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First Avenue South Bascule Bridge, Seattle, Washington

by

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FIRST AVENUE SOUTH BASCULE BRIDGE,

SEATTLE, WASHINGTON

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INTRODUCTION

The existing First Avenue South Bascule Bridge was constructed in the early 1950's to carry four lanes of traffic over the Duwamish River, a busy marine traffic waterway serving several major port facilities. Traffic growth and safety dictated the need for a new parallel bridge which would allow three lanes plus shoulders on both the new and the existing bridge. Both bridges will be owned and operated by the Washington State Department of Transportation.

Structure Overview

Layout

The new bridge is slightly larger than the existing with a span of 294 feet (90 m), center to center of trunnions, and a roadway width of 53 feet (16 m). It is a double-leaf, bascule bridge with a clearance of 39 feet (12 m) above mean high. water. The channel width is 145 feet, and the bridge crosses on a 36° skew angle. Construction cost is \$35 million.

Structure

Because of the rain in Seattle, it was decided that the bridge deck surface should be concrete. This doubled the weight of each leaf to 5,000 kips, perhaps the heaviest bascule leaves ever built. The concrete bridge piers measure 98' x 66' (30 m x 20 m) in plan and are 54' (16 m) high. The bridge is in a Seismic Zone III with a rock acceleration of 0.30g. It is founded on 77, 24-inch diameter concrete-filled steel pipe pile under each pier. The bascule leaf is



framed with two steel trusses spaced at 57 foot centers. Structural low alloy steel AASHTO M222 or M223 50 grade was used throughout. The trusses are welded box members with 7/8" diameter AASHTO M164 bolted connections. Behind the live-load shoe, the truss transitions into a steel plate girder. The deck is framed with conventional floor beams and stringers that support a 5-3/16" deep grid deck. The deck is half filled with a 1-inch overfill of Microsilica Modified Concrete (MCC).



Hydraulic System

Although the focus of this paper in on the development of the machined parts, a brief description of the Hydraulic System, the Control System and the Operating Procedure will set the context. The hydraulic drive system consists of three 100 horsepower pumps on each side. It is designed to operate normally on all three pumps but can be operated at reduced speed on two or even one pump. There are two hydraulic cylinders on each end of each trunnion beam, one pushing and one pulling (for a total of eight). The cylinders have a 20-inch diameter bore with an 11-inch rod and a 10-foot stroke. Operating time was set at two minutes. Hydraulic pressures were increased by 500psi over AASHTO Code Section 2.5.18, for each of the three operating conditions.



The hydraulic system for the centerlock was a separate 10 H.P. system located in the pier with lines extended to the centerlocks at each truss tip.

Electrical and Controls

Electrical power is provided to each side of the river separately. Each side has a 600 KVA backup generator. There is a utilidor under the river adjacent to the bridge for large water and gas lines. The control system intertie is routed through this utilidor.

The new control tower is designed to contain the control system for both the new and the existing bridge. The bridges are controlled by separate PLC systems since the new bridge is hydraulic and the existing is electro-mechanically driven. They have separate side by side control panels with integrated traffic controls. A standby central processing unit is provided. The bridge can also be operated by hardwired controls from a hand held pendant on each pier.

Operating System Description

A detailed operating system description was developed to guide the design process. This document describes the design criteria and interface between the bridge control system, the hydraulic system, and other components. It is included as an appendix to this paper.

Trunnion Beam and Bearing

One of the most unique aspects of the new First Ave. South Bascule Bridge is its 10-foot (3 m) diameter trunnion shaft and bearings. The trunnion beam runs the width of the bridge extending through and



affixed to the two trusses. It cantilevers out $4^{\circ}-9^{\circ}$ to the trunnion bearings, then another $3^{\circ}-3^{\circ}$ to the hydraulic turning cylinder connections, for a total length of 73 feet.

The trunnion shaft is made of steel plate ranging in thickness from 1-1/2" near the center to 3" thick at the bearings. The shaft was fabricated in three pieces that are connected with high strength bolted "T" flanges about 12 feet from each end. The trunnion beam rotates with the bridge and was made round so that the moment of inertia (stiffness) remained constant no matter what the angle of rotation.

