HEAVY MOVABLE STRUCTURES, INC.

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FAILURE AND QUICK RECOVERY OF MOVABLE BRIDGE ON THE ACELA LINE

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PERFORMANCE/CONSTRUCTION/MAINTENANCE

On December 29, 2000 a railroad drawbridge over the Connecticut River became completely inoperable due to total failure of the bridge electrical system.

The following will describe how the quick response, hard work, ingenuity, persistence and sometimes pure luck, helped the railroad to recover from this devastating failure and gain control of the drawbridge in order to provide reliable operation.

DESCRIPTION AND HISTORY OF THE BRIDGE

- Original Construction
- Original Service
- Changes Made to the Bridge
- Wound Rotor Motor System
- Replacement of Tread and Track Plates
- Replacement of Pinion, Racks and Secondary Gearboxes
- Replacement of Differential Drive Gearbox
- Electrical Systems Remain Intact

The Connecticut River Bridge (Mile Post CT 106.89) a.k.a. the Old Saybrook Bridge is a typical rolling lift structure designed and built by the Scherzer Rolling Lift Bridge Company of Chicago. The original design documents are dated May 1905. The bridge was actually built and commissioned for N.Y.,N.H. & H.R.R. Co. (New York, New Haven and Hartford Railroad) in 1907.

The bridge is located between the town of Old Saybrook and Old Lyme spanning the Connecticut River in the east-west direction.

The bridge is a ten-span structure having nine fixed spans and one 161-foot draw span. The total length of the entire structure is 1569.6 feet bearing-to-bearing.

As part of the Northeast Corridor the bridge provides service for Amtrak, Providence and Worchester railroad and Shore Line East Commuter Line. Prior to electrification of the New England territory that began in 1997 and continued thru the 2000, all railroads were using diesel engines for their trains.

The drawbridge has been rehabilitated several times during its life. A major structural rehabilitation took place between 1974 and 1976 when the track and segmental rolling girders were reconstructed and tread and track plates were replaced.

As a part of the entire Northeast Corridor Improvement Project the Connecticut River Bridge was rehabilitated again in 1981. During this rehabilitation the entire machinery and electrical systems were replaced with new components. New lock machinery was also installed.

At that time the electrical systems were state of the art SCR-type drives utilizing two heavy duty crane-type wound rotor motors. The bridge had successfully served for another fifteen years.

In 1996-1997 due to extensive wear of the rack and pinion components and deterioration of track and tread plates (they were 20 years old by then), the bridge had undergone one more machinery rehabilitation. At that time the new track and tread plates were installed as well as new operating machinery components excluding the primary differential reducer. The electrical power and control systems were kept unchanged.

The differential gear box was replaced in-kind at the later date.

PREPARATION FOR HIGH SPEED RAIL SERVICE

- Addition of Electrification Catenary System
- Balance of Bridge Changed

Amtrak future heavily depends on success of the new High Speed Rail System. The High Speed Service started to take shape during 2000 when the electrification of the New England (the North End) territory was winding down to completion.

All draw bridges including the Connecticut River Bridge were outfitted with new structures, both movable and stationary, designed to support the catenary systems for new electric traction train sets. Inadvertently, the state of the balance of the movable bridges had changed, and in most cases the proper balance was restored.

DISASTER

- Operator Reports Trouble
- Electricians Report to Bridge
- Mechanics Report to the Bridge
- Call in the Army of Engineers
- Forcing the Bridge Down
- Restoring Train Traffic
- What Next?
- Fuel Barges Blocked
- Power Plant Calling for Oil
- Commercial Heating Oil Supply is Low
- Burned Boards
- Non Usable Controls
- No Emergency Drive System
- No Means to Open Bridge
- Friday before New Years Eve Holiday Weekend
- All Vendors Closed

During the early morning of December 29, 2000 the bridge operator reported difficulty during bridge openings using one of the drive-and-motor setups. He received a directive from the bridge electrical maintenance supervisor to switch the bridge speed controls to the other motor and drive combination. This action resulted in several satisfactory bridge cycles.

