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Movable Bridge Operational Testing Strain Gage and Electrical Load Recordings Case Studies and Lessons Learned

Ryan Kanagy, Ralph Giernacky, Yang Zheng
Wiss, Janney, Elstner Associates, Inc.

RENAISSANCE ORLANDO AT SEAWORLD
ORLANDO, FLORIDA

Introduction

Strain gage recordings have been historically used to evaluate bridge imbalance, with a well-documented record of success over decades of use in the movable bridge industry. However, for some movable bridges there are complications that introduce challenges into the balance analyses, with the result that accurate imbalance assessments may depend on specific analysis techniques that are best informed by experience. In addition, the value of strain recordings should not be limited to balance analysis. The evaluation of recorded strain may be used to document other operational issues related to drive load-sharing, unexpected machinery inefficiency, or control system issues. When evaluating imbalance or other movable bridge operating characteristics, the addition of electrical load recordings provides a more complete assessment of the electro-mechanical drive system as a whole. The integrated approach of utilizing mechanical and electrical measurements can yield data such as the total load and energy equation of the bridge mechanical and electrical operating system, the efficiency of the electrical drive, the electric motor efficiency, overall operating electrical losses and machinery system and component efficiencies.

This paper provides case studies of the use of these mechanical strain gage recordings and electrical load measurement techniques to solve movable bridge operational issues.

Case 1: Poor Control of a Span Drive Vertical Lift Bridge

Bridge:

NS B-210.21 over the Black River in Lorain, Ohio

Issue:

Poor control of this span drive vertical lift bridge caused excessive machinery torque oscillations during operation. Raising and lowering resulted in an uneven “see-saw” movement end-to-end of the lift span, with the two ends alternating between static and dynamic conditions. The span drive operating ropes and the other drive machinery components were subjected to impact loads due to the halting nature of the operation.

FIGURE 1. NS B-210.21 Span drive Vertical Lift Bridge in Lorain, Ohio.

The perceived cause of the issue was in dispute among railroad and subconsultant personnel with some attributing the issue to poorly maintained span drive operating rope tensions, imbalance, or system friction, and others attributing it to improper tuning of the replaced control system.

Investigation:

The investigation included a review of the mechanical systems and mechanical and electrical load recordings. Mechanical loads were recorded via strain gages at the output of the primary gear reducer (FIGURE 2) and electrical recordings at the drive to assist in the investigation. These tools are invaluable when troubleshooting operation issues as they provide the drive loads close to the power supply and close to the moving span.

Strain gage recordings from the baseline operating condition are shown in FIGURE 3, which documents the excessive load oscillations noted at the instrumented shafts.

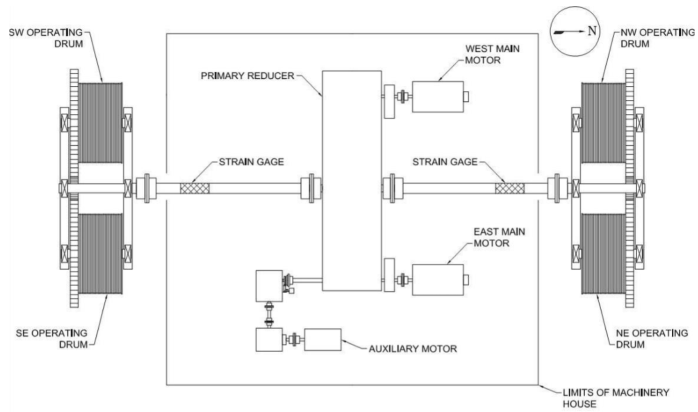

FIGURE 2. Lorain Lift Bridge. Machinery Arrangement and Gage Location.

This behavior was most severe during lowering of the lift span with the rope tensions oscillating between completely taut and completely slack conditions end to end of the lift span. The operation of the lift span could be described as a “see-saw” movement; one end of the span would stop while the other end lowered, then the ends would reverse with the opposite side stopping. This behavior imparted significant impact loads to the operating ropes and to the machinery.

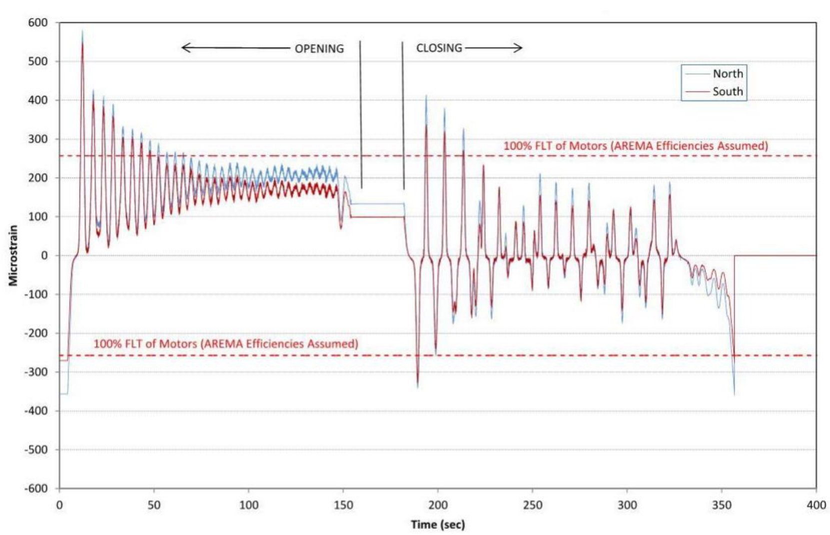

FIGURE 3: Lorain Lift Bridge. Baseline Strain Gage Recording.

The load oscillations evident with the strain gage measurements had similar characteristics as seen in the electrical recordings. The magnitude of the load oscillations when raising the bridge at full speed appeared to represent that of an underdamped control system but eventually damped before the bridge reached full open. When lowering the bridge, the magnitude of the oscillations did not diminish and damp out with time but were maintained until the speed of the bridge was reduced at the nearly closed position. These results were consistent with the values and variability of the constants associated with the 2nd order differential equation for the bridge load/drive model.

Corrective Action:

Based on the initial review, there were noted issues that were identified as possible contributors to the bridge operational issue apart from tuning the drives including excessive imbalance, and misadjusted span drive operating rope tensions. The adjustments to the imbalance and the operating rope tensions were performed prior to any of the drive adjustments, with strain gage and electrical recordings performed before and after each adjustment to verify their impact.

Operating rope tension adjustments had no discernable impact on the behavior of the lift span. The imbalance was reduced by adding counterweight ballast to the counterweight pockets. The imbalance was successfully reduced however the balance change did not improve the load oscillations or the uneven operation of the bridge. In the raising direction, the change had minimal effect. In the closing direction, the imbalance was nearly equal to system friction, and the result of the change increased the magnitude load oscillations (see **Error! Reference source not found.**). Although the modifications did not improve the operation of the bridge, a return to the heavier span imbalance was not recommended as this would increase the loading on the machinery and reduce the capacity for the system to handle additional design loads (wind, snow, ice, etc.) as required by AREMA.

