closing the span. At The North Hero - Grand Isle Drawbridge, they are supported by a steel frame designed to distribute both longitudinal and transverse forces into the pier's concrete walls, ensuring stability and smooth operation. The centerline rotation tolerances for these trunnions need to be extremely precise and are set to thousandths of an inch to maintain the bridge's alignment and balance. All other machinery supports are constructed to be very rigid to withstand the stresses of movement and weight, yet they remain adjustable through shimming, allowing for fine-tuning during installation or maintenance. Additionally, to enhance corrosion protection, the design excludes structural steel machinery supports below the ordinary high-water elevation. This careful consideration in design not only extends the lifespan of the bridge components but also reduces maintenance requirements and ensures reliable operation over time.

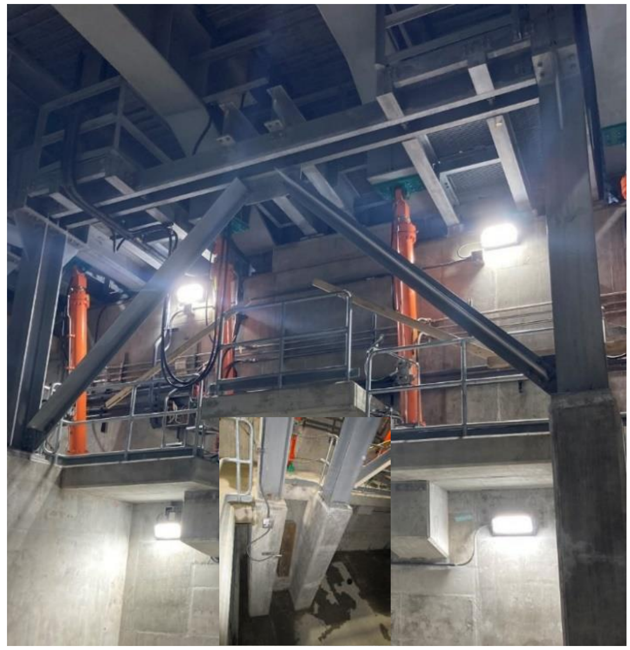

PHOTO 7: View Of Trunnion Supports In Foreground And Hydraulic Cylinders In Background

Enhanced Corrosion Protection

One of the key project goals was to provide a minimum design life of 75 years and to target a 100-year service life for all components of the crossing, and to meet this goal improved corrosion protection has been provided. The team chose level III corrosion resistance solid stainless rebar in the deck/curbs/abutment backwalls above the beam seats (basically everywhere exposed to roadway deicing chemicals). The piers are constructed within the lake, so level II corrosion resistance galvanized rebar was used everywhere in the piers. The rest of the reinforcement on the project was level I corrosion resistance, typically black/uncoated bar except there was epoxy coated bar used in the approach slabs, which were below membrane and pavement.

PHOTO 8: Bascule Girder Field Assembly

To provide extended service life all bridge steel components have enhanced corrosion protection. The photo on the right is a good primer on the methods used in the project as it shows the tail section of the metalized exterior girder. Structural Steel is metalized using 99.9% zinc (8-12 mils thickness) and has a clear sealer coat of 1-2 mils.

Corrosion protection applied to other bridge steel components can be summarized as follows:

- Support hardware such as trunnion support columns and framing are typically Hot Dipped Galvanized and are also Painted in some locations.
- The bridge deck is hot-dipped galvanized.
- Mechanical equipment was painted with a 2-coat system.
- Fixed mechanical equipment finish coat is green.
- Moving mechanical equipment is orange for safety.

PHOTO 9: Painted Trunnion Bearing Assembly

Mechanical Design

Improved Machinery Access

The longevity and reliability of movable bridges hinge significantly on regular and thorough maintenance. Access to critical components such as span locks, navigation lights, trunnions, bearings, limit switches, drive machinery, counterweights, and cable boxes is essential for performing necessary inspections and repairs. These components, often situated below deck, must be readily accessible to maintenance personnel to ensure the bridge operates safely and efficiently. During the North Hero - Grand Isle Drawbridge design, considerations for maintenance access were incorporated from the initial stages. This resulted in all critical machinery and electrical components having an easy maintenance access from below the deck and will reduce the long-term maintenance costs for VTrans.

