HOOD CANAL BRIDGE

A FLOATING LIFT DRAW BRIDGE

BY

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Introduction

The Hood Canal is a deep channel branching off Puget Sound in the State of Washington. In 1961, a mile long floating bridge designed by the Washington Toll Bridge Authority was completed across the Canal. Because of the depth of the water, over 300 feet, a fixed bridge was not economically feasible at the site.

Other site characteristics determined the features of the bridge. To allow for tidal changes of over 18 feet and to provide longitudinal restraint to the floating portion of the bridge, a 280-foot-long, hinged, transition steel truss was provided at each end of the floating portion. The bridge was transversely anchored to the canal bottom with steel cable anchor lines attached to concrete gravity anchors. In order to provide the 600 foot opening necessary for accommodating large naval ships, the center portion of the bridge incorporated two movable draw spans. The pontoons utilized cast-in-place reinforced concrete with a small amount of longitudinal prestress.

Frequent storms coming off the Pacific Ocean subject the Hood Canal bridge to the dynamic forces induced by waves. On February 13, 1979, a particularly severe storm, remembered by local residents for the extensive damage it did to the surrounding forests, destroyed the western portion of the bridge.

New Bridge

In order to restore traffic as quickly as possible and, at the same time, provide for a new bridge, a three stage construction plan was developed (see Figure 1). The first stage involved replacing the western half of the bridge (Unit 1) with all fixed pontoon units. The second stage (Unit 2) called for removal and storage of three of the Unit 1 pontoons and their replacement with a new movable span. The Unit 2 work was completed in the Fall of 1983. When funding is available, the third stage will replace the eastern half of the bridge with a new structure which makes use of the three stored pontoons from Unit 1.

The original truss was reused after having been fished out of the water, repaired, and strengthened with a new longitudinal strut. All new and much larger gravity anchors were installed. Because of the staged construction, two additional anchors were installed during Unit 1 to be used for Unit 2 construction. (During Unit 2 construction, two of the Unit 1 anchors were abandoned.)

Figure 2 shows the present pontoon and anchor layout. Including approaches, the bridge is 7,863 feet long, with two 280-foot-long transition spans, and a 6,470.8'-long floating portion. The roadway is 30 feet wide to allow for two traffic lanes, one in each direction and includes provision for bikers on the shoulders. The roadway is supported a minimum of 20 feet above the water in order to minimize exposure to spray from waves striking the pontoons.

The pontoons are constructed of prestressed concrete. Typical pontoons are 60'-0" wide by 18'-0" deep and 360'-0" long. Each pontoon is subdivided into 30' x 20' wide watertight cells. The pontoons are post-tensioned longitudinally, transversely, and vertically. They were designed to be built using either precast segmental construction or cast-in-place construction.

The typical superstructure span is 60'-0" long and is made up of four prestressed concrete girders with precast concrete slab forms and a cast-in-place concrete deck. The girders are Washington State Department of Transportation (WSDOT) standard girders modified in width to provide additional cover for the reinforcing steel. The pier bents are conventionally reinforced concrete utilizing 2'-6" to 3'-6" Ø columns, depending upon their height.

While the general configuration of the new bridge follows that of the original design, a major revision was made at the movable span. There, three 104-foot-long steel spans are raised hydraulically to allow the draw pontoon to retract. This change eliminate the dangerous flare in the original roadway and was estimated to be more economical. Each lift span is made up of a steel grid deck, stringers, and floorbeams at 24'-3" feet on centers and two longitudinal girders 75'-0" apart. In the down position, the girders are supported at each end by a reinforced concrete column. A portion of the column continues above the girder to serve as a guide for the lift span when it is being raised.

Expansion and contraction of the entire bridge, from fixed pier to fixed pier, is absorbed at the eastern movable span. When Unit 3 is complete, this movement will be absorbed at the roadway level by a finger joint between the eastern lift deck and the eastern draw pontoon. The motions are due to the transition truss swinging as it moves with the tide, temperature variations, and creep of the prestressed concrete pontoons. Fortunately, the water temperature in the Canal remains fairly constant so that the temperature movement is not excessive for a mile-long bridge.

Due to potential corrosion and maintenance problems, the amount of steel on the bridge was minimized and almost all the structural steel was galvanized. As additional protection, the galvanized steel was painted with a zinc-rich paint and then top-coated with a vinyl paint. Although expensive, the system is expected to have a very long life and should only require minor touch-up painting.

The movable span operations are controlled by an operator in a control tower through the selection of appropriate pushbuttons, selector switches, and drum controllers on a control desk. The operator must supervise the operation of the roadway and barrier gates, lift spans, end locks, longitudinal locks, and drive motors. The draw motors are wound rotor with selenium controlled rectifiers used to vary their speed.

