PROPOSED CONCRETE SWING BRIDGE

by

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BACKGROUND

Replacement of a 1930 vintage bascule bridge in Seattle is necessitated by a future channel widening project. The existing bridge and its replacement are in the shadow of a new six lane freeway bridge that was completed, under budget, in 1983. Monies left over from the high-level bridge allowed funding for a replacement of the old bridge which has been officially designated a hazard to navigation.

The proposed replacement bridge crosses the Duwamish Waterway in an industrial area of South Seattle. It will carry 12,000 motor vehicles per day on a two lane road with shoulders and provide a 12 foot wide pedestrian/bicycle pathway (see Figure 2).

The bridge will allow a 250 ft. wide waterway channel and have a clearance height of 55 ft. This clearance will allow 85 percent of the maritime traffic to pass under the bridge, thus decreasing the number of openings to approximately seven per day.

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SELECTING THE BRIDGE TYPE

Early studies considered two and four lane bridges at various heights, on as many as 18 alignments within the corridor. Most of these were discarded due to economic or right-of-way considerations. Final considerations narrowed down to a two lane bridge located within the existing right-of-way and set at the 55 ft. clearance. The existing street crosses the Waterway on a 45° skew angle. This skew angle, combined with other constraints, had considerable influence on the bridge type selection process.

A vertical lift bridge on a straight alignment was given early consideration. This bridge would have a span of about 500 ft. and would be required to lift to 140 ft. clearance. This would require towers to be over 200 ft. high. Although the lift bridge provided the most conventional solution, it was ruled out because of cost and appearance.

A bascule bridge on a straight alignment yielded a prohibitively long span. Various skew angles were tried until an alignment with a 60° skew was found to provide the best compromise of span length and roadway curvature within the available right-of-way. This bridge would have a trunnion to trunnion span length of 386 feet, making it the longest bascule bridge in the world by about 50 feet. The bascule bridge was carried to a more detailed level of study in the Type, Size & Location Study. The costs appeared to be about 15 percent higher than the swing bridge, so it was dropped from consideration.

A double leaf swing bridge on a straight alignment, with piers on each bank, appeared to offer the most cost effective and functional solution. Such a structure would be segmentally cast concrete, a system that proved very cost effective on the recently completed adjacent high-level freeway bridge. This relatively new technology has had very limited application on movable bridges. A second option, also relatively new, was a steel box girder with a prestressed composite concrete deck. Since both superstructure types had similar requirements for approach structures, substructure, pier protection and machinery, a decision was made to proceed with alternate designs.

This paper describes the concrete alternate which is estimated to be the lower cost option.

BRIDGE SUPERSTRUCTURE

The swing bridge has a 480 foot main span, 240 foot cantilever from each pier and 173'-6" tail span cantilevers. The overall structural width is 51'-0" and the box varies in depth from 8'-0" at the tips to 25'-0" at the piers. See Figure 1 for bridge layout and Figure 2 for typical sections.

The bridge is located within the constraints imposed by the adjacent high-level bridge. The edge of the bridge in the open position, clears the edge of the channel by 20 feet. In this position it clears the left bank high level column by about four feet. The tail spans have been reduced from optimum balance to clear the right bank high level column. "Ballast" concrete has been added to the tail span to achieve static balance about the pivot pier by thickening the box section.

The box is designed for segmental cast-in-place cantilever construction. The front span segments are 16'-6" long and the tail span segments 12'-0" long. Concrete is standard weight (160 pounds per cubic foot) 6000 psi 28 day strength. The deck is longitudinally and transversely post-tensioned with the remainder of the box elements conventionally reinforced.