Then the worst had happened. While opening for marine traffic, the motor drive cabinets began to smoke and most of vital SCR components had melted. The bridge remained in the open position bringing the rail traffic to a screaming halt.

All available electricians were quickly dispatched to the bridge in order to assess the damage. A local electrical contractor that was familiar with the recent systems was also called in.

At first, there were suspicions that interference in the bridge machinery or the bridge structural components might have caused the electric system to overload. A quick inspection by the experts was necessary. Engineers from Hardesty and Hanover were called to the bridge to help determine whether there were possible problems with the machinery and/or structural systems.

Alex Ostrovsky, Amtrak's in-house movable bridge engineer, was notified of the bridge failure during early morning of the December 29. He was on his ski vacation in the Northern Vermont and it took him several hours to drive to the bridge. He knew that he would be able to determine whether there were any problems with the bridge machinery but he also knew that he would not be much of a help in the electrical department.

A decision was made to involve someone who is experienced in the actual integration of drive systems for movable bridges and who had resources local to New England. Amtrak management had contacted APEC Corporation located in Hingham, Massachusetts to assist in restoration of the burnt electrical systems.

Arriving at the bridge site several hours after receiving the call Paul O'Neill of APEC had joined the crowd of Amtrak engineers and maintenance crew already working on restoring the rail traffic. At this time the bridge was fully seated and locked.

Apparently, after discovering that the bridge had totally lost its electrical drives and controls a decision was made to attempt to close the span manually. It took an army of B&B mechanics and electrical maintainers to initiate the span movement from its fully open position toward seating.

The idea was to bring the bridge from being counterweight heavy by applying the force from under the rolling girder in the direction of span closing. This was accomplished using several hydraulic jacks and manually rotating the drive shafts inside the machinery room. With great caution and after many exhausting hours the span was brought to a near seated position. A hi-rail crane was used to assist in the seating of the bridge by driving it on the bridge toward the toe. After overcoming resistance of the air buffers the bridge was finally chained down and locked. The lock machinery was operated by hand. The rail traffic was finally restored. The Coast Guard was notified that the bridge is temporary inoperable and that the work is in progress to restore the channel for marine navigation.

At this point it was not clear in which direction to proceed. Armed with the experts from Hardesty and Hanover, the bridge machinery and structural features were thoroughly inspected for possible interference and damage. It was found that there were no machinery interferences or structural abnormalities that could have caused the electrical systems to overload and self destruct.

It was clear that the major challenge was still ahead. Oil barges were waiting to deliver their payload to hospitals and residents in the neighboring towns. Commercial boats were not able to go through the channel. This was simply unacceptable.

The situation at hand was that there was no emergency operating system on the bridge and no immediate means of raising and lowering the bridge safely. The bridge drives were burnt, the control circuitry that remained in the control desk was non usable since there were no drives to control.

The fact that this was late afternoon on Friday before New Years Eve Holiday Weekend had further aggravated the situation. If something was going to happen it must happen quickly.

EMERGENCY BYPASS SURGERY

- Back to Basics
- Go Around Obsolete Control
- Prime Mover Still Intact
- Make the Motor Run

After it became apparent that the existing control system was history and that there would be no chance of restoring the existing control in the immediate future, it was time to step back and see what other options were available.

There was no clear story how the failure occurred. The root cause of the failure remained to be a mystery. With that piece of the puzzle missing, it was not evident as to the extent of the damage. With that conclusion in mind, and having not been up for the last 20 hours struggling with a very tenuous situation, being fresh and clear minded, I stepped back from the chaos and boiled down what was the most basic way to get the bridge open. The use of hydraulics to jack the bridge "up" as was used to jack the bridge "down" was not practical since the structure had no jacking point in that direction. One suggestion at the time was a mule team of workers to all manually rotate the shafting by hand, with pipe wrenches, or anything else available. That would only take 16 hours. It was amazing to see that after working 20 hours, these workers were still willing to do whatever it took to keep operating the bridge. The final solution chosen was to assume that one of the two motors was still in good shape, and devise some way to apply power to the motor and get the span to raise. Working in parallel, we got part of the crew to get what materials they could find to reroute and tap electric power around the existing control directly to the motor. At the same time, we called all types of vendors, electrical supply houses, looking for a 150 HP contactor. Those vendors which answered their phone that Friday afternoon suggested we call back on Tuesday when they would reopen from the New Years Eve Holiday.