Mechanical System

Like several newer movable bridges, the bascule span operating machinery consists of (four) hydraulic cylinders per each leaf that are powered by hydraulic power units. The reduced operating time to a mere 95 seconds in one direction is a testament to the speed and flexibility these systems offer. The use of stainless steel for all piping ensures durability and rigidity, while the redundancy of the operating system enhances reliability, requiring only two cylinders for movement. The incorporation of structural trunnion “torque tubes” assist in transmitting span torque in the event of a failed cylinder, maintaining leaf rigidity. Each cylinder includes a stop tube, cushions, check valves, chrome plated rod, and rod boots. This design not only reduces upfront costs due to minimal alignment issues but also promises a substantial service life of 75 years, with maintenance intervals every 25 years. Although hydraulic systems are better suited for warm locations, this bridge is shut down and not operated during the winter. This is a practical measure since Lake Champlain freezes over in the winter months.

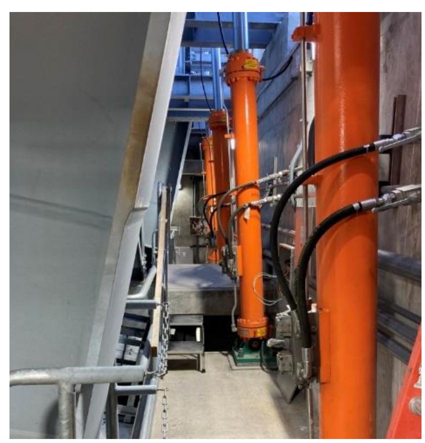

PHOTO 10: Hydraulic Cylinders

Other hydraulic component features include redundant, variable displacement axial piston pumps with electric motors. Should either a pump or motor fail the span can operate at reduced speed. Proportional throttle valves are used to control the acceleration, deceleration and creep speed of the span and counterbalance valves provide for dynamic braking.

PHOTO 11: Tail Lock Machinery

At the toe of each leaf is center lock machinery, which is electromechanical. There are four locks, two per bascule leaf in order to better balance each leaf. Having a center lock at each girder addresses AASHTO requirements and offers redundancy, such that a single lock can be taken out of service without disruption to roadway traffic. The incorporation of marine-duty linear actuators was a strategic choice, as they are not only readily available but also reduce the need for custom parts, which in turn can significantly decrease lead times and costs. The lock bar guides are designed to be individually accessible and independently adjustable to compensate for wear over time.

The tail lock machinery is also electromechanical. There are four locks, two per bascule leaf, located at the rear, outside corners of the girders. Linear actuators, similar to the center lock actuators, drive the tail locks beneath strike plates, which are fully adjustable.

Electrical Design

The electrical distribution and control systems in movable bridges, such as bascule bridges, are critical for their operation. The electrical distribution system, distribute power to energize the bridge drive systems, traffic control system, span locks system, security system and all bridge lighting and hotel loads. The bridge control system provide control and monitoring for bridge operations including safety interlocks to safely control the span during bridge operations ensuring protection of bridge maintenance staff, roadway and marine traffic.

Due to the rocky nature of the lake bottom, the trenching process to install typical submarine cable system was going to be very challenging to the contractor, Based on the feedback received from the contractor, the HDR team designed the power distribution and control system to eliminate the need for installing a submarine cable.

Each bascule leaf was designed to have an independent electrical service and its own backup generator system. This redundancy enabled each leaf to be powered independently with a primary and backup power source.

PHOTO 12: Backup Generator

There is a motor control center (MCC) at each pier that is used to distribute power to all bridge devices without the need to send power signals across the channel.

In addition to the bridge control system, each bascule pier is equipped with:

- Interior Lighting & Receptacles
- HVAC system
- CCTV system
- Telephone & Intercom system
- Warning and barrier gates on the approach span
- Stop & Advanced Warning Lights on the approach span
- Navigation lights on the fender

The North Hero - Grand Isle Drawbridge employs a sophisticated PLC-based control system, ensuring precise and reliable operations of the bascule span mechanism and also aligns with modern standards of technology integration in public infrastructure. Each leaf was designed with a redundant PLC to provide monitoring and controls for all bridge control and drive systems components for the leaf.
To provide communication with the control house and enable full bridge operation from the central control house, a redundant wireless connection link was installed to transfer signals across the channel, in addition to bridge control signals, a wireless CCTV system was also installed to transfer the CCTV system data to be displayed on the monitors inside the control house.