Lift Spans

The lift span is raised hydraulically. Each span has its own power unit, consisting of two 75 hp motors and two 120 gpm pumps. A flow divider is used to equally proportion the fluid to the four lifting cylinders. The cylinders are 12" diameter with a 9'-0" stroke and a neoprene boot to protect the rod. Each cylinder is equipped with a "Bear Loc" to grab the cylinder rod when the span is in the up position on to hold the load in case of loss of fluid pressure. The "Bear Loc" is a patented device which utilizes a hydraulically expanded sleeve around the piston rod. In order to control the lowering of the span, a counterbalance valve is used so that the span is in effect pumped down. The lift spans operate sequentially, after one starts to move, the next unit follows. Each span takes about 75 seconds to rise. While a flow divider was used to equalize the flows in all four cylinders, there is a potential that variations in the system may cause the lift span to go out of level. In order to compensate for this possibility, the spans are leveled at the end of every up or down stroke. This is done by operating the pumps until there is an indication from a limit switch attached to the top (or bottom) of every cylinder that the span is fully opened (or fully closed). The entire operation is controlled from the control house with all the power units inside a cell. The hydraulic lines also run inside the cells.

The design of the hydraulic system, was based on criteria found in the AASHTO Movable Bridge Specifications as well as a draft of the hydraulic machinery criteria for the American Railway Engineer's Association Manual for Railway Engineering, Chapter 15.

There was a significant savings in using hydraulic machinery in lieu of a counterweighted mechanical system. In addition to the reduced machinery costs, the elimination of counterweights and the ability to locate the operating machinery in a remote pontoon made a hydraulic system particularly appealing.

The bridge's owner, WSDOT had successfully used hydraulics for the longitudinal locks in two floating bridges for a number of years. In addition, the City of Seattle had successfully used a hydraulically operated bridge for a number of years. A number of other states and one other city which had used hydraulic machinery were pleased with their performance.

In addition to an uncertainty about future maintenance costs, the only other disadvantage to hydraulic machinery was the demand charge and electrical equipment needed to power the pumps. Had the system used a counterweighted drive, the size of the motors and other electrical equipment would have been much less.

To raise the span, the pumps start and pump fluid back into the reservoir. A piggy back lock pump causes the lock supply line to be pressurized to 3000 psi and the Bear Locs to release by closing a valve. The main solenoid valve then closes, causing fluid to bypass the counterbalance valve and go to the flow divider. The flow divider equally divides the fluid so that each cylinder receives an equal volume and evenly raises the span. When the limit switches at the top of the cylinders sense that all four cylinders are raised, a solenoid valve opens causing the Bear Locs to set. Then the main valve opens, and the pumps stop. The pumps continue to pump until all four cylinders have reached their full stroke in order to even out any errors in speed of operation among the four cylinders. A relief valve allows the pumps to continue pumping to all cylinders without overpressurizing the system.

To lower the lift span the same operation is repeated except that the direction of fluid flow is reversed. Also, fluid now passes through the counterbalance valve. The counterbalance valve senses if the load is tending to race ahead of the pumps and if so will act to slow the speed. The pumps will continue to operate until all cylinders are bottomed out. A check valve prevents cavitation when not all cylinders have reached full stroke. When the lift span is seated, all load is off the cylinders.

For emergency operation several safeguards are employed in the system. If the pump supplying the Bear Locs fails, the lock can be operated with a hand pump. If either of the main pumps fail, it can be taken out of the circuit and the circuit can be operated with only one pump. The only difference will be a reduced speed of operation. If any electrical solenoid fails, the solenoid operated valves have manual overrides and they can be operated by hand. If a hydraulic line fails, the pressure sensors in the circuit will sense the loss of pressure, set the Bear Locs and shut off the pumps. As an additional safety measure, check valves have been added to the blind end of the hydraulic cylinder. They lock the fluid in the cylinder if a hose fails and the Bear Locs fail to grab.

Operating Machinery

Figure 3 shows a general layout of the operating machinery for the draw span. There are four machinery houses which protect the machinery. Under normal conditions, the draw span moves 309 feet in three minutes. Each machinery house contains a seventy-five horsepower motor, acting through couplers to drive the gear trains, see Figure 4. These gear trains consist of a reducer unit, a pinion, and an idler gear. The idlers engage racks which are bolted to the draw pontoon. A brake is located between the drive motor and reducer. The bridge is designed to withstand a one-year storm with the draw span extended. For greater storms, the span is withdrawn until the storm passes. As shown in the figure, there are five guide roller assemblies. These assemblies are doubled at the fully extended position due to the greater loads. The guide rollers, see Figure 5, are oriented at 45° to a horizontal plane. This arrangement permits the guide rollers to be mounted in a way that will not penetrate the pontoon walls, and will, at the same time, be out of the water to facilitate adjustment or replacement.

The motors are sized to operate the draw span in a storm with 50 mile per hour winds - a one year storm. As AASHTO does not consider how to operate a floating draw span, the design loads were based on a rational approach. The span was designed to move in three minutes with one minute each of acceleration and deceleration and one minute of uniform speed. The design forces included the force necessary to accelerate the mass of the pontoon (which was considerable), the force necessary to move a floating barge through the water (as the bow and stern of the draw pontoon were raked this was not a large force) and a wind pressure on the end face of the pontoon.

