HEAVY MOVABLE STRUCTURES, INC.
FOURTEENTH BIENNIAL SYMPOSIUM

October 22 – 25, 2012

Machinery Rehabilitation at the East 11th Street Bridge over the Hylebos Creek Waterway

Tacoma, Washington

Robert J. Tosolt, P.E.
Stafford Bandlow Engineering, Inc.

CARIBE ROYALE HOTEL
ORLANDO, FLORIDA

INTRODUCTION

The Hylebos Waterway Bridge carries East 11th Street over the Hylebos Creek Waterway in the port of Tacoma, Washington. The bridge has an overall length of 334'-0" and comprises three elements: an east approach, a double leaf trunnion bascule bridge, and a west approach. The bascule bridge spans 216'-10" center to center of trunnions and supports a 24'-0" roadway. The navigation horizontal clearance under the bridge is 150 feet between bridge pier protections, and the navigation vertical clearance is 21 feet with the span closed.

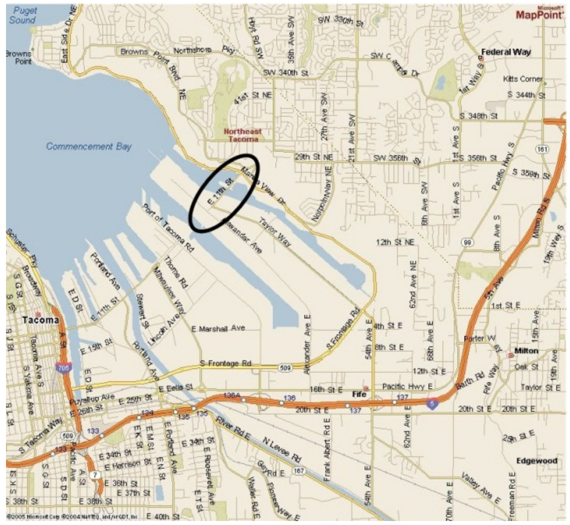

Figure 1. Area map locating Hylebos Bridge in Tacoma, Washington.

The bridge was originally constructed circa 1939 and retained the majority of its original machinery through 2000. However, deterioration of the bridge in general, and failure of the mechanical/electrical systems in particular, resulted in the bridge being taken out of service in 2000. This paper shall focus on the mechanical aspects of the rehabilitation design required to return the bridge to service.

PROJECT MEMBERS

The primary project members involved in the mechanical portion of the project which is discussed in this paper are as follows. The City of Tacoma is the bridge owner and provided resident and support engineering services throughout construction. The prime consultant for the work was Parsons Brinckerhoff with the Seattle, Washington office managing the work; Stafford Bandlow Engineering, Inc., Doylestown, Pennsylvania working as a subconsultant to Parson Brinckerhoff, provided the engineering for the mechanical machinery systems. The Primary Contractor for the work was Quigg Bros. Inc. of Aberdeen , Washington. Quigg utilized Jesse Engineering based in Tacoma, Washington as the primary machinery fabricator. Quigg provided in-house personnel to perform the machinery installation.

BACKGROUND

In the mid to late 1990s, the bascule bridge exhibited a pattern of deteriorating reliability. When the City of Tacoma hosted an open house in 2001 seeking public feedback on the path forward, the following chronological events were cited:

1999 – intermittent closures due to electrical and mechanical failures

2000 – continued intermittent closure due to electrical and mechanical failures

2000 – prolonged closure due to shear lock failure

2001 – prolonged closure due to broken shaft

The broken drive shaft cited above would ultimately render the bridge inoperable until completion of the ensuing rehabilitation work which is the focus of this paper. While the source of the failed drive shaft is not definitively documented, inspection documentation from this time period indicates an aging system with worn components and outdated controls which allowed shock loading of the machinery during stopping and seating.
Following shaft failure, the bridge was secured in the open position and the roadway was blocked, limiting access to the East Blair Peninsula.

Figure 2. Hylebos Bridge in 2007. Road closed and leaves secured in open position.

Following the open house in 2001, rehabilitation of the bridge was put off until project funds became available. By 2004, interests in revitalizing the Port made the repair of the Hylebos Bridge a priority to facilitate access. An RFQ for engineering services necessary to return the bridge to service was put out with a due date of August 2004. Parsons Brinckerhoff of Seattle, Washington, with Stafford Bandlow Engineering, Inc. as a mechanical sub consultant, pursued and was ultimately awarded the project in September 2004.

PROJECT TIMELINE

Following the project award, the project proceeded according to the following timeline:

RFQ for Rehabilitation - July 2004

Notice of Award - September 2004

Funding of Project and Notice to Proceed – June 2005

Coordination of Peregrine Habitat– July 2005

Site Scoping Inspection - August 2005

90% submittal - October 2006

Funding delay

100% submittal - May 2008

Signed and Sealed Documents - August 2008

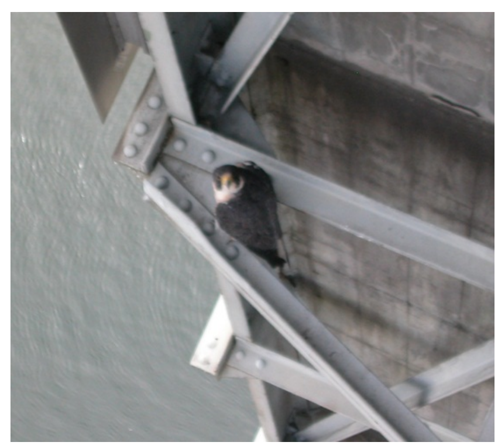

Figure 3. Along with fish spawning concerns, the resident peregrine falcons influenced scheduling at various phases of the project.

Contract Award - April 2009

Project Completion in Spring 2012

Significant aspects of the project are presented below.

ASSESSMENT OF MECHANICAL SYSTEMS

The Hylebos Bridge is equipped with span drive, span lock and span support machinery systems. The primary focus of the mechanical scope of work as identified in the 2004 RFQ was on rehabilitation of existing machinery wherever possible with replacement as a last resort.

Preliminary assessment of prior inspection findings, as well as a limited assessment of machinery capacity, suggested little possibility of rehabilitating the existing span drive machinery due to noted wear, damage and the critical shaft failure. However, the prior condition assessment of the span lock and span support machinery suggested that rehabilitation of these systems appeared viable.