Analysis of the trunnion beam was accomplished using a SAP 90 finite element computer model. The model elements were rather course in the middle 2/3 of the beam where the stresses are predictable, and very fine in the region around the truss connection and bearings which had higher stress levels. Variations in bearing stresses as well as shear and bending stresses in the shell and stiffeners were studied using various stiffener configurations. Several iterations were made before the final configuration and plate thicknesses were decided. The primary loads carried by the trunnion shaft are the 5,000 kip dead load, a seismic load of about 2500 kips in both the longitudinal and transverse direction and a torque of 3,500 kip feet from the operating cylinders.





The trunnion bearing carries the same loads (except the transverse seismic load which is transmitted to stops at either end of the trunnion shaft). Preliminary designs considered both roller bearings as well as necking the trunnion beam down to a solid shaft at the bearing. The roller bearing manufacturers that were contacted were a bit tentative about a bearing of this size and capacity. Among other things, there were concerns about possible brinelling of flat spots when the bridge is in the down position and also about accomplishing and maintaining alignment. A solid shaft and smaller diameter bearing were initially sized and determined to cost more than simply extending the ten-foot diameter shaft through the bearing. The final design uses standard bronze bearings cut into 30° segments for ease of handling and future replacement. An automated greasing system supplies a measured amount of grease to each bearing just prior to each opening.

The bronze bearings are housed in a welded steel bearing housing that is 16 feet high, 14.5 feet long and 29" wide. The housing is centered on the pier counterweight pit wall, with the wall extending up the sides to provide resistance for the seismic loads. Each bearing rests on five- W30x191# columns embedded in the wall which extend to the footing.

Detailing the Trunnion Beam and Bearing

The connection between the truss and the trunnion girder is accomplished by welding a flange around the trunnion beam that aligns with the web of the plate girder which is the truss extension in the pit area. Double splice plates with 192 structural, high strength bolts in double shear complete the connection.

Splices in the trunnion beam (12 feet from each end) are accomplished by 14" wide by 3-1/2" thick flange plates welded to the edge of the shell plate and connected by 192 1-1/4" diameter turned bolts. These flange plates are made of "Lukens Fine Line" steel to provide through thickness strength. Welds throughout the trunnion beam are fracture critical. Welds in the trunnion bearing housing were also designated as fracture critical, but due to the relatively low tension loads in many of the welds under the bearing area this requirement was relaxed during fabrication at the owners' request.

The selection of the journal bearing surface on the trunnion shaft took special attention. The grade 50 steel used for structural strength did not have sufficient surface hardness suitable to match the bronze bearings. Inserting a higher strength steel was considered but it presented difficulties retaining its hardness through the stress relieving process. Various surface hardening techniques were considered and rejected. Finally, a decision was made to use a forged ring journal bearing of through-hardened AISI 4340 material placed over the trunnion shaft with a 0.0150" interference fit. The interference fit put about 60 ksi stress in the 35" wide x 2" thick ring which in turn compressed the trunnion shaft shell plate and stiffeners. The net affect was a significant reduction or elimination of tension in the welds in this area, thus allowing considerable relief in the cyclic loading criteria of the welds while at the same time providing the hardened bearing surface desired.

Tolerances specified in the design were discussed with several machine shops prior to completing the plans and specs. (But as luck would have it not with the winning bidder). Tolerances on the journal bearing were set at diameter +0.040" - 0.000"; cylindricity at 0.005", and total run-out at 0.020". Tolerance at the flanged joints between beam segments were to be set by the fabricator providing the final tolerances at the journal bearings was met. Shop and field run-out tests were specified.

Tolerances on the bearing housing were set at bore diameter +0.015" - 0.000" with the bronze bearing segment thickness set to a tolerance of +0.0025 - 0.0025". The nominal grease gap was set at 0.060".

Fabrication and Construction Issues

Shortly after contract award, meetings began between the owner's Project Engineers, the general contractor, his machinery subcontractors and the designers. The general topic was quality control and specifically "do we really mean these tolerances and do we really need welds to that high a quality?" An alternate set of tolerances was proposed at two to four times more lenient than specified. Doubts were expressed that the specified tolerances could be achieved. The designers and the owner indicated that we really wanted the specified tolerances, and that we saw no technical reason that they could not be accomplished. The machinery subcontractor indicated that he would try his best and see how it came out. In the final analysis all tolerances were met with little difficulty. The shop total run-out test indicated that the fabricator had accomplished one half the allowable tolerance specified.