RAID THE JUNK PILE

- Where can we get a really big contactor?
- A really big autotransformer is even better
- Really handy consumables

After exhausting over a dozen different electrical vendors, we started to get desperate. Mr. Paul O'Neill of APEC ordered his electrical installation workboxes as well as the largest electrical panels on hand to be transported from the APEC shop, including contactors, inverters, motor starters, as well as a meg-ohm meter. The largest contactor on hand was 75 HP, undersized, but maybe better than nothing. Paul O'Neill of APEC also started inquiring surplus electric supply houses which were still open. He continued to inquire for at least a 100 amp contactor until he found a surplus supplier who answered that they had an autotransformer which had three (3) 150 amp contactors in it. The surplus electrical component vendor was concerned that it may be too large for us. Mr. O'Neill replied that it would work just fine for us. Before Mr. O'Neill could get off the phone with the vendor, the Division Engineer had dispatched Amtrak trucks to pick up the material. We took a dinner break while we waited for the materials, autotransformer, and meg-ohm meter to arrive at the bridge, and to take some rest before we began working through the evening on the problem.

WALK BEFORE YOU RUN

- Conduct Meg-Ohm Motor test
- Disconnect Motor Coupling from Load
- Connect Motor to Autotransformer
- Test Run Motor and Check Rotation

After dinner, we returned to the bridge and saw a "Petibone" crane traveling down the tracks with a metal enclosure. This was the last hope, and everyone was wondering what was inside the box, especially what condition the components were in. We opened the box and were pleasantly surprised that the components were, although not new, in very good condition. The wire and meg-ohm test equipment arrived earlier that evening. The electrical foreman tested the motors at the motor disconnect switches, and it showed that both motors were intact, with one motor having better results than the other. With our initial inspection of the autotransformer, and the mixed results of the meg-ohm test, we decided to install the autotransformer. The workers hand carried the autotransformer enclosure by hand up to the control house. The next challenge was to decode were we could mount the enclosure. We chose a spot as close as possible to the existing cabinets. While installing the enclosure, we asked the B&B mechanics to physically disconnect the motor chosen to be wired to the autotransformer. We ran the motor leads from the existing cabinet into the autotransformer cabinet. Not having any idea which way the motor would spin, we test ran the motor without load and made a notation of the direction of rotation of the motor. Next, we studied the drive train of the bridge, including the single reduction gearboxes recently installed on the rack pinion drive, to determine which direction of rotation would produce the desired result, opening of the span. We needed to re-phase the motor leads and retested to make sure we had proper rotation.

THE CRITICAL MOMENT

- Connect the Motor Shaft Coupling to Load
- Get Ready to Throw the Main Breaker
- Lookouts Everywhere for Smoke and Sparks
- Man the Brakes, Manually
- Throwing the Switch

Everything looked positive so far. We asked the B&B mechanics to re-couple the motor to the load, which they did. Once completed, we checked that the motor brakes were manually released and that the come-along holding the bridge down on the buffers was released. The Petibone crane was driven off the span and the span popped up a few feet. We then checked with the Division Engineer if he was ready to give it a try and he said to go ahead. Before we threw the switch, we asked the electrical foreman to stand by the main breaker "just in case" and had separate multi-meters set up on motor leads, and other electricians standing by the electrical disconnect switches. We also had radios up with the workers at the thruster brakes, and we instructed all the workers to keep all unnecessary radio traffic to a minimum. We instructed the B&B workers that we would signal to them when to lock the brakes. At 11:00pm, with everyone in place, we turned the switch ON and the first contactor kicked in, the bridge started to move slowly, the amp meter up to 300 amps, and then the second contactor kicking in, the bridge amperage dropping to 110 amps and the bridge lurching through the jet black sky. A little nervous, we asked the Division Engineer when he would like to turn the autotransformer off. He replied "keep going, keep going, don't stop..."Once the bridge reached 75 degrees, the Division Engineer said "stop, set the brakes" at which point we turned the Autotransformer off. Everyone was relieved that everything went smooth. The next obvious question was could we get the autotransformer to get the bridge down. Paul O'Neill of APEC replied to the Division Engineer that we could by re-phasing the power, which we could do by recycling some of the old contactors from the blown panel and set up a crude reversing contactor scheme. The electricians on the bridge understood what needed to be done and by morning they had fashioned a new circuit which did the job of closing the bridge.