Due to the lag in time between the bridge being taken out of service in 2000 and the commencement of the rehabilitation design in 2005, a site visit was necessary to verify existing component condition and formalize the scope of work. The scoping inspection was conducted in August 2005 with the following findings:

Span Drive Machinery

The overall condition of the existing span drive machinery was evaluated against prior inspection findings. The primary machinery is located inside an enclosed machinery room and was generally found in good condition on the West Leaf. The machinery for the East Leaf was subjected to damage from a fire which occurred following the bridge being taken out of service from the shaft failure. The fire, which was attributed to vandalism, resulted in widespread damage compromising the integrity of all components located inside the machinery enclosure.

Figure 4. Span Drive Machinery, West Leaf.

Figure 5. Span Drive Machinery, East Leaf.

The low speed and final reduction components are located outboard of the machinery enclosure. Aside from the shaft failure at the NE rack pinion shaft, prior reports had also documented issues with inadequate support at the outboard rack pinion bearings, which were anchored in the pier wall. Field findings confirmed both issues. At the SE location, jack screws had been installed between the bearing cap and the top of the cutout in the pier wall to stabilize the cap.

Figure 6. Northeast Quadrant, Span Drive Machinery. View of missing gear where shaft failed.

Figure 7 Southeast Outboard Rack Pinion Bearing. Jack screws have been installed to stabilize cap.

In addition to these findings, new deficiencies were noted at the main rack pinions and racks. The rack pinion teeth generally exhibited moderate plastic flow. However, several teeth on each rack pinion also exhibited severe abrasive scoring.

Due to the internal gear configuration with the span being left in the open position, all racks served as catch trays and were generally packed with water and debris. A limited number of rack teeth were cleaned to the extent necessary to verify that while the overall integrity was adequate, those teeth which mated with the severely abraded pinion teeth exhibited corresponding damage.

Figure 8. Representative Rack Pinion. Note severe abrasion evident across tooth width at bottom of photo.

Figure 9. Representative Rack. Note sever abrasive wear across tooth width at center of photo.

Span Lock Machinery

The span lock machinery utilizes a standard shear key arrangement common to Washington State. The machinery had been rehabilitated circa 1976 at which time the actuating unit had been replaced and the guide and jaw castings were weld repaired and retrofitted with steel wear plates.

The actuating unit, at an age exceeding 30 years, had exceeded its serviceable life and was considered for replacement. While the guide and jaw castings appeared of stout construction, the original design, and the subsequent retrofit, did not provide for future adjustment of the components due to wear. Our inspection found that the retrofit wear plates exhibited deformation and that the weld repairs had failed at multiple locations. Salvage of these components was not possible.

Figure 10. Shear Lock Receiver. General View.

Figure 11. Shear Lock Receiver. Failed weld at wear shoe.

Trunnion Bearing Assemblies

Each leaf is supported by two trunnion assemblies. Each assembly comprises a trunnion mounted in the truss that is simply supported in two trunnion bearings. The intent of the inspection was to validate the reported good condition of these components and thereby ensure their suitability for continued usage. One issue that became the primary factor in evaluating these components was the fire damage at the East Pier.

As was evident in the photo for the East Leaf span drive machinery, the fire at the East Pier had consumed the machinery enclosure in its entirety so that only charred timbers remained. All steel in this vicinity, which included the trunnion bearings, showed evidence of heat exposure. A concern existed that the heat which the bearing housings were subjected to could have 'cooked' the grease and reduced it to a tacky consistency.

Figure 12. West Leaf. General view of trunnion bearings. Inboard (right) cap is raised for inspection.

Figure 13. East Leaf. View of fire damage in vicinity of trunnion bearings.

As part of the field work, bearing caps were removed from a representative number of bearings. The cap removals at the East Leaf did not substantiate the concern over damage to the grease, however the internal inspection did identify spotty areas of noteworthy corrosion, which are thought to have resulted from water infiltration when the fire was extinguished. Nonetheless, the physical condition of the bearings substantiated their reuse provided that limited clean-up was performed as part of the rehabilitation.

The field inspection of the bearings also encompassed measurement of bearing clearances.

TRUNNION BEARING MEASUREMENTS						
LEAF	BEARING	BEARING CLEARANCE (in inches)			WEAR (in inches)	LOCATION OF MAXIMUM CLEARANCE
		RC6	RC9	CURRENT		
WEST	South-OB	.016	.045	.033	.018	Top.
	South-IB	.016	.045	.030	.014	Top.
	North-OB	.016	.045	.027	.011	Top.
	North-IB	.016	.045	.020	.004	Top.
EAST	South-OB	.016	.045	.030	.014	30 Deg. Cwt Side of Top
	South-IB	.016	.045	.027	.011	30 Deg. Channel Side of Top
	North-OB	.016	.045	.035	.019	30 Deg. Cwt Side of Top
	North-IB	.016	.045	.018	.002	60 Deg. Channel Side of Top

Figure 14. Trunnion Bearing Clearance Measurements Acquired During Scoping Inspection.

Whereas the visual inspection of the bearings did not reveal any significant impact from the fire, the clearance measurements generated significant concern. As presented in the table, all measurements for the West Leaf (non fire damaged) bearings occurred at the top of the bearing as expected. In a heavily loaded bearing such as the trunnion bearings which support the entire dead weight of the movable leaf, the maximum clearance should exist at the top of the bearing if the bearings are well aligned to the trunnion journals.

All measurements for the East Leaf were substantially offset from the top of the bearing. In order for this condition to exist the bearing housings must be severely misaligned with the trunnion journals. The cause for this damage was attributed to structural deformation of the bearing supports from fire damage. A review of the bearing clearances suggest that the Strauss girder (trunnion support) had bowed so that the middle of the girder protruded toward the channel, which is consistent with the heat source (i.e. fire) being applied from the machinery room side of the girder. Further limited investigation provided direct evidence that the web of the support girder was bowed as indicated.

PRELIMINARY DESIGN CONSIDERATIONS

Following the scoping inspection, a design memorandum was prepared to document the options and preferences for either rehabilitating or replacing the existing machinery components. The options presented to the City for confirmation prior to progessing the design are as follows:

Span Drive Machinery

Based on the failure of the rack pinion shaft, inadequate bearing design and fire damage, combined with a subsequent load analysis which indicated the majority of drive components did not rate per current code requirements, repair or re-use of the existing machinery was not an option. A primary consideration in developing the replacement design concept was the span constraints imposed by site conditions which resulted in some unique constraints and challenges in developing the new machinery concepts.