The high quality welds in the trunnion shaft were accomplished with little difficulty. The welds in the lower bearing assembly were a different story. The fabricator experienced numerous problems achiev-

ing quality welds in this area. The issue was resolved by running more detailed finite element analysis of the housing and determining not only which welds were in tension but which portion of each weld that was in tension and quantifying the tension along the weld. This additional design refinement allowed a considerable reduction in the number of welds that needed to be designated as fracture critical, thus providing relief to the fabricator.

Some parts of the fabrication went much easier than anticipated. There was concern about the interference fit of the forged bearing rings. There was only one chance to get it right, and if that chance were missed the ring would need to be cut off and a replacement made. All four interference fit rings slipped into place without incident.

Another happy story occurred when the contractor proposed to ship and erect each leaf in only two pieces. Since the trunnion beam would never be disassembled after the shop run-out test there was no need for the field run-out test, so it was eliminated. The portion of the leaf in the pit area including an empty counterweight box and the trunnion beam was gently lowered onto the bearings. A few weeks later the entire cantilever portion of the leaf in front of the live load shoes was lifted into place and attached without incident.

Other Machine Parts

There are several other aspects to the machinery of this bridge but insufficient time and space to describe them in detail. The design and testing of hydraulic dampers would offer enough information for a presentation in itself. The design and construction of the hydraulically operated jaw type centerlocks also provides many interesting opportunities beyond our time/space limitations.

Credits:	
Owner:	Washington State Department of Transportation
Structural Design:	Washington State Department of Transportation, Bridge and Structures
	Section - Myint Lwin, Bridge Engineer; Jerald Dodson, Design Engineer;
	Tom Madden, Project Engineer
Mechanical Design:	Sverdrup Civil, Inc.
Hydraulic Design:	Hamilton Engineering
Electrical & Controls	
Design:	Sverdrup Civil, Inc.
General Contractor:	Atkinson Construction Co.

The following bridge operational sequence was first published in June of 93 to guide the design process. It has had numerous revisions and updates. This version represents our design criteria at the conclusion of PS&E design.

This document describes the design criteria and interface between the bridge control system the hydraulic system and other components. It is divided into the following operations or functions:

- Normal Opening
- Normal Closing
- Emergency Stops or Steps at Mid-Opening
- Buffer Operation (when closing)
- Operation Under High Wind or Ice Loads
- Operating on Three Cylinders
- Operating on Two Cylinders
- Manual Opening and Closing

FIRST AVENUE SOUTH BRIDGE OPERATING SYSTEM DESCRIPTION

By Tom Mahoney October 21, 1994

A. Bridge Normal Opening On Four Cylinders

- 1. Bridge will be started by operator pushing the "SPAN OPEN" push-button or joystick.
 - a. Continuous pressure is required on the button during opening.
 - b. Bridge will accelerate for about four seconds (at 1,500 psi compensator setting).
 - c. Five seconds after start of opening, the compensator setting will be shifted from 1,500 psi to 1,850 psi by the PLC.
- 2. At 74.5 degrees rotation, the limit switch near the end of the trunnion shaft will activate the deceleration valve via the PLC. The bridge will decelerate to approximately 1/10th speed in 1.5 degrees which will take approximately 3.0 seconds.
 - a. Two limit switches will be set logically in series so if either one triggers the deceleration will be initiated.
 - b. The control between the limit switch and the deceleration valve with be through the PLC.
 - c. The PLC will display that the bridge is "fully opened", via the illuminations of the green span open light.
- 3. Five seconds after the deceleration valve activates, the directional control valve will center, stopping the bridge between 75.5 and 77.5 degrees, depending on wind loads.
 - a. The timer and control to center the directional control valve will be through the PLC.
 - b. When stopped, the bridge will be locked by the counterbalance valves.

