BONNEVILLE LOCK AND DAM CONCRETE SWING BRIDGE

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Introduction

The U.S. Army Corps of Engineers has long been known for their involvement in unique projects. Included among these is the well known Bonneville Dam and Lock on the Columbia River 40 miles east of Portland, Oregon which they operate and maintain. Due to a tremendous increase in the quantity of traffic and size of vessels navigating along the Columbia River, the Corps recently made a descision to replace the existing navigation lock. Located above the downstream end of the lock is a swing bridge that is also to be replaced, consequently, by one of the first **concrete** swing bridges in the United States. Although steel is the traditional material used in construction of swing spans, concrete was selected for this design because of the relatively inexpensive cost when compared to rising steel prices in that region of the U.S. Additionally, the Pacific Northwest produces a high quality concrete due to the availibility of good material components. Aesthetics was a concern of the architects on the design team and thus was another factor in the selection of concrete over steel.

The overall configuration of the bridge is quite unique. The "bob-tail" swing span contains a 117'-6" forward cantilever span and a 69'-4" counterweight span that are supported on a pivot pier which rests high on the embankment out of the navigation channel. (Refer to Figure 1.) The bridge which exhibits an overall width of 32'0" was designed to carry two (2) lanes of vehicular traffic and a pedestrian sidewalk over the channel between landside on the south shore and a powerplant on the dam. The superstructure is of post tensioned box-girder construction and is to be cast-in-place on falsework. The depth varies from 12'-0" at the pivot pier to 6'-10 7/8" and 9'-8 7/8" at the cantilevered ends of the forward span and counterweight span, respectively. During operation, the span undergoes 110 degrees of rotation until it aligns with the skewed navigation channel.

The swing span is of center bearing design and utilizes balance wheels to support the unbalanced loads and stabilize the span during operation. (Refer to Figures 2 and 3.) The superstructure is held in place while the span is closed (i.e., open to vehicular traffic) using center wedges at the pivot pier and a system of