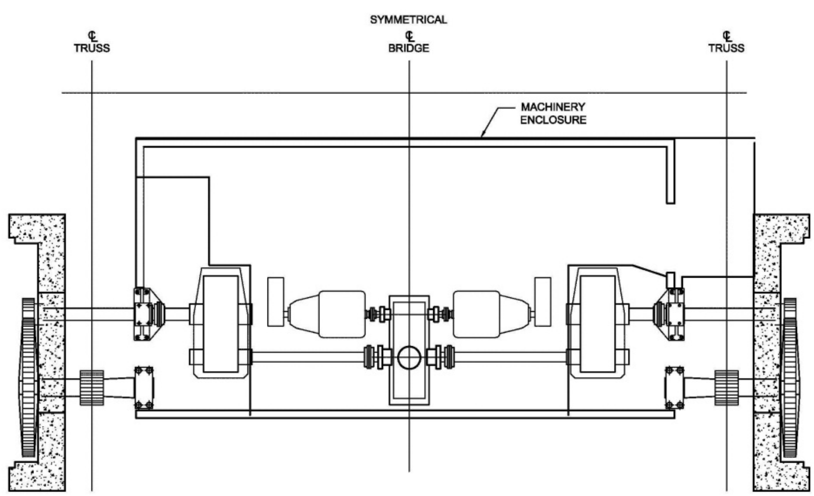

Figure 15. Plan View of Existing Machinery.

The existing machinery utilized conventional mechanical components for the power train with the primary reduction being provided by one primary differential and two secondary enclosed gear reducers. All of the primary components were located in an enclosed machinery room, whose dimensions were constrained by the bascule trusses on either side, the trunnion girder and counterweight fore and aft, respectively, and further by the fact that the counterweight swings within approximately 6" of the existing enclosure flooring. The final reduction was provided through one open gearset driving the final pinion which mated with the rack secured in each truss. The open gearset was cantilevered outboard of and supported by bearings mounted in the pier wall. The rack pinion which was integral with its shaft, was straddle mounted between the pier wall and the bottom edge of the machinery enclosure support frame. Therefore, the available support for the new machinery was constrained to the dimensions of the existing machinery enclosure and/or pier wall cutout.

All rehabilitation concepts were based on removing all existing machinery, stripping the machinery enclosure to its primary support members (removing all paneling, demolishing the concrete flooring and secondary support members) and providing localized enlargement of the hole through the pier wall to facilitate removal of the existing bearing support shaft.

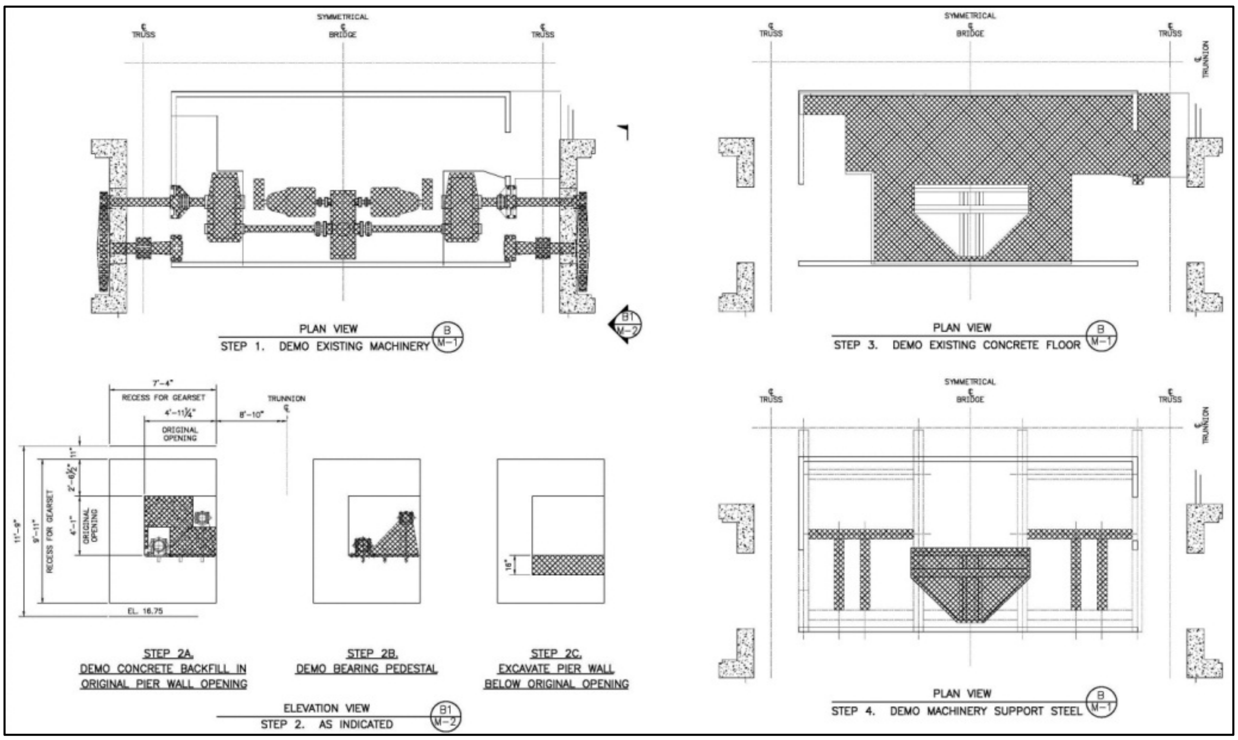

Figure 16. Removal of Existing Span Drive Machinery and Supports.

Utilizing the noted constraints, three concepts were developed as part of the preliminary engineering process. The design objective was to provide a durable system to ensure reliability and a service life of at least 50 years if properly installed and maintained. To meet this objective while minimizing maintenance requirements, the focus was on eliminating the open gearing in favor of enclosed reducers and eliminating sleeve bearings in favor of roller bearings. Additionally, each option was sized for operation via one motor but provided with two motors to allow alternate operation so that one motor could be removed for service without affecting bridge operation. A description of the options in the preferred order follows.

Option 1

The first option was driven by the desire to contain all machinery within the machinery enclosure to provide optimal protection from the elements. Due to the lateral, transverse and depth constraints imposed by site conditions, the only way in which this objective could be met, while still providing machinery sized to meet current code, was to employ a powertrain which utilized a universal joint between the reducer output and the rack pinion shaft. This was primarily a function of the swing of the counterweight below the machinery enclosure.