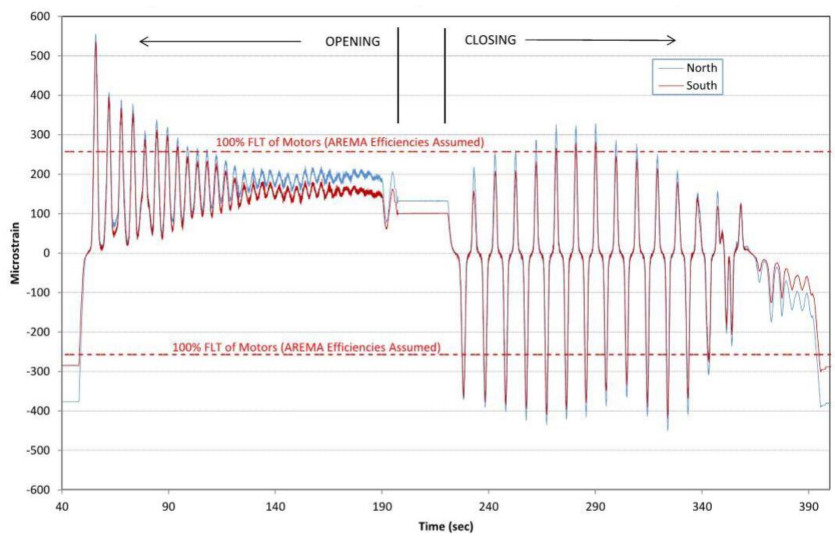

FIGURE 4: Lorain Lift Bridge. Strain Gage Recording Following Balance Change and Rope Tension Adjustments.

After the imbalance and operating rope tensions were addressed a drive tuning procedure was developed in consultation with the drive manufacturer (Bardac). This strategy consisted of minimizing initial torque overshoot and the damping out of torque oscillations during bridge operation.

The procedure included iterative adjustments to the acceleration time, the proportional gains, and the integral time constant associated with each drive. The effect of the gain and integral time constant adjustments were recorded with bridge operations in ten foot increments and included strain gage and electrical load recordings. Gain and time constant effects are shown in FIGURE 5 and FIGURE 6.

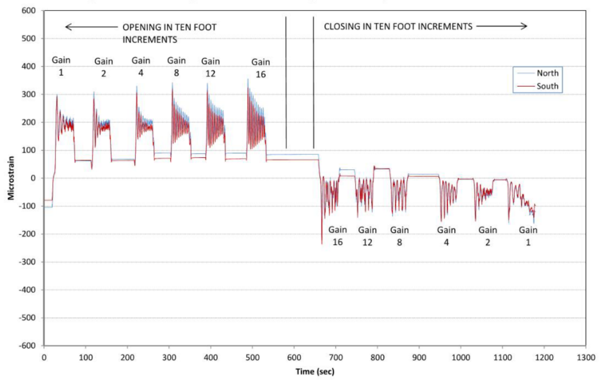

FIGURE 5: Lorain Lift Bridge. Strain Recordings of Proportional Gain Adjustments at the Drive.

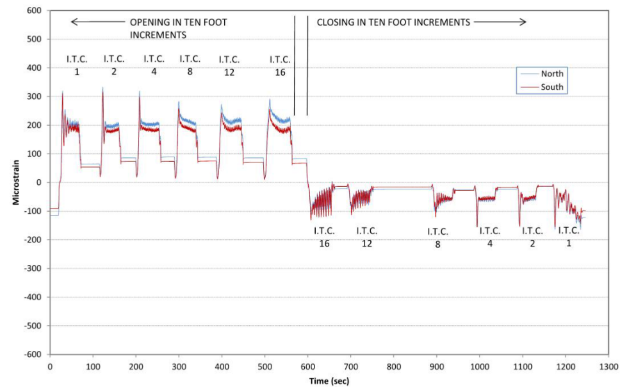

FIGURE 6: Lorain Lift Bridge. Strain Recordings of Integral Time Constant Adjustments at the Drive.

Based on the testing shown in Figure 5, a proportional gain of 4.0 was selected as it provided for the short period of unstable operation with less pronounced oscillations. After selection of the proportional gain, an integral time constant was selected. The 2.0 second integral time constant was selected as it minimized the duration of oscillations. As a final adjustment, after the proportional gain and integral time constant were optimized, the accelerating ramp time was modified. The accelerating ramp time was short and a cause of excessive torque. The accelerating ramp time of the drives was increased to decrease the inertial loading and reduce the accelerating torque being applied to the bridge machinery. The final operating characteristics are shown in Figure 7.

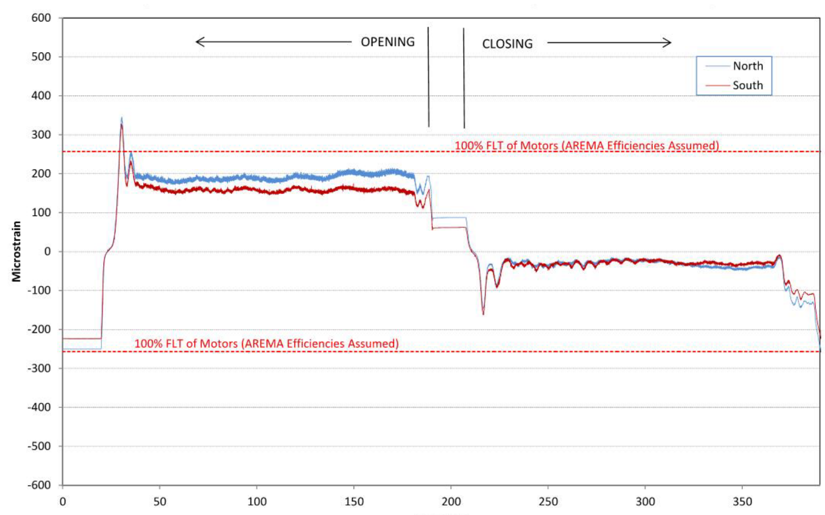

FIGURE 7: Lorain Lift Bridge. Strain Gage Recording Following Drive Adjustments.

Lessons Learned:

The root cause of the operational issue was demonstrated to be improper drive tuning. After the tuning, span operation had minimal load peaks, negligible oscillations, and an elimination of the uneven "see-saw" behavior. The combined use of mechanical and electrical load recordings were valuable in that they provided real-time feedback when making drive updates.

Case 2: Investigation of Drive Tripping at Swing Bridge Machinery

Bridge:

Hines Memorial Bridge over the Merrimack River in Amesbury, Massachusetts

Issue:

High loads and a disparity in load sharing between this center bearing swing bridge's independent span drives led to nuisance operational faults.

Investigation:

The Hines Memorial Bridge included two separate drivetrains, located on opposite sides of the center bearing. Each drivetrain included a 7.5 hp / 1200 rpm electric motor coupled to an enclosed right angle reducer that was, in turn, coupled to a bearing supported rack pinion shaft. Each rack pinion engaged with a section of the ring gear which was secured to the pier. The electrical design included two separate Emerson variable speed drives, one dedicated to each electric motor.

The electric drives were tripping due to thermal overload during the final stages of construction. Drive tripping occurred during cold weather and, typically, after multiple sequential operations of the swing span, which were performed as part of final mechanical alignment reviews.

The preliminary evaluation relied solely on mechanical strain gage load recordings. The baseline strain gage recording is shown in Figure 8. The recording confirmed poor load sharing between the two drivetrains. However, despite the relatively high loads noted with electrical recordings at the drives, the strain gage load recordings were lower relative to the expected full capacity of the motors. The expected electrical drive loads would be lower than measured if estimated reducer efficiencies from AASHTO (LRFD 5.8.4.2.1) were assumed. The investigation also included checks of the alignment of all of the components in the mechanical drivetrains. All components were found to be well-aligned.