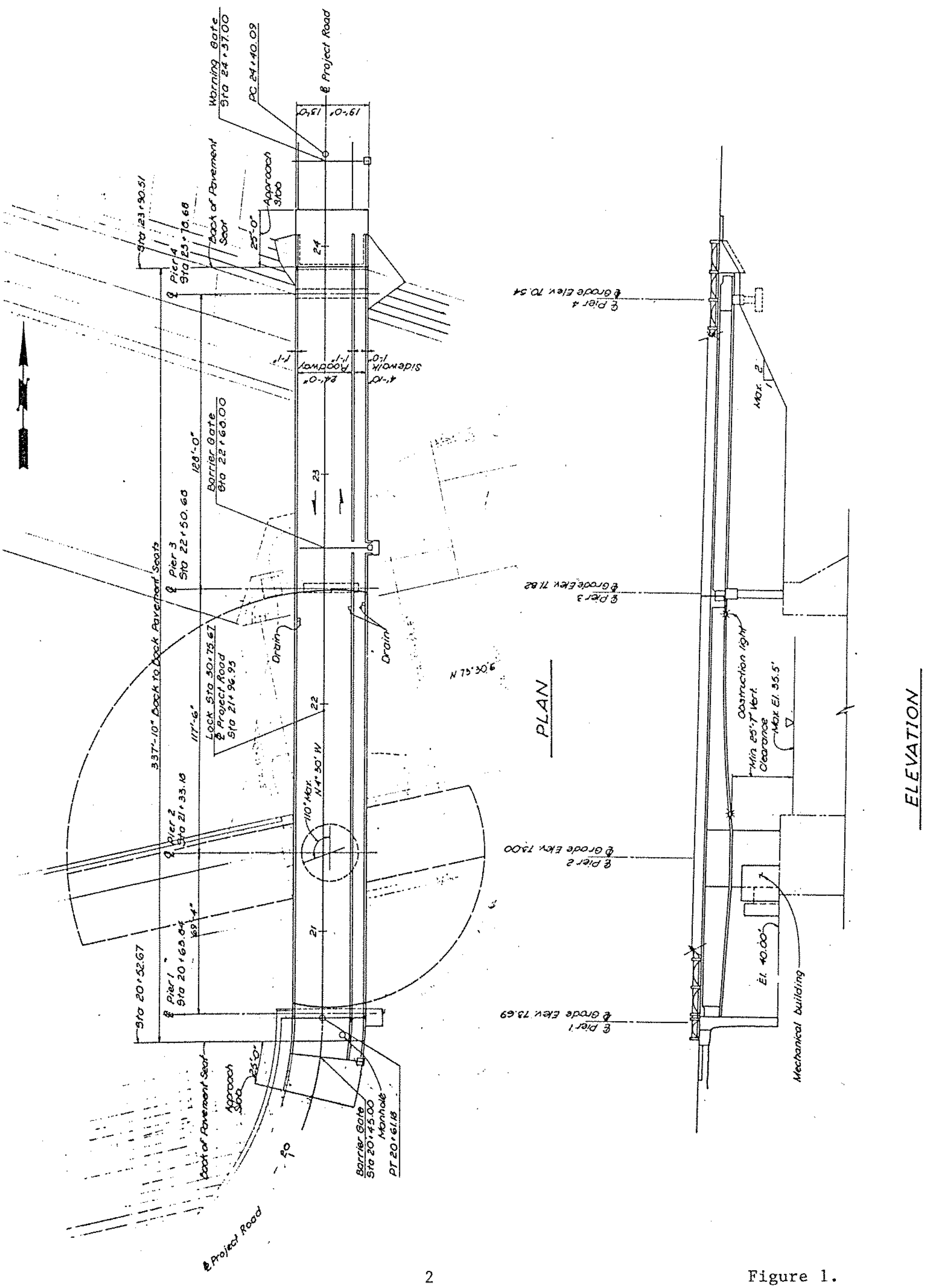

Warning Gate Sta 24+37.00
PC 24+40.09
℄ Project Road
19'-0"
13'-0"
Approach Slab
25'-0"
Back of Pavement Seat
Sta 23+90.51
Pier 4 Sta 23+70.68
24
1'-1"
Roadway 24'-0"
1'-1"
Sidewalk 4'-0"
1'-0"
Barrier Gate Sta 22+60.00
128'-0"
23
Pier 3 Sta 22+50.68
337'-10" Back to Back Pavement Seats
Drain
Drain
N 75°30' E
Lock Sta 30+75.67 ℄ Project Road Sta 21+96.95
117'-6"
22
110' Max. N 4°30' W
Pier 2 Sta 21+33.18
69'-4"
21
Pier 1 Sta 20+63.84
Sta 20+52.67
Approach Slab
25'-0"
Back of Pavement Seat
20
Barrier Gate Sta 20+45.00
Manhole
PT 20+61.18
℄ Project Road
PLAN
℄ Pier 4 ℄ Grade Elev. 70.54
Max. 2 1
℄ Pier 3 ℄ Grade Elev. 71.82
Obstruction light
Min 25'-7" Vert. Clearance
Max. El. 55.5'
℄ Pier 2 ℄ Grade Elev. 73.00
El. 40.00'
Mechanical building
℄ Pier 1 ℄ Grade Elev. 73.69
ELEVATION

Figure 1.

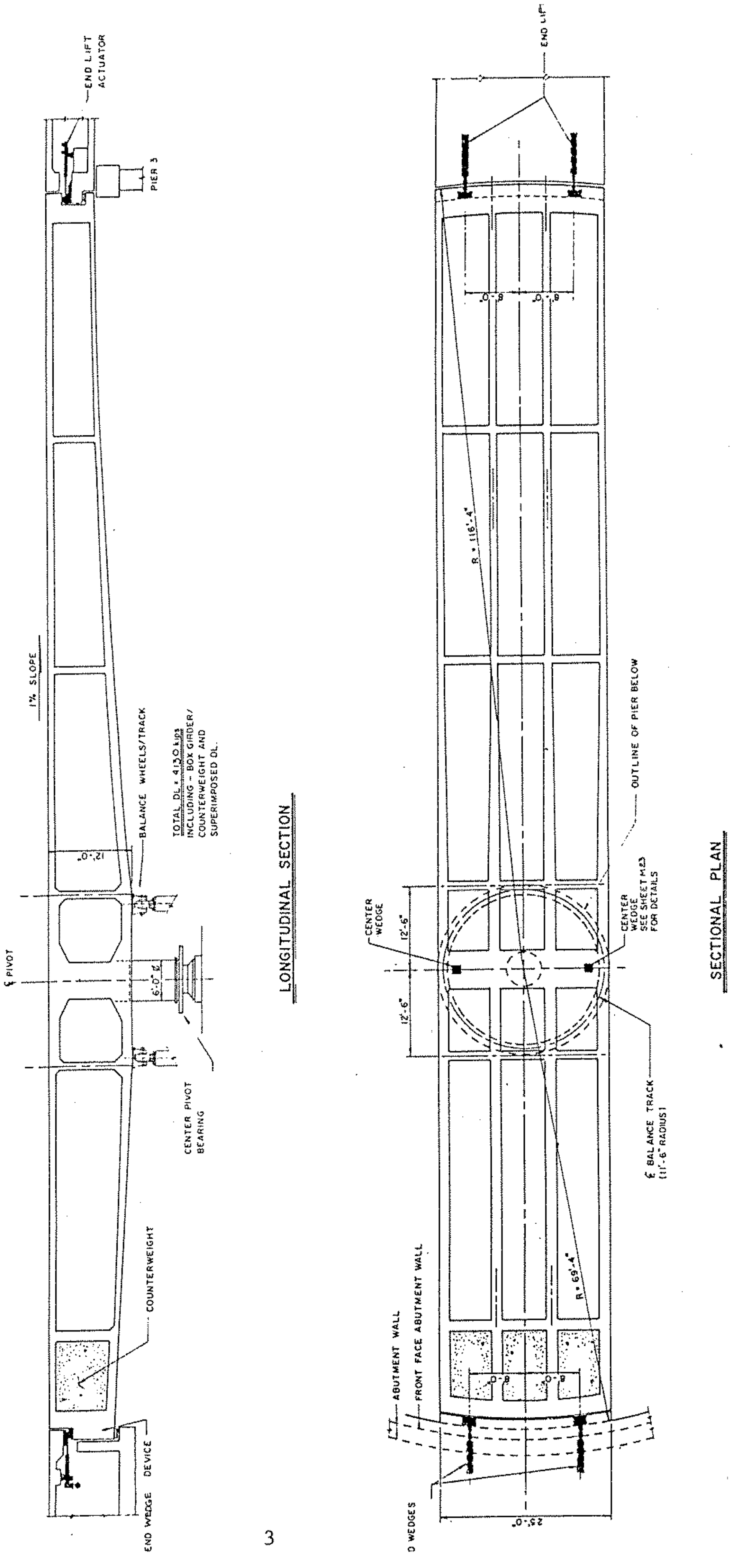
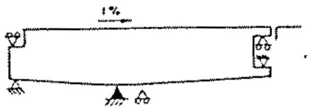