In addition to these forces, the largest operating force turned out to be the force necessary to move the span against the friction of the guide rollers. There were two friction forces to be considered, first the rolling friction of the rollers on the wear plate and second, the trunnion friction. This is of course similar to the design for the friction forces on a lift span's guide rollers. The pressure of the current in the Canal, which is not insignificant, as well as the wind pressure on the exposed face of the draw pontoon causes the draw pontoon to ride against the rollers and is the source of most of the resistance. While waves also cause the reaction on the rollers (and hence the roller friction) to increase, this force was judged to be sufficiently intermittent so as not to be of concern and was not considered. On days when the wind is calm and the current is not at a maximum, the operating forces are relatively small.

Although the span was designed to operate with four motors, it can operate on two drive motors, particularly if the environmental loads are not large.

Centering Pyramids and Locks

There are two 6' high by 4' wide centering pyramids located at mid-channel on the east draw pontoon with mating yokes on the west pontoon, see Figure 6. As the pontoons come together, the tapered pyramids enter the yokes and bring the pontoons into alignment. The yoke opening has been sized to allow for an initial ±2.5 feet of vertical and ±1.5 feet of lateral misalignment between the east and west draw pontoons prior to final mating. In the closed and locked position the pyramids transmit shear forces. The shear forces are produced by inaccurate adjustment of flotation and alignment of the pontoons on either side of the joint. Additional shear forces are produced by wind, wave, live load and current on the floating structure, which lift, roll and try to move the east draw and the west draw pontoons out of phase with each other. These dynamic motions reach considerable proportions. Neoprene and Fabreeka pads in the yoke and the pads on the end walls of the pontoon in the joint tend to cushion the impact effect of these motions. Once the pontoons are mated, they are held together with two hydraulically actuated lock bars which automatically reach out and capture the mating pontoons. To compliment the pyramids and yokes in holding the span in alignment, shear bumpers have been provided. The shear bumpers are made up of corrugated steel castings with a neoprene facing. An automatic control then maintains a constant pull between the two pontoons. For each lock, there is a hydraulic unit consisting of a pump, reservoir, accumulator, valves and pressure gauges all operated electrically. As the cylinder is pressurized to hold the adjacent draw span, the pressure is also built up in the accumulator. When the hydraulic pressure reaches a predetermined level, the pressure gauge shuts off the pump and closes a solenoid valve. If any pressure is lost due to the leakage in the system, the compressed gas in the accumulator will expand and tend to keep the system pressure at an almost constant level. If the pressure drops too low, the pump will restart and build up the pressure again. Thus the accumulator serves as a "bottle of energy" and keeps the motor and pump from frequent starts. An advantage of this type of hydraulic lock is that if the loads on the lock increase well beyond their design level, there is a pressure relief valve on the system which will open and allow the pressure to bleed off, thus preventing the system from being overloaded.

Buildings

In addition to the four reinforced concrete machinery buildings, there is a four-story control tower and a two-story storage building. The control tower and storage building are reinforced concrete construction to the second level. Above that they have a galvanized steel frame and an exterior of fiberglass reinforced concrete panels. The control tower contains an emergency generator on the first floor, switchgear on the second floor, a day room on the third floor, and the control desk on the fourth floor. The storage building contains a maintenance shop on the first floor and switchgear on the second floor.

Electrical System and Controls

The electrical system is quite complex as it involves both the supply and distribution of high voltage power to the bridge and the low voltage control systems. Primary service is at 12,470 volts. This is distributed at 480 volts to the equipment and cells. Lighting systems are provided for roadways, pontoon decks, cells, buildings, and navigation lights. The controls were particularly difficult for Unit 2, as they involved controlling the new west span as well as the existing east span from the new control tower on the west half of the bridge.

The control consists primarily of solid state static devices except for a primary three-pole contactor which is an electro-magnetic switch. Reversing is accomplished by an image set of thyristors and gates. Gate control of the thyristor pairs will cause them to operate as a static reversing switch so that the use of contactors for power reversal switching is not necessary. The primary electro-magnetic switch serves only the purpose of isolating the power circuit in the event of a safety device operation or during a period of inactivity. By means of controlled proportioned gating of these line thyristors the draw pontoon AC wound rotor drive motor is obliged to run at subsynchronous speeds. Through the use of a tachometer attached to the motor shaft provisions are made to control the speed down to zero.

When the drive motor control switch is advanced to a preselected speed, power is applied to the motor. The reference input voltage established by the ramp function generator will advance the thyristor gate firing angle applied to the open thyristor (non-conducting). The drive motor will accelerate until the feedback voltage from the tachometer generator is nearly equal to the reference voltage. The drive motor will continue to accelerate as long as the reference voltage continues rising. If the load should be overhauling a small increase in the tachometer speed will produce a feedback voltage in excess of the reference voltage which in turn will fire the reverse direction thyristors and apply counter torque to the drive motor to maintain the speed called for by the reference.