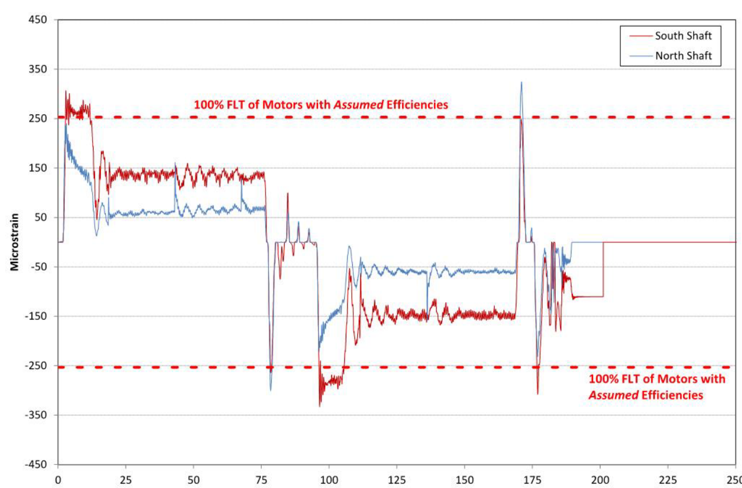

FIGURE 8: Hines Memorial Bridge. Rack Pinion Shaft Strain Gage Baseline Recordings.

With no apparent root cause of the nuisance tripping, the next step of the investigation included recording of electrical parameters at the drives concurrent with the strain gage load recordings at the rack pinion shafts. The electrical recordings confirmed operation at or near the limits of the drives and poor load sharing between the two drives. In addition, the electrical measurements demonstrated poor control of the drive outputs in the form of oscillations (under-damped controls).

The electrical and mechanical testing was repeated with additional strain gages installed at the input side of the enclosed reducers. Data at this location confirmed the electrical load recordings; the drives were operating at or near established limits. A lower-than-expected reducer efficiency was a contributor to the issue.

The performance of the reducers was closely reviewed with the reducer manufacturer. It was determined that there were no manufacturing issues within the reducers that were the cause of the reduced efficiency relative to AASHTO assumptions. The manufacturer determined that the reducers were consistent with their expectations and significant corrective action was not necessary.

Corrective Action:

Multiple adjustments were made to the systems to address the nuisance tripping:

- Optimization of the Drives
  The noted poor load sharing resulted in higher-than-necessary loads at the two drives and nuisance tripping. Several updates were made to the drives to address the issue.

  - Drive Tuning
    Using both an auto-tuning process and manually adjustment of drive parameters, the motor characteristics were tuned to their respective drives and a more efficient energy transfer between the drive and the driven motor was accomplished. The manufacturer performed this work using both electrical parameter recordings and mechanical strain gage recordings to provide real-time feedback for optimization.

    The drive output current oscillations that were occurring were caused by the under-damped nature of the control loop that had been set up. These oscillations caused detrimental transient loads to be generated and applied to the mechanical system. This phenomenon is known as “Ringing”. Under-damping occurs when the control system integral and proportional gain constants are set too low based on the motor load characteristics. The elimination of this “Ringing” was achieved by an iterative process of increasing the integral and proportional gain constants in increments to obtain the desired critically damped response for the drive output currents.

    Figure 9 and 10 show current recordings over a complete bridge operation prior to tuning (baseline) and following drive tuning. As can be seen by comparing the two recordings, the tuning and increasing of the integral and proportional current gain constant parameters of the drives eliminated the oscillations. The limiting of the unnecessary drive load oscillations thereby lowered the RMS (root mean square) loads during accelerating periods.

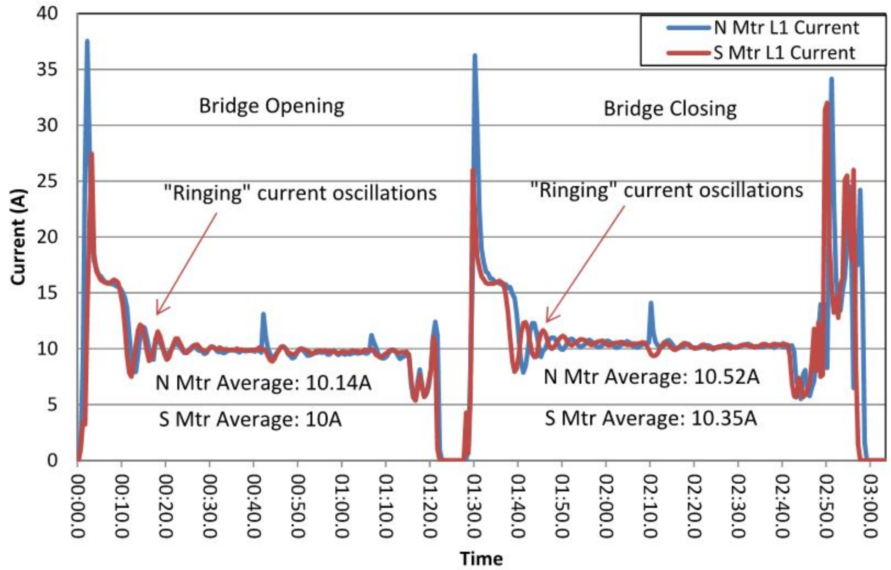

FIGURE 9: Hines Memorial Bridge. Motor Current Baseline.

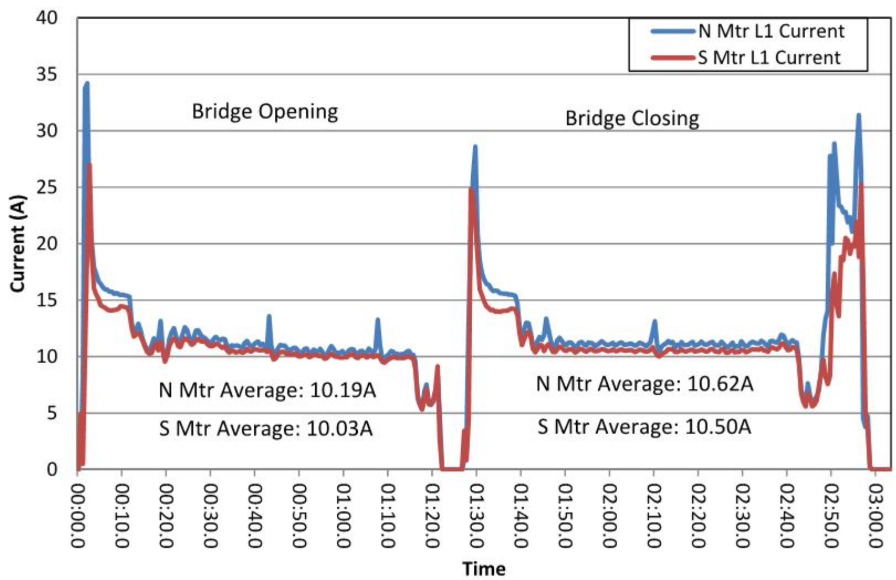

FIGURE 10: Hines Memorial Bridge. Motor Current after Tuning.

- Load Sharing
  The intent of load sharing was to achieve equal loading of both the north and south mechanical and electrical operating systems during bridge operation. The approach taken to achieve the desired load sharing was to arrange the drives in a Leader-Follower torque configuration. This necessitated the addition of an analog module in the Leader drive (north) to provide a current signal (% torque) with an applied scaling factor that was inputted to the symmetrical current limit of the Follower drive (south).

