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MACHINERY REHABILITATION FOR MAIN STREET BRIDGE, DAYTONA BEACH, FL

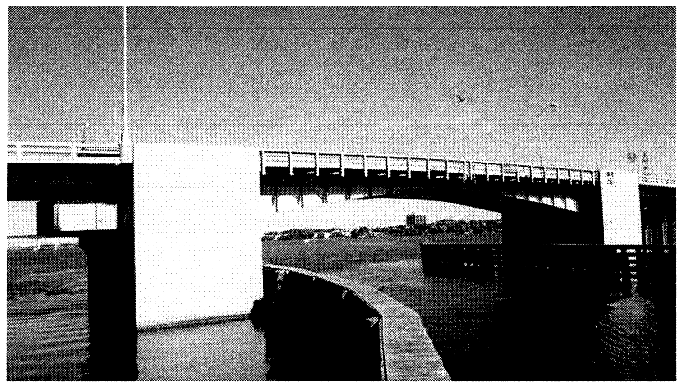
John R. Williams, P.E.
Lichtenstein Consulting Engineers

Introduction

A 1999 in-depth inspection of the Main Street Bridge in Daytona Beach, Florida by Lichtenstein Consulting Engineers (LCE) revealed multiple deficient conditions with the span drive machinery that required corrective action in the short term despite the fact that the span drive machinery had been rehabilitated within the last five years. This paper discusses the causes of the deficient conditions and the steps taken to prevent a recurrence of these conditions and ensure a robust, reliable design over the long term.

Description

The Main Street Bridge is a double leaf trunnion bascule bridge. The span drive operating machinery for each bascule leaf is identical. Figure 1, page 2 is a schematic of the span drive machinery with component designations. The machinery is located below roadway level on the bascule piers. The machinery rooms are accessed through the operator's house for the West Leaf and through a hatch in the sidewalk at the northeast approach for the East Leaf.



The normal power for each span drive is obtained from one 25 HP, 875 RPM electric motor with an integral disc type solenoid brake. The motor is mounted to one side of an enclosed differential reducer with double extended input and output shafts. The motor is coupling connected to one end of the double extended input shaft to the differential reducer.

A thrustor operated shoe type brake is located between the motor and the reducer. The brake wheel for the thrustor brake is mounted on the reducer input shaft extension adjacent to the motor coupling. This brake provides the only braking for the span drive system other than that provided by the integral motor brake.

The machinery driven by the double extended output shaft of the differential reducer is symmetrical about the differential centerline.

Transverse floating shafts are utilized to transmit power output from the reducer to the first of two open gear sets. The inboard end of each floating shaft is coupled to a reducer output shaft extension. The outboard end of each floating shaft is coupled to a shaft that is simply supported in two bearings. The couplings used are single engagement gear type couplings. These couplings accommodate small amounts of angular and offset misalignment that may exist between the reducer output shaft and the mating shafts. A pinion, being the first gear in the open gear train, is straddle mounted on the mating shaft between the bearings. All open gears with the exception of the rack and rack pinion that comprise the final gearset in the gear train are keyed to their shafts and the shafts are supported in sleeve type split bronze bearings mounted in pillow block housings. The rack pinion is integral with the rack pinion shaft. The rack is mounted to a frame at the underside of the bascule girder and aligned radially about the trunnion.