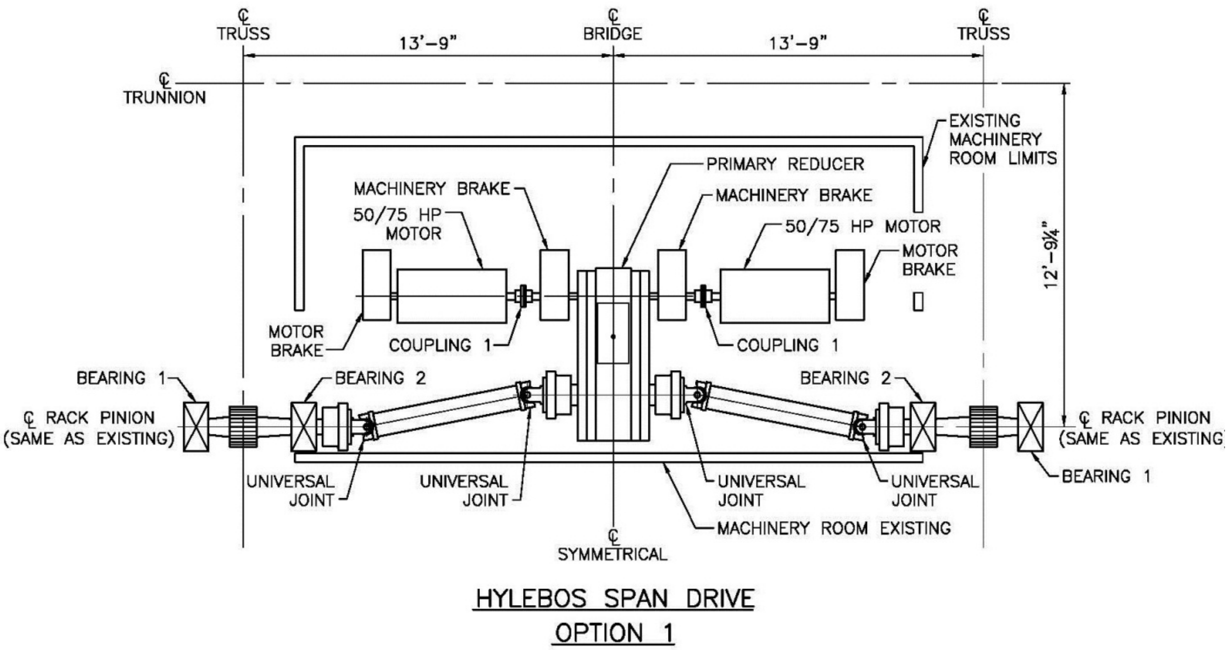

Figure 17. Preliminary Span Drive Concept

Reuse of the existing rack effectively dictated the position of the new pinion. Since the existing pinion had been located at the lower extremity of the machinery enclosure framing, this defined the shaft position. Locating a new reducer to center the output shaft on the rack pinion shaft would result in the reducer protruding below and beyond the longitudinal limit of the machinery enclosure so that it would result in interference with the counterweight when seated and during leaf operation. The only way to reposition the reducer to avoid interference with the counterweight and still make the connection with the rack pinion shaft would be through use of an universal joint. While not widely used in the industry, there are instances where these components have functioned effectively over time.

<u>Option 2</u>

The second option was most similar to the design of machinery on new movable bridges. The primary high speed machinery was housed in the machinery enclosure between the bascule girders while the secondary machinery transmission was located outboard of the bascule pier wall.

All of the machinery is easy to maintain and all of the components have proven service in the movable bridge industry. Additionally, the machinery brake was able to be located after the differential reducer which is the preferred location when possible. The major disadvantage to this option is that the configuration of the existing pier provided no support for the secondary reducers and structural modifications/enhancements to the pier wall would be required.

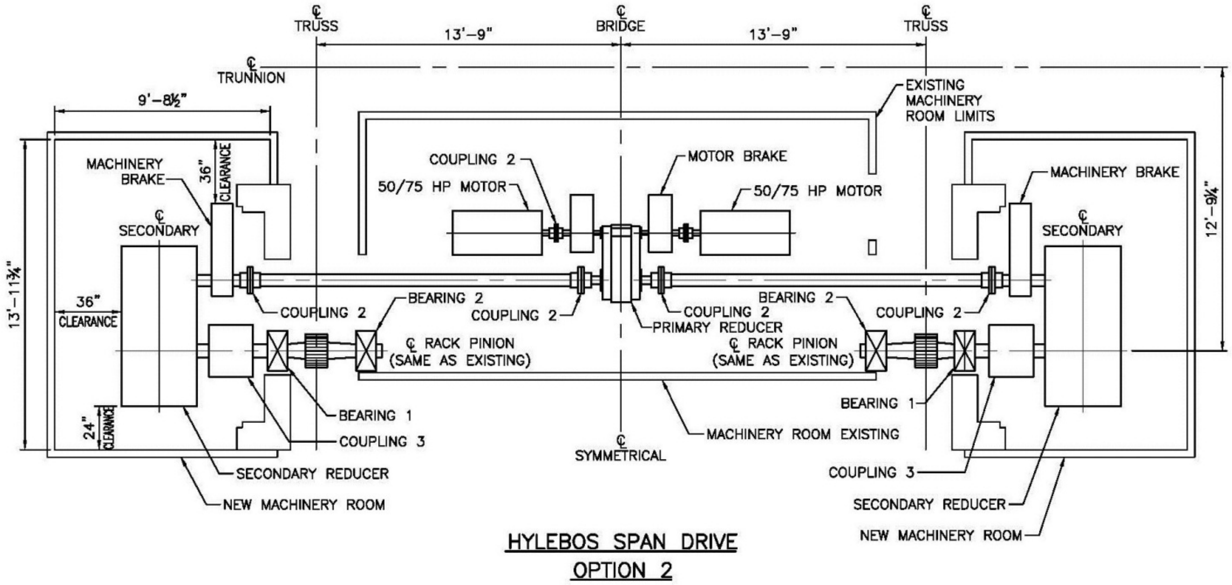

Figure 18. Preliminary Span Drive Concept

<u>Option 3</u>

The third option was most similar to the existing machinery configuration. The significant difference is that only speed reducer is used in the machinery enclosure which reduces maintenance requirements and increases space for maintenance.