  The result of this torque feedback loop was to set the motor current output from the Leader drive to approximately 10% higher than the Follower drive as opposed to 20% lower as originally installed. The electrical load sharing as measured at the output of the drives was improved from a 54/46% (south/north) split of the load from baseline testing to roughly a 50/50% sharing of the load after the addition of the Leader-Follower configuration.

- Thermal Overload Protection Modification
  To further reduce the possibility of nuisance tripping, the drive parameters were adjusted to increase the thermal time constant (in terms of I^2t). The adjustments were discussed with both the motor manufacturer and the drive manufacturer, and both agreed in writing that the applied changes in thermal protection settings would not in any way damage or reduce the life expectancy of either the motors or the drives.

  This modification allowed the motors to operate in an overloaded state for a greater period of time but still be adequately protected from overloads that could cause motor damage.

- Reducer Oil Change
  The reducer manufacturer recommended a change to the oil viscosity to improve the efficiency of the reducers. They reviewed the application and determined that a change could be made that would reduce losses and continue to provide suitable lubrication for the operation year-round. The reducer oil was changed from an AGMA 5 oil to an AGMA 3 oil. Strain gage measurements before and after the oil change demonstrated that the changed improved the reducer efficiency by approximately 10%.
- Speed Reduction
  The motor operating speeds were reduced to reduce power draw. This change resulted in an increase in the bridge operation cycle, which was reviewed with the owner and determined to be acceptable.

The adjustments had the desired effect. Optimization of the drive tuning and the load sharing provided significant improvements to the control of the bridge. The loading was reduced through the oil change and the speed reduction. These changes, combined with the modification of the drives' thermal overload protection, eliminated the nuisance tripping. The final electrical power recordings are shown in Figure 11.

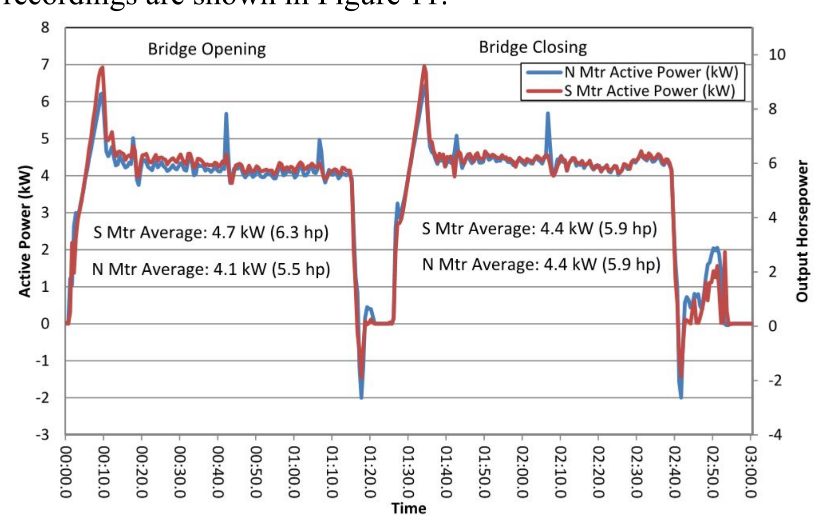

FIGURE 11: Hines Memorial Bridge. Final Electrical Power Measurements.

Lessons Learned:

The changes implemented at the Hines Memorial Bridge eliminated the nuisance drive tripping issues. There were several lessons from the work that warrant consideration for future projects:

- When utilizing independent drives, achieving adequate electrical load sharing can be challenging. Consideration should be given to increasing the capacities of drives and mechanical drivetrains to ensure that they have sufficient capacity to accommodate load sharing deficiencies.
- The sole use of mechanical strain gage recordings provides an incomplete evaluation of a mechanical / electrical movable bridge drive system and may be misleading. Strong consideration should be given to incorporating both electrical parameter recordings and mechanical strain gage recordings into bridge commissioning work and for troubleshooting operational issues. For the Hines Memorial Bridge, the disparity in the mechanical and electrical load recordings helped to highlight unexpected losses at the span drive reducers, which were then improved with an oil change. It is clear that the combined electrical and mechanical recordings provide a more complete picture of the integrated mechanical and electrical system.
- Close attention should be given to drive adjustments and controls work during bridge commissioning. For the Hines Memorial Bridge, careful adjustments were required to eliminate nuisance drive faults, but a careful tuning process is recommended for any movable bridge as limiting undesirable load fluctuations will benefit the machinery in the long term.
- Designers should be cautious when assuming the “preliminary estimates” of reducer efficiency that are provided in AASHTO 5.8.4.2.1. It is recommended that the efficiency be discussed with the manufacturers in the design process to accurately assess expected loads.

Case 3: Bascule Span Drive Machinery Differential Repairs

Bridge:

LaSalle Causeway Bascule Bridge over the Rideau Canal in Kingston, Ontario

Issue:

There was poor load sharing between the two rack pinion shafts of span drive machinery for this single leaf Strauss bascule bridge.

Investigation:

Strain gage loads were recorded to determine the imbalance as part of an inspection of the bridge. The gages were installed at the output of an open gear differential assembly, located centrally in with the drive assembly. See Figure 13.

FIGURE 12: LaSalle Causeway Bascule Bridge

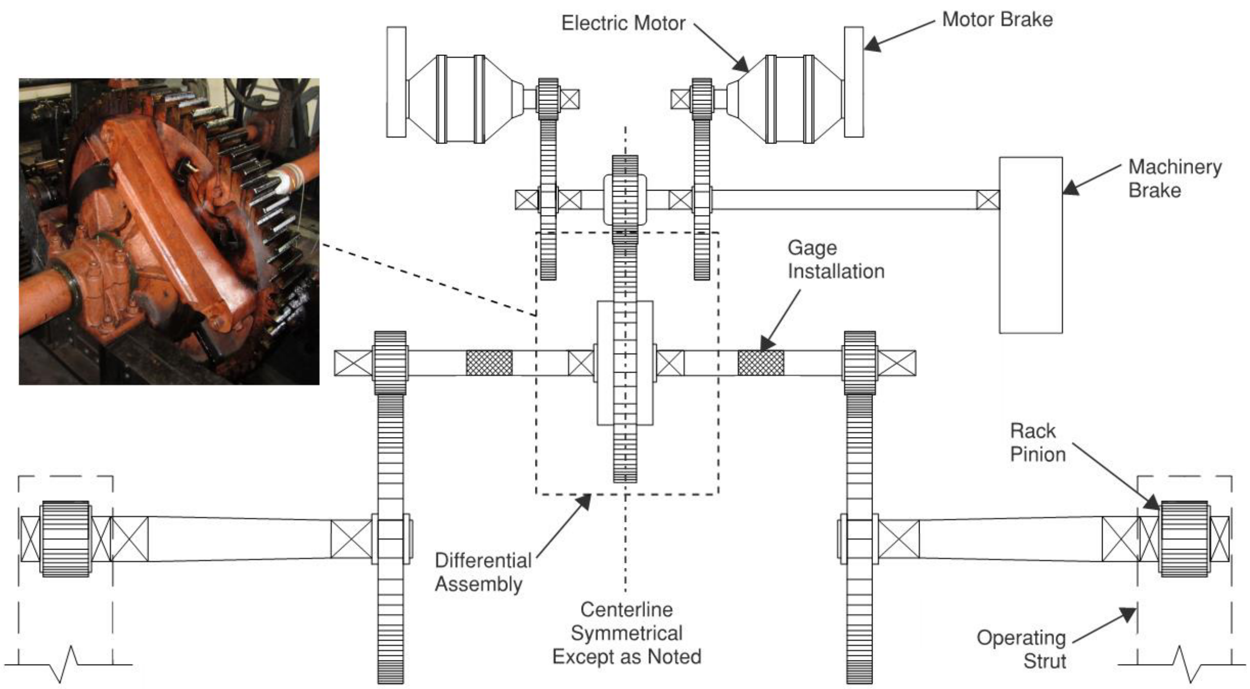

FIGURE 13: LaSalle Causeway Bascule Bridge. Span Drive Machinery Schematic.