To operate the span, the operator follows these steps:

(A) Set traffic signals
(B) Lower all warning gates
(C) Raise lift spans
(D) Pull locks
(E) Release brakes
(F) Open span
(G) Set brakes

For closing operations, the following sequence is used:

(A) Release brakes
(B) Close span
(C) Insert locks
(D) Set brakes
(E) Lower lift spans
(F) Raise all warning signs
(G) Deenergize traffic signals

The cable transfer system consists of a motorized cable reel, a cable wiper, roller guides, cable pulley, two-way payout guide and cable deflector. The purpose of the cable transfer system is to provide a flexible power and control connection between the flanking pontoon and the draw pontoon. All other components are a cable guide to transfer the cable from the reel to a cable trough on the movable draw pontoon as it moves between its terminal positions.

Credits

The bridge replacement was designed by a joint venture of Parsons Brinckerhoff Quade & Douglas, Inc. and Raymond Technical Facilities (now Raymond Kaiser Engineers) under contract to the Washington State Department of Transportation. The State was represented by Anthony D. Andrews, Design Engineer, C.S. Gloyd, Bridge and Structures Engineer, Robert Krier, Deputy Bridge and Structures Engineer and Mr. Myint Lewin, project manager. The design was truly a team effort and much credit must go to the State. They had already utilized some of the design ideas discussed above on their other floating bridges, and were very active participants in the entire design process.