END LIFT ACTUATOR
PIER 3
1% SLOPE
TOTAL DL = 4130 kips
INCLUDING - BOX GIRDER/
COUNTERWEIGHT AND
SUPERIMPOSED DL.
BALANCE WHEELS/TRACK
12'-0"
℄ PIVOT
6'-0" Ø
CENTER PIVOT BEARING
COUNTERWEIGHT
END WEDGE DEVICE
LONGITUDINAL SECTION
END LIFT
8'-0"
8'-0"
R = 116'-4"
OUTLINE OF PIER BELOW
CENTER WEDGE
CENTER WEDGE
SEE SHEET M23
FOR DETAILS
12'-6"
12'-6"
℄ BALANCE TRACK
(11'-6" RADIUS)
R = 69'-4"
8'-0"
8'-0"
ABUTMENT WALL
FRONT FACE ABUTMENT WALL
D WEDGES
25'-0"
SECTIONAL PLAN

Figure 2.

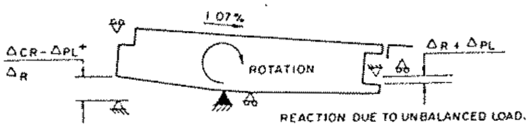
OPERATION SCHEMATIC

1. BRIDGE - CLOSED (OPEN TO VEHICULAR TRAFFIC).



2. PULL CENTER WEDGES, PULL END WEDGES.

3. PULL END LIFTS (SPAN ROTATES TO CLEAR BEARINGS AND RESTS ON BALANCE WHEEL).



4. SWING SPAN MAINTAINING ROTATED POSITION.

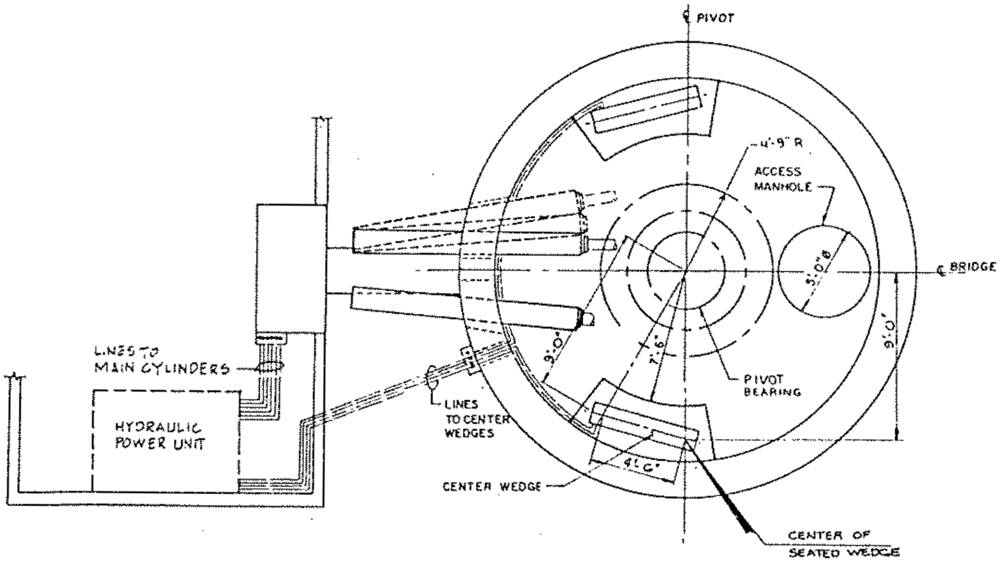
5. WITH SPAN IN CLOSED POSITION, DRIVE END LIFTS.

6. DRIVE END WEDGES, THEN CENTER WEDGES (SAME DIAGRAM AS 1)

Δ_{CR} = DEFLECTION AT COUNTERWEIGHT END DUE CREEP AND SHRINKAGE

Δ_{PL} = DEFLECTION DUE PRELOAD INCLUDING 1/4" LIFT AT END LIFT AND TEMPERATURE EFFECTS.

Δ_R = MOVEMENT DUE TO ROTATION; 1" AT LIFTS, 5/8" AT WEDGES.



PLAN BELOW SWING SPAN
NTS

Figure 3.