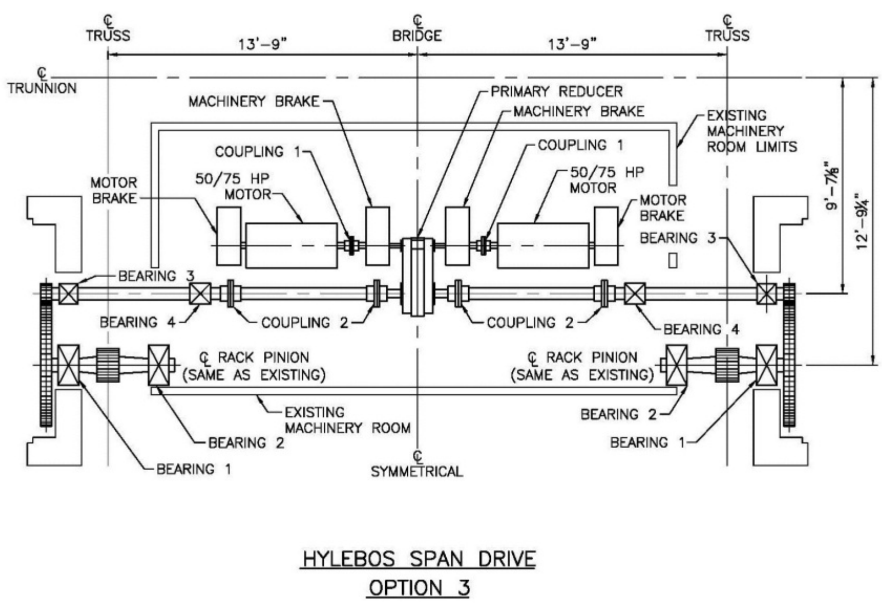

Figure 19. Preliminary Span Drive Concept

Disadvantages to this option include the use of open gearing which is more maintenance intensive than the enclosed reducers proposed in options 1 and 2, as well as the fact that the machinery brake is mounted on the input side of the differential reducer which is not as desirable as Option 2.

Span Support Machinery

Based on the inspection findings, the trunnion bearings that support the west leaf were suitable for continued service, whereas the East Leaf trunnion bearings were not due to the fire damage.

Following the scoping inspection finding that the Strauss Girder exhibited apparent deformation due to fire damage and that the bearing clearances suggested misalignment consistent with the girder deformation, SBE performed a subsequent site visit to assess the trunnion alignment via the piano wire alignment measurement method.

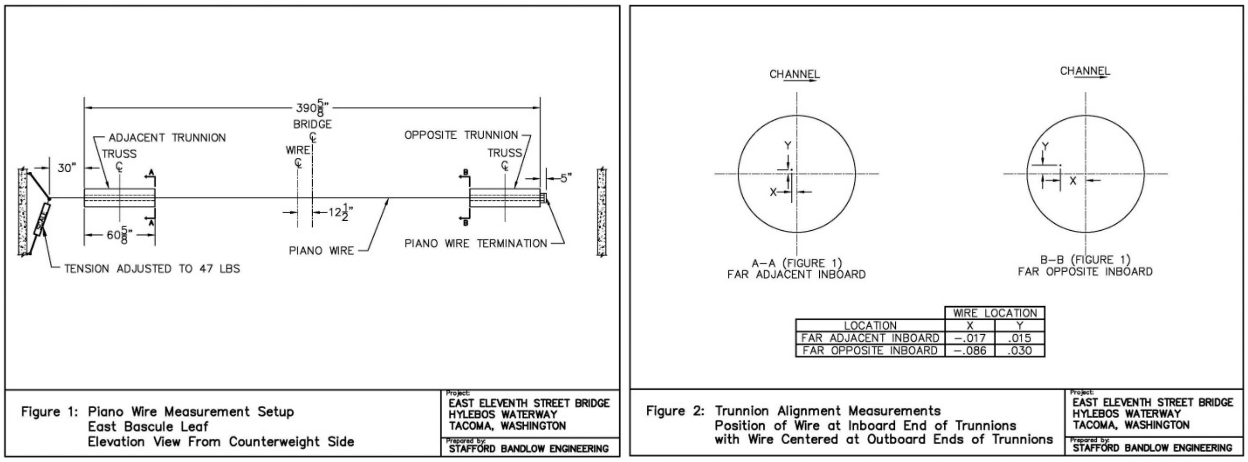

Figure 20. Piano Wire Alignment Measurement. Figure and Results

The measurements indicated that the inboard end of both trunnions were offset towards the channel in the horizontal plane and that both trunnions were offset down in the vertical plane. The measurements were consistent with the bearing clearances and observed girder deformation. While not significant from a structural perspective, the noted misalignment both with regard to magnitude and orientation is significant in terms of the function of the mechanical components. If left uncorrected the noted misalignment would contribute to localized loading of the bearings, higher contact stresses and an increase in system friction, all of which would shorten the service life of the components and would likely result in damage or failure over time. Therefore, the scope of the rehabilitation was expanded to include correction of the bearing alignment. Due to the magnitude of this task, which required the leaf to be jacked and independently supported so as to relieve load on the bearings, it was decided to replace the bearings outright to minimize any potential for scope creep and time loss should the existing bearing housings or bushings prove to have been damaged by the fire or misalignment.

Span Lock Machinery

Based on the shortcoming of the original span lock design to incorporate wear shoes, combined with the scoping inspection finding of the failed efforts to address the wear shoe issue as part of a previous rehabilitation, re-use of the existing components was not an option. Having satisfactory experience with the shear lock design on other structures, the design team proposed to rehabilitate the shear locks to provide new guides and receivers utilizing a similar design but incorporating bronze wear shoes in both the guides and receivers with shims to facilitate initial and future adjustment. The rehabilitated system utilizes a new self-contained electro-mechanical linear actuating device similar to what was used for the original system but updated to ensure reliability.

Air Buffers

Though not a feature of the original design, air buffers were proposed. Air buffers assist in seating the leaf as well as preventing catastrophic impact in the event of machinery and/or drive failure. While modern electrical drives are capable of controlling leaf seating to minimize peak loading, air buffers still provide a measure of safety in the event of failure or improper setup of the drives.

FINAL DESIGN CONSIDERATIONS

In progressing the preliminary design concepts to completion, several notable findings were encountered which warrant discussion.

Span Drive Machinery

Upon discussion of the preliminary design report with the City of Tacoma, it was decided that the span drive concepts would be pursued in the order of Option 1, Option 3, then Option 2 on the combined basis of their technical merit and cost. Each of the concepts was ultimately explored in order to provide a workable solution.