APPENDIX

- 4. Should both limit switches or the deceleration valve malfunction, the cylinders will bottom out on a cushioned stop inside the cylinders.
 - a. The cylinder cushion to start at 77.5 and deceleration to 79.5 degrees.
 - b. Cylinders will bottom out at 80.5 degrees.
 - c. The bumper in pit will be set to bottom out at 80 degrees.
 - d. A cylinder over-travel limit switch shall activate at 79.5 degrees. The limit switch is located in the counter weight pit.
- B. Bridge Normal Closing On Four Cylinders
 - 1. Bridge will be started by the operator pushing the "SPAN CLOSE" pushbutton or joystick.
 - a. Continuous pressure is required on the button during closing.
 - b. Bridge will accelerate for about four seconds (at 1,500 psi compensator setting).
 - c. Five seconds after the start of closing, the compensator setting will be shifted from 1,500 psi to 1,850 psi by the PLC.
 - 2. At 3.5 degrees above final stop, the deceleration limit switch near the end of the trunnion shaft will activate the deceleration valve via the PLC. The bridge will decelerate to 1/10th speed in 1.5 degrees which will take approximately 3 seconds.
 - a. There will be two limit switches logically in series to signal the PLC, deceleration will accure.
 - b. These two limit switches will be cross checked against each other for consistent signals each operation. Inconsistencies, i.e. different signals, will be alarmed to the control panel.
 - c. The location of the limit switch may be field adjusted between 4 and 3 degrees to adjust docking time to about 15 seconds.

- 3. At the end of the deceleration phase, the bridge will continue in docking mode of 1/10th normal speed. The hydraulic pressure during docking mode will be reduced to 450 psi.
 - a. The reduction to 1/10th speed and 450 psi will be controlled by the PLC.
 - b. One second after receiving the deceleration limit switch signal the PLC will verify that the deceleration valve has activated and the compensator valves are set to 450 psi. If these two functions are not performed at that time the PLC will stop the bridge by shutting off power through an MCR stop (similar to an E stop).
 - 1. Docking may proceed by cycling the "master control power" switch, pushing the "Initiate Opening" switch to restart the pumps then push "Span Close" button.
 - 2. PLC will shut off the pump that has the malfunctioning compensator valve and bridge can operate at 2/3 speed.
 - 3. If the deceleration valve has malfunctioned, span will close but may not be re-opened until repair is made.
 - c. Either leaf may be docked first.
 - d. Docking motion will continue until the span live load shoe is touched (approximately 15 seconds).
 - e. When the deceleration limit switch triggers, the "SPAN CLOSE" push button may be released and docking will continue automatically.
- 4. At the end of the docking phase, the bridge will be physically stopped by the live load shoe.
 - a. Limit switches, located at each liveload shoe will signal the PLC that the leaf is closed. When both leaves are closed, the center lock may be operated.
 - b. The liveload shoes will absorb the kinetic energy of the 1/10th speed plus the torque of 450 psi as the leaf is driven into the docked position.
 - d. The equivalent torque of 450 psi will be applied to the liveload shoe constantly until the center lock is engaged.

- 5. After the center lock is engaged, the PLC will center the main directional control valve and shut off the hydraulic system.
 - a. The centered valve will allow the cylinder pressure to gradually drop to nearly zero.
 - b. This will conclude the closing sequence.
- C. Emergency Stops and Stops At Mid Opening
 - 1. If, at any position, the operator pushes the Emergency Stop push-button, the power will be cut off to the hydraulic system and all devices which cause motion.
 - a. The directional control valve will automatically center by spring.
 - b. The bridge will decelerate to a complete stop on the counterbalance valve pressure setting in about 1.5 seconds.
 - c. When stopped, the bridge will be locked by the counterbalance valves.
 - d. This function operates during either opening or closing.
 - 2. Should the operator release the open or close push-button at any point, the PLC will signal the system to stop under normal deceleration of three seconds with two seconds creep at 1/10th speed then stop.
 - a. This will be accomplished by simulating the deceleration valve limit switch signal to the hydraulic system.
 - b. When stopped, the bridge will be locked by the counterbalance valves.
 - c. This function operates during either opening or closing.
- D. Buffer Operation (when closing)
 - 1. Should the system experience failure of a line or valve during deceleration, the leaf will be slowed to approximately 1/5th speed by the buffer before it reaches the liveload shoes.
 - a. The buffer will become fully engaged at a position 1.5 degrees before the bridge finally stops and its position will be adjustable.