The strain gage recordings showed poor load sharing between the two shafts at the output of the differential assembly. The baseline recording is shown in Figure 14.

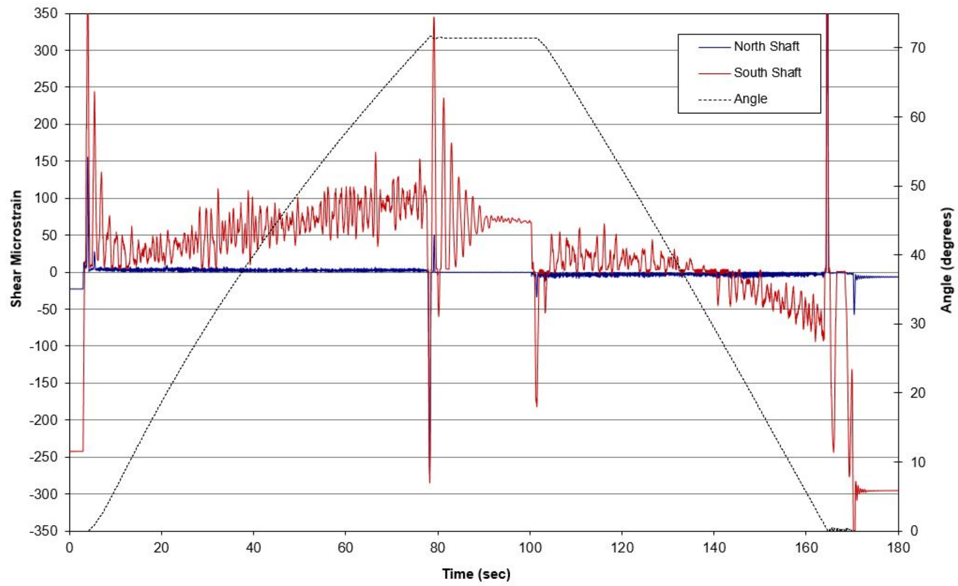

FIGURE 14: LaSalle Causeway Bascule Bridge. Baseline Strain Gage Recording.

The span drive machinery differential assembly is designed to mechanically equalize the loading at the two cross shafts and, ultimately, to each of the two rack pinions and operating struts. Figure 14 demonstrates that, with the exception of transient spikes in loads, the north shaft carried no load.

Corrective Action:

Based on the strain gage recordings, the differential assembly was repaired. Figure 15 provides a chart of the strain gage recordings *following* the repair. Note that the chart also reflects improvements made to the control system to minimize impact loading during operation.

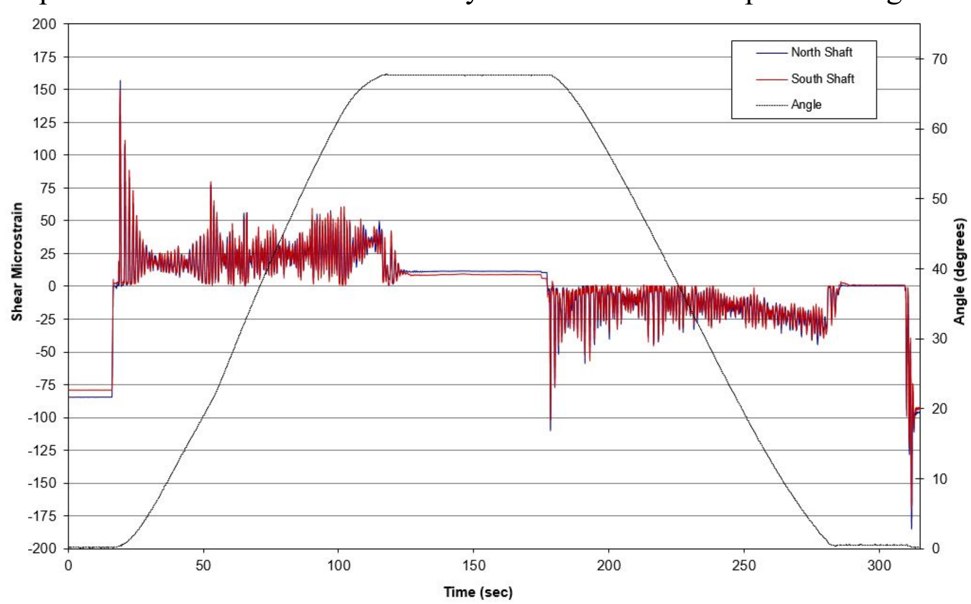

FIGURE 15: LaSalle Causeway Bascule Bridge. Strain Gage Recording After Repairs to the Differential Assembly.

Lessons Learned:

The identification and repair of the LaSalle Causeway Bridge span drive differential assembly was an added benefit to the intended scope of work. Strain gage recordings add value for inspection, maintenance, and construction services as they may be used to identify previously unknown maintenance issues. In this case, it would have been challenging or nearly impossible for maintenance and operation personnel to identify the issue simply with routine practices. The strain gage recordings also provided the ability to quantify the effect of the repair. The load measurements following the repair provide proof that the issue with the differential assembly was addressed, and the recordings provided a baseline against which future work could be evaluated.

Case 4: Vertical Lift Bridge Imbalance Variations

Issue:

The imbalance of vertical lift bridges changes from the seated to the full open position. As a minimum, the change is due to the effect of the movement of the counterweight ropes from the span side to the counterweight side as the bridge is lifted. On many bridges, the effect of the counterweight ropes is counteracted with an auxiliary counterweight system intended to accommodate the bulk of the difference, thereby limiting the change in loading to the drive machinery.

When reviewing the imbalance of a vertical lift bridge, recorded span drive strain gage data is typically fit to the expected curve based on a theoretical expression that accounts for both the transfer of weights from the counterweight ropes and the effect of the auxiliary counterweight system. In some cases, the curve fit matches well with the change in imbalance expressed by the theoretical expression. Sometimes, however, the fit varies substantially. In fact, the quality of the curve fit sometimes varies corner-to-corner or end-to-end on a given bridge.

Construction specifications often provide imbalance tolerances for a given corner and for a given end of the bridge. Sometimes specifications will also prescribe load sharing criteria targeting an equalization of loads throughout operation. The variation in corner-to-corner behavior affects the ability to meet corner imbalance requirements and the ability to achieve load sharing.

A review of this issue at specific bridges is beneficial and their implications for possible balance criteria will be reviewed.

Bridge:

Marine Parkway Bridge, a tower drive vertical lift bridge in Brooklyn/Queens, New York

Investigation:

November 2018 testing results indicated a disparity in the corner loads and imbalance reactions for this tower drive vertical lift bridge. The behavior of the north tower machinery is described in Figures 16 through 19. Figure 16 shows the strain gage strip chart from the north tower. Figure 17 shows the imbalance curve fit from the two corners combined. Figure 18 and 19 show the imbalance curve fit data for each of the two corners, analyzed separately.

