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Rehabilitation of the Fremont Bridge in Seattle, Washington

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INTRODUCTION

Construction of the Fremont Bridge, 1916 *Seattle Municipal Archives Photograph Collection*

The Lake Washington Ship Canal, which runs through Seattle, Washington connecting Lake Washington to Puget Sound, is a system consisting of, from east to west, Union Bay, the Montlake Cut, Portage Bay, Lake Union, the Fremont Cut, Salmon Bay, the Hiram M. Chittenden Locks, and Shilshole Bay. Started in 1911, the canal was officially completed in 1934, though the Locks had opened 17 years earlier.

The Canal's crossings, from east to west, are:

- The Montlake Bridge carrying Montlake Boulevard over the Montlake Cut
- The University Bridge carrying Eastlake Avenue over Portage Bay
- The Ship Canal Bridge carrying Interstate 5 over Portage Bay
- The George Washington Memorial Bridge (commonly called the Aurora Bridge) carrying Aurora Avenue N. (State Route 99) over the west end of Lake Union
- The Fremont Bridge connecting 4th Avenue N. to Fremont Avenue N. over the Fremont Cut
- The Ballard Bridge carrying 15th Avenue over Salmon Bay
- The BNSF Railway's Salmon Bay Bridge over Salmon Bay

The Fremont, University, Ballard and Montlake bridges are all Chicago style, trunnion bascule bridges designed and built by the City of Seattle from 1916-1925. The Fremont Bridge was opened on Friday June 15, 1917 at a cost of $410,000.

Fremont Bridge, circa 1917 *Seattle Municipal Archives Photograph Collection*

Fremont Bridge, 1936 during re-decking *Seattle Municipal Archives Photograph Collection*

All four of these bridges are still in operation today, although ownership of the Montlake Bridge has been transferred to the Washington State Department of Transportation. Of the movable bridges, the Fremont bridge has the lowest clearance (30') from the water. As a consequence, the opening frequency is the highest. According to the City of Seattle, the Fremont Bridge currently opens an average of 35 times per day or almost 13,000 times per year, making it one of the busiest movable bridges in the world despite being closed to water traffic during rush hours. The Fremont Bridge celebrated its' 566,000th opening in January.

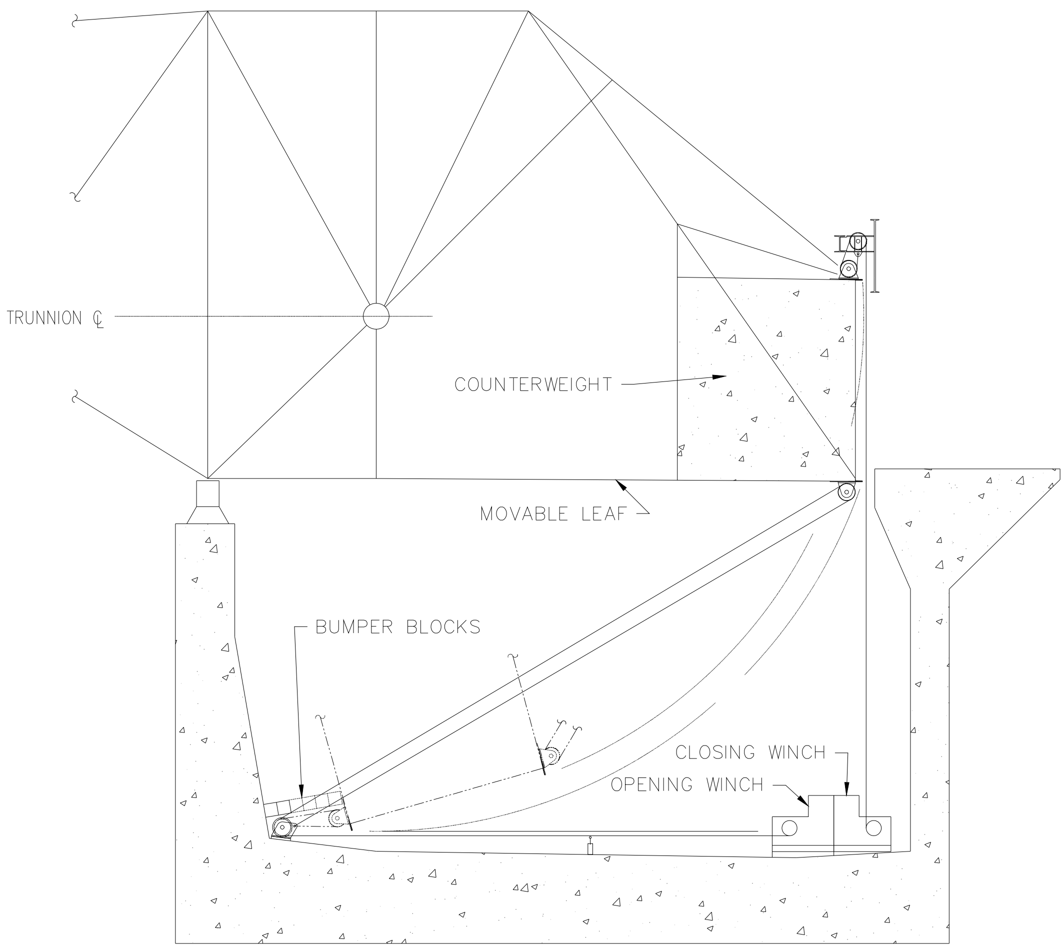
In the mid 1980's, the City undertook a program to rehabilitate and modernize the structural, mechanical and electrical systems of the three remaining, City owned movable bridges. Stafford Bandlow Engineering (SBE) was retained as a sub consultant to provide the mechanical design for the rehabilitation of all three bridges. Sverdrup Civil was the Prime Consultant for the rehabilitation of the University and Ballard bridges. Parsons Brinckerhoff was the Prime Consultant for the rehabilitation of the Fremont Bridge.