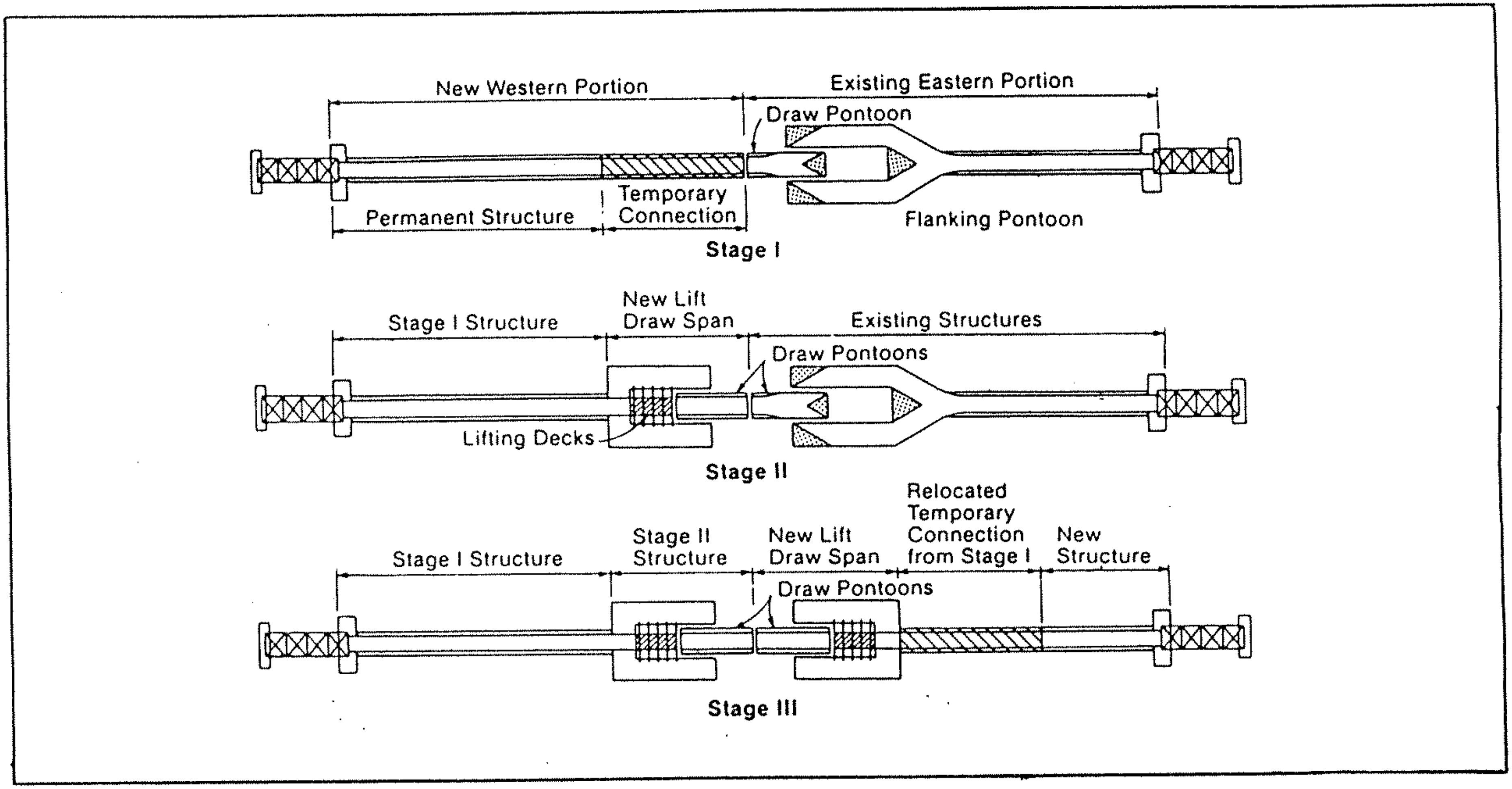
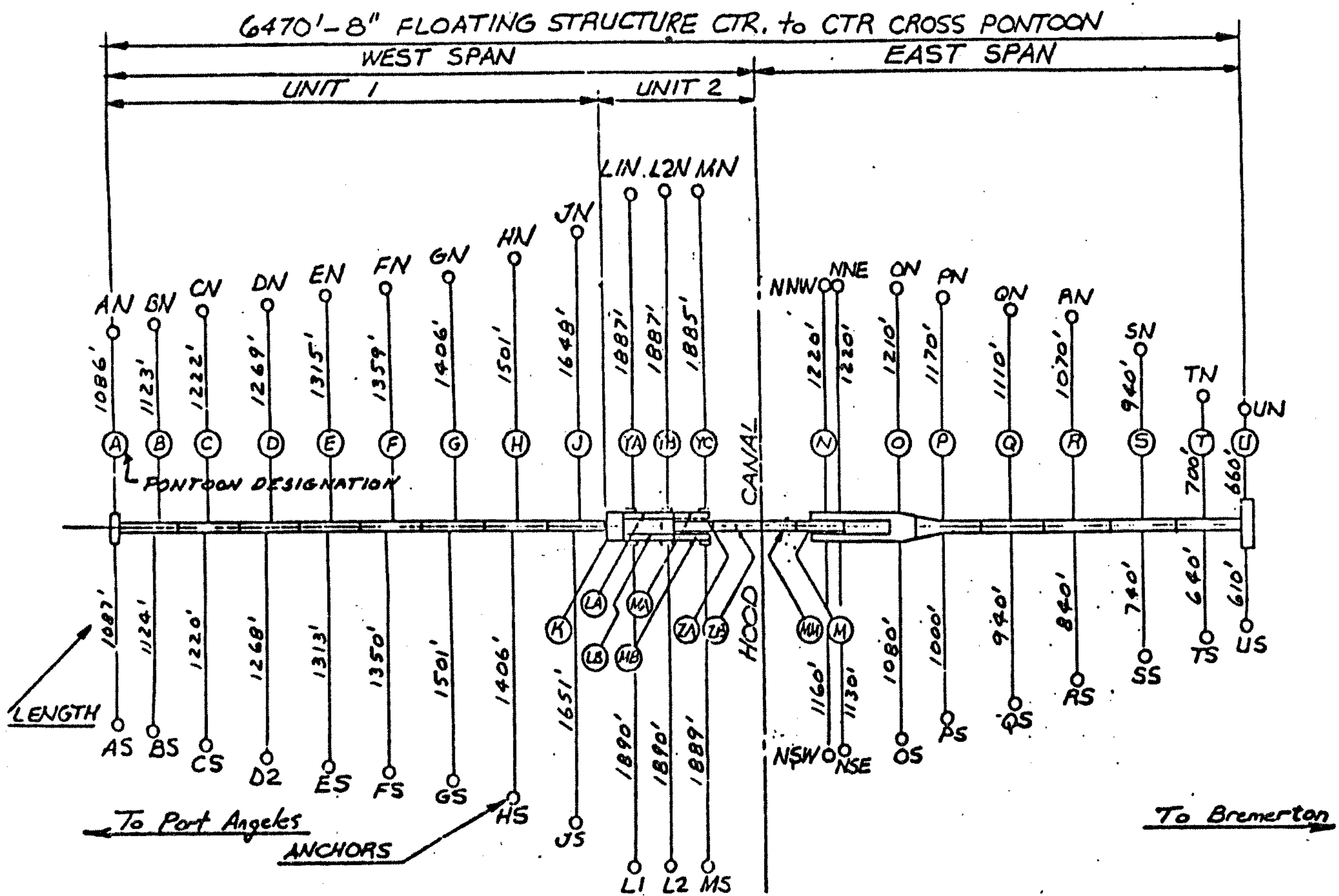