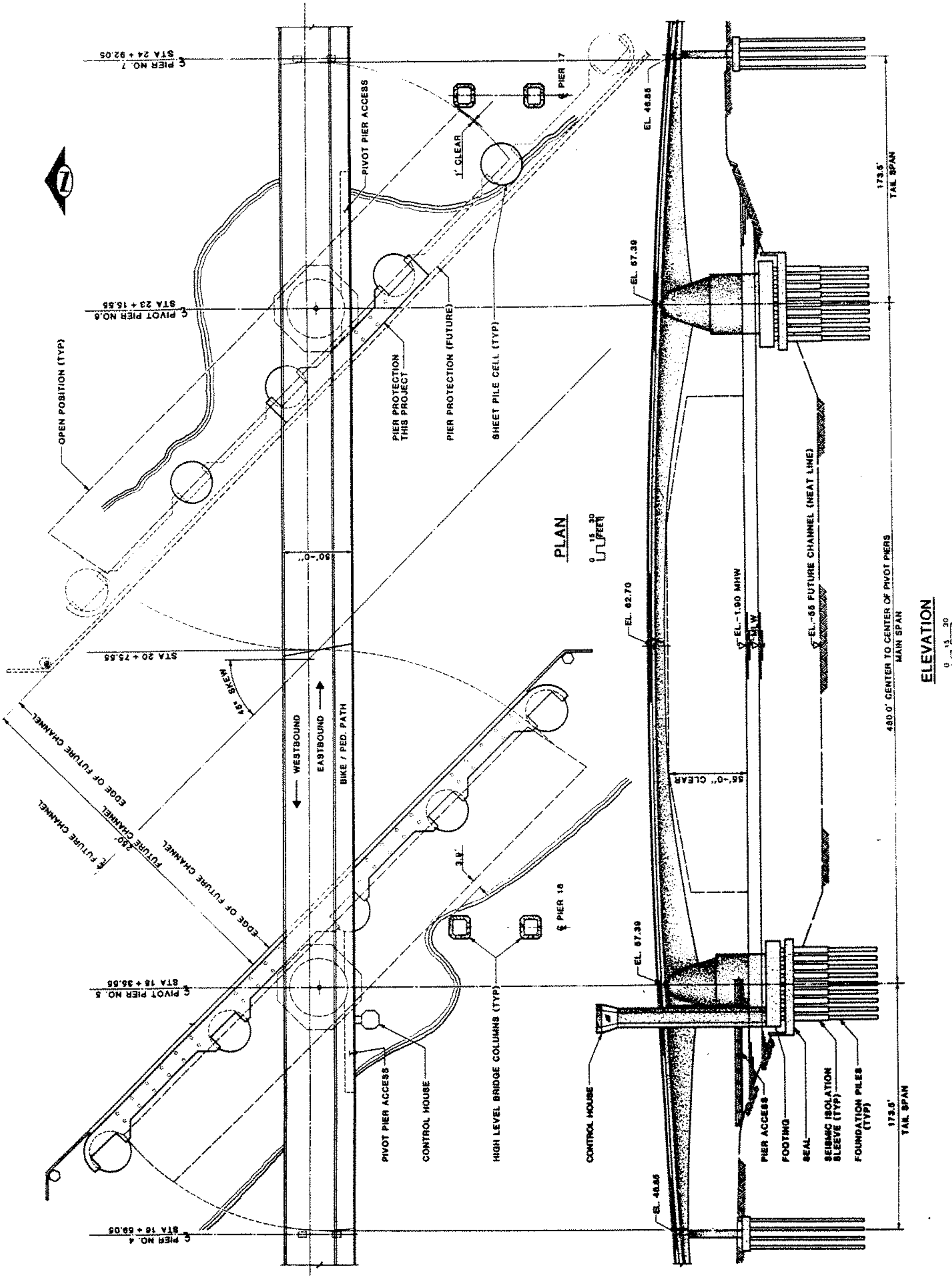

PLAN
ELEVATION
OPEN POSITION (TYP)
PIVOT PIER ACCESS
1' CLEAR
℄ PIER 17
℄ PIER 18
PIER PROTECTION THIS PROJECT
PIER PROTECTION (FUTURE)
SHEET PILE CELL (TYP)
℄ PIER NO. 7 STA 24 + 92.05
℄ PIVOT PIER NO. 6 STA 23 + 15.55
STA 20 + 75.55
℄ PIVOT PIER NO. 5 STA 18 + 35.55
℄ PIER NO. 4 STA 16 + 59.05
45° SKEW
50'-0"
WESTBOUND
EASTBOUND
BIKE / PED. PATH
EDGE OF FUTURE CHANNEL
FUTURE CHANNEL
250'
℄ FUTURE CHANNEL
3.0'
CONTROL HOUSE
HIGH LEVEL BRIDGE COLUMNS (TYP)
EL. 46.86
EL. 57.30
EL. 62.70
EL. -1.90 MHW
MLLW
EL. -55 FUTURE CHANNEL (NEAT LINE)
55'-0" CLEAR
173.5' TAIL SPAN
490.0' CENTER TO CENTER OF PIVOT PIERS MAIN SPAN
PIER ACCESS
FOOTING
SEAL
SEISMIC ISOLATION SLEEVE (TYP)
FOUNDATION PILES (TYP)
0 15 30 (FEET)

