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East Half Replacement – Hood Canal Bridge

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East Half Replacement of the Hood Canal Bridge

ABSTRACT

The 7,869 feet long Hood Canal Bridge, is believed to be the world's longest floating bridge in an ocean environment. The Hood Canal is a natural inlet off Puget Sound and the site of a U S Navy submarine base, several miles inland from the bridge crossing. The first Hood Canal Bridge was designed by the Washington State Department of Transportation, construction was completed in 1963. A floating bridge was selected for the site because the width and depth of the Canal, over 300 feet deep, precluded a normal fixed structure. The bridge included a 600 foot floating draw span, one of the largest movable spans in the world, to allow for marine traffic.

In 1979, a severe storm struck the area causing the West Half of the bridge to sink. As the bridge was the only crossing in the area its loss was a significant hardship. The West Half was replaced in two stages, and while a temporary ferry service provided some relief, its capacity was much less than that of the bridge. The West Half Replacement was completed three years later, in 1982.

After completion of the plans for the West Half Replacement, plans were prepared to replace the East Half, but due to funding constraints, and the fact that the East Half is somewhat more sheltered, it's replacement was not immediately required. However it was anticipated that due to East Half's age and limited capacity, it would need to be replaced sometime in the future. Hence the East Half Replacement plans were put on the shelf.

Now, approximately 20 years later, the Department has decided to replace the East Half and at the time of this writing the construction is underway. In order to accommodate traffic growth in the area, as well as changes in bridge technology, the construction will increase the width of both the East and West Half Roadways, from 30 to 40 feet, as well replace the West Half power and control system. It is a rare opportunity when one can design a structure, try it out for 20 years, and then have the opportunity to revisit the design.

I. INTRODUCTION

Construction of the first Hood Canal Bridge began January 1958, and on August 12, 1961, the two-lane, 1.5-mile, concrete floating bridge was opened to traffic extending Highway 104 across Hood Canal, a fjord-like arm of Puget Sound. The cost to construct the bridge was $