The integration of Human-Machine Interface (HMI) technology in bridge operations exemplifies modern engineering's commitment to safety and efficiency. The main control console, housed centrally in the

PHOTO 13: Main Control

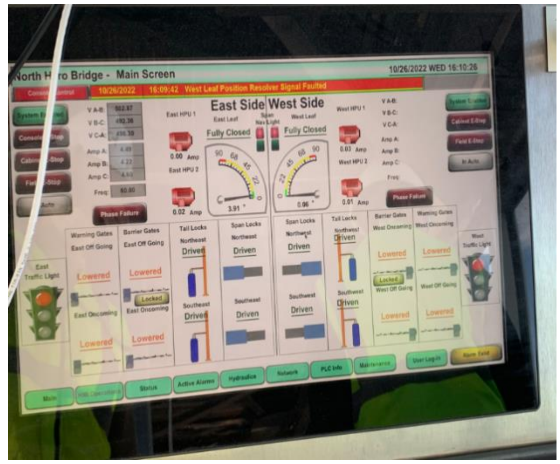

PHOTO 14: Typical HMI Screen Layout

control house, ensures a comprehensive overview of the bridge's functionality with its redundant screens, providing a fail-safe mechanism in case one fails. Additionally, the presence of backup consoles at each bascule pier signifies a robust design, allowing for localized control and monitoring, which is crucial during complex operations like bridge lifting. These custom HMI screens are not just operational tools; they are also vital for routine maintenance and troubleshooting, offering operators real-time data and diagnostics to preemptively address potential issues, ensuring the bridge systems' longevity and reliability.

PHOTO 15: Wireless Transceiver Mounted On Pier Wall

PHOTO 16: Typical Position Sensor

Field devices are a crucial component of control systems, providing the necessary interface between the system and the physical environment. Leverless sensors, known for their extended sensing range, play a pivotal role in such setups. These sensors can detect the presence or absence of objects without physical contact, which is particularly beneficial in harsh or inaccessible environments. The extended sensing range allows for greater flexibility in sensor placement and can contribute to more efficient system design. Furthermore, fully sealed sensors offer enhanced durability by protecting sensitive components from environmental factors.

Bascule Pier Construction

Once the old bridge was removed, the foundations for the piers could be constructed. The piers were built within sheeted cofferdams. Each consisted of a mass tremie concrete sub footing poured over the existing bedrock, which supported a 6' thick reinforced concrete footing, which then supported the pier exterior and interior concrete walls. The existing bedrock profile is always an estimate and the design team expected that shallow rock elevation at some locations may complicate the cofferdam and tremie seal design and construction.

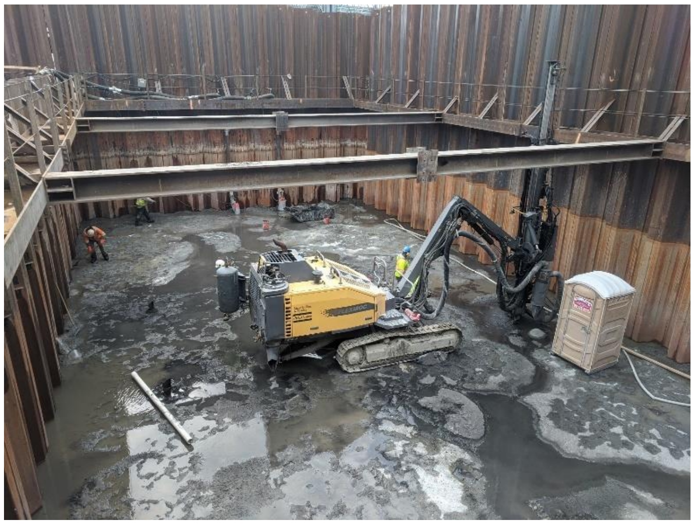

PHOTO 17: Installation of Rock Anchors Through Tremie at Pier 2

To avoid expensive rock excavation, rock anchors had to be installed through the tremie concrete to increase the safety factor for resistance against buoyancy forces and to improve sliding resistance. The use of rock anchors was included in the project on an "as needed" basis to account for the condition of shallower than expected bedrock. The number of anchors installed was within the number originally budgeted for.