FIGURE 1

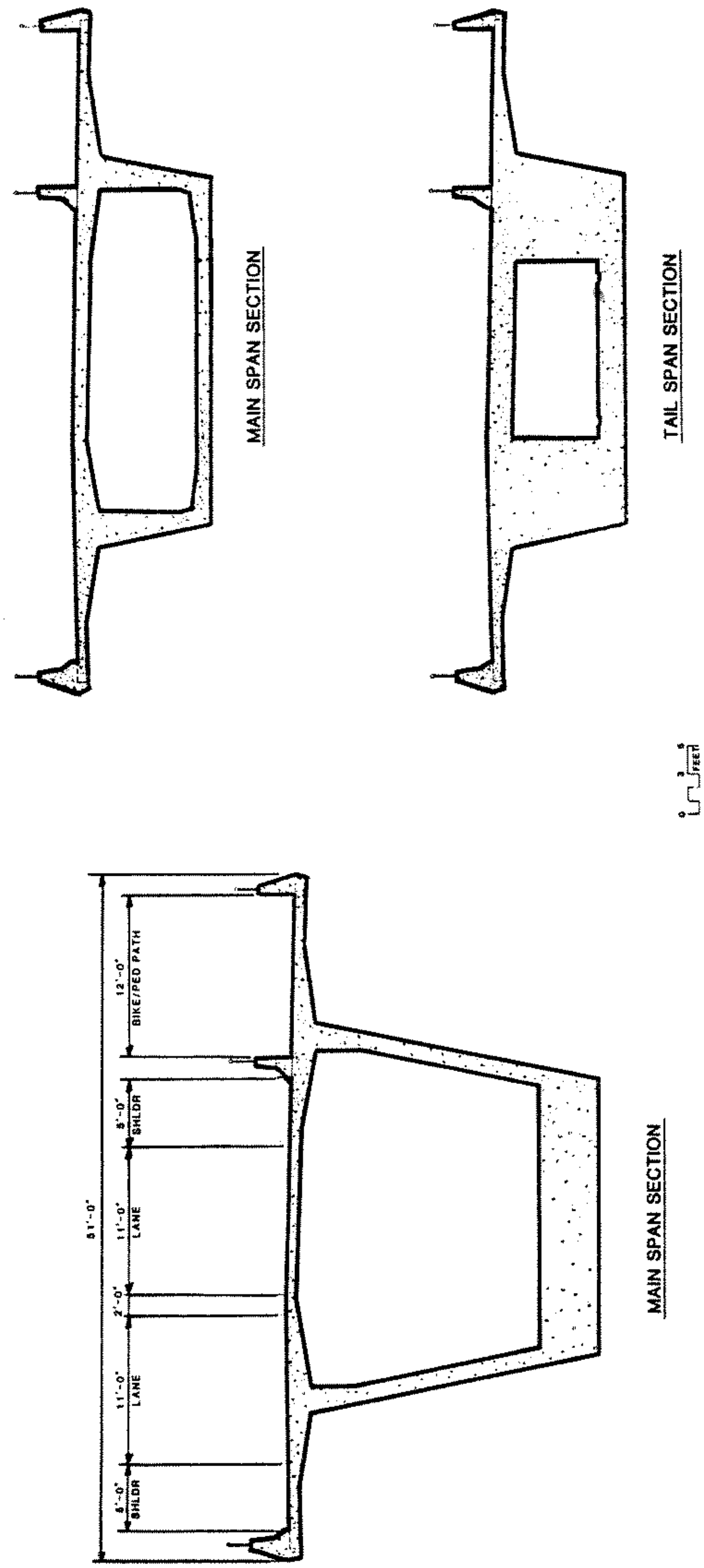

MAIN SPAN SECTION
TAIL SPAN SECTION
0 3 5 FEET
51'-0"
12'-0" BIKE/PED PATH
5'-0" SHLDR
11'-0" LANE
2'-0"
11'-0" LANE
5'-0" SHLDR
MAIN SPAN SECTION

FIGURE 2

Concern for camber and creep control leads to the decision to increase the longitudinal post tension by about one third. This allows the bridge to be load balanced, with the prestressed forces offsetting the dead load moments. Any creep or shrinkage would simply shorten the structure without raising or lowering the tips. Additional provision for camber control includes the installation of two extra ducts four ungrouted (greased and wrapped) tendons, and detailing to provide for additional exposed tendons inside the box.

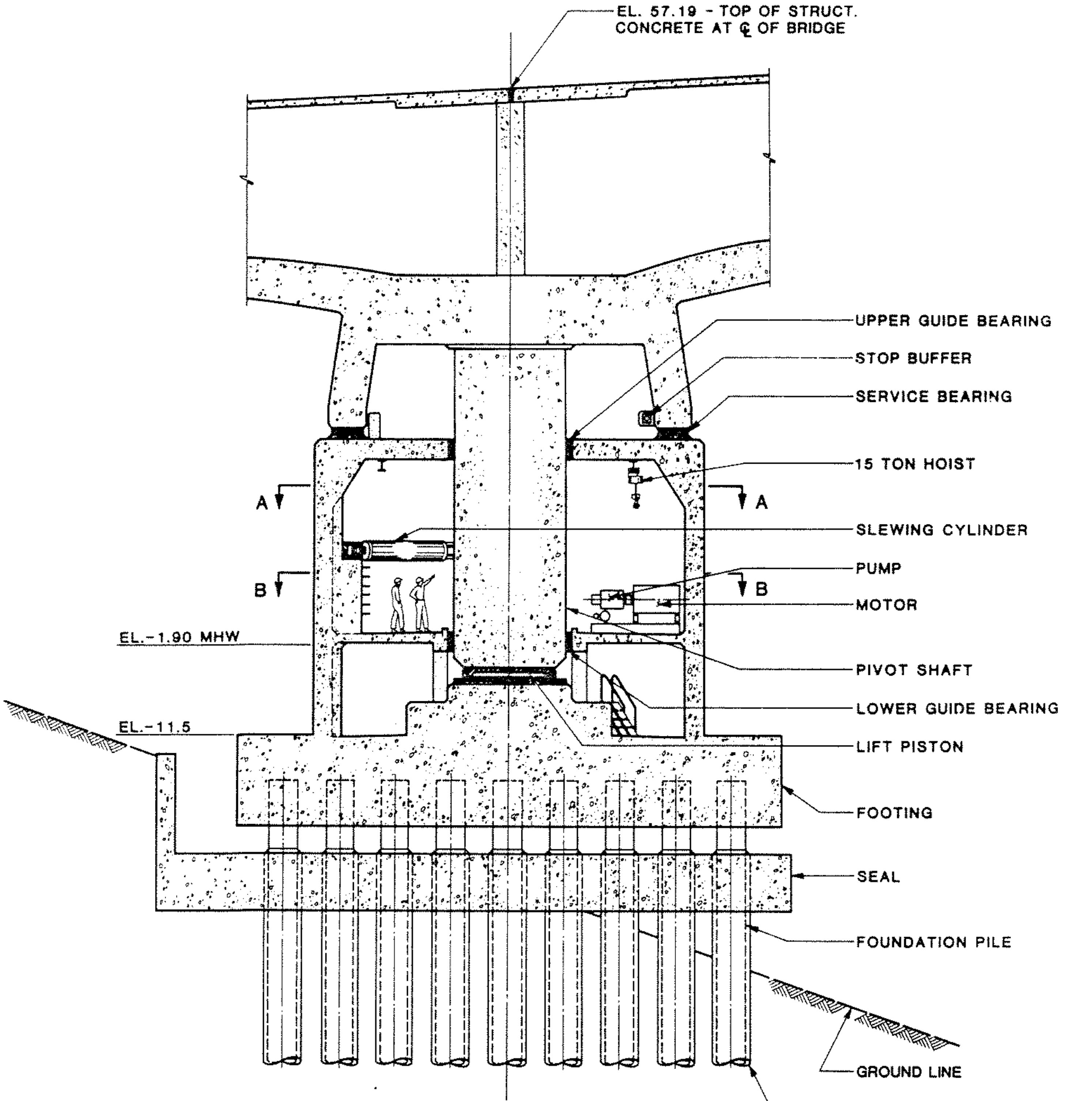
The plinth at the pivot pier (Figures 1 & 3) serves as the transition element between the box girder and the supporting substructure and is sized for load distribution to the supports. The plinth provides two separate load paths for the vertical loads and moments. Load transfer in the normal service or closed position is through the outer shell of the plinth to the service bearings located at the top of the machinery housing. Load transfer in the slewing or open position is through diaphragms and the base slab into the pivot shaft to the guide bearings and lift piston.
The pivot shaft is 12 feet outside diameter. The shaft is composed of a 1-3/4" thick steel outer shell stiffened by bracing and diaphragms. The annular space inside the shell is filled with high strength concrete which is made composite with the steel. The shaft not only serves to lift the superstructure free from the service bearings, but also to stabilize the bridge against overturning moments due to wind or accidental eccentricity during the swing operation and to carry the swing torque from the slewing cylinders to the superstructure.