RECOVERY PLAN

- How to Close the Bridge
- Coordinating Marine Traffic with U.S. Coast Guard
- Training Gangs in Emergency System Operation
- Elimination of Autotransformer
- Installation of Soft Starter

After the new circuit had been fashioned to close the bridge, the new circuit was tested first with the motor disconnected as an initial precaution. Next, the motor was connected and the bridge was closed. Everything went smooth except the final closure, which was extremely difficult with the autotransformer since it had no speed control. The technique developed that seemed to work for the moment was to nearly close the bridge and let it coast until it touched the buffers. Next, the B&B foreman would call in the Petibone which would drive up on the nearly closed span to the end of the span. The weight of the Petibone would be enough to cause the bridge to fully seat. Next, B&B mechanics would use chain come-along and chain down the span. The lock bars would be driven next, and the come-along remained in place as added security. A viable emergency plan had been developed on the fly, although it took a large crew to perform. The rest of the weekend was spent rotating gang members through the operation of "Connecticut River" making sure we would not run out of trained personnel, drinking lots of coffee, and everyone acknowledging all of their hard work being a success. Nevertheless, there is always someone to spoil every party, and Paul O'Neill of APEC reminded the Director of Field Support that the autotransformer was a big unknown as far as what it might be doing to the existing motors, as well as how many cycles were left in this recycled piece of equipment. The other issue at hand was the autotransformer was the only life-raft that we had. If we lost the autotransformer, we would be in the same predicament. Before the weekend was out, we were discussing how to replace and/or supplement the autotransformer. Could we get a second, new autotransformer? This was unlikely. Could we get a large contactor from the local area? Possibly, but this would stress the bridge even more than the autotransformer. After a short meeting on Monday morning with Director of Structures of Amtrak, we decided to obtain a soft starter which APEC located in Connecticut and had delivered later that day. The soft starter was installed in the second electrical cabinet, and a scheme and procedure of connecting one or the other provisional devices was developed. If the autotransformer failed, we would switch to the soft starter. Once the soft starter was working, we used the autotransformer as the backup device. It was still necessary to eliminate the autotransformer. After studying what was left of the existing equipment, which was the existing control panel and the motors, APEC suggested to Amtrak that the existing wound rotor motors, which were once controlled by the cooked SCR control, be converted to vector operation and controlled by a new vector control.

RETROFIT AND INTEGRATE DIGITAL VECTOR DRIVE

- Reuse existing wound rotor motors
- Retrofit of Encoder to Wound Rotor Motor
- Sizing the Vector Drive to the Existing Load
- Discovery of Burned-Out Resistor Banks
- Shorting Out the Slip Rings
- Decouple and Autotune
- Couple the Motor and Manual Tune
- Mating the 24VDC inputs to the 110 VAC panel