<u>Option 1- Universal Joint</u>

This option was initially regarded as the preferred machinery arrangement both from a cost and maintenance standpoint. However, this concept had to be abandoned early in the design process when it was established that it would not fit in the available space. The existing rack pinion shaft was 7” in diameter at the bearings. A load rating analysis performed in conjunction with the design indicated the existing shaft was substantially overstressed when evaluated per the 1988 AASHTO design specification and that a shaft size of 9.5” in diameter was required in order to rate per the same specification. The larger shaft size also required larger support bearings, which was significant given that the inboard bearing was mounted to the lower extremity of the machinery enclosure and there was little ability to expand downward without interfering with counterweight travel during leaf operation. The larger shaft size also impacted the selection of the proposed universal joint. When the specifics of the design were discussed with the product manufacturer, it was determined that an upsized universal joint was required with the result that it would not fit in the available clearance envelope.

<u>Option 3 –Open Gearset / Shaft Mount Reducer</u>

Through discussions with the City, this option was prioritized in front of the outboard reducer option due to the additional expense inherent in providing support for the outboard reducer. Once Option 1 had proven not to be viable and this option was evaluated in earnest, the design effort focused on mitigating or eliminating the negative aspects of the open gearset. This goal was achieved with the introduction of a shaft mount secondary reducer in lieu of the open gearset. This development eliminated the safety and maintenance concerns associated with the open gearset and improved the overall integrity and efficiency of the system from a design perspective, as well as simplifying the constructability of the design.

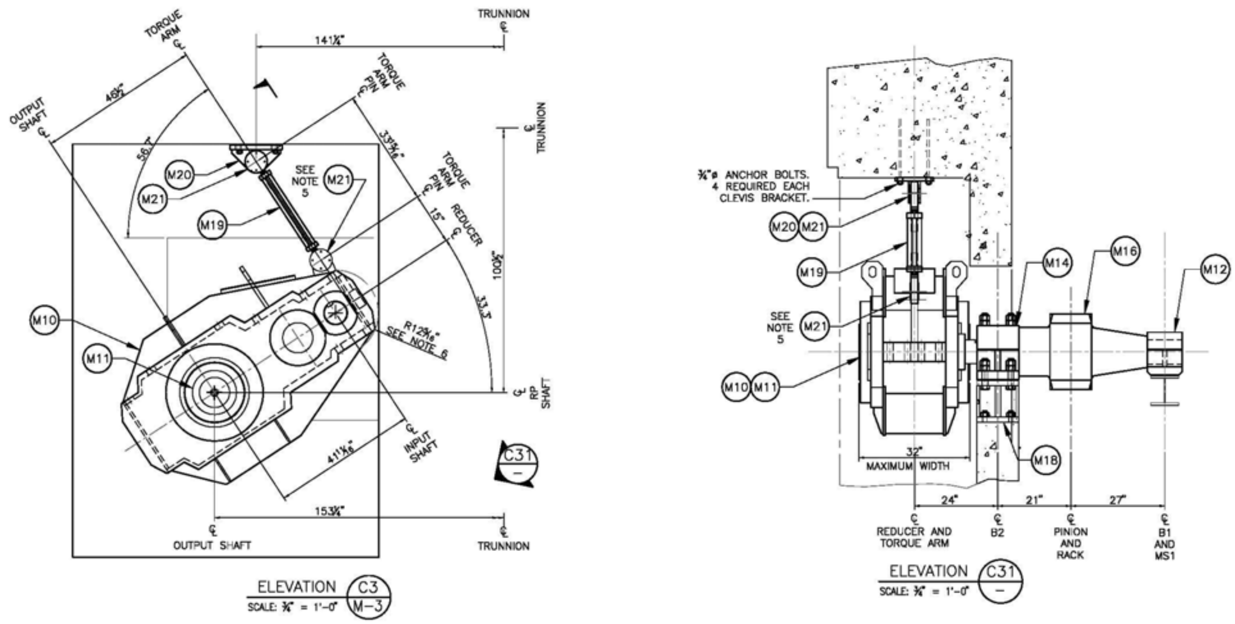

Figure 21. Shaft Mount Reducer Concept

Once the mechanical viability of the concept was established, close coordination with the structural and electrical disciplines was necessary. The mechanical loading of the structure and supports was conveyed to the structural engineers to verify acceptable mounting details. The following areas of concern were identified.

Torque Arm: A support needed to be anchored to the pier wall to take out the reaction of the torque arm from the reducer. Even after taking measures to minimize the reducer width, the pin connection of the torque arm to the anchorage bracket was slightly cantilevered off the pier wall. Several options were investigated utilizing different bracket geometry and bolt mounting details to attempt to arrive at a solution without modifying the existing wall. However, the preferred solution ultimately involved locally increasing the wall section above the cutout for the reducer to allow a direct mount of the bracket that was in-line with the torque arm.

Truss Loading Limitations: The structural engineers identified that one or more truss members would be overstressed if subjected to the maximum breakdown torque which the motor could produce at specific bridge opening angles. This required further refinement of the loading analysis to determine the governing loads for each incremental leaf opening angle taking into account the difference between leaf opening and leaf closing load requirements. It was determined that the problematic loading conditions could be negated, yet still have sufficient motor capacity to power the bridge under all loading conditions, by having the electrical drive limit the motor torque to the accelerating overload allowance provided in the 1988 AASHTO SSMHB. To that end, the maximum continuous dynamic load the bridge would be subjected to would be 180% FLT full load torque (FLT) of the drive motor. This load could occur at any leaf position. The maximum continuous static load of the bridge would be 225% FLT; the static load would be induced by the brakes under maximum wind load with the leaf in the fully open position where loading of the truss was not problematic, and would decrease with lowering leaf angle so that it did not impact the limiting truss loading position.

Bearing Supports: The rack pinion shaft bearing loads were provided to the structural engineers to verify the adequacy of the supports at normal machinery design loads (150% FLT). No problems were noted at the anchorage of the outboard pinion bearing to the pier wall, which was initially a concern due to the noted damage at the existing outboard pinion bearings. A problem was noted, however, at the inboard pinion bearing. The problem at this bearing, which is mounted at the lower back corner of the machinery enclosure framing, is that the framing does not have sufficient rigidity to limit movement of the bearing under the design loading. The vertical support for the back end of the machinery enclosure is suspended off the overhead roadway stringers; it was determined that this framing arrangement could result in over one inch of movement of the stringer and bearing under the concentrated load imposed by the machinery design loading, an amount that is not problematic for vehicular traffic but that would be damaging to the machinery.