Rehabilitation of the University Bridge was completed in 1988. Due to funding limitations, the rehabilitation of the Ballard and Fremont bridges was delayed, and in the case of the Ballard Bridge, was completed in phases. The mechanical and electrical rehabilitation of the Ballard Bridge was completed in 2001. The rehabilitation of the Fremont Bridge, including replacement of the approach spans, began in September 2005 and was completed in 2008.

Fremont Bridge original span drive machinery, 1936 *Seattle Municipal Archives Photograph Collection*

Temporary Span Drive Machinery

All three of the movable brides over the Lake Washington Ship Canal are heavily used by vehicles, pedestrians, bicycles and marine vessels. Maintaining operation of the bridges for all of the users during a major rehabilitation project was a priority. In order to maintain operation of both movable leaves during the replacement of the span drive machinery, a temporary span drive operating system would need to be utilized. A temporary winch operating system was selected for use on the basis of simplicity, low cost, and the flexibility of the system to be used during the rehabilitation all three of the City's bascule bridges.



Elevation of the Temporary Winch Span Drive Operating Machinery arrangement.

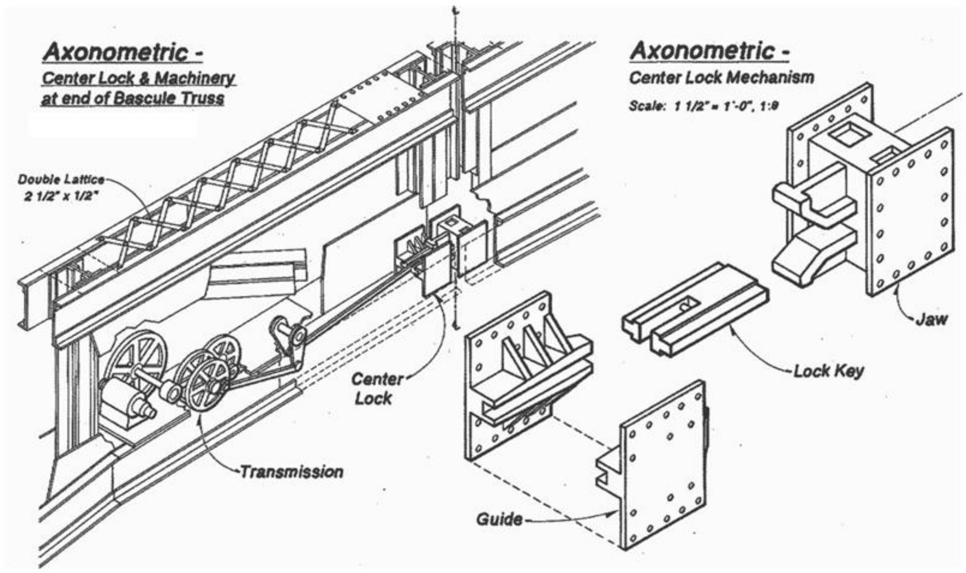
The system designed by SBE was built for use on the University Bridge rehabilitation, loaned to Multnomah County, Oregon for use during a rehabilitation of the Broadway Bridge in the 90's. The system was returned to Seattle and used at the Ballard Bridge rehabilitation before utilizing it for the Fremont rehabilitation project.

Temporary winch span drive equipment being prepped for installation.

After installation of the winch system, the span drive machinery and electrical control system are removed. Due to the fact that the opening time is increased under temporary winch operation, single leaf openings were used except for three scheduled double leaf openings each day. The time of opening for the temporary winch system is approximately 3 ½ minutes.

Span Lock Machinery

The Fremont Bridge utilizes a novel center lock that was developed by the City of Seattle Engineering Department and utilized at all of the City-owned bascule bridges. The design features an overlapping jaw and guide design that virtually eliminates bending stresses from the lock key, allowing for a relatively compact lock key.