SUBSTRUCTURE

The 42'-8" diameter cylindrical housing (Figures 3 & 4) transmits the superstructure loads in the closed position down through the walls to the foundation. Vertical and overturning loads are transmitted to the top of the wall through a ring of 16 service bearings. Lateral loads are carried through the pivot shaft. In normal operation there is only a small component of force normal to the walls because of the arrangement of the slewing cylinders. At the base of the pivot shaft is a stepped plinth which distributes the load from the Lift/Turn cylinder into the footing.

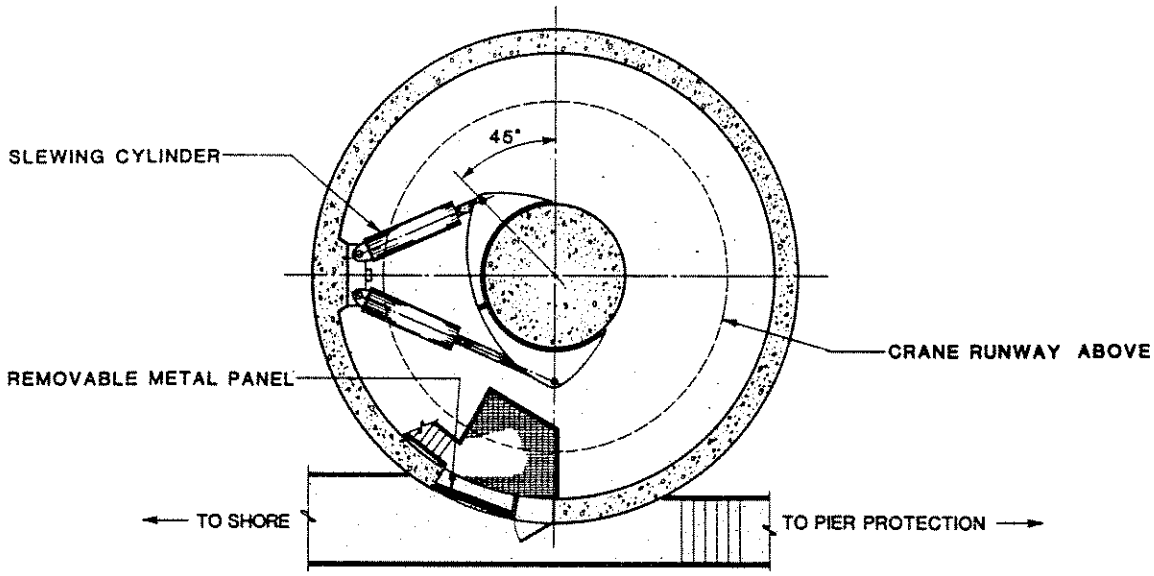
The foundation consists of a 9'-6" thick pile cap resting on 32 pile, each 36 inch diameter steel pipe. These pile will be driven to 600 ton capacity into a hard glacial till layer about 150 ft. down, then filled with concrete. The pile are designed to act fully fixed for translational moments top and bottom.