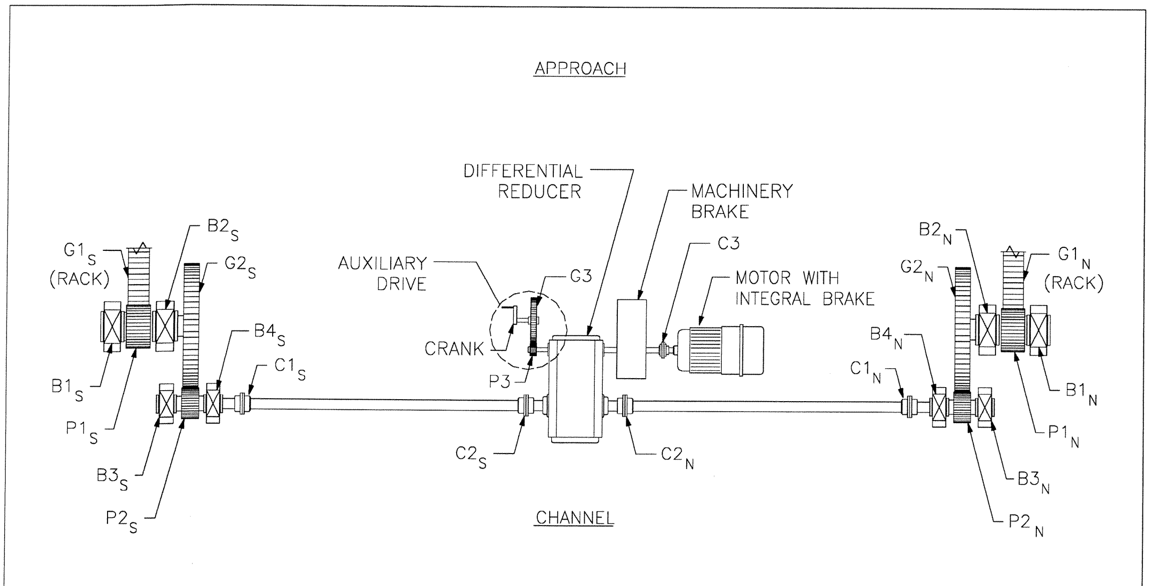


Figure 1. Span Drive Machinery
West Leaf Shown.
East Leaf Mirrored about Span Centerline.

Project:
Main Street Bridge
Volusia County, FL
1999 In-Depth Inspection

Prepared by:
Lichtenstein Consulting Engineers

During normal operation, the electric motors are used to operate the bridge. Rotation of the electric motors causes the bascule leaves to rotate about the trunnions, providing an open channel for marine traffic.

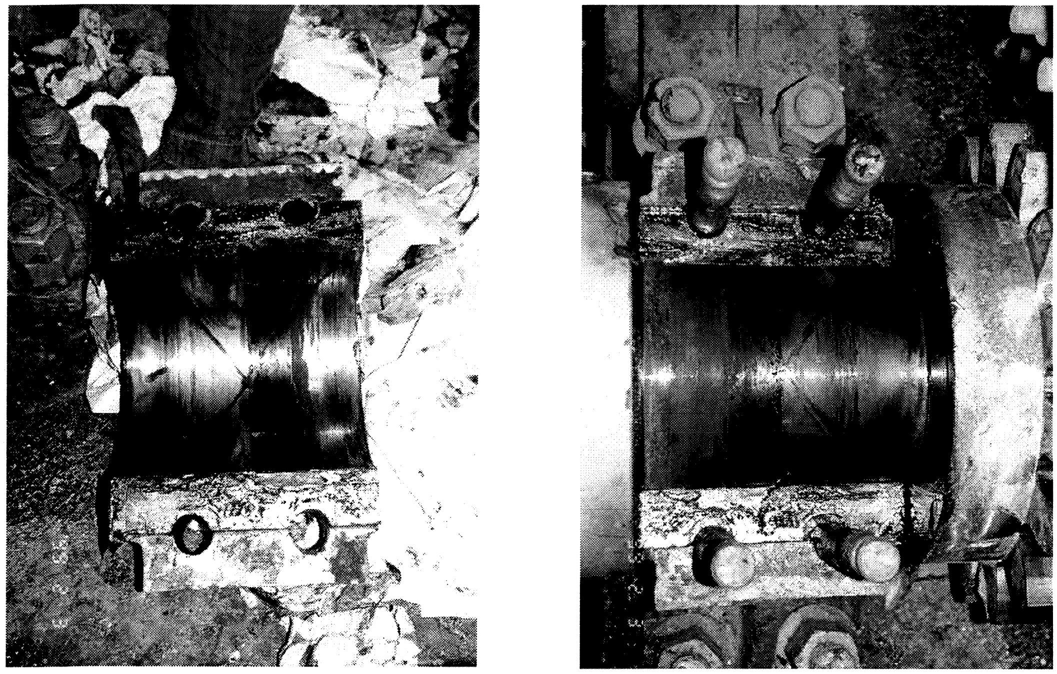
Background

An in-depth inspection of the mechanical machinery was performed by LCE in 1999. The scope of the inspection included measuring bearing clearances and also removing bearing caps for internal inspection of a representative number of bearings.