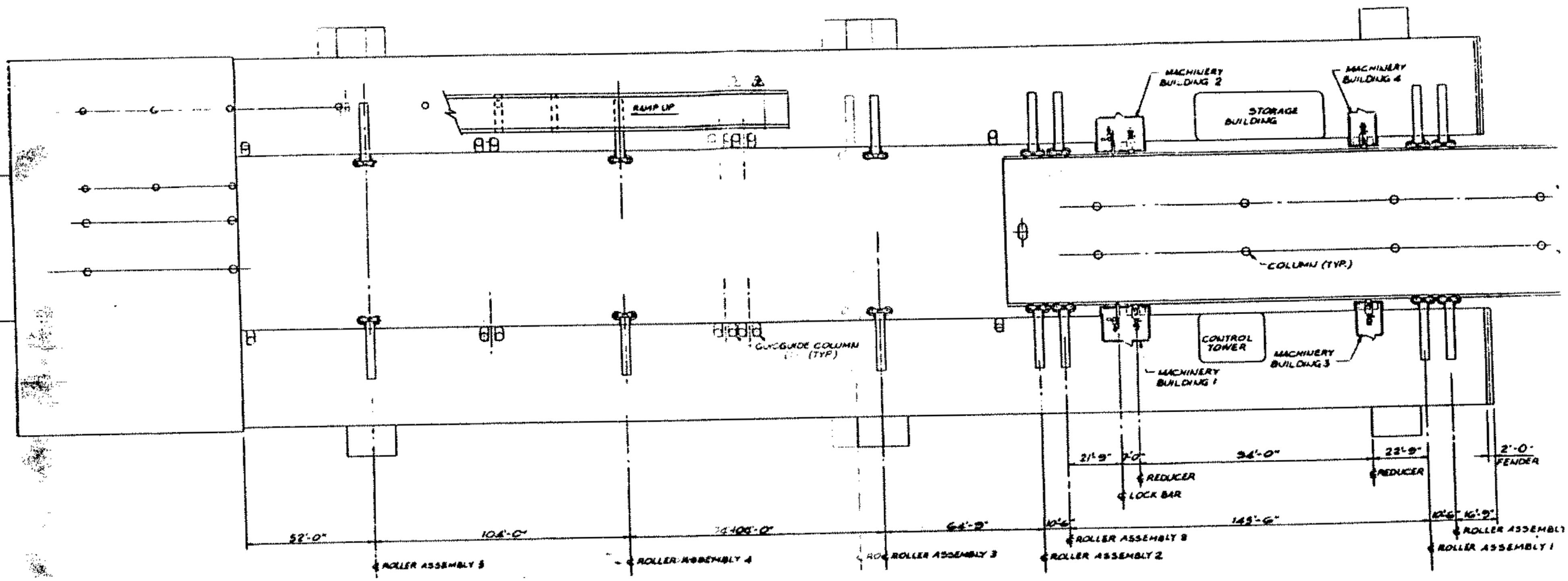