The project is located in a moderately active seismic zone. Current seismic design philosophy recommends that every structure has a pre-selected ductile system to limit energy and isolate damage to repairable areas. Most fixed bridge design utilizes the columns to provide ductility. This structure, like most movable bridges, has no columns in which to provide ductility. It was decided that the steel pipe pile acting in a translational moment mode provided the only opportunity for introducing seismic ductile resistance. The pile are designed to yield slightly during the predicted 500 year earthquake. Small observation pipe are installed in four of the pile to determine if and where deformation has occured following an earthquake.

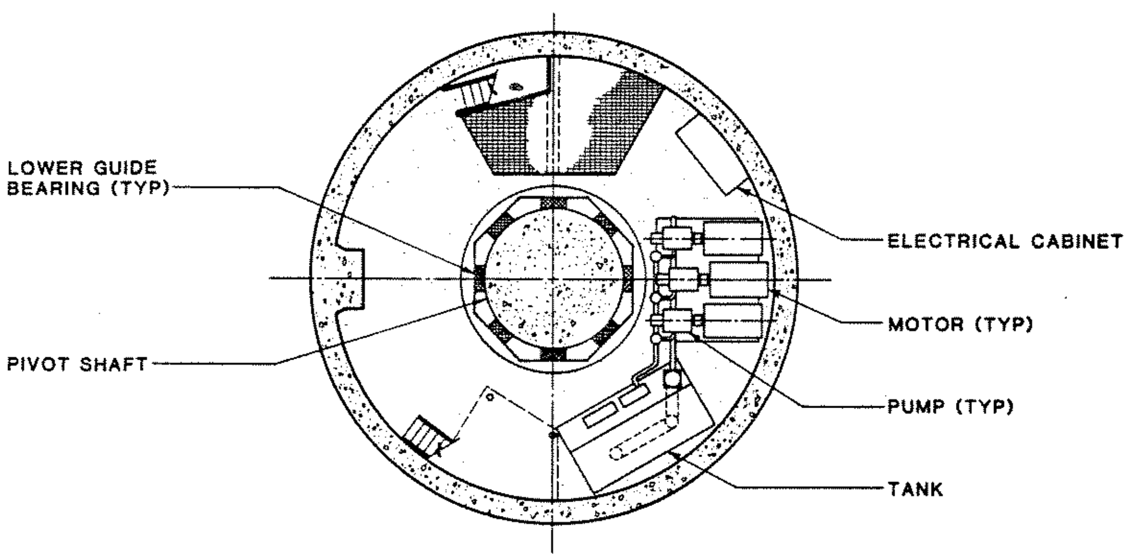


PIVOT PIER SECTION

FIGURE 3



SECTION A-A



SECTION B-B

FIGURE 4

A significant problem with the pile foundations is the location of the pivot pier in the slope of the future channel. Pile foundations placed directly on this slope would result in a large variation in pile lateral stiffness depending upon the elevation of the slope surface. This would lead to uneven distribution of shear loads to the piles and eccentricity of the pile group shear resistance with respect to the supported mass. This eccentricity would lead to increased seismic response forces from excitation of torsional response modes.

