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Machinery Repairs to Maintain Operability of an 1890's Swing Span

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STATEMENT OF PURPOSE

Maintaining each movable bridge in acceptable operating condition presents its own challenges due to a wide variety of factors including differing designs, differing operating conditions and environmental exposure, differing age of equipment, and differing levels of maintenance that may or may not have been performed over the equipment life. It is important to have an understanding of these factors in order to provide a proper assessment of overall condition.

In a sense, the essence of this paper can be distilled down to the statement that as part of an emergency call-out to this 1890s vintage swing span to assist troubleshooting an operational problem at the end wedges, we found the failed end of a 4¾" diameter bolt.

Figure 1 - View of failed end of 4 ¾" diameter bolt. Bolt is resting on standard walking grating adjacent to track for reference of size.

This statement is in fact overstating the case, or perhaps underscoring depending upon your preference, as the failed end of this bolt was in fact brought to our attention as a passing comment in conversation with maintenance staff, who had previously identified the bolt and then moved it out of the way. As will be discussed, this bolt was not the immediate cause of the call-out nor the immediate solution to return the wedges to service. However, what was at issue was the recognition of the significance of this failed bolt to the stability of the movable span.

Bridge Description

Bridge DM-84.35 carries a single railroad track over the Nanticoke River in Seaford, Delaware. The movable span of the bridge is a 172-foot-long through girder center bearing swing span. The bridge provides a 48-foot-wide navigable channel when opened.

The movable span is equipped with span drive machinery, span support machinery, rail lift machinery, and span locking devices. The bridge dates to 1890 and the majority of the mechanical operating systems are original. The systems utilize extensive runs of shafting, bearings and open gearing to transmit power as was common for equipment of that vintage.

Figure 2: View of swing span from south approach. The span is aligned and supported for rail traffic.

The span drive machinery utilizes an electro-mechanical drivetrain mounted on the movable span with the exception of the ring gear, which is mounted to the center pier. The power for the span drive is obtained through a 15 horsepower, 690 rpm electric motor. The motor powers a drivetrain consisting of shafting, bearings, and spur and bevel gears that terminates at a single rack pinion which engages the pier mounted rack. The drive machinery is operated from a control house located on the approach near the northwest corner of the span. The span drive machinery originally provided for 360 degree operation. However, at present span operation is limited to 90 degree rotation.

The span support machinery comprises a center pivot bearing, balance wheels and track, two center wedges, and four end wedges.

The center pivot bearing and balance wheels are passive mechanical components mounted to the underside of the swing span at the center pier. The center bearing assembly supports the full dead weight of the swing span during operation as well as some amount of live load under rail traffic. The center bearing assembly uses a unique design that is discussed in further detail later in this paper. Eight balance wheels are arranged in four pairs to provide support against longitudinal or transverse tilt of the swing span during operation. The balance wheels are not intended to carry dead load.

Center and end wedges are provided to stabilize the span in the closed position and to support live load of rail traffic. The center and end wedge machinery utilize a common electro-mechanical drivetrain powered by a 15HP 690 rpm electric motor. The motor and high speed end of the drive is located at mid-span and utilizes an extensive series of longitudinal and transverse shafting, bearings and spur and bevel gears to transmit power to the center and end wedges. A timing gear is present in the central drivetrain to sequence the motion of the center and end wedges. The center wedges are mounted to the underside of the center cross girder and the end wedges are mounted to the underside of the longitudinal girders at the ends of the span. The wedges bear against seats mounted to the piers.

Figure 3: Bridge Placard
Pencoyd Bridge Construction 1890

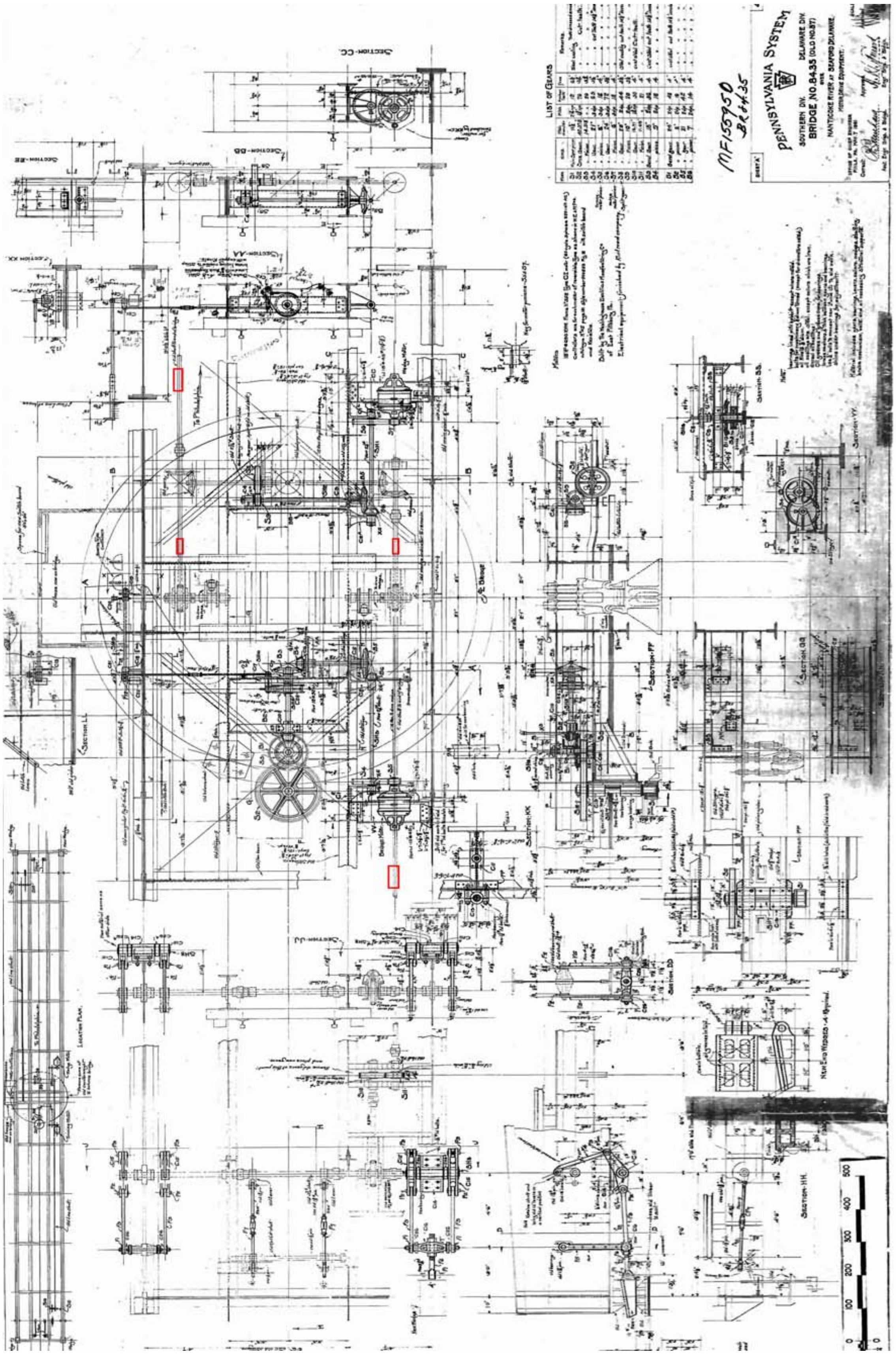

Figure 4 – Machinery Layout at Mid Span. Red boxes indicate strain gage locations.
Excerpt from 1890s Design Plan.

Emergency Callout

The author's involvement in this project initiated when Stafford Bandlow Engineering, Inc. (SBE) responded to an emergency callout to assist in troubleshooting a failure of the end wedge system. The overt cause of the failure was a localized key failure adjacent to one of the end wedges. Maintenance staff identified that one of the gears in the end wedge drive train had sheared both keys which secured the gear to the shaft. Attempts to remove the gear from its shaft to replace the failed keys were unsuccessful with the available field tools. Maintenance personnel subsequently welded the gear to the shaft in attempt to restore functionality. The initial attempt to drive the wedges following the weld repair was unsuccessful due to weld failure. Maintenance personnel performed a second weld repair and provided a larger weld. The author arrived on site at the completion of this second repair and witnessed the subsequent attempt to operate the wedges. Wedge operation was successful. However, loading of the wedge system seemed significant during operation based on the whine of the motor and the shuddering of the machinery during operation.

To quantify the loading of the wedge drive machinery, and to further investigate system loading to provide a basis for the cause of the key failure, the investigation expanded to quantify the operating loads. SBE instrumented the wedge drive machinery with strain gages to document the operating loads throughout wedge operation. Gage installation location is identified in Figure 4. A series of wedge operations was performed to document that the wedge loading was repeatable.

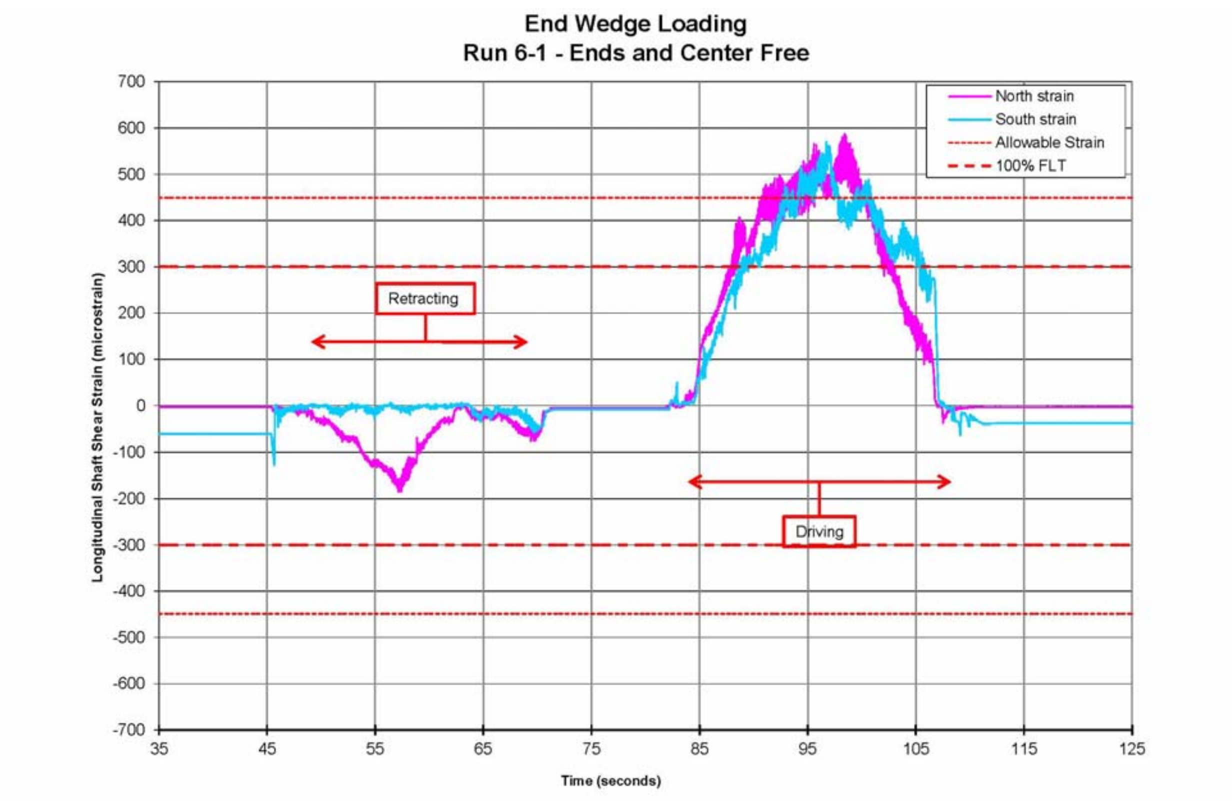

Figure 5 - Strain Recordings for Wedge Drive System following initial repair.

As illustrated in Figure 5, the strain recordings yielded very high loading when driving the wedges. The loading not only exceeded full load torque of the drive motor, but also exceed allowable strain levels for the machinery.

SBE also worked with maintenance personnel to determine the end deflection reactions via a jacking operation and to document the actual deflection imparted at each wedge. The jacking results are presented in Figure 5. The maximum corner reactions are high but are not alarming per se, however, they do exhibit a transverse shift in loading from east to west.

	Corner Reactions (lbs)			
	NW	SW	NE	SE
measured	44,000	44,000	22,000	36,000
anticipated	38,000	38,000	38,000	38,000
% difference	116%	116%	58%	95%

Figure 6 - Corner Reactions determined from Jacking Operation

In discussing the above findings, maintenance personnel commented on the following additional historical behavior:

- The span has been previously noted to orbit during operation so that the rack pinion and rack teeth have come out of engagement in the past. Maintenance have compensated for this behavior by installing spacers between adjacent rack segments to effectively push out the pitch circle of the rack so as to maintain engagement throughout operation.
- The swing span makes noise during operation.
- The balance wheels ride hard on the track during operation.
- The center pier is low to the water and is frequently overtopped by water.

While discussing these items, another finding was brought to our attention in passing. Maintenance was interested in having us look at a failed bolt which they had found. The failed bolt in question was a 4¾" diameter bolt. While it is not atypical to see large machinery on movable bridges, the use of extremely large fasteners is fairly uncommon and notable. The failure of such a fastener should raise significant concerns over not only how the fastener failed but also how the load intended to be carried by this fastener is now being redistributed through the structure.

Figure 7 – Failed Bolt. As found at siding. The workman's boot behind the nut at top provides a reference for size.

We promptly looked to establish the function of this failed bolt. We had maintenance walk back to the source of the bolt failure which was visible from track level at mid-span. The failed bolt was one of four such assemblies at this location. A rudimentary check was performed to sound the nuts at the remaining three locations to check integrity. A concern was quickly identified at the nut adjacent to the failed bolt. A track jack was installed to lift the rail and gain clearance over the nut and a track bar was used to pry to corner of this nut. The nut and accompanying bolt thread was able to be lifted within the available clearance, indicating that this bolt had also failed. The remaining two nuts located under the adjacent rail could not be moved and appeared sound.

Figure 8 – The bolt to the right of the open hole was also identified to be failed.

Problem Recognition

A subsequent review of the original contract plans, which were available at site, established that the failed bolts were part of the center bearing assembly. The center bearing assembly on this bridge uses an arrangement that is uncommon by present design but that we have subsequently found to have had moderate use for similar sized swing bridges circa 1890.

The transfer of the entire weight of the movable swing span to the center bearing assembly which is anchored to the center pier is through four (4) 4¾" diameter studs. Per the original plans, each stud carries 117,000 lbs. The studs are suspended from a grillage resting on top of the center bearing assembly and bear against the bottom of two diaphragm beams which are framed in to the center cross girders of the swing span.

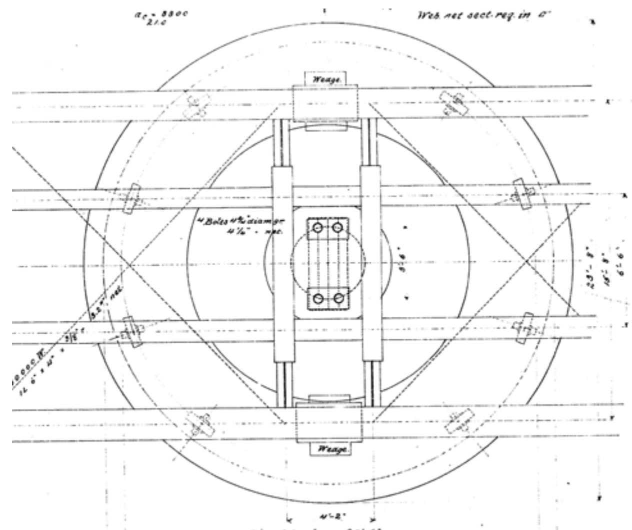

Figure 9 – Plan View at Center Span.
Excerpt from 1890s Design Plan.

As illustrated in Figure 9, the 4 studs are symmetrically located around the center bearing assembly to provide a balanced system and uniform loading of the assembly. Failure of one or more of the bolts compromises the symmetric load transfer and must contribute to a shift of the grillage on top of the center bearing similar to an unbalance bar scale. The load normally taken by the failed bolt(s) must either redistribute through the grillage resulting in an overload of the remaining bolts or transfer through the structure into the balance wheels and center wedges, which components were not intended to carry the dead load of the structure. At some point, failure of the bolts will result in a complete loss of support at the center bearing and compromise the stability of the bridge.

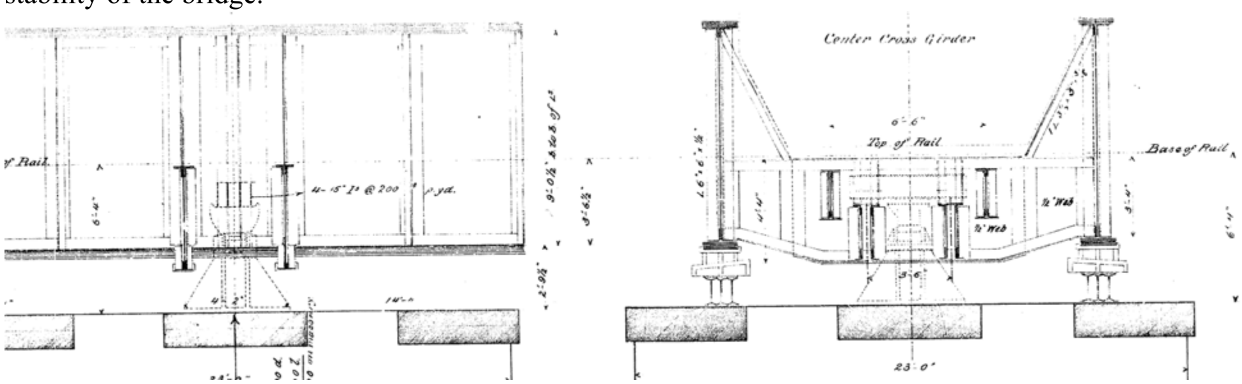

Figure 10– Elevation View of Center Support Assembly.
Excerpt from 1890x Design Plans.

As found, 2 of 4 bolts had failed. As a result, half of the weight of the structure had redistributed to areas not intended to carry this load. Re-evaluating the end wedge failure and observed bridge behavior in light of this finding, it can be surmised that the redistribution of loading resultant from the bolt failure contributed to: overloading of the end wedges, extreme loading at the balance wheels, and a shift in the position of the center bearing contributing to bridge orbit during operation. Without correction, it can be expected that deterioration would progress until the swing span would have dropped off the center bearing. Whether this occur under rail traffic or during operation, the result would have been unacceptable.

Problem Resolution

Upon recognition of the potential consequence of center bearing bolt failure, the following immediate actions were taken:

- Cribbing was installed under the center cross girder to provide additional support to the span in the closed position.
- Bridge openings were curtailed. The problem was identified at the end of the navigation season and the bridge is normally closed for the winter, so this did not present a significant obstacle to the marine community.
- The integrity of the balance wheel axles were assessed through ultrasonic inspection prior to any additional openings to ensure that overload had not compromised the integrity of the wheel axles.
- A shop detail was prepared to replace the failed carrying studs.

Maintenance personnel had previously identified issues with the machinery including suspected excessive wear at the center bearing. Noted issues included orbiting of the span during operation resulting in pinion/ring gear engagement issues and interference with the balance wheels and track/rack installation, heavy wear and damage at the rack/track segments, and evidence of heavy contact at the balance wheels. As part of field verification to verify these issues, it was identified that the support structure for the center bearing, including the upper grillage as well as the structural diaphragms which frame in to the cross girders, was heavily corroded and deteriorated. Therefore, the repair effort was expanded to encompass complete replacement of the center bearing grillage and diaphragms as well as the mounting studs.

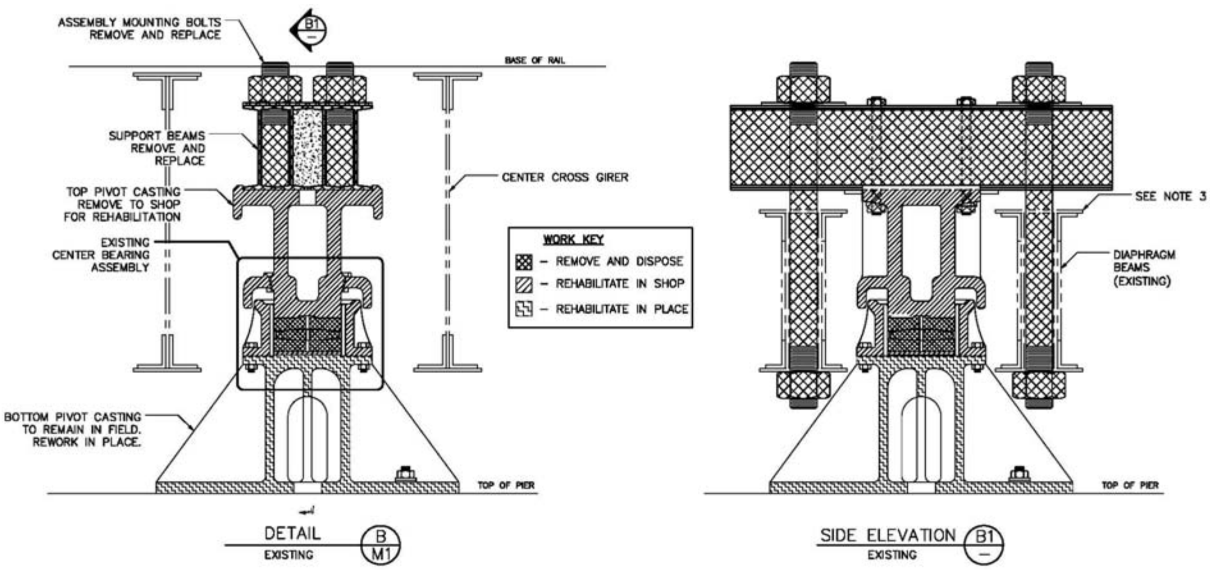

Figure 11 – Rehabilitation Plan for Grillage, Diaphragms Carrying Studs and Center Bearing

As the center bearing had to be unloaded to perform this work, the center bearing was to be replaced. New rack and track segments were provided in the operating range of the bridge and were reset to achieve the proper operating pitch diameter. The balance wheels were refurbished and adjusted to provide the proper clearances with the track.

Each of these items had their own specific challenges and will be discussed in further detail in the presentation. The focus of this paper is on condition assessment and problem recognition. None had as much significant to the stability and integrity of the span as the carrying bolts.

Rehabilitated Systems

The rehabilitation work was performed over the ensuing winter shutdown. At the completion of the work, the integrity of the center bearing assembly was restored. The overall operating behavior was significantly improved. The bridge was restored to rotate about its true center, the rack pinion maintained engagement with the newly installed rack segments, clearances were maintained between the balance wheel and track throughout operation, and the previously noted noises during operation had ceased. There was also a significant reduction in operation loads. Strain gage operating loads recorded at the outset and completion of this project dropped by half, as illustrated in the following figures:

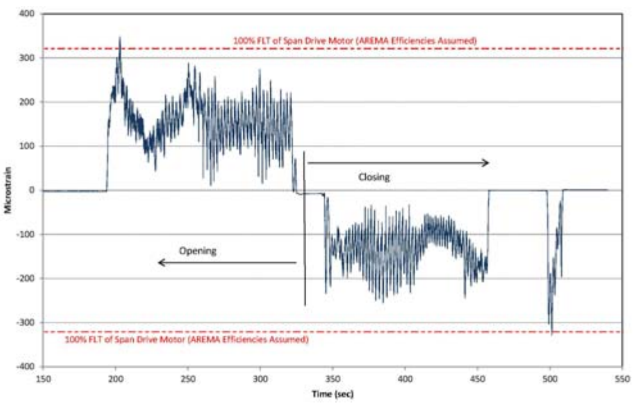

Figure 12 – Span Operating Loads at Outset

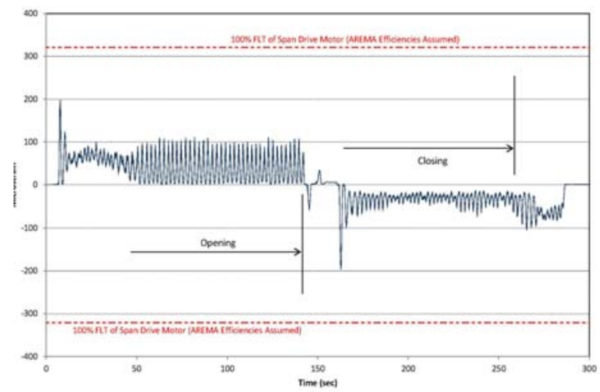

Figure 13 – Span Operating Loads at Completion

For physical confirmation of this numeric load reduction, the bridge operator indicated that whereas the drum controller had previously required near full power to operate the bridge, it now operated in its second power point.

Operating loads were also monitored in the wedge machinery at the completion of the work, which had been the original source of the call-out. The wedge machinery loading does not present as compelling a comparison as the span drive operating loads. While there is in fact a reduction of at least 100 microstrain off the peak loading, which is not insignificant and brings the loading within machinery allowable stresses, the nominal loading during wedge driving remains high and exceeds normal full load motor torque. The wedge drive system is largely original and was not addressed as part of this rehabilitation. There is evidence of deterioration throughout the system including worn bearings and gears and deformed shafts and cranks. Gage placement was fairly far back in the system so the recorded load likely reflects the inefficiency of this aged operating system.

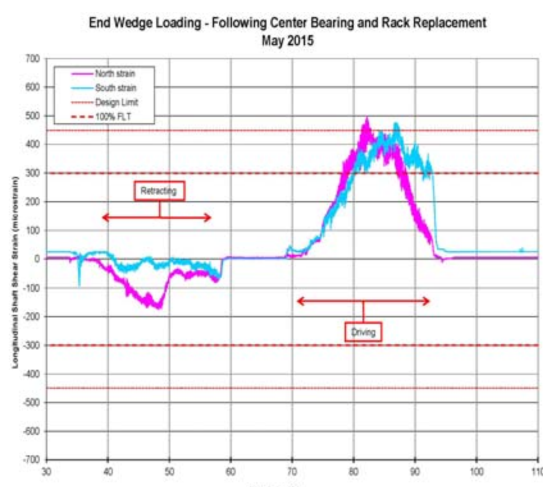

Figure 14 – Strain Recordings for wedge

Rehabilitation of the wedge drive system is necessary to improve the performance and reliability of the wedge drive system and to prevent future failures, which can be expected with the present machinery.

Closing Assessment

The immediate cause of the emergency callout that initiated this project was only the symptom of a larger problem at this structure. This case underscores the need to chase problems to their source as well as for the proper recognition and correction of identified problems.

Figure 15
As-Found Condition of Center Support Assembly.
(after removal of rail and ties)

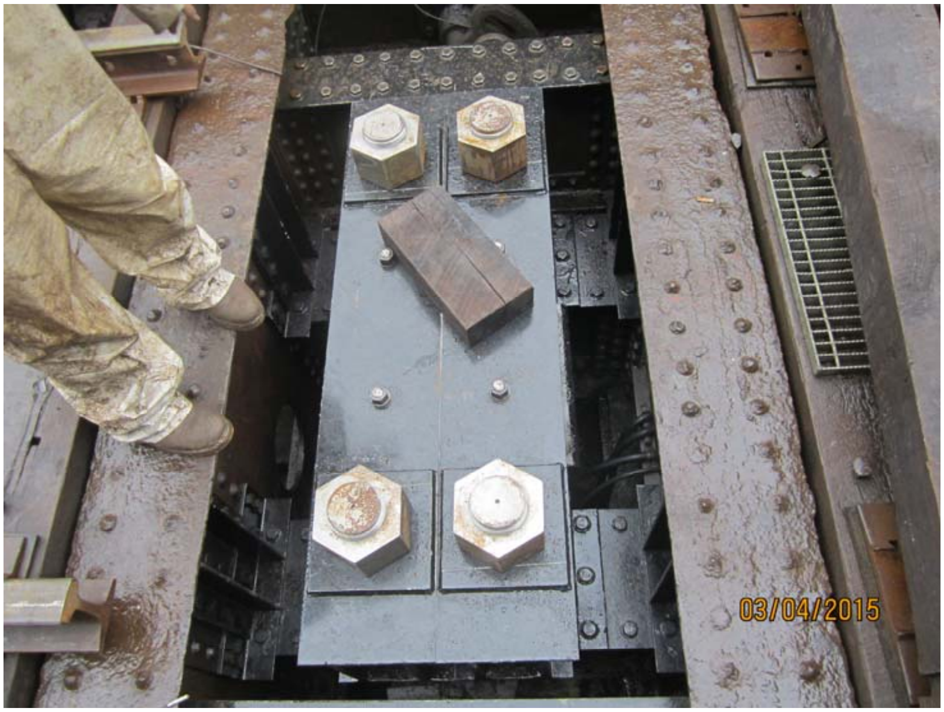

Figure 16
Condition after Replacement of Center Support Assembly.

An observant and knowledgeable maintenance and inspection staff is instrumental in the proper upkeep of our infrastructure, knowledgeable not just in the general tasks normally associated with maintenance but also the specific workings of the system being maintained.