Illustration of staged construction plan.
FIG. 1



PONTOON AND ANCHOR LAYOUT

FIG. 2

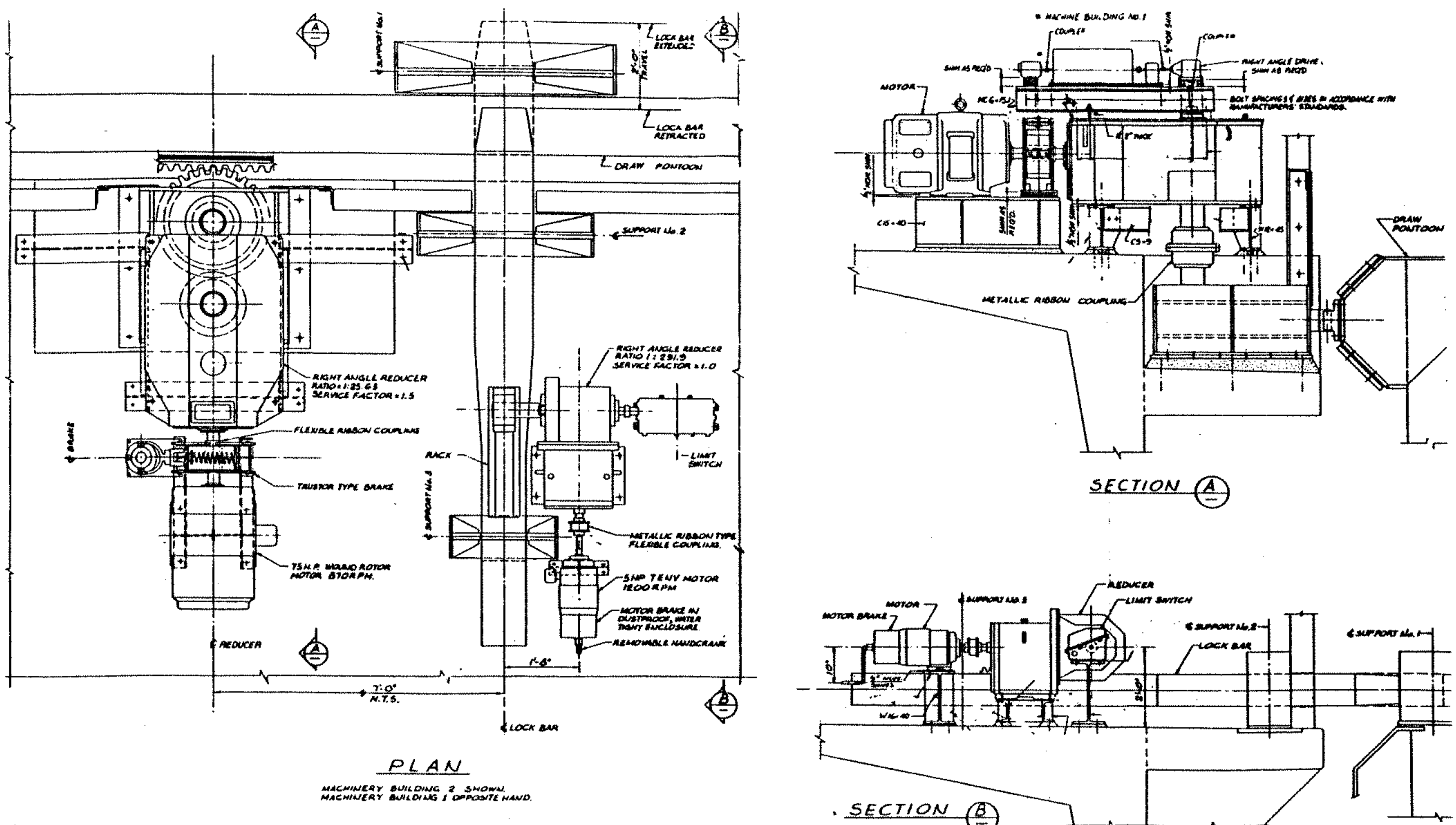


OPERATING MACHINERY GENERAL LAYOUT

NOTES:

1. TIME OF OPERATION = 2 MINUTES.
2. DISTANCE OF TRAVEL = 309 FEET
3. AVERAGE SPEED = 2.575 FEET PER SECOND
4. ACCELERATION = 0.0429 FEET PER SECOND^2