County personnel indicated that approximately 2-3 years prior to this inspection, there was a mechanical rehabilitation at the bridge. All of the bronze bushings in the drive train were replaced, as were all of the open gears with the exception of the rack. Issues with slight movement at the B1 and B2 bearings were reported upon completion of the rehabilitation work. Then the adhesive anchors that secured the B1 and B2 bearings to their pedestals failed during an emergency stop and the anchors pulled out of the concrete pedestals. Subsequent attempts to re-secure the bearings were only partially successful. As a result there was an ongoing problem with movement of the B1 and B2 bearings at this bridge. This condition was confirmed during the inspection. In addition to the movement of the B1 and B2 bearings, the following issues were noted during the inspection:

Bearings

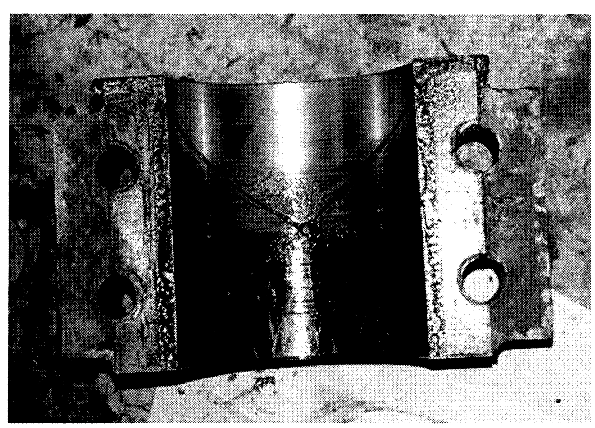
1. The wearing components for bearing B2N, West Leaf were in the worst condition of any of the opened bearings. Upon removal of the cap, it was apparent that the bearing had a problem. There was no fresh lubricant on the journal and hardened grease deposits were present on the journal and cap including in the grease grooves and lube port. These signs are indicative of excess heat build up. Although the actual clearance was not known since the bearing was



Bearing B2N, West Leaf Opened for Inspection Prior to Cleaning

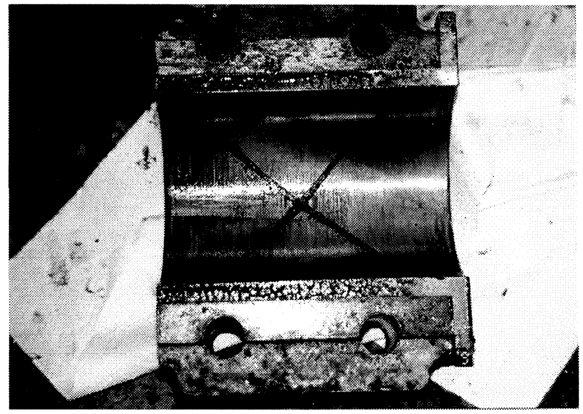
inaccessible for measurement, it was surmised that inadequate clearance in the bearing was the cause of the heat buildup. The cap was re-installed and the bridge operated. The heating of the bearing during operation was confirmed. The cap was removed and the existing shims for the bearing were measured. The east side of the bearing had 1/32" less shims than the west side. A total of 1/32" of shims was added to the east side of the bearing so that the shims on each side were equal (1/2"). The bridge was operated through 2 cycles following the addition of shims. There was no noticeable heat buildup at this bearing following this adjustment.

2. Two bearings that the clearance measurements indicated to be misaligned (i.e. taper across width of bearing) were opened for inspection. The wearing components at bearings B1N, East Leaf and B1N, West Leaf confirmed the measured misalignment. The wearing components for both bearings exhibited a moderately to highly polished band of wear which covered less than 25% of the available contact area. The remaining journal area was unworn and exhibited varying degrees of deterioration and corrosion.



Bearing Cap B1N, West Leaf Removed for Inspection Prior to Cleaning

3. The remaining three opened bearings exhibited inadequate contact area. The polished wear area in the caps for B3S, West Leaf and B3N, East Leaf indicated limited and irregular contact. The wear in the cap for bearing B4S, West Leaf was limited to a 2" polished band located midway between the end of the cap opposite the thrust face and the middle of the cap.



Bearing Cap B3N, East Leaf Removed for Inspection Prior to Cleaning

4. AASHTO specified an RC6 fit for sleeve bearings such as the span drive bearings at the time of the rehabilitation. Since the original bearing clearances taken at the time of construction were not available, it was assumed that the bearing clearances were within the range of an RC6 fit. Apparent wear is calculated as the amount by which the measured clearance exceeds that of an RC6 fit. The clearance at 6 of 12 measured bearings exceeded the maximum allowable value for an RC6 fit. The maximum apparent wear recorded was .021" at bearing B1S. This amount of wear is considered excessive for a bushing that has been in use for 5 years. The excessive wear is attributed to poor bearing alignment, possibly due to the ongoing movement at the bearing.
5. AASHTO requires that all machinery be mounted directly on a self contained steel frame or base using turned bolts to prevent any relative movement between the machinery and the base. The inspected bearings were found to rest on shims that bear directly on the concrete pedestals. This mounting arrangement provides limited ability to adjust bearing alignment and is inadequate for resisting movement due to operating loads.