- b. The buffer will be sized to slow the leaf from its maximum speed while the hydraulic system continues to drive at 450 psi pressure.
- c. The buffer will apply only 10 percent of its maximum force when the leaf is rotating at 1/10th speed.
- E. Operation Under High Wind or Ice Loads (AASHTO Conditions B and C)

Under adverse wind or ice conditions, the leaf may operate at 1,850 psi with up to 10 percent higher speeds or one half normal speed. The location of the deceleration valve limit switches will allow for safe operation under either of these conditions.

- 1. The opening position could vary by one degree with the leaf stopping between 75 and 78 degrees depending on wind direction.
- 2. The docking creep duration at 1/10th speed could be decreased to 10 seconds or increased to 25 seconds depending on the leaf speed at the time the deceleration valve is activated.
- F. Operating on Three Cylinders
 - Transducers will be installed in the hydraulic system that will sense when one or more cylinders is not functioning. If, at any time, including during mid opening or mid closing, one cylinder should cease to function due to a broken hydraulic line or blown seal, the bridge operating system will be adjusted by the PLC as follows.
 - 2. One pump will be automatically shut off by the PLC thus reducing the flow to 2/3 of the normal. This will have the effect of slowing the motion to 85% to 90% of normal.
 - a. An alarm will enunciate a hydraulic system malfunction.
 - b. The leaf will accelerate and decelerate more slowly, especially under adverse conditions of wind and ice.
 - c. The pressure settings and limit switches in the hydraulic system will not be changed.
 - d. The leaf could temporarily stall out during high gusts of wind.
 - e. The leaf could drift over to the physical bumper stop in the pit under maximum 20 psf wind load or could creep downward until the wind pressure is relieved due to the reduced exposed area.

- G. Operating on Two Cylinders
 - 1. Should the transducers described in F, above, indicate that two cylinders have ceased to function, the PLC will automatically perform the following:
 - a. Two pumps will automatically be shut off by the PLC reducing the flow to 1/3 of normal.
 - b. Bridge will lower at 2/3 normal speed.
 - c. Docking mode will be similar to normal.
 - d. Re-opening will be prohibited until system is repaired or adjusted as described in 2 below.
 - 2. Should the State elect to operate on the remaining two cylinders, mechanical changes would be required to modify the hydraulic system.
 - a. The pressure relief valve and the compensator valve would need to be adjusted to operate at 1.5 times normal maximum pressure settings (2,800 psi).
 - b. Two hydraulic pumps would be shut off. The remaining pump would be set to 50% flow so the system would operate on 1/6 the volume. This would allow the system to operate at 1/3 speed maximum.
 - c. Operating under these conditions would reduce the factor of safety against yield on the machinery components from the normal 3.3 down to 2.2.
 - d. The pressure setting of the counterbalance valves would not be changed.
 - e. Operation under normal loading conditions in this configuration may continue for a few days while repairs are in progress. Operating in adverse loading conditions (high wind or ice load) is not advised.

- H. Manual (Hardwired) Operation
 - Description Should the PLC's be inoperable or should a manual operation be desired, each leaf can be operated bypassing the PLC. Located at the control panel, each motor control center and PLC I/O Énclosure is a "Manual - Off -Automatic" switch. All of these switches must be turned to "Manual". On each pier, located in a box on the deck near the waterway, is a pendent operator, which will raise and lower that leaf. On the North pier the box also contains traffic gate and center lock controls. The center locks and span control are interlocked with the oncoming traffic gates.
 - 2. Raising the Leaf on Manual
 - a. Lower oncoming traffic gates.
 - Activate "center lock withdraw" for 10 seconds. A Light will indicate when center locks are fully open. <u>Caution</u> - Do not try to raise <u>either</u> leaf until center locks are open.
 - c. Press leaf raise button (on pendant) until leaf reaches full open position (74.5 degrees) where it will do a normal stop at 77 degrees <u>+</u>. This stop will be activated by the limit switches and relays.
 - d. If button is released prior to reaching 77 degrees <u>+</u> leaf will stop on counterbalance valves similar to an E-stop in 1.5 seconds.
 - 2. Lower the Leaf on Manual
 - a. Press leaf lower button until leaf is on live load shoes. Leaf will go through the normal docking operation on relays, activated by the 3.5 degrees almost closed limit switch.
 - b. If button is released leaf will stop on counterbalance valves in 1.5 seconds.
 - c. When both leaves are on liveload shoes press center lock drive button. Lights will indicate when the center locks are set and pressurized.
 - d. Open oncoming traffic gates.