FIGURE 3



OPERATING MACHINERY

FIGURE 4

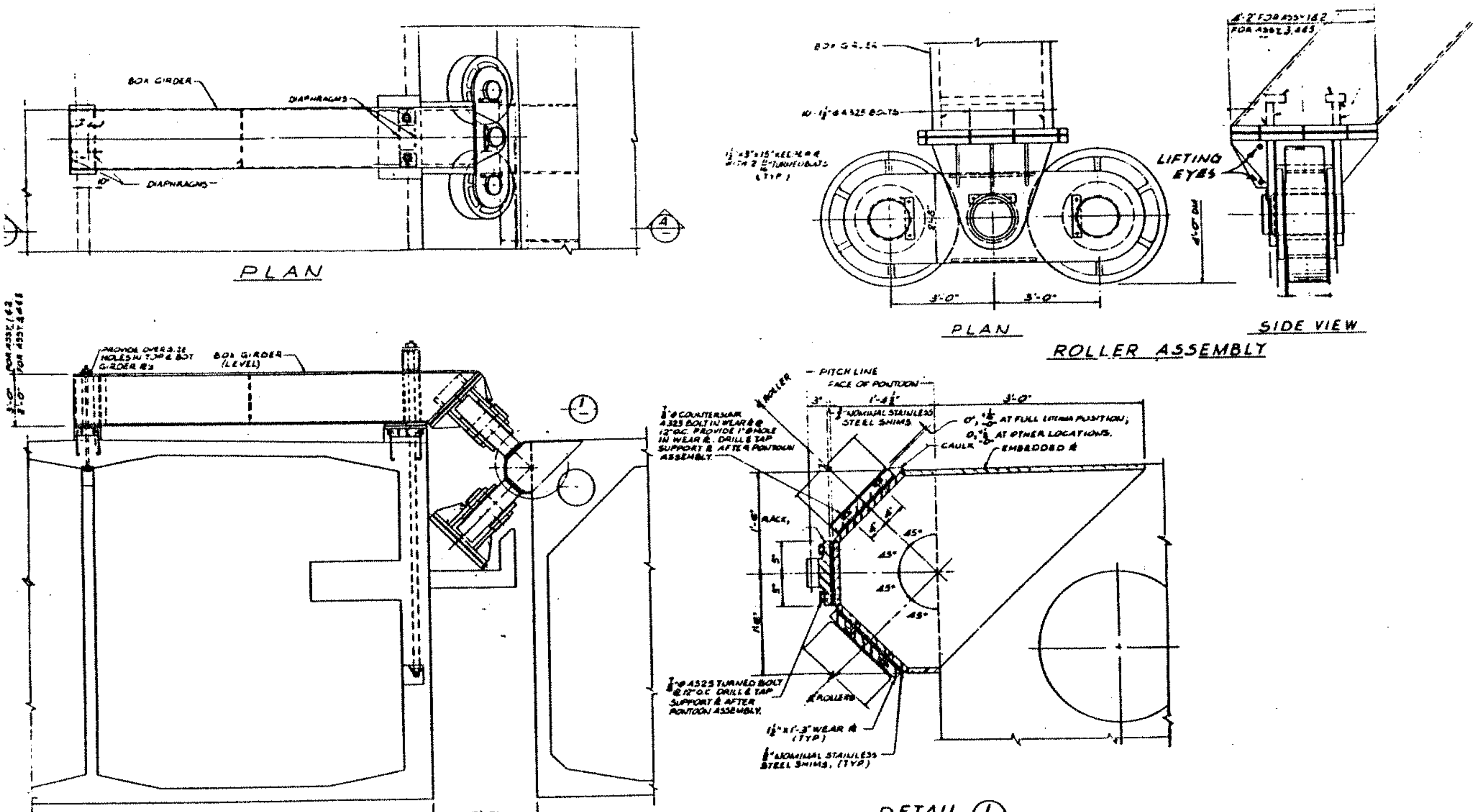
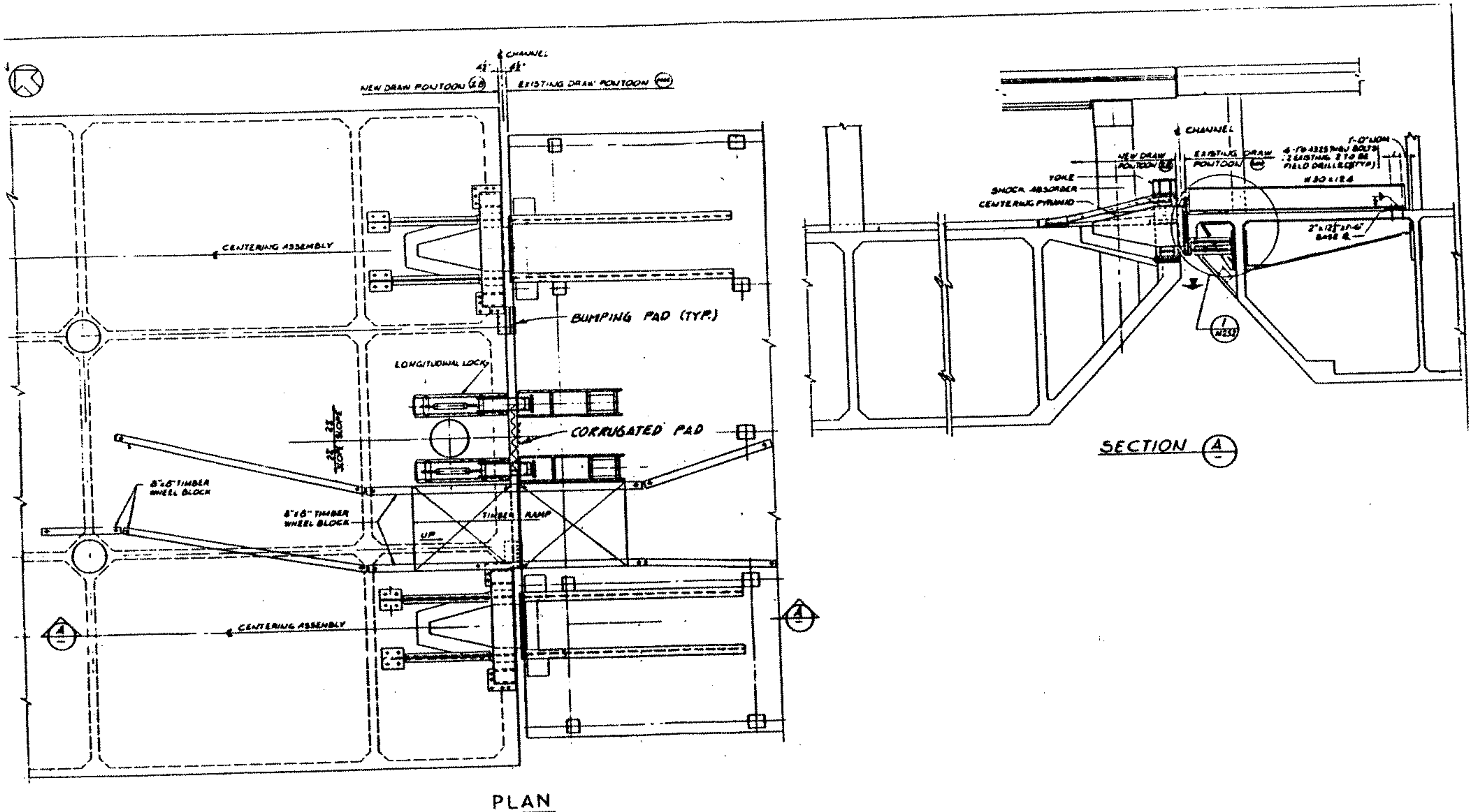


FIGURE 5

ROLLER ASSEMBLY



CENTERING ASSEMBLY

FIGURE 6