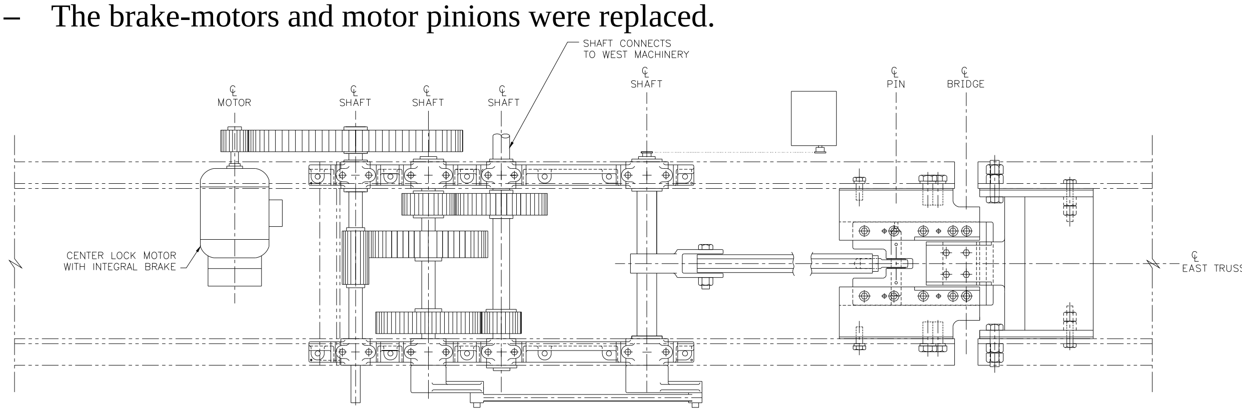


General Arrangement of the original span lock machinery, *Historic American Engineering Record*

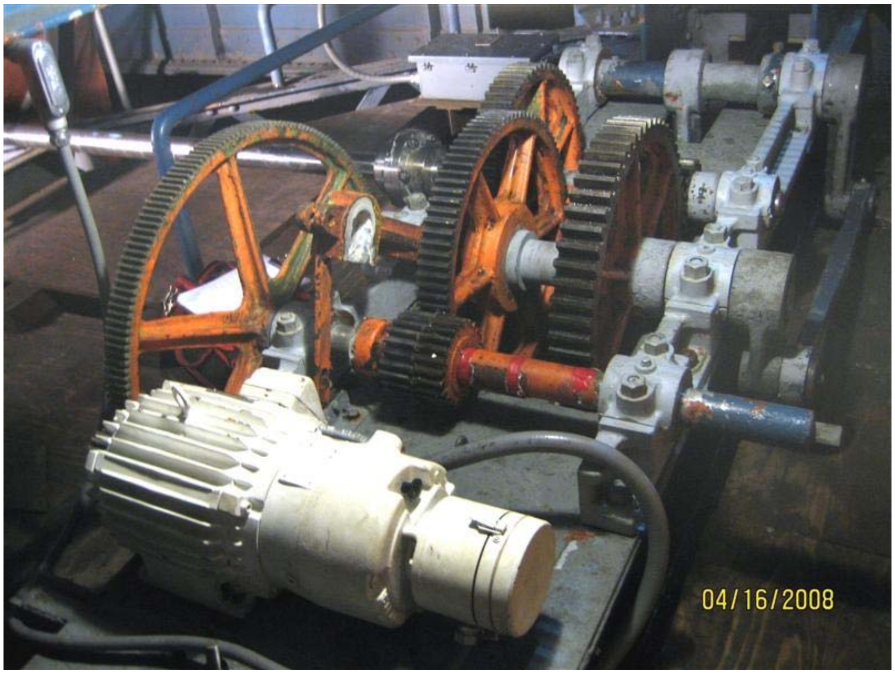
The center lock machinery utilizes an electric motor driving open gearing and cross shafting located under the roadway. Cranks drive the lock keys via connecting rods to drive and pull the lock keys upon rotation of the motors.

The original lock operating machinery was rehabilitated as follows:

- The bearing journals were polished
- The bearings were re-babbitted and re-bored
- The cross shafts were replaced.
- The brake-motors and motor pinions were replaced.