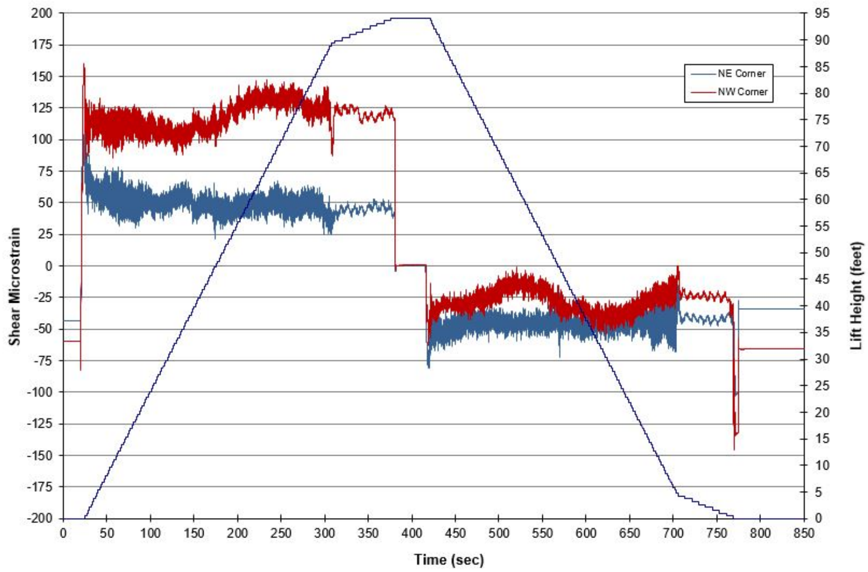

FIGURE 16: Marine Parkway Bridge. North Tower Strain Gage Recording.

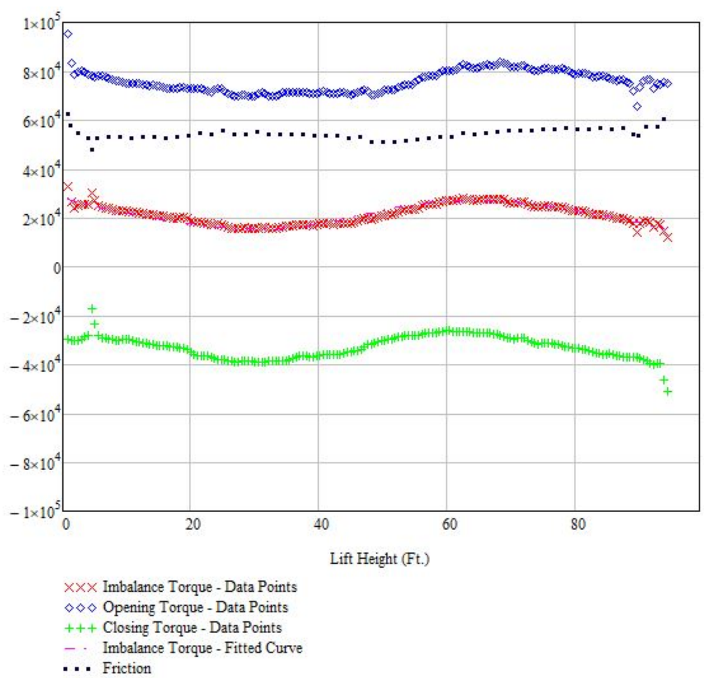

FIGURE 17: Marine Parkway Bridge. North Tower Imbalance Curve Fit for Two Corners Combined.

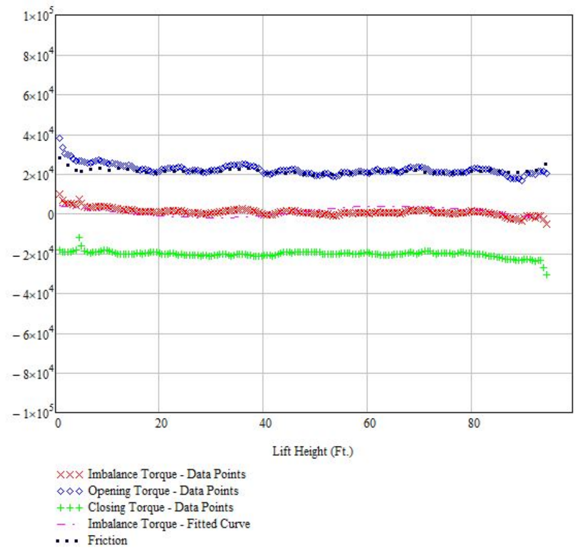

FIGURE 18: Marine Parkway Bridge. Imbalance Curve Fit for the Northeast Corner.

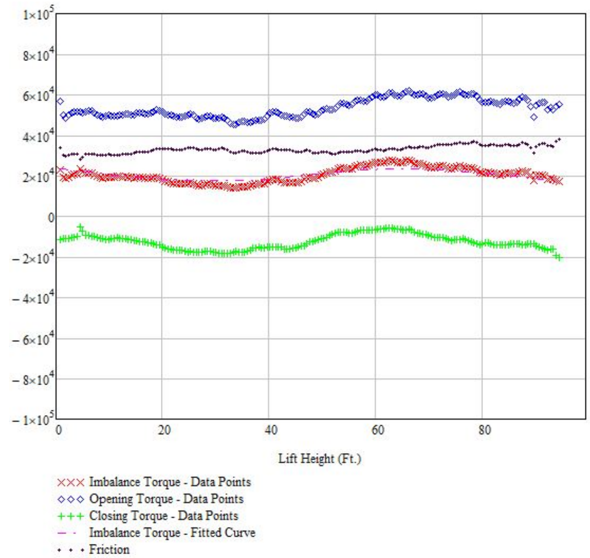

FIGURE 19: Marine Parkway Bridge. Imbalance Curve Fit for the Northwest Corner.

The theoretical imbalance behavior for this bridge, combining the effect of the counterweight ropes and the auxiliary counterweight system, is a sinusoidal curve. A sinusoidal curve was noted when evaluating the combined loading of the two corners. However, the evaluation of the individual corners yielded disparate trends. While the loading at the northwest corner was sinusoidal, the trend at the northeast corner was nearly a straight line. The observed loading suggests that one corner at the north tower was taking substantially more load, and the other corner was effectively "going along for the ride."

The noted corner-to-corner imbalance deviation is significant when evaluating the transverse imbalance of the lift span. Where the acquired data conforms to the theoretical operating behavior, there is a high probability that the analysis would yield actual span imbalance. However, when the acquired data does not conform to the theoretical operating behavior, it is likely that the analysis would not.

Bridge:

Rt. 1&9T over the Passaic River, a tower drive vertical lift bridge in Jersey City, New Jersey

Investigation:

2021 maintenance efforts at this bridge included a review of imbalance and indexing (load sharing) for this tower drive vertical lift bridge. Testing demonstrated a difference in the corner-to-corner balance trend during lift span operations. The behavior of the west tower machinery is described in Figures 20 through 23. Figure 20 shows the strain gage strip chart from the west tower. Figure 21 shows the imbalance curve fit from the two corners combined. Figures 22 and 23 show the imbalance curve fit data for each of the two corners, analyzed separately.