A seismic isolation scheme was developed to separate the seal and the footing. The foundation piles are separated from the seal by sleeves extending down into the soil. The sleeves are larger diameter piles which carry the weight of the seal to the slope soil. The annular space between the foundation pile and the sleeve pile is partially backfilled (to elev. -44 feet) with granular material. The annular space above that level is left open. The purpose of the sleeve pile is to create a uniform level at which the lateral soil support for the foundation pile begins. All pile of the group will thus share the shear loads equally and the excitation of torsional response modes will be minimized. The space between the seal and the footing will be left open.

OTHER ELEMENTS

Approximately 400 to 500 feet of approach structure lead from the grade level over adjacent roads and railroads on each end of the main span. These structures are precast I girder construction with cast-in-place composite slab. Spans range from 127 feet up to 164 feet. Bents are typically two columns with a flush cap beam and are supported on precast concrete pile.

The control tower is an independent structure set adjacent to the West bank pier. It extends 120 feet above the water and is oriented to provide an excellent direct line of sight view of both the roadway and the Waterway. Constructed of cast-in-place concrete, it resembles an air traffic control tower. It is equipped with many modern amenities such as an elevator, air conditioning and supplemental closed circuit T.V. to observe the traffic gate areas.

Because the existing bascule bridge has had several incidents of ship impact which disrupted traffic, there was great emphasis placed on pier protection. Forty five foot diameter sheet pile cells are placed upstream and downstream of the bridge ends when in the open position. A massive horizontal concrete beam extends along the length of the bridge, supported on 36" and 48" pipe tripods. An expendable and easily repairable timber facing runs continuously along and beyond the concrete beam. Construction of much of the pier protection on the East bank will be delayed until after dredging because it would be located at the current shore line.

OPERATION

The operating time to fully open or close the bridge (exclusive of traffic control devices) is 120 seconds. The bridge need only swing through a 45° arc which obviously takes less time than a 90° swing, however, much of the time is spent accelerating and decelerating the huge mass.

The superstructure including the pivot shaft weighs 7800 tons per leaf. Because of the large mass of the structure, most conventional swing bridge operating mechanisms were beyond their practical load and size limits. New methods were investigated using hydraulic components for movement and static bearings for traffic loads. See Figures 3 and 4 for Pivot Pier details. The superstructure rests on service bearings which carry the vertical loads when the bridge is in the closed position. As the bridge starts to open, a large diameter, short stroke, hydraulic cylinder, located at the base of the pivot shaft, lifts the bridge free of the service bearings and acts as a hydraulic bearing during the swing operation. The basic idea is as old as the barber chair, however, the application and size are rather unique.

The details of the hydraulic and control systems are the subject of another paper presented in the "Hydraulics" portion of this seminar. Description here will be limited to what the system does rather than how it does it.

Service bearings are located at the level of the roof of the machinery housing. These bearings carry dead load, live load, wind, and seismic loads directly to the walls of the machinery housing when the bridge is in the closed position. There are 16 bearings for each leaf equally spaced around a 37 foot diameter circle. Each bearing is 3'-0" diameter reinforced elastomeric assembly attached to the roof of the pier housing. These bear on a continuous steel ring which is cast onto the bottom of the superstructure transition cone. The bearings are carefully set into a true plane perpendicular to the axis of the pivot shaft. Thus, the movable leaf may be lowered onto the service bearings at any point in the swing arc. Each service bearing is capable of being individually removed for repair or replacement.

Lifting of the leaf is accomplished by a hydraulic Lift/Turn Cylinder which operates between the bottom of the pivot shaft and a pedestal on the footing. These hydraulic-cylinders are 108 inches in diameter with a normal 1 inch stroke, but with the ability of a total 5 inch stroke for maintenance. Operating pressure for the normal lift is 1700 psi. By blocking at the service bearing level these lift pistons may also be removed for maintenance or replacement.