PLAN OF CENTER LOCK
ENGAGED



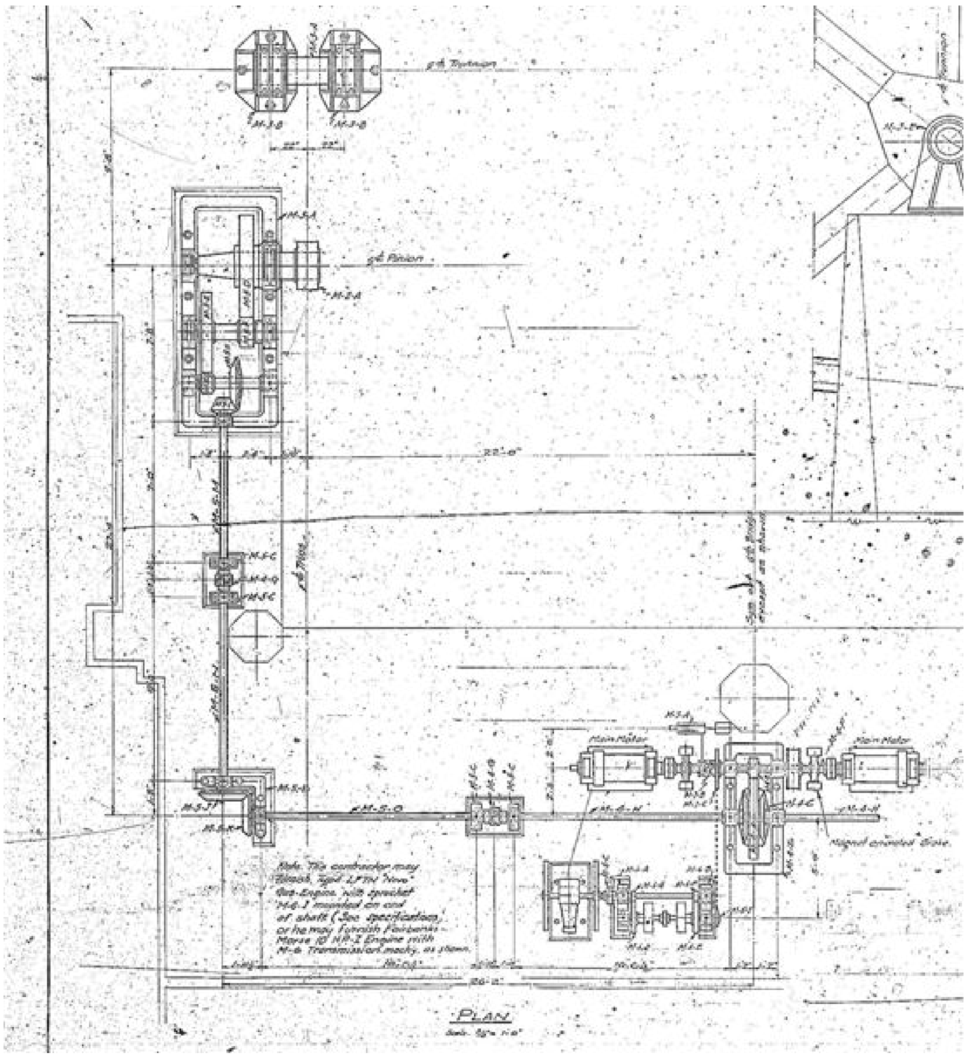
Rehabilitated span lock operating machinery

The only failing of the original design was the lack of the ability to adjust the clearances in the jaw and guides to account for wearing of the parts. A prior rehabilitation modified the guides to incorporate wear shoes, however no such retrofit was possible for the jaws. During the current rehabilitation, the guides and jaws were replaced with a new design that included bronze wear shoes. A similar design was used at the retrofit of the University Bridge and the feedback from the City after 20 years of service was that that design was performing well.

New span lock connecting rod, lock key and guides with bronze wear shoes, shown disengaged.

Span Drive Machinery

The original span drive machinery was still in service at the time of the current rehabilitation. The arrangement of the original machinery placed the 100 HP electric motor, brakes and an open bevel gear type differential in a machinery room enclosure to the rear of the counterweight at the bridge centerline. Line shafting extended from the differential to bevel gear sets. The bevel gear sets are connected to an open gear frame located outboard of the bascule leaf by additional line shafting. Rack pinions are on the final shafts. The rack pinions drive 5 ½" circular pitch internal curved racks mounted on the bascule trusses.