Figure 22. Span Drive Machinery Support Framing. View looking down on hanger for back end of machinery enclosure framing. The approach roadway has been removed from stringers during construction.

Due to the existing structural framing, there was no expedient way to stabilize the back end of the machinery frame to resist the uplift from the bearing load. The bascule trusses sandwiched the enclosure on either side and the counterweight boxed in the back side of the enclosure, as well as swept under the enclosure during operation.

Since stabilizing the back end of the frame for the imposed load was not practical, the final span drive concept was explored.

<u>Option 2 –Outboard Reducer</u>

This option had originally been regarded as the superior technical option but also the highest cost option due to the need to construct a new support for the reducer outboard of the pier wall. However, after neither options 1 nor 3 proved viable due to site conditions, this option was further evaluated.

The original concept for this option had utilized a simply supported rack pinion shaft similar to what was used in Options 1 and 3. However, following the finding that adequate support could not be provided at the inboard bearing to make the simply supported shaft a viable concept, subsequent analysis focused on removing the load from the machinery enclosure support framing. This was accomplished by mounting the rack pinion directly to the output shaft of the secondary reducer and requiring that the reducer be sized to support the cantilevered load. While this concept requires a more substantial reducer design to support the overhung load, and alignment during installation is more challenging since the entire reducer must be shifted to alter the contact at the rack pinion gearset, the design team had direct experience with this concept on several prior rehabilitations and were satisfied that it would provide satisfactory performance provided that the identified issues were addressed during fabrication and installation.

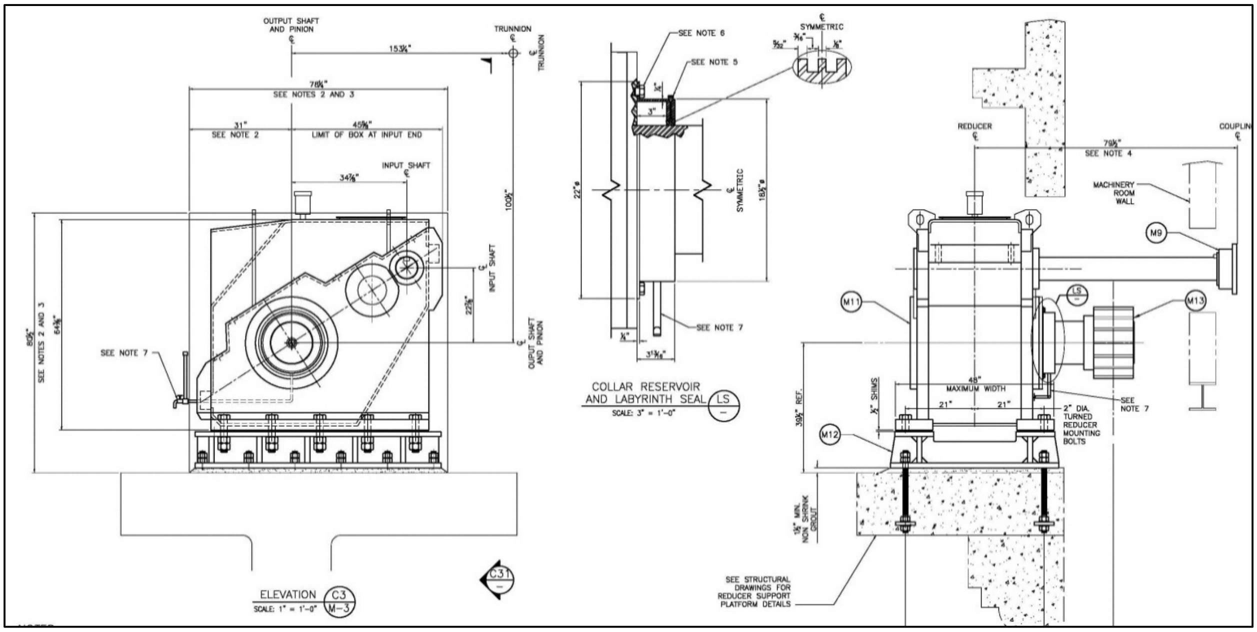

Figure 23. Outboard Foot Mount Reducer Concept

From a mechanical standpoint, the sizing and selection of components was straightforward. The challenge lay in the coordination of the reducer mounting details with the structural group to ensure that the reducer was adequately supported. A comprehensive summary of anchor bolt loads was prepared to address loading at each bolt for each direction of leaf rotation. From this summary, it was possible to evaluate the various loads and twisting moments which the reducer support would need to resist.

In order to minimize cost, instead of the machinery room which was originally envisioned to house the reducer, protect it from exposure and provide ample maintenance access, the design focused on a simple pedestal mounted off the existing wall. As environmental concerns prohibited the installation of pilings to provide direct support of the pedestal, the existing pier wall had to be reinforced to support the load. The structural group used FEA to refine the analysis of the reinforced pier wall and ensure that it was adequately sized for the imposed loads.

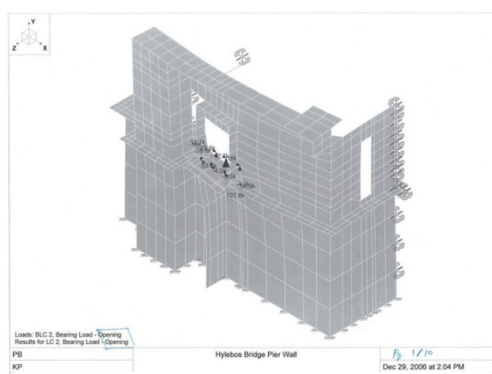

Figure 24. FEA Analysis of Pier Wall and Reducer pedestal.

Through this combined design effort, the viability of the reducer mount was confirmed and this concept was progressed to completion.

Trunnion Bearings

The primary challenge in the replacement of the East Leaf trunnion bearings was arriving at an acceptable removal and replacement scheme. With limited stiffening of the Strauss trunnion girder, it was possible to jack and support each leaf directly beneath each trunnion. The height required to jack the leaf for bearing removal required consideration of the structural framing. The forward support for the approach roadway was mounted between the trunnion bearings. The endmost supports prohibited axial removal of the inboard bearing housing. The leaf would need to be jacked over 9" to allow the bottom of the journal to clear the housing split line and allow the housing to be slid under the journal. This jack height was a concern as the jacking work would be done with the leaf in the raised position where it could be subjected to the maximum wind load.

Figure 25. Jack and Support below trunnion for leaf jacking.