Wound rotor motors are different than traditional squirrel-cage motors, and vector motors are different than conventional squirrel cage motors. A wound rotor motor can produce high torque at low RPM. A conventional motor produces low torque at low RPM, high torque at high RPM. A vector motor can produce 100% torque at 0 RPM. Wound rotor motors and vector drives, the combination of a vector motor and a vector control, both have the ability to handle high-inertia systems commonly associated with large movable structures. The way they accomplish this is many ways the same and in many ways different. A conventional motor is made up of a rotor and stator. Once you apply AC power of constant cycles and constant voltage, it builds up speed, and then builds up torque capacity. A wound rotor motor has slip rings and through a combination of SCR drives and resistor banks, low voltage and high current are applied to produce high torque at initial startup. A vector drive accomplishes the low speed torque of a wound rotor motor without slip rings. Instead, it relies on a digital encoder on the back end of the motor which senses the position of the rotors in the motor. It also relies on a computer to generate vectors of flux on the motor to generate torque at any speed. It's a digital system rather than analog. A vector motor is nearly identical to a conventional motor except for the encoder on the end of the motor. A wound rotor motor is nearly identical to a conventional motor except for the rotors are interrupted by slip rings so different voltage can be applied to them. By bypassing the resistors altogether and jumping the slip rings together, we converted the wound rotor motor to conventional operation. When we started to wire the bypasses at the resistor banks, we discovered many of the resistors were badly damaged and burned. We think this may be part of the original failure of the old SCR control, but it's hard to tell for sure which failed first. We tested the motor with the slip rings jumped and no load on the shaft and the motor spun freely. We next installed a vector drive sized to the amount of current being called for by the bridge, which was 150 HP drive. Usually motors of lower RPM demand higher currents than their counterpart 1760 rpm motors. At the same time, with the assistance of the B&B crews, we fashioned an encoder feedback device on the back of the motor. We hooked up the encoder to the vector control, decoupled the shaft of the motor from the bridge load, and performed an auto tune of the drive. An auto tune is where the computer in the vector control spins the motor back and forth automatically and studies the characteristics of the motor, such as direction of rotation, inertia of the rotor, saturation of the motor poles, slippage, and a few more characteristics. Once the motor was tuned, we coupled the bridge load back to the motor and ran the bridge up and down with keypad control. Many of the electrical crew at Amtrak were not familiar with vector technology, and had never seen a vector drive. The initial installation of the vector drive and retrofit of the wound rotor motor took around 10 days.

RESULTS OF RETROFIT

- Smoother Bridge Operation
- Softer Starts and Stops
- Replacement of Motors with Vector-duty Motors

As a result of retrofitting the existing wound rotor motors to vector duty, it gave us the ability to program the exact number of seconds needed to accelerate the bridge from 0 rpm to full speed (ramp up), as well as the time for stopping (ramp down). Another benefit of vector duty is that the bridge coasts and pushes down on the buffers with regulated speed, not regulated torque, so the seating operation is much smoother. After everyone was satisfied with the operation of the vector drive, a second vector drive was added and the motors were replaced with new vector duty motors.

LESSONS LEARNED

- Should Have Autonomous Drive System
- Own Source of Motivation Available to Operator of Bridge
- Should Have Mechanical Backup Plan
- Crain and Hoist
- Hydraulics
- Competent Crew
- Should Have Electrical Backup Plan
- Spare Parts
- Spare Critical Failure Items
- Control Bypass Method

<u>Conclusions are obvious:</u> be prepared for any conceivable bridge outage or pay the price!

The best way to be ready for most of bridge operational problems related to main drive and controls is to have a totally independent autonomous operating and control system. This paper would not discuss or recommend any specific back up system. This decision should remain with the individual bridge owners. However, there is a method which can be utilized in preparation for similar emergencies.

Budged permitted, each movable bridge should have an independent back up drive installed on the bridge. If electro-mechanic system is used for this purpose, the power to such drive should be available from the totally independent source, such as secondary power feed or on-site generator. The back up drive should be controlled locally and not be incorporated into the main bridge control circuitry. The back up drive should have a hand operation alternative built to it. There should be written emergency operating procedures on the bridge depicting step-by-step instructions in the event of emergency.

If totally independent back up drive system is not yet available or not affordable, other provisions to keep the bridge operational should be made. There should be clear and concise instructions for the operator and maintenance crews, both mechanical and electrical, directing them how to proceed in case of emergency or operational outage. All conceivable resources should be utilized. Hydraulic power equipment should be inventoried and securely located on the bridge. Cranes and other portable power transmission equipment should be made available quickly. Members of the maintenance crew should be trained to recognize the need of emergency power equipment and its application.

An inventory of spare parts both mechanical and electrical should be made available for speedy repairs.

A list of contacts should be assembled so that all personnel responsible for bridge operations are quickly informed of emergencies.