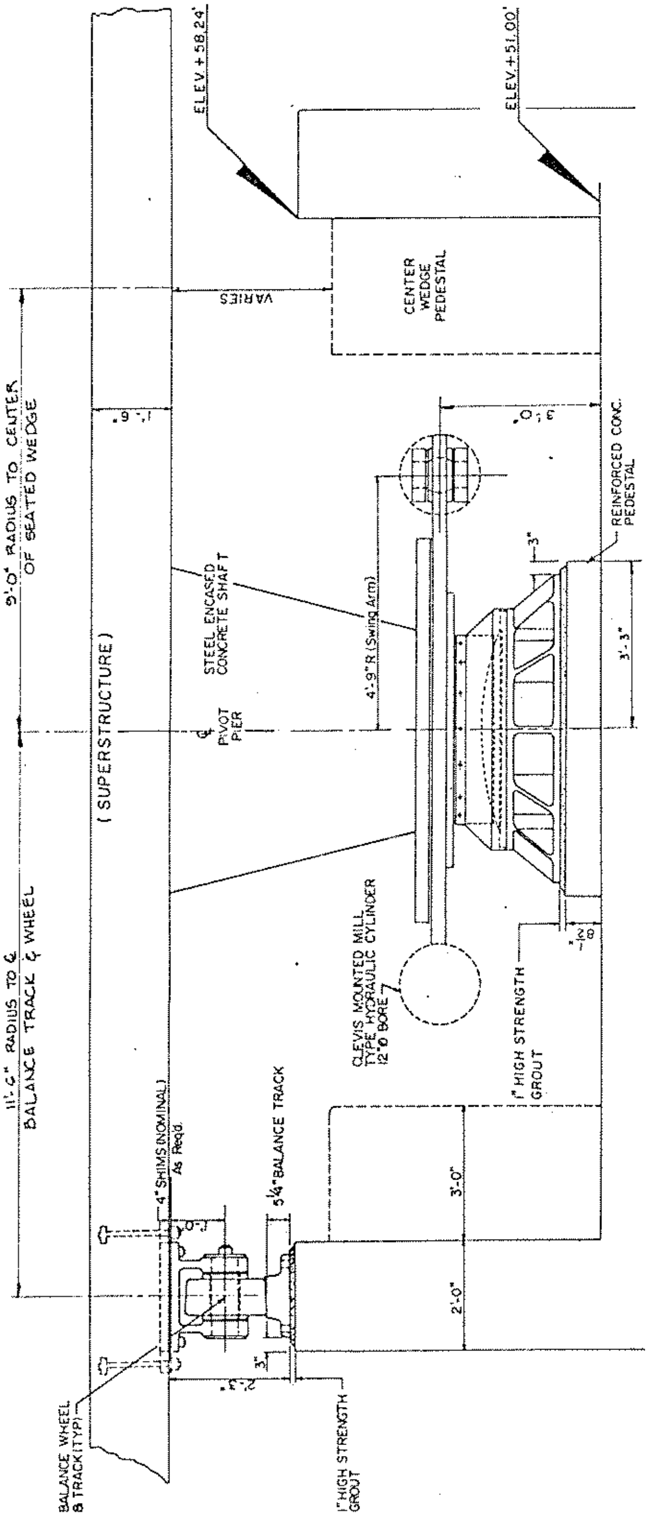
bearings and wedges at the counterweight end and bearings and lifts at the cantilever end. The span is driven using a pair of hydraulic cylinders which operate in opposite directions (i.e., one extends while the other retracts.)

Unlike most steel swing spans, while the span is closed the dead load and live load are almost solely supported upon the center pivot bearing. The tremendous stiffness of the diaphragm over the center bearing makes it nearly impossible to redirect live loads through the center wedges. The center wedges and end lifts and wedges are driven to a pre-loaded amount to provide stability and prevent uplift due to live load, wind load and thermal movement. To open the bridge, the center wedges and end wedges at the counterweight end are first pulled to release the span from its locked position. The span is purposely unbalanced towards the forward cantilever side (by an amount equal to 150% of the load required to tilt the span against bearing friction) so that it rests upon the end lifts and end bearings at this location. As the end lifts are withdrawn, the span tilts to clear the bearings at each end of the span and comes to rest on a set of balance wheels at the forward side of the pivot pier. The span is then rotated counterclockwise to its open position. This procedure is reversed to close the bridge.

In comparison to a typical steel swing span of this size, the concrete swing span exhibits much larger inertial forces and vertical reactions. Additionally, the concrete swing span exhibits creep, shrinkage, and thermal movements that are not found in steel swing spans that create complications in the design and operation of the span. This paper discusses the simple, yet innovative design solutions used to overcome these problems.

Center Bearing

The concrete superstructure produces a 4000 kip center bearing reaction. This reaction creates problems in design of both the center bearing and its lubricant system. A spherical "ball-joint" design with omni-directional rotation was selected for the bearing because of the advantages of allowing the span to both tilt forward under the unbalanced load and pivot during span operation while maintaining a uniform pressure distribution under forces of variable magnitude and direction. Due to the geometric contraints provided by the size of the pivot pier and the path of the hydraulic drive cylinders, the size of the bearing had to be reduced to a minimum. (Refer to Figure 4.) A steel bearing substrate was selected over traditional bronze because of increased bearing capacity thus resulting in a bearing of smaller design. A 42" diameter steel bearing with an 80" radius of curvature could be used compared to a 60" diameter bronze bearing. Additionally, the steel spherical bearing avoids much of the unequal deformations or



PIVOT PIER SECTION

Figure 4.