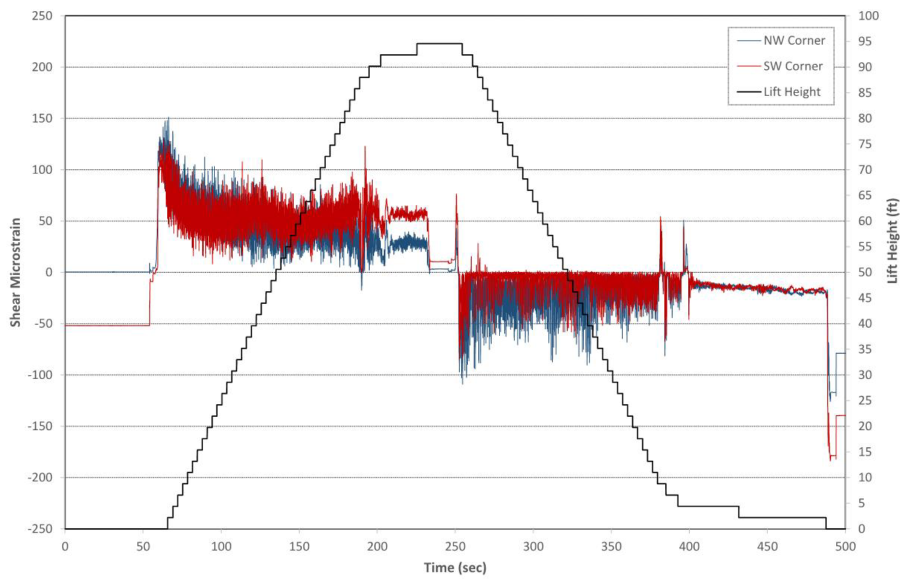

FIGURE 20: Rt. 1&9T over Passaic River. West Tower Strain Gage Recording.

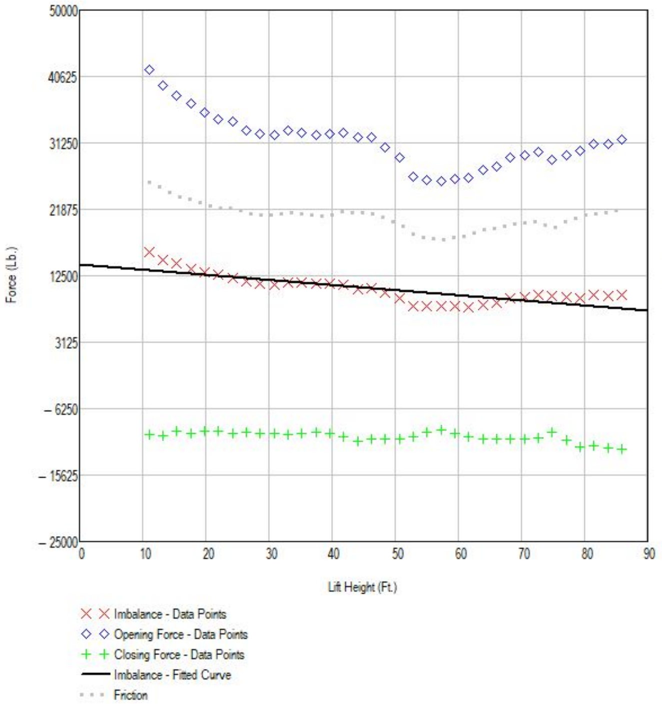

FIGURE 21: Rt. 1&9T over Passaic River. West Tower Imbalance Curve Fit for Two Corners Combined.

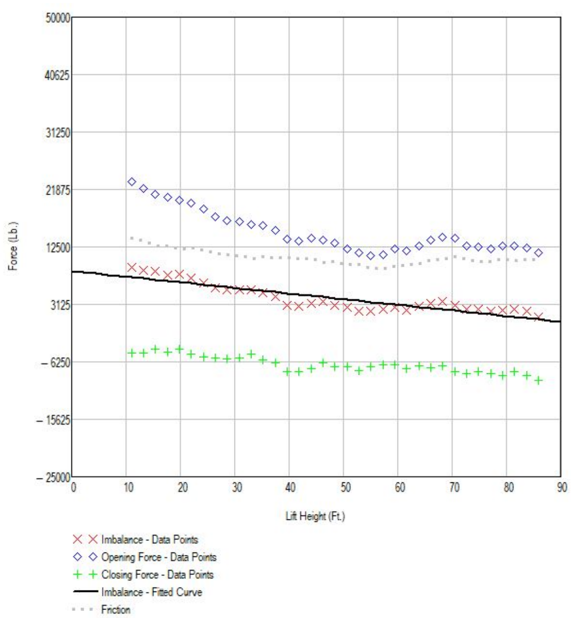

FIGURE 22: Rt. 1&9T over Passaic River. Imbalance Curve Fit for the Northwest Corner.

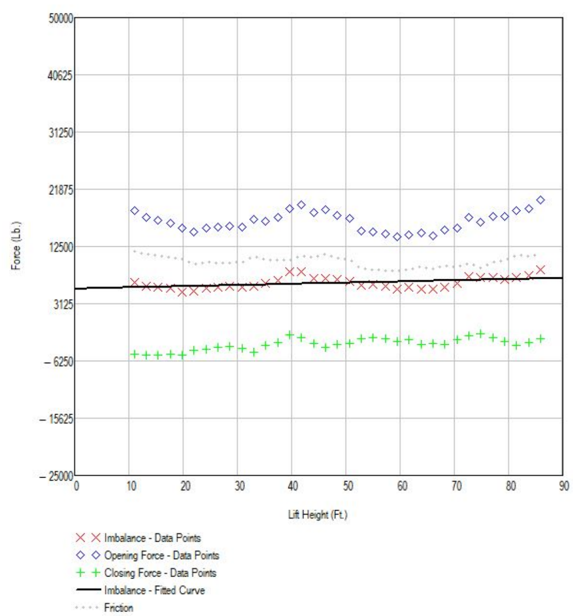

FIGURE 23: Rt. 1&9T over Passaic River. Imbalance Curve Fit for the Southwest Corner.

The theoretical imbalance behavior, combining the effect of the counterweight ropes and the auxiliary balance chains, results in a linear reduction in imbalance as the span is raised. The combined imbalance trend is shown in Figure 21. A linear trend was apparent in the analyses, but the trend differed at the corners. The imbalance at the northwest corner was reduced as the span was raised, but the southwest corner increased slightly as the span was raised. See Figure 22 and 23.

The cause of the difference between the two corners' balance trends was not determined. Although the magnitude of the trend varied, the differences between the corners was apparent throughout the duration of the project, over multiple tests. The difference in the behavior of the corners could be a physical trend related to the ropes, balance chains, or other installation details. The difference may also have been related to load sharing behavior related to the machinery installation. In fact, load sharing and imbalance targets between corners was challenging to meet due to repeated counterweight rope slippage over the sheaves.

Bridge:
Robert F. Kennedy Bridge, Harlem River Lift Bridge, Manhattan/Queens/Bronx, NY

Investigation:

The bridge is a tower drive vertical lift bridge with an auxiliary counterweight system. The operating forces should change with lift height as a result of the counterweight ropes passing over the counterweight sheaves and due to the effect of the auxiliary counterweight system. A mathematical equation for the change in span balance versus lift height was derived based on the geometry and weights provided for the auxiliary counterweight system on the original 1938 design drawings for the bridge. See Figure 24.