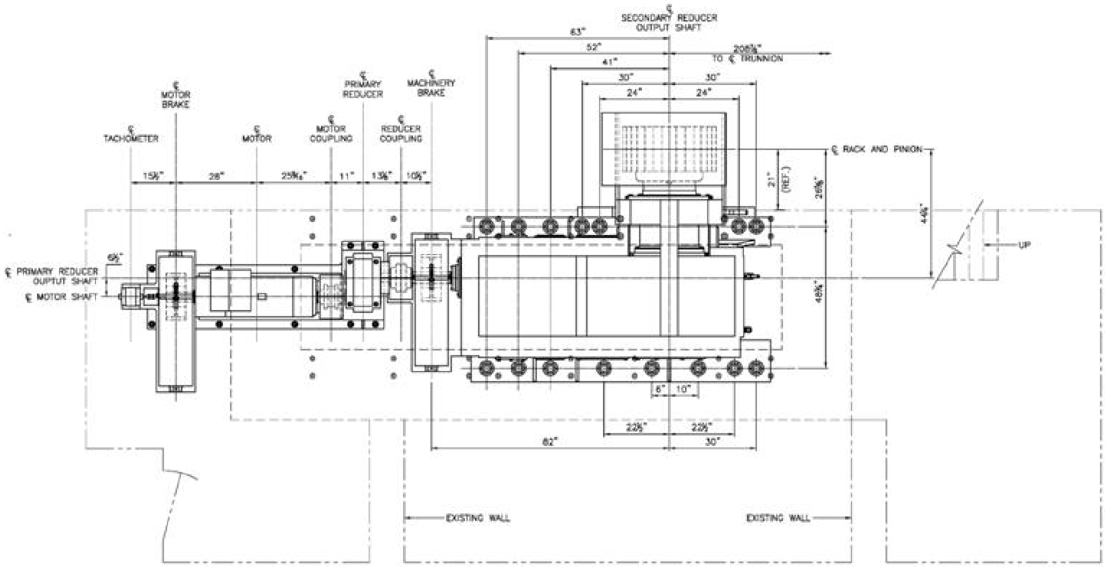


Arrangement of existing span drive machinery

All of the existing span drive machinery, with the exception of the racks, was replaced as part of the rehabilitation. Mechanically independent drives were utilized at each quadrant of the bridge. This configuration offered the following advantages:

- The space utilized for the existing machinery rooms that contained the original motors and differential gears was not large enough for this equipment plus all of the new electrical equipment. The elimination of the differential avoided the need for additional electrical room space.

– The independent drives provide an additional degree of mechanical and electrical redundancy in that each leaf can be operated using one drive at normal speed. The only limitation is the maximum acceptable wind speed for operation is reduced.



SPAN DRIVE MACHINERY
PLAN VIEW

Each drive is provided with a 75 HP motor. The number of teeth on the rack pinions was increased by one from 16 to 17. The new drive machinery was designed to open the bridge 74° in a time of 76 seconds.

The design of the new machinery features a new, custom designed secondary reducer with the rack pinion shaft mounted on the overhung output shaft extension. The machinery brake is mounted on a support that is integral with the secondary reducer housing. All of the other machinery, including the motor, motor brake, primary reducer and electrical control equipment was mounted on a single support. All of the machinery was mounted, aligned and inspected in the shop prior to delivery to the bridge site. The only field alignment required was to mate the rack pinion with the existing racks, anchor the secondary reducer, align the reducer coupling and anchor the machinery support.

Construction

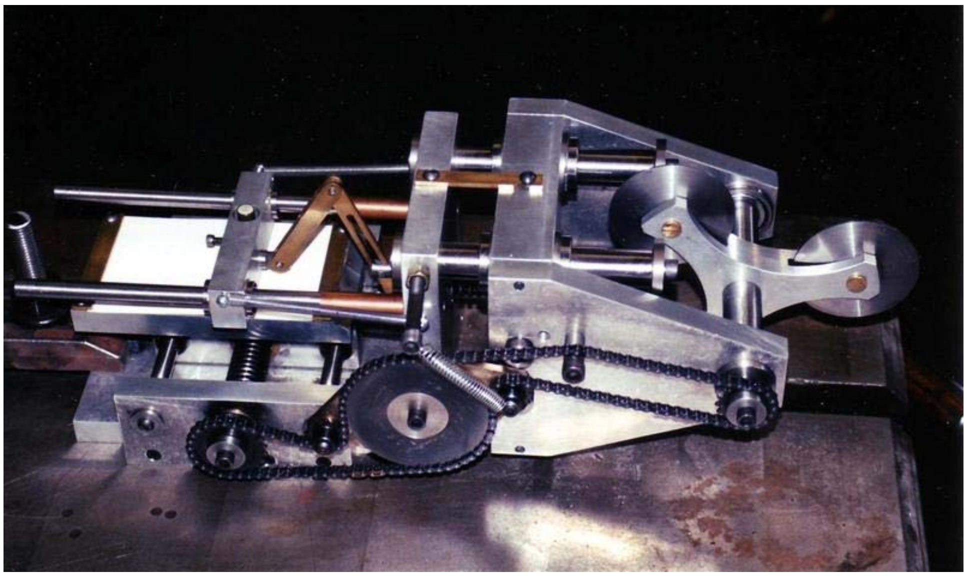
The rehabilitation contract was awarded in September, 2005. The Prime Contractor for the rehabilitation was the Mowat Contruction Company. The contract value was $36.3 million. Of this, $28.8 million is for replacing the approaches and $7.5 million is for upgrading the mechanical and electrical system.

The project was staged so that the work on the approaches was started immediately. While the work on the approach replacement was underway, the shop drawings were developed and fabrication, testing and shop inspection of the machinery was completed. The replacement of the approaches was completed in May 2007.