Vermont is known for harsh winters and Lake Champlain gets frozen every winter. VTrans performed a site-specific ice loads study during the preliminary design phase to address these wintry weather conditions. Based on that study, bascule piers were designed for 24ksf ice pressure loads to a 2.5 ft thick sheet of ice. Here we see the galvanized reinforcement extending all the way to the top of one of the piers, with the outline of the approach span seat on one side and the bascule span beam seats one the other side. The exterior walls of the piers are 3' thick. Ice forces do not mess around.

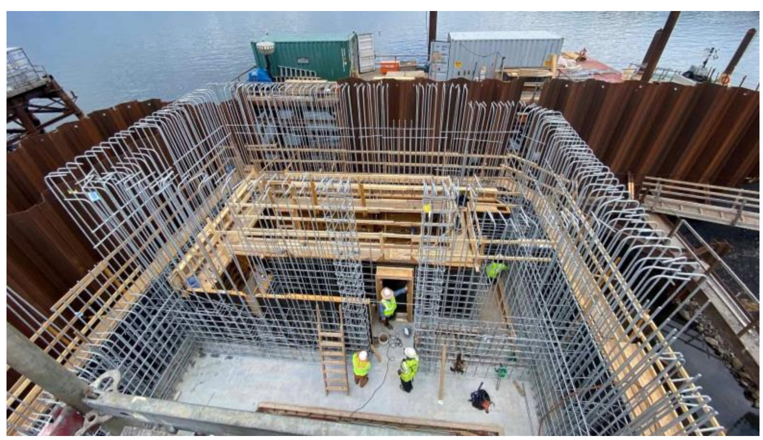

PHOTO 18: Bascule Pier Wall Reinforcement Placement

Bascule Leaves Fabrications and Erection

Once the fabrication of the individual components of a bascule leaf was completed, they were brought together, fully assembled, and aligned in the shop. While the steel framing of a bascule leaf is generally constructed to steel fabrication tolerances it needs to work well together with machinery to ensure that the bridge will operate properly and provide years of safe and reliable operation and that testing, and alignment are very important steps in bascule leave construction. Once testing was completed the bascule leaf superstructure steel was disassembled for shipment.

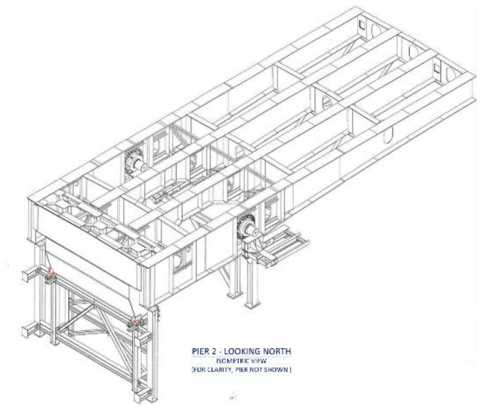

FIGURE 6: South Bascule Leaf View

The photo below shows both bascule spans with steel installation and leveling complete. They had to line up at the toe and the road break. We can see the counterweight boxes at the heels of both spans. The construction of the control house framing and roof is partially complete here as well.

PHOTO 19: Bascule Piers and Leaves Erection

Fabrication and Construction

Key Dates

- Contract Executed 4/3/2018
- Notice to Proceed with Construction 6/5/2018
- Construction of Temporary Bridge 7/2018 – 5/2019
- Demolition of Existing Bridge 5/2019 – 12/2020
- New Bridge Open to Traffic 11/2022
- Final Completion 7/2023