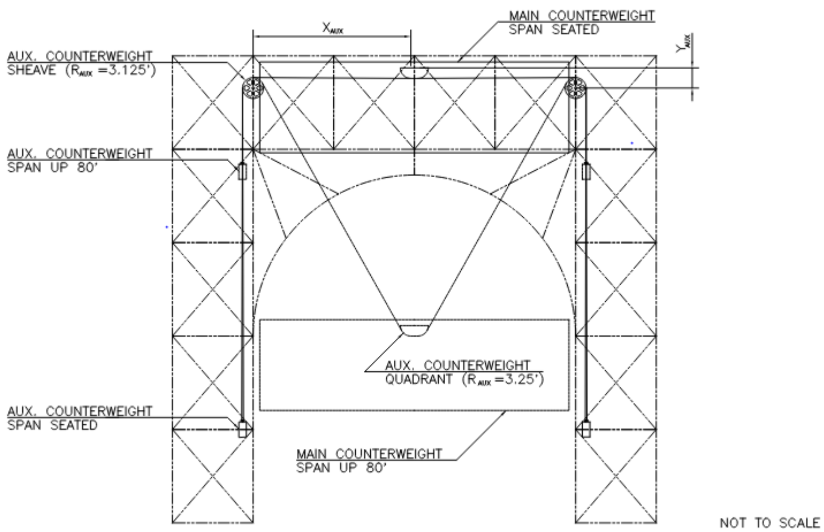

FIGURE 24: Harlem River Lift Bridge. Auxiliary Counterweight System Layout Per Tower. Note two auxiliary counterweights per tower.

The analysis of strain gage recordings revealed that the theoretical imbalance curve deviated from the recorded data. The poor curve fit was noted at the start and the end of the data, near the full closed position and the full open position. See Figure 25. The force characteristics should match the curve defined by this equation. A deviation from the theoretical curve fit raises a question. Either the recorded strain does not solely result from imbalance and friction or one or more of the assumptions for the imbalance equation were incorrect.

It was determined that an improved correlation could be achieved by increasing the weight of the auxiliary counterweight in the theoretical equation that defines the curve. The improved imbalance curve fit using this change in the auxiliary counterweight is presented in Figure 26.

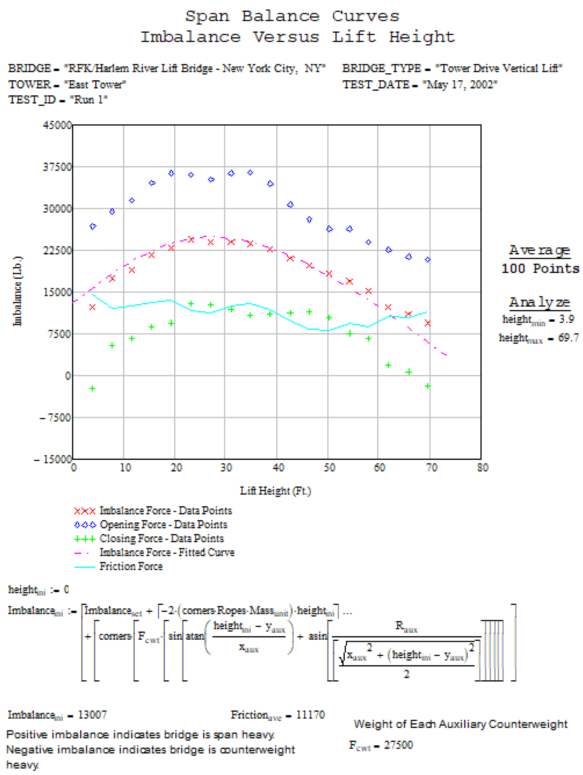

FIGURE 25: Harlem River Lift Bridge. East tower imbalance analysis using 27,500 lb. auxiliary counterweight weight.

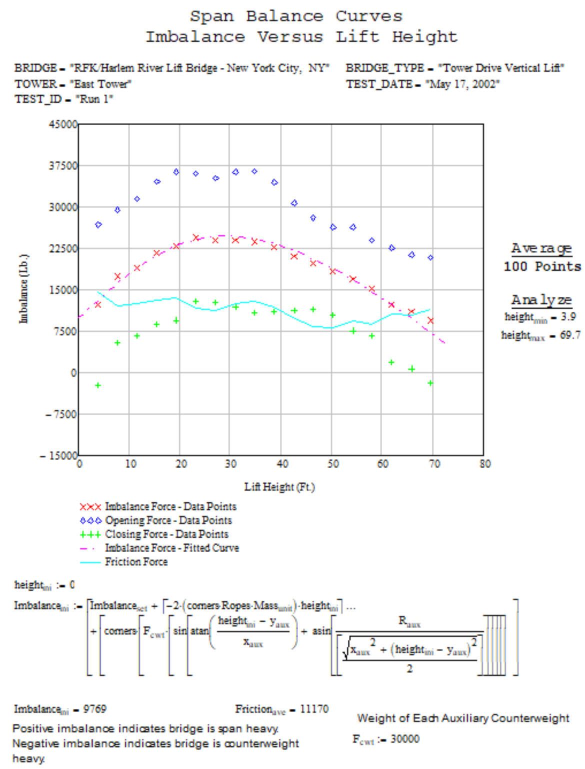

FIGURE 26: Harlem River Lift Bridge. East tower imbalance analysis using 30,000 lb. auxiliary counterweight weight.

Based on the improved fit, the heavier auxiliary counterweight was utilized in the equation to determine the imbalance of the lift span at the seated position. Without weighing the auxiliary counterweights, one cannot be certain if this is the reason for the fit issue with the theoretical curve. However, whether due to an inaccurate theoretical equation or another unknown factor, the recorded data describes the real behavior of the bridge.

Lessons Learned:

The curve fits of vertical lift bridge span drive strain gage data sometimes deviate from the theoretical expressions that account for both the transfer of weights from the counterweight ropes and the effect of the auxiliary counterweight system. The deviations will sometimes present challenges in meeting an imbalance tolerance for a corner, or for achieving load sharing between two corners. Strong consideration should be given to recording loads and reviewing the machinery indexing to understand load sharing challenges prior to specifying imbalance criteria. One should prepare for iterative transverse weight changes to target satisfactory loading and seated imbalance. When fitting data to theoretical curves, the trend of the measured data should govern as it represents the real behavior of the bridge. A close review of the imbalance theoretical equations should be performed to address deviations of measured data from theoretical curves where possible.

Conclusions

Strain gage recordings are a common tool in the movable bridge industry often used to determine the imbalance of a bridge. Recordings may also be used to identify load sharing issues due to either a malfunctioning differential assembly or other machinery indexing issues. Imbalance curve fits for vertical lift bridges will sometimes deviate from the theoretical expressions that account for both the transfer of weights from the counterweight ropes and the effect of the auxiliary counterweight system. Sometimes the imbalance at the end of the bridge is consistent and matching the theoretical, while the corner-to-corner fits vary. When this occurs, it may be a challenge to meet an imbalance tolerance for a corner or to achieve load sharing between two corners. Prior to specifying imbalance criteria, operating loads should be recorded, and machinery indexing should be reviewed to understand load sharing challenges.

When fitting data to theoretical curves, the trend of the measured data should govern as it represents the real behavior of the bridge. A close review of the imbalance theoretical equations should be performed to address deviations of measured data from theoretical curves where possible.

Mechanical strain gage recordings only provide one part of the evaluation of movable bridge machinery. An integrated approach should use both mechanical and electrical measurements. Combined measurements provide valuable insight into the total load of the bridge mechanical and electrical operating system, the efficiency of the electrical drive, the electric motor efficiency, overall operating electrical losses, and machinery component efficiencies. The combined measurements provide essential feedback for drive tuning and other operating improvements, assisting in the optimization of movable bridge machinery installations.