North approach replacement underway

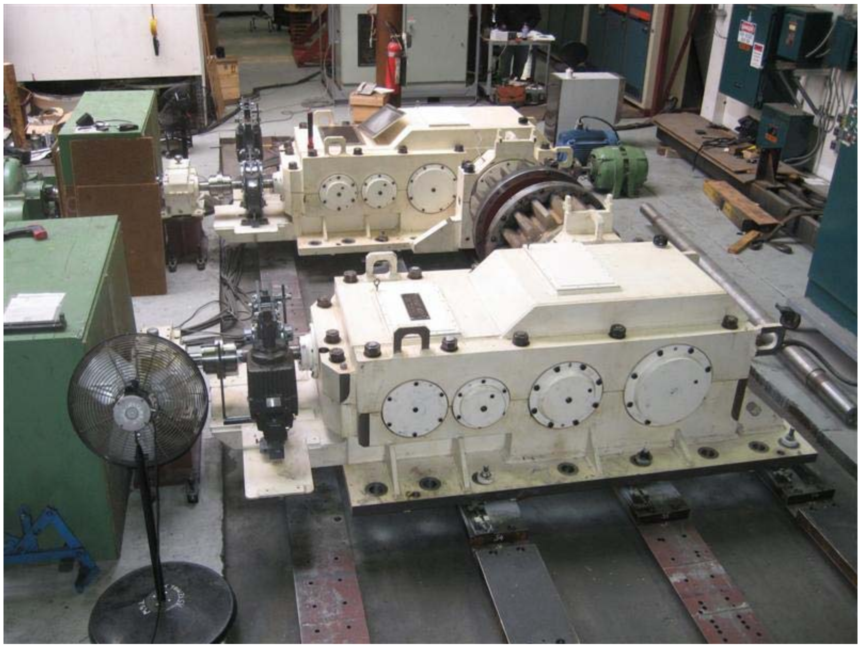
South approach replacement underway

During development of the shop drawings, prior to removal of the existing machinery, the Contractor was tasked with performing detailed measurements of the existing racks to facilitate speedy installation of the new machinery. The span drive machinery sub-contractor was The Gear Works, located in Seattle. Field measurements of each existing gear rack were taken to ascertain the point of tightest mesh with the new output pinions. This required the use of a unique portable composite tester specially built for the project (nicknamed the “slinky”). The slinky accounted for the uneven wear of the existing cast steel rack teeth. Based on these measurements, each pinion was custom manufactured with a special modified tooth form to optimize the strength of the teeth and ensure that the desired backlash could be achieved without the risk of tip interference.



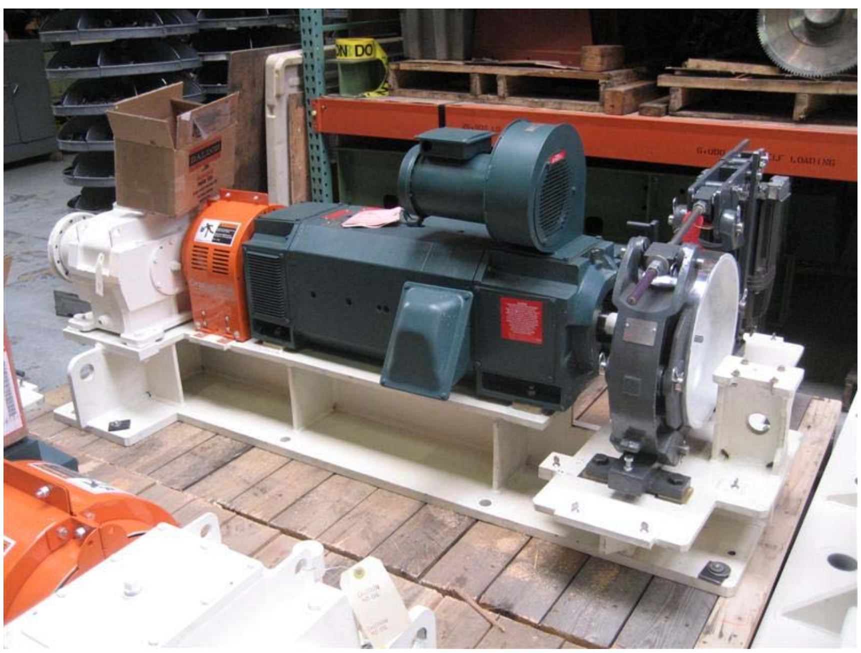
The “slinky” portable composite tester built by The Gear Works

A 200% load test was applied to the gearboxes by using an electrical regenerative method. Over 2,500,000 lb./in. of torque was applied to the low speed shafts in both directions. The load tests were conducted at The Gear Works manufacturing facility in Seattle. The gearboxes were assembled back to back on an 18" thick concrete foundation to allow for rigid load test positioning. All gear contact patterns and bearing settings were checked and recorded before and after testing.