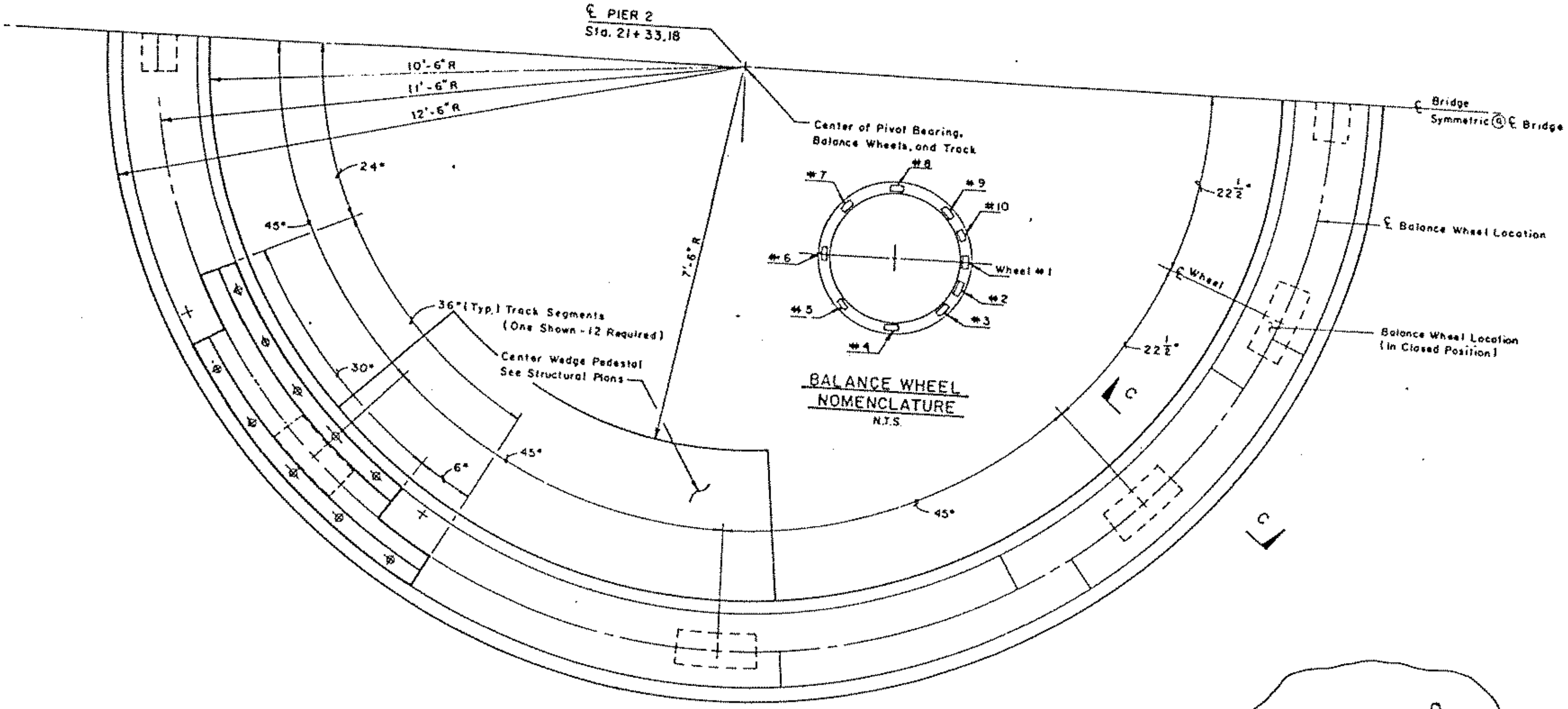
lack of parallelism in the upper and lower sliding surfaces caused by large dynamic forces. A stainless steel welded overlay was additionally added for corrosive protection and scoring resistance. Because a steel bearing exhibits a higher coeffient of friction than a similar bronze bearing when utilizing conventional supplmentary lubrication, a lubricant system which exhibits a low coefficient of friction that is independent of the substrate material was selected.

The friction forces are a function of the large vertical reactions. Thus a woven teflon fabric (PTFE surface) was selected as the lubricant system for the center bearing because of its low cofficient of friction (which varies from 0.04 to 0.09 according to manufacturers specifications) in order to reduce the demand by the drive machinery. The PTFE surface was additionally chosen because of its ability to resist breakdown under high static loads over sustained periods of time. This permeanant solid thick-film lubricant requires virtually no maintenance and no form of supplementary lubrication. The woven teflon fabric has several advantages over the traditional teflon surface. For example, the fabric is mechanically interlocked to a geometrically grooved surface which provides a superior bond compared to resin bonded teflon lubricants. Additionally, according to the manufacturer, the woven teflon fabric exhibits more than 30 times the bearing capacity of a regular teflon surface and a much greater shear resistance thus eliminating plastic flow and insuring a low coefficient of friction and uniform lubrication.

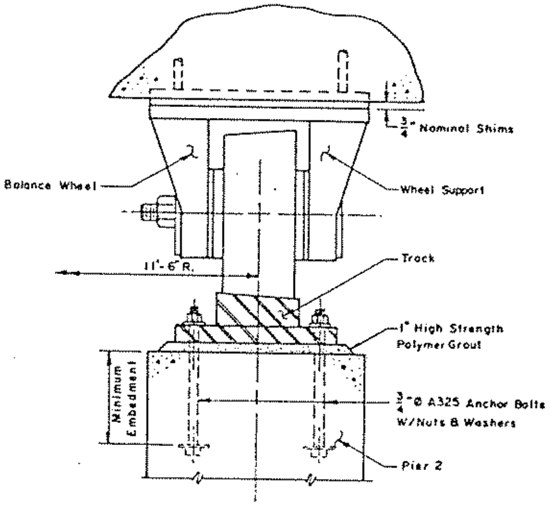
Balance Wheels

The balance wheels are chiefly designed to support the unbalanced load after the end lifts at the forward cantilever side are withdrawn and the span tilts to clear the end bearings. A set of five (5) wheel assemblies are attached to the underside of the superstructure along the forward most 90 degrees of the circular track. (Refer to Figure 5.) Additional wheels are spaced along the track at the rear and sides of the pivot pier to stabilize the span when it is subject to high winds during opening. When the center and end wedges are driven, the balance wheels are designed to clear the track and therefore avoid loads. When the span is tilted forward under normal unbalanced load, all five (5) forward wheels are designed to provide positive contact with the track; shims are provided for adjustment. The design additionally maximizes the number of wheels in contact under other loading conditions. The typical forged steel wheels are tapered (as is the track) so that they experience rolling only during movement thus reducing friction and wear at the wheels.