Vertical stability in the open position is maintained by two sets of guide bearings against the pivot shaft. One is located at the roof level of the machinery housing and the other at the machinery floor level. These bearings have bronze bearing surfaces backed by a reinforced elastomer. There are 8 bearings at each level.

Rotational torque is applied to the pivot shaft by a pair of push-pull slewing cylinders. Each cylinder is 22 inch diameter bore by 84 inch stroke and has a 10 inch diameter rod. A single cylinder is capable of operating the bridge at half speed (i.e., 2 times normal operating time). Operating pressures under normal conditions are based on 1000 psi.

Hydraulic power for lifting and slewing is provided by three variable flow hydraulic pumps in each machinery housing. Normally two of the three pumps are used on an alternating basis with the third pump as a back-up. Each pump is powered by a 100 horsepower electric motor. A standby diesel driven generator set is provided in each pivot pier with sufficient power for reduced speed operation in the event of a power failure.

Stopping the swing of the superstructure was an area where redundant systems were considered essential. Normal breaking is accomplished by throttling the flow in the slewing cylinders on a pre-programmed basis. Hydraulic buffers are located at the interface between the tailspan and the adjacent approach structure to provide an emergency stop in the closed position. A pair of hydraulic buffers located on the roof of each pier housing provide for emergency stop in the event of over travel in the open position. These buffers are sized to stop the structure at its maximum rate of swing. Loads induced in various structural elements by the emergency buffers are kept at a level below seismic design loads.

A single center lock is provided at the center joint between the two movable leaves. A larger single lock is located between each tail span section and the adjacent approach structure. These locks prevent relative vertical and horizontal movement between adjacent elements, thus maintaining a smooth riding surface. The torsional stiffness of the box girder is such that one lock in each location is adequate for controlling relative displacements due to live load.

The deck joints have reinforced steel edges that provide about 1/2 inch of gap on the warmest day and about 2-1/2 inches on the coldest days. Provision is made to adjust the gap for anticipated shrinkage and creep.

Construction of the bridge superstructure will be accomplished in the open position to allow clearance of the maritime channel. As the superstructure is nearing completion, temporary closings to check alignment of the center and tail closures will be made. Construction, including demolition of the existing bridge, is anticipated to require 18 months. During this time traffic will be diverted over the high level bridge.

The project owner is the City of Seattle with funding assistance to be provided by the Port of Seattle. Design consultants are the West Seattle Bridge 2 Design Team, a joint venture of Andersen Bjornstad Kane Jacobs, Inc., Parsons Brinckerhoff Quade & Douglas, Inc., and Tudor Engineering Company. Hamilton Engineering Company assisted in development of the hydraulic and control systems design. Construction of the project is scheduled for late 1986.

FUTURE CONSIDERATIONS

Concrete swing bridges may provide an economical design solution for longer span movable bridge applications. Economical spans would seem to range from 250 ft. to 600 ft. Adjacent clear area to accommodate the tail swing is required. Balanced cantilevers (main span and tail span cantilevers the same length) provide the optimum solution. Where extensive approach spans are a requirement the tail span reduces the length of these approaches which was found in this case to provide a significant cost saving. Maintenance costs on this structure are projected to be much less than other movable bridge types. As with any swing bridge, exposure to ship impact is along a more extensive reach of channel. However, damage to the concrete structure would probably be less than to a steel structure.

Regarding application of codes, this unique structure required interpretations in several ares. Questions were:

1. When is an element, such as the 12 foot. pivot shaft a structural element and when is it a piece of machinery?
2. What are the proper safety factors and load factors to apply to such elements?
3. What is a proper safety factor on elements in excess of the load that can be applied by hydraulic systems that are limited by pressure relief valves?
4. How does one approach the seismic design on movable bridges which have no ductile elements?
5. How does one consider the center locks in seismic design?
6. What is the policy for seismic design for a bridge in the open position?

These are some of the interesting questions which challenge us as engineers in the movable bridge field.