Reducer 200% Load Test Arrangement at The Gear Works, Seattle

Following acceptance of the load tests and other shop inspection, the temporary winch drive system was installed at the north leaf. The winch system was commissioned during a night time closure of the bridge to vehicular traffic. The existing span drive machinery and electrical systems for the north leaf were then removed and the piers were prepared for installation of the new machinery.



Machinery support assembly ready for installation.

In order to install the new secondary reducers and machinery support assembly, the leaf was opened and the reducers were lowered into the counterweight pit. Rigging was then installed to lift the reducers and machinery support assemblies up to the machinery level where they were placed over their anchor bolts, which had been previously installed.

Secondary reducer installation sequence.

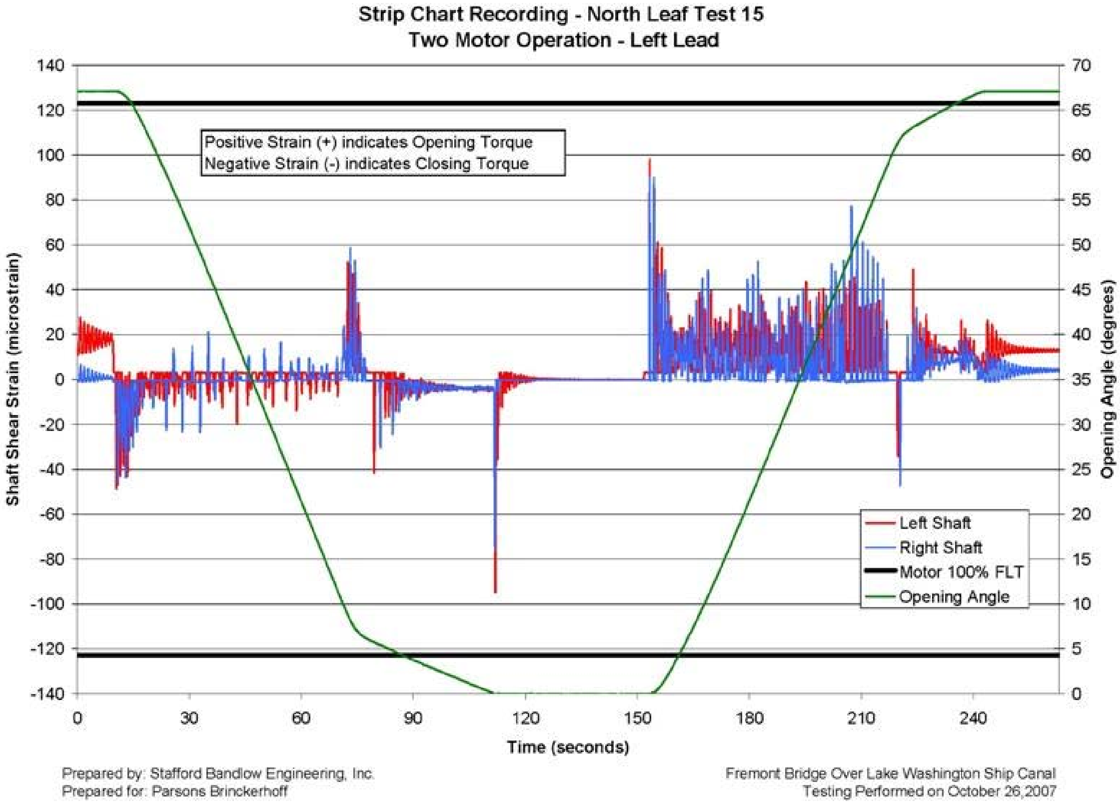
Once all of the machinery was in position for the North leaf, the secondary reducers were lowered into position so that the rack pinion engaged the rack during a night time closure to vehicular traffic. The leaf position corresponding to the minimum backlash had been previously established based on the "slinky" measurements. The leaf was opened to that position, the pinion was aligned and the reducer secured with the desired backlash and the leaf was opened using the winch to establish the contact pattern on the new pinion and existing rack.

Evaluating rack pinion tooth contact during installation of the secondary reducers.

Each secondary reducer was aligned during a single night time closure and temporarily secured against jack screws. The machinery support assembly was then positioned so that the reducer couplings were aligned. The secondary reducers and machinery supports were then grouted and anchored permanently using epoxy anchors. Each of the anchors was pull tested to design capacity to verify integrity and then hydraulically tensioned.