The circular track exhibits a 23'-0" diameter and rests atop the wall surrounding the pivot pier. For ease of installation and to



HALF SECTION THROUGH PIVOT PIER
SHOWING TRACK SEGMENTS & BALANCE WHEEL LOCATIONS



SECTION C-C

Figure 5.

insure a level rolling surface, the track is assembled using twelve (12) steel weldment arc segments, machined to remove any warping and irregularities. Leveling screws and a high strength grout pad are used to insure an overall level installation. Dowell pins are also used between track segments to insure the transitions remain smooth.

Hydraulic Drive Cylinders

Two (2) dual operating hydraulic cylinders work in opposing directions to drive the swing span. (Refer to Figure 3.) The cylinders were chosen over other modern drive systems (i.e., hydraulic motors, or variable speed electric motors) because of their cost effectiveness and ability to accomodate large inertial forces. In general, hydraulic systems offer advantages over electric motor systems in particular movable bridge applications, such as those requiring delivery of high torque without space for extensive gear reduction. Because the large inertial and friction forces, which are always present, controlled the design loads, the drive system would face near maximum loads during every operation. This compares to a typical bridge which faces the maximum loads only under rare high wind conditions. The ability of the hydraulic cylinder system to operate under these higher loads without penalty enhanced its position. Motor systems require brakes to meet holding forces produced by high wind loads, but a cylinder system is already designed to accomodate this case.

Design resulted in two (2) 12" diameter bore mill-type hydraulic cylinders designed and sized for a maximum operating pressure of 3000 psi. The cylinders are not NFPA industrial tie-rod construction cylinders as are typically used on movable bridges in the United States. Instead, the mill-type cylinders were selected for their improved chevron type rod seals, increased buckling resistance, and superior durability. Although initially more expensive than NFPA standard cylinders, indications are that mill-type cylinders will be more economical over the life of the bridge and reduce the need for timely and extensive rehabilitation.

Another unique feature of the operating cylinders is the presence of a built-in safety buffer. The blind end of each cylinder is equipped with a special cushion vented through a relief valve. In the unlikely event the bridge were to swing past the fully open or fully closed position the piston would engage the cushion. As the cushion is engaged the pressure behind the piston will be held at a relief valve setting. The cushion stroke is sized such that one cylinder's cushion will absorb the energy of the moving span before the cylinder bottoms out.

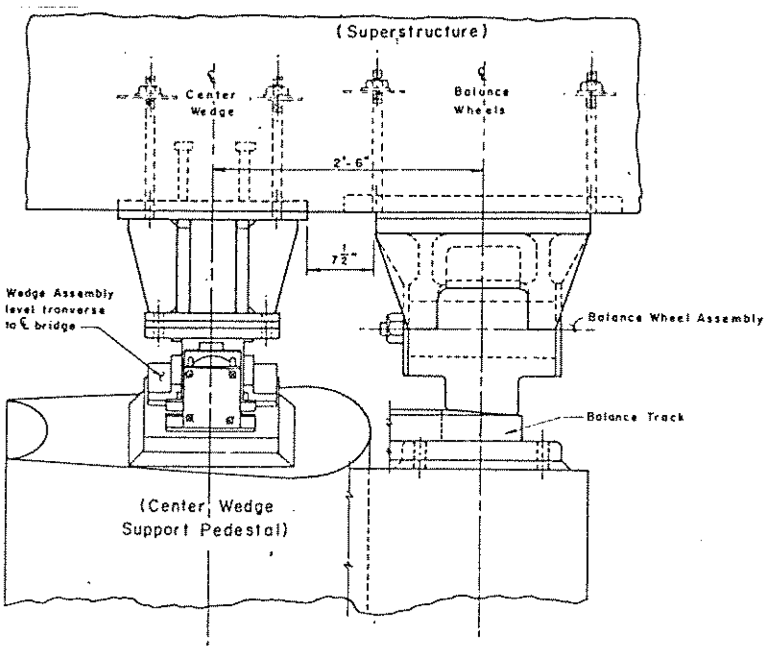
The two (2) cylinders operate in opposite directions, i.e one extends while the other retracts, and exhibit an operating stroke of 8'-0". Due to geometrical considerations, they are clevis mounted to a swing arm at the pivot bearing and, because of their length, to a structural column outside the pivot pier wall. The clevises contain plain spherical bearings to allow for the tilt and pivot of the span and to accomodate any misalignment associated with installation; this significantly reduces the wear on the rod seals.

Redundancy is designed and built into the operating system to improve reliability and allow for in service maintenance. The bridge is designed for operation using only one cylinder. That is, if either cylinder is inoperable, the power unit and other cylinder have the capacity to operate the bridge at one-half normal speed. Redundancy is also incorporated into the power unit. The unit is composed of two (2) 25 Hp (18.6 kW) pump/motor units, a 100 gallon reservoir, and manifold mounted valving. Should a pump or motor require service, the bridge can be operated with either pump/motor at half normal speed. Additional provision is made for full manual operation should the main control system, a programmable controller, fail.