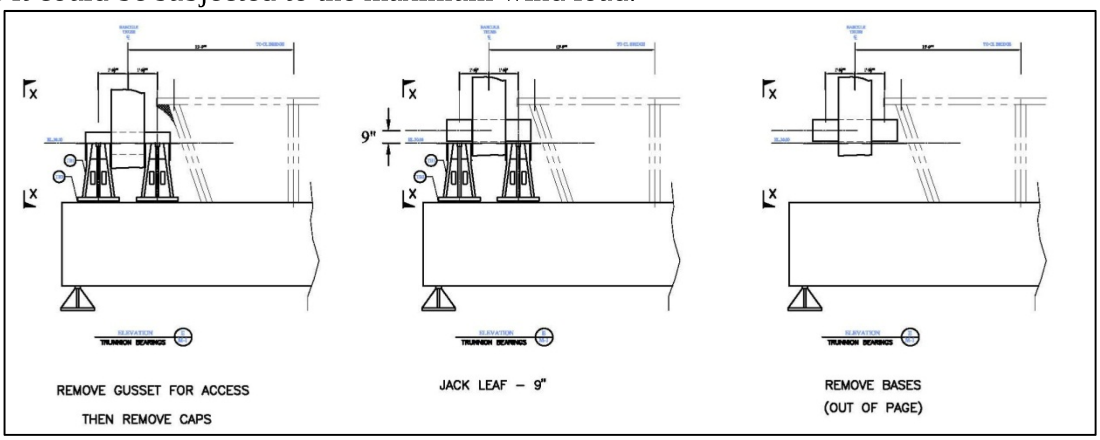

Figure 26. Trunnion Bearing Removal – Option 1

By removing the endmost posts and providing temporary shoring posts, the leaf jacking height could be limited to approximately 1" as the housing would only need to be slid axially away from the trunnion. This latter choice minimized the concern over stabilizing the support against wind loading and was adopted for the final design.

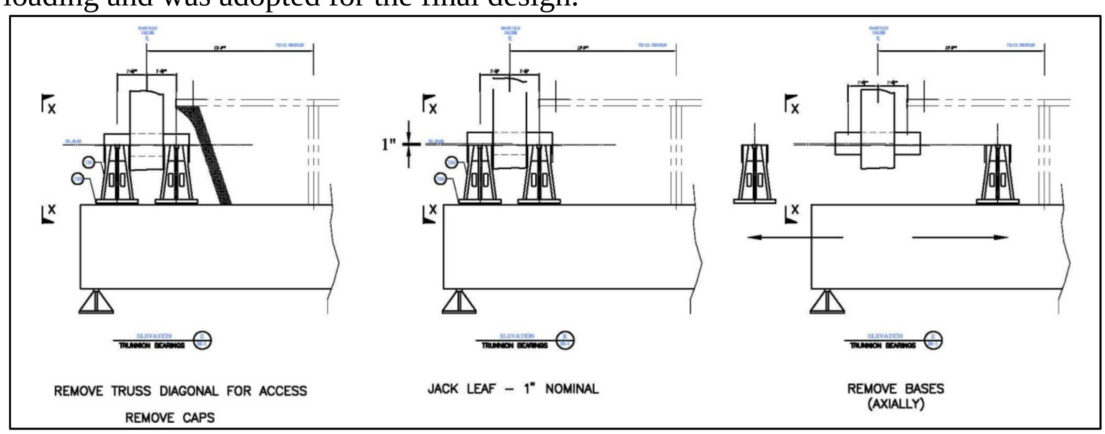

Figure 27. Trunnion Bearing Removal – Option 2

Air Buffers

The primary challenge in the implementation of the air buffers was identifying a location where they could be installed. The preferred location was at the back of the counterweight to optimize the moment arm. However, little space existed between the back of the counterweight and the face of the rear wall. Coordination with the structural group determined that two cutouts could be placed in the rear wall to accommodate the buffers. Several iterations were required to determine the optimal placement for the cutout in the wall taking into consideration structural concerns over the strength of the mounting surface and mechanical concerns over the buffer stroke and resultant swing radius of the strike plate on the back end of the counterweight. If the buffer was mounted too high, the upper wall did not have sufficient strength. If the cutout was too low, the buffer stroke was too long and the swing radius of the strike plate resulted in interference with the counterweight pit floor. Ultimately, the swing radius of the strike plate was maximized without contacting the pit floor and the upper wall was strengthened for the imposed load. As an electrical room had been added to the back side of the rear wall, the buffers would be accessed through purpose built doors in the electrical room for maintenance purposes.

Figure 28. Cutout in Rear Wall for Air Buffers

CONCLUSION

The design was completed in late 2008 and awarded to Quigg Bros., Inc. in Spring 2009. The bridge was substantially complete with acceptance testing occurring in early 2012. Strain data acquired during the testing indicates that the machinery is operating at low load levels; peak loads during normal operation were approximately 20% of full load motor torque. The measured loads substantiate that the machinery is adequately designed and that the trunnion realignment on the East Leaf has been successful. Further the measured loads are indicative that the machinery has ample reserve capacity to overcome environment loading and future balance changes.

The bridge was officially re-opened on June 20, 2012. The completion of the rehabilitation will ensure long term reliable operation of the Hylebos Waterway Bridge for years to come.

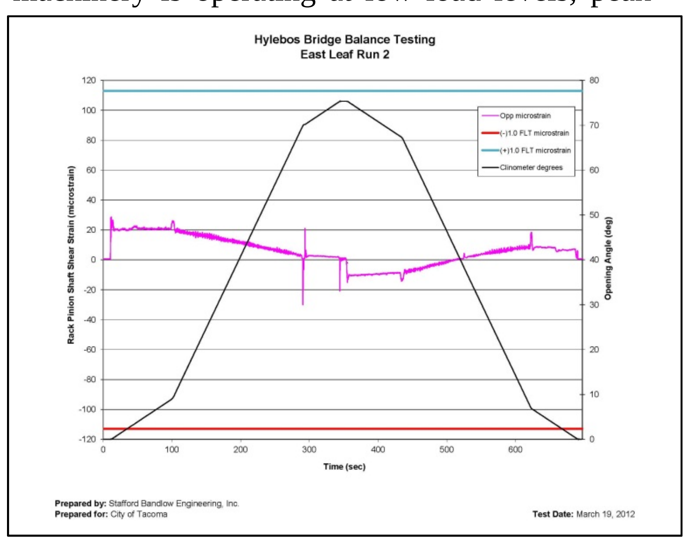

Figure 29. East Leaf Operational Strain Stripchart.