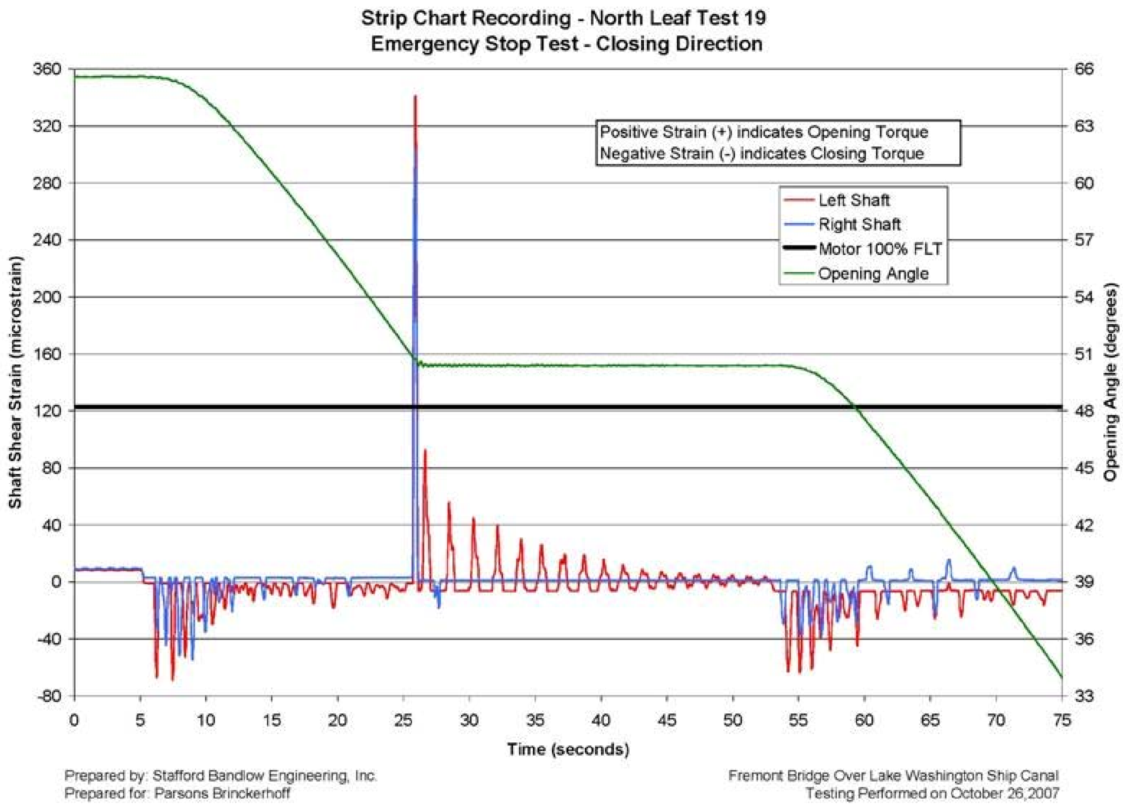
Operational Testing

Following completion of the anchorage of the machinery, the new span drive machinery and controls were commissioned. SBE performed dynamic strain gage measurements during the commissioning tests for the dual purposes of verifying the electronic load sharing functions of the drives and also for determination of span balance.



Operational testing of new span drive machinery

One interesting piece of information that was gained from the strain gage testing related to the brake performance under emergency stop conditions. The shoe brakes are spring set, thrustor released units and are provided with an adjustable time delay. During the initial testing, the motor brake time delays were set at their minimum setting and the machinery brakes were adjusted with a 4-5 second delay. After physically verifying the brake torque with a torque wrench (equivalent to ~95% FLT of the motor) using the breakaway method, an emergency stop was performed with the bridge operating at full speed. It was noted that the peak braking torque was nearly 300% FLT of the motor. Further testing with a time delay of approximately 2 seconds resulted in a nearly 50% reduction in peak braking torques. In order to avoid excessive shock loading of machinery, a 2 second time delay was utilized at all motor brakes and a 6 second time delay was used for the machinery brakes.



Emergency stop testing of new span drive machinery with no time delay

Once the new span drive machinery for the north leaf was successfully tested, the winch operating system was removed and installed at the south leaf, where the process was repeated.

The rack, new pinion and machinery shield viewed from inside the bascule leaf.

The new span drive motor, primary reducer, motor and machinery brakes viewed from the machinery room.

Construction Issues

There were very few problems encountered during the mechanical rehabilitation that related to existing field conditions. Two of the notable issues related to the poor condition of existing concrete.

During construction of the temporary winch system it was necessary to anchor sheave brackets to the counterweight box. It was intended that epoxy anchors would be used. During construction large voids and poor quality concrete were discovered. Despite attempts to fill the voids with grout, it was not possible to anchor the sheave brackets and an alternative plan involving welding the brackets to the counterweight box was used.

Machinery anchorage modifications.

Unsound concrete was also discovered during modifications to the machinery floor that the secondary reducers were anchored to. In order to ensure the integrity of the reducer anchorage, the unsound concrete was chipped out, reinforced and re-poured.

Commissioning of the south leaf span drive machinery was completed in February 2008 followed by functional testing of the electrical control system. Rehabilitation of the span locks was completed in April 2008.

The completion of the mechanical and electrical rehabilitation of the 91 year old Fremont Bridge will ensure continued long term reliable operation of a critical component of the infrastructure of the City of Seattle.

Fremont Bridge, opening for the tall ships parade. *Seattle Municipal Archives Photograph Collection*