Center Wedges

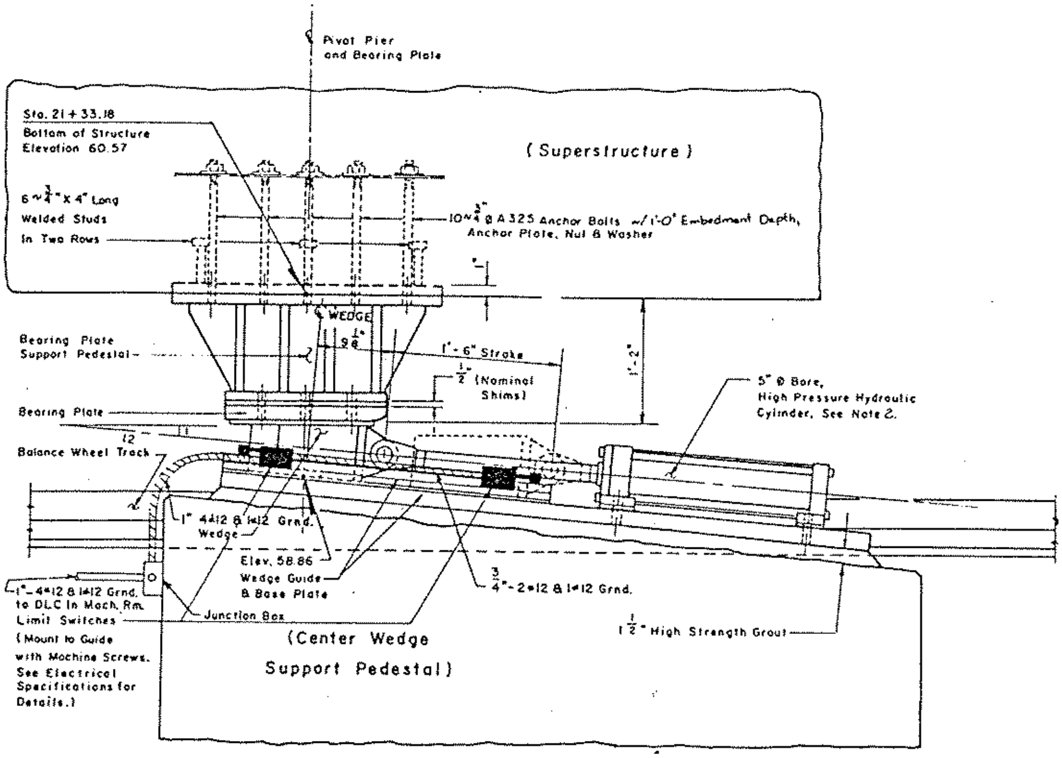
Two (2) center wedges are provided at the pivot pier to lock the swing span and provide a positive reaction to resist lateral overturning about the center bearing due to live load and wind load. (Refer to Figure 6.) On typical steel swing spans in which the center wedges are located on the transfer girder beneath the main girders, live loads are transferred directly through the center wedges. The large stiffness of the concrete box-girder diaphragm over the center pivot, however, doesn't allow redistribution of live loads to the center wedges. The wedges are preloaded to a force equal to 150% of that required to provide positive contact under all loading conditions. The large force that was required and the limited amount of space available for the actuator stroke dictated that hydraulic cylinders be used to drive the wedges. This selection was additionally appropriate as the cylinders could be easily and inexpensively tied into the hydraulic system used to power the main drive cylinders.

The design resulted in two (2) NFPA standard tie-rod cylinders with a 5" diameter bore and a 1'-6" stroke. The relatively small tie-rod cylinders were a cost-effective selection in this situation as they are quite accessible for inspection, maintenance, or replacement. To avoid the use of long flexible hydraulic lines the wedges are not mounted on the swing span. Instead they are mounted on inclined concrete pedestals on the pivot pier while the wedge guides were mounted to the superstucture; as the wedges are withdrawn they clear the guide allowing free movement of the swing span.