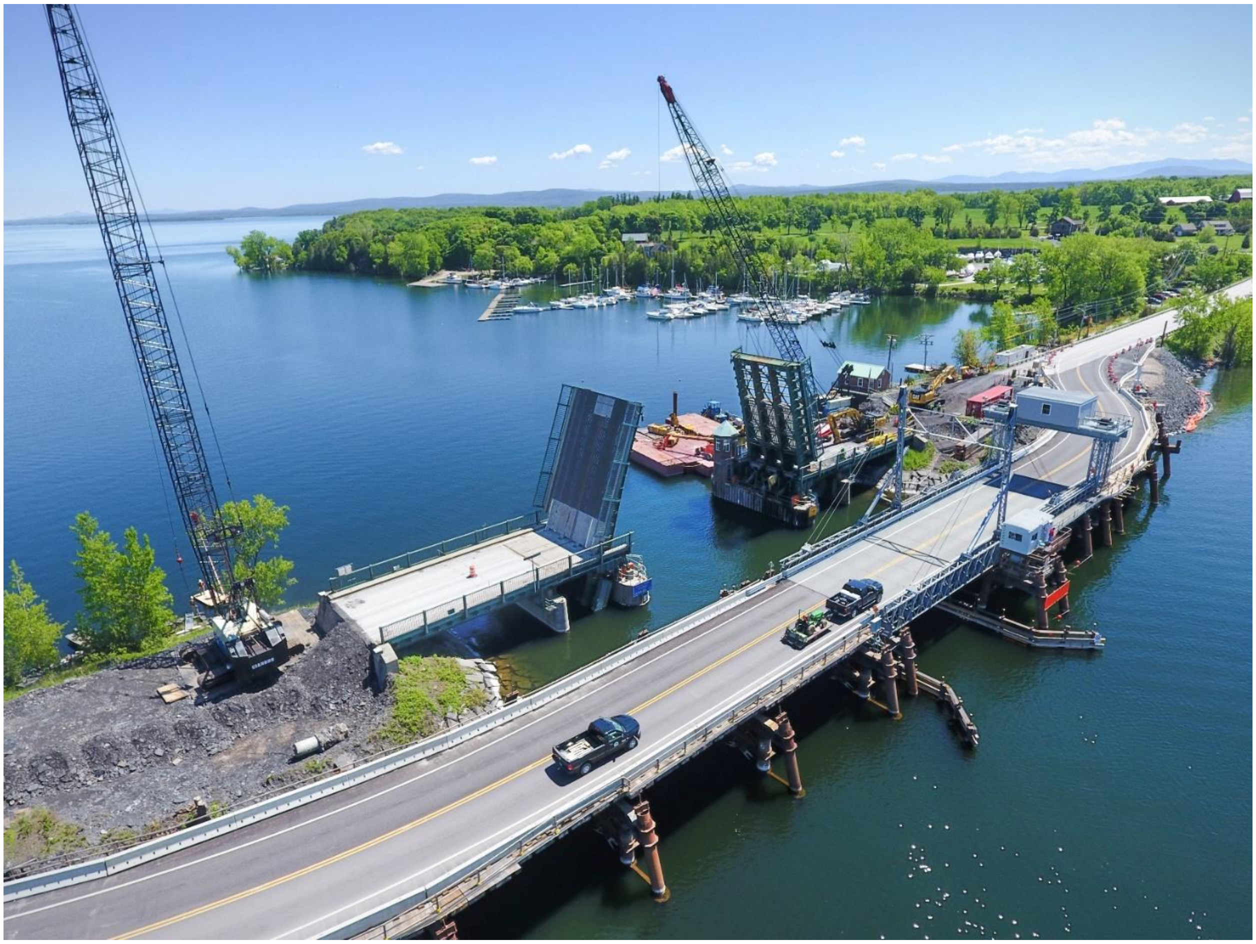

PHOTO 20: Demolition Of Existing Bridge Proceeding After The Temporary Bridge Was Completed

PHOTO 21: Finished North Hero - Grand Isle Drawbridge (Aerial View)

The bridge was opened to vehicular traffic in November of 2022 and construction activities were completed in July 2023. The bridge lift season is from May 15 to October 15. There is a set schedule of lifts, at top and bottom of the hour from 8 AM until 8 PM. Boaters can contact the operators to schedule off-time lifts if needed. During the off season while the bridge is normally closed to marine traffic, VTRANS has 48 hours to open the bridge upon request of the U.S.C.G.

Conclusion

The North Hero - Grand Isle Drawbridge stands as a testament to resilience and collaboration. Despite initial setbacks, such as the discovery of contaminated soil and the subsequent delays, the project team's dedication never wavered. Their ability to navigate through the complexities of a global pandemic and supply chain issues exemplifies the strength of their collective effort. Now complete, the bridge not only connects communities but also symbolizes triumph over adversity, promising to serve as a vital transportation conduit for years ahead.

Acknowledgments

Vermont Agency of Transportation – owner
HDR- designer
Cianbro – CM/GC
Cianbro Fabrication & Coating and G&G Steel – bridge steel fabricators
ACROW- temporary bascule bridge supplier
Panatrol Automation and Controls – bridge control system
Atlantic Industrial, Inc. - hydraulic machinery