Open Gearing

1. The measured tip clearance and backlash values were typically in excess of recommended values for a new installation. This condition appears to have been exacerbated by the ongoing movement experienced at the B1 and B2 bearings.
2. The open gearing typically exhibited light wear and was in fair condition overall despite less than ideal alignment evinced by the contact patterns on the teeth and the tip clearance values.

Brakes

1. The integral motor brakes are spring set, solenoid released disc type brakes. These brakes apply instantaneously when the solenoid is de-energized.
2. The integral motor brakes were each set to provide 330 lb.-ft. This value is over 2 times the rated motor torque (150 lb.-ft.) for the system. The torque setting of these brakes is not adjustable.
3. There were significant variations in the torque settings of the machinery brakes on each leaf (65 lb.-ft. on the East Leaf and 169 lb.-ft. on the West Leaf).
4. The combined effect of the motor and machinery brake is 395 lb.-ft. on the East Leaf and 499 lb.-ft. on the West Leaf (2.63 and 3.33 times rated motor torque respectively).
5. County personnel indicate that the motor brakes were added to the system as part of a control system modernization in 1991. Prior to this contract, the machinery brakes were the sole brakes in the span drive system.

6. A study, based on AASHTO requirements, was conducted to determine the proper brake settings. Based on this study, the motor brake capacity could be reduced by 53%. The machinery brake settings would be standardized to 200 lb.-ft. These settings correspond to a decrease in total braking capacity of 5% for the East Leaf and 25% for the West Leaf.
7. It is hypothesized that the excessive torque and instantaneous loading produced by the motor brake was ultimately the cause of the anchor bolt failures.

Recommendations

The following recommendations were provided to the County regarding the deficient conditions that were identified during the inspection:

1. Modify the motor brakes and adjust the machinery brakes to produce the required braking torque for the span drive machinery in accordance with AASHTO guidelines.
2. Properly secure the B1 and B2 bearings to resist the machinery operating loads. The bearings should be mounted to a steel support with turned bolts. The support should be grouted and anchored in place.
3. Rehabilitate the worn and/or corroded bearing journals and bushings and align the bearings to improve contact and reduce the rate of wear.
4. Align the open gearing to reduce backlash, improve contact, and reduce the rate of wear and deterioration of the gear teeth.

Due to the fact that the overall integrity of the span drive machinery was compromised by the inadequate restraint for the bearings in the machinery and the excessive braking torque, it was recommended that corrective action be taken in the short term.

Design

Following submission of the inspection report, the County agreed with the assessment that the long-term benefits of correcting the deficiencies warranted the cost and inconvenience of another rehabilitation project on this bridge after such a short interval. LCE was contracted to provide design services for the rehabilitation effort. The intent of the rehabilitation would be to ensure long term reliability through a robust design. There would also be the ever present challenges involved with any rehabilitation project: impacts on marine traffic and the community as a result of a bridge closure were a consideration and unanticipated pre-existing field conditions could complicate the installation and cause delays. Attention to detail would be imperative in meeting the joint goals of a speedy rehabilitation that would last. The following are highlights of design details that were incorporated to meet the requirements of the project:

- The County opted for a complete roadway closure to minimize the impacts to marine traffic.
- The motor brake manufacturer would be utilized to modify and refurbish the existing motor brakes. The specified braking torque would be reduced by 53% and would be verified by the manufacturer at the factory.
- The machinery brakes would be adjusted to the proper torque setting per the Contract Documents.
- The actual torque setting of both brakes would be verified with a torque wrench in the field. The final torque setting and corresponding spring length would be posted on each machinery brake.
- The existing bearings and open gearsets would be removed from the bridge and sent to a shop for repairs.
- The existing concrete pedestals would be removed and the rehabilitated machinery would be supported on new steel machinery supports.

- The bearing bushings would be replaced. Each bearing pair would be installed on its[2] support in the shop with a semi finished bore. With the bearings aligned and secured with turned bolts, both bearings would be bored through in-line to achieve "perfect alignment" of the bores.
- The existing bearing journals were re-ground to clean up any wear, damage and/or corrosion. The shafts were pre-assembled in the bearings in the shop and proper alignment was verified.
- The existing open gears were in good condition and just cleaned.
- With the machinery pre-assembled in the shop, the only field alignment of the machinery required was the alignment of the rack and rack pinion (G1/P1 gearset), the G2/P2 gearset, and the floating shaft couplings.
- The new machinery supports would be anchored with mechanical concrete anchors. The anchors would be tensioned to ensure adequate capacity to resist the machinery operating loads. Grout would then be inserted to lock in this load and protect the anchor from corrosion.
- The Contractor would be required to field verify specific information critical to the installation of the rehabilitated machinery and submit that information to the Engineer.
- The work was to be completed in July-August 2001.

Post Design (Construction)

While the County utilized their in-house construction management personnel to manage the rehabilitation, LCE provided shop drawing review and specialized on-site and shop inspection during critical steps of the project since County personnel did not have the requisite experience with machinery installations. Notably, this included participating in all field measurements of the existing machinery prior to the closure. There are several benefits inherent in having these measurements be performed in the presence of the Engineer:

1. This ensures that time is taken in the midst of a hectic construction schedule to complete all of the steps defined in the Contract Plans.
2. Many of the issues that would or could arise during the installation were identified and discussed. The removal and installation procedure (previously submitted in writing) was discussed in much greater detail than that afforded by written review comments, in a much shorter period of time.
3. Information regarding the criteria for acceptance of the installation defined in the Contract plans was clarified. This step was critical in the case of the alignment criteria for the rack and rack pinions. The alignment, backlash and tip clearance for each rack and rack pinion was documented at each of four locations over the full range of opening for the bridge. This established what the existing alignment was and how it changed as the bridge opened. This was critical information when tasked with aligning a relatively new pinion to a more heavily worn rack with a substantial amount of runout.
4. Most important to the project, all involved in the measurements agreed that the measurements confirmed that it would be possible to obtain good alignment of the open gearing versus the current conditions. There would be no disputes during the installation as to whether or not it was possible to obtain good gear tooth contact due to the condition of the rack or other gears.

After approving the installation of the machinery on the supports in the shop, LCE returned to the bridge to provide oversight for the installation of the supports and the alignment of the open gearing and couplings. The installation procedure was as follows:

1. Prior to the installation of the bearing supports, each of the anchors for the supports was tested to its full tension.
2. The supports were installed over the anchor bolts.

3. The alignment of the open gearing was performed.
4. The machinery was temporarily secured by the anchor bolts on hard shims and the leaves were operated by hand to assess the rack/rack pinion alignment over the full opening range.
5. Final adjustments were made to obtain optimum gear tooth alignment.
6. The bearing supports were grouted in place.
7. The bearing support anchors were tensioned and the annular space around the anchor bolts was filled with grout.
8. The bridge was re-opened on August 21, 2001.

The most complex aspect of the machinery installation was the alignment of the relatively newer rack pinion with the older rack. An example is the issues encountered during installation of the North East Rack and Rack Pinion. It had been previously determined that there was .111" of runout at the North East Rack. In order for the teeth to mesh properly, the backlash and tip clearance would have to be adjusted at the tightest location. In addition to the runout, the rack had worn in somewhat with ~~its~~ its original pinion, and the tooth surfaces were no longer parallel. When the pinion was installed so that the tip clearance was equal at both ends of the teeth, there was better than 80% contact on one face of the tooth, and less than 25% contact on the other face of the tooth. By measuring the taper between the teeth on both faces over the length of the rack, it was apparent that when the bridge was constructed, there was end loading misalignment at this location. Since the teeth had worn in to accommodate this misalignment, the original misalignment would have to be duplicated in order to obtain the best possible contact. When the pinion was adjusted so that the tip clearance was approximately .060" less on the south end of the teeth versus the north end and then re-aligned, the contact was more uniform on both tooth faces. It is important to note that the AGMA recommended backlash values were not obtainable due to the wear on the rack. Had the center distance of the gearset been decreased to reduce the backlash to within the ideal range, the tip clearance would have been inadequate and tooth bottoming would have been the result.

Conclusions

LCE visited the Main Street Bridge in June 2002 to perform a biennial safety inspection. The span drive machinery had been operating problem free since the time of the rehabilitation and the open gearing and bearings generally appeared to be in good condition.

The problems experienced at the Main Street Bridge present an excellent example of the need to consider the span drive machinery as a system when designing repairs or making improvements. Although the machinery design may be adequate based on the rated torque of the drive motor, the brakes must be properly sized and adjusted in order to not exceed the capacity of the machinery. Lack of attention to these details presents a significant risk to the span drive machinery as illustrated by the damage to the machinery at the Main Street Bridge during an emergency stop.

Although there were multiple construction issues that caused delays during the project, the work was completed with minimal impact to the overall schedule. The ability of the Owner and Contractor to keep the project on course with satisfactory results can be attributed to several key factors:

- The skill and experience of the Contractor's personnel performing the work and effective management of the project by the Contractor.
- The elimination of as much field assembly of machinery as possible in the design.
- Continuous involvement and oversight of all phases of the project by the Owner utilizing personnel that are experienced and skilled with projects of similar scope and complexity.