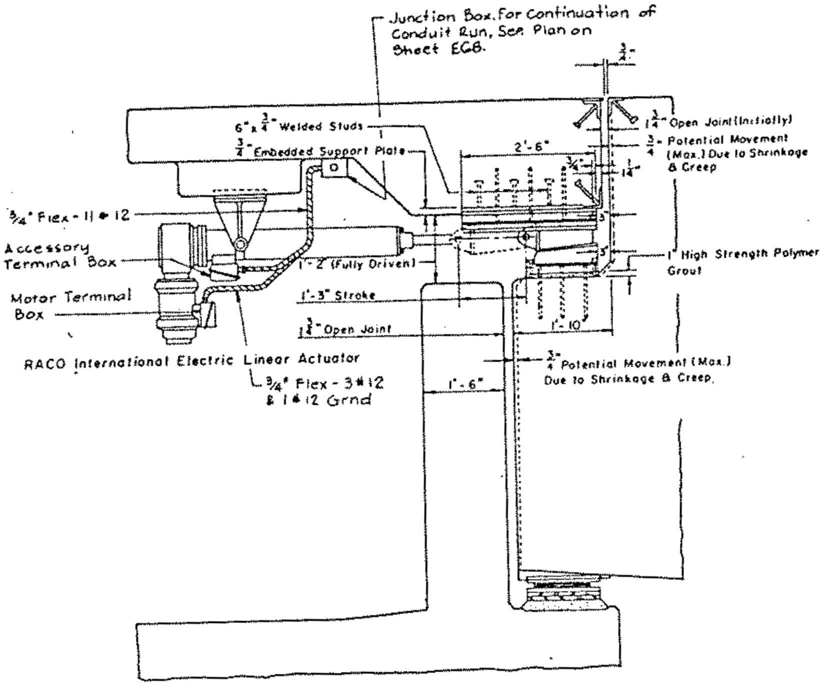
END VIEW

CENTER WEDGE ASSEMBLY

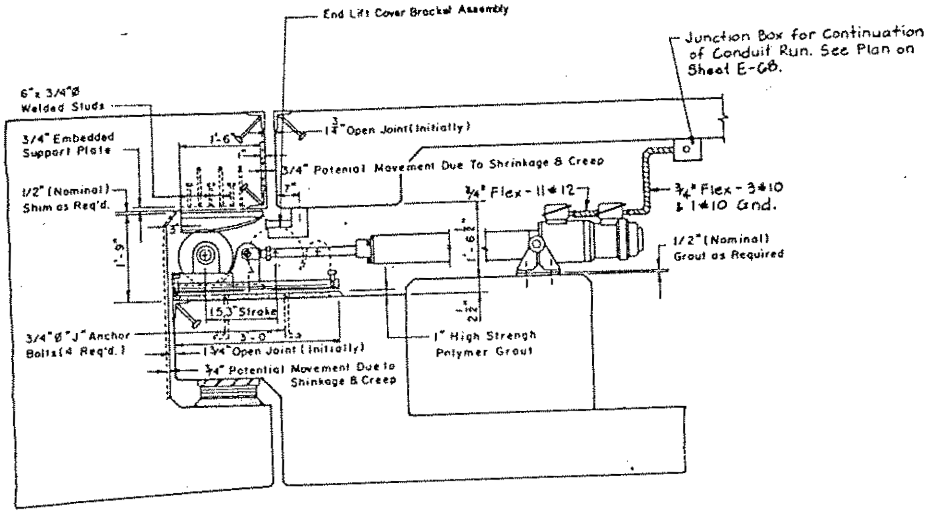


SIDE VIEW

Figure 6.



END WEDGE ASSEMBLY



END LIFT ASSEMBLY

Figure 7.

End Lifts, Wedges, Bearings

To insure the cantilever ends of the swing span provide positive contact under all loading conditions a wedge and bearing system at the ends of the span was developed. (Refer to Figure 7.) As the bearings must be clear of the superstructure to open the span and because the overall cantilever deflections are relatively small the concept of tilting the superstructure was adopted. This method is commonly used on small swing bridges such as this. Rotation corresponding to 1" of vertical movement at the forward cantilever span and 5/8" at the counterweight end was found to provide adequate clearance for span operation under normal conditions.

However, although the post tensioned concrete superstructure was designed for uniform axial compression (i.e., prestressing forces were designed to balance the dead loads) it was felt that the box girder may still undergo unexpected non-uniform creep and shrinkage redistribution which could result in undesirable cantilever deflection. The span is also subject to temperature gradients where the top surface becomes hotter (or colder) than the bottom surface thus resulting in additional deflection of the cantilevers. Each of these effects result in deflection that may move the ends upward or downward which must additionally be accounted for. The maximum predicted movement at each of the ends, including span rotation is 3" at the forward cantilever end and 1-3/4" at the counterweight end.

Although the mechanisms at both ends of the bridge resemble wedge assemblies, the assembly at the counterweight end functions as a wedge while the assembly at the forward cantilever end functions as an end lift. During the opening sequence, the end wedge is withdrawn thus releasing the tail. Due to the unbalanced conditions the span rests upon the end lift and its corresponding neoprene bearing. As the end lifts are withdrawn, the span tilts to clear the bearings and wedges at both ends. Limit switches are provided to indicate whether the span has tilted and is clear. During the closing sequence, the end lifts are driven raising the forward cantilever end to the established elevation dictated by a set actuator stroke. This additionally brings the tail into contact with the counterweight bearing. The end wedge is then driven a predetermined stroke which corresponds to a preload amount to insure positive contact.

Two (2) wedges are provided at the counterweight end which are of typical wedge block and guide configuration. The angle of incline of the ramp, length of stroke, and the required driving force were optimized in design of the wedges. Independent acme screw electric linear actuators were selected to drive the wedges due to their isolated location. The use of hydraulic cylinders for this application would have required independent power units at each end of the span.

To reduce the force required to drive the end lift, the assembly utilizes a guided wheel which rolls up an incline with a variable slope. The wheel assembly itself slides in a guide. The assembly thus experiences sliding friction on one side and lesser rolling friction on the other side instead of sliding friction on both sides. Additionally, as the span is lifted, the counterweight end comes into contact with its bearing. The resistance due to the stiffness of the superstructure must be overcome which increases linearly with the vertical lift. By decreasing the slope on the ramp the force required to drive the end lift is lessened although the stroke is lengthened. The slope is thus optimized with respect to the driving force and the stroke length. Independent electric linear actuators were used at this location as well.

Protective covers are provided over the wedge and end lift assemblies below the open joints to deflect roadway debris, snow, and rain thus promoting longer life and better performance of the wedges and lifts.

Conclusion

As evidenced with the Bonneville Lock and Dam Swing Bridge, concrete swing bridges exhibit many unique problems which must be overcome. Perhaps the most challenging constraint placed on this project was the cost of the structure imposed by the Corps of Engineers of $1.6 million dollars. The use of concrete for the superstructure results in a substantial cost savings over steel, especially in that region of the United States. However, this savings is offest by the cost of the machinery required to operate the concrete span. Although many different solutions could be used to solve the unique mechanical problems, in nearly all of the components, a non-mechanical constraint (cost) dictated which solution should be used. By using relativley simple innovative solutions, such as those presented in this paper, along with modern methods and equipment these unique problems can be cost effectively resolved thereby making a concrete swing bridge a viable alternative to a steel swing bridge.

The winning bid for this project was a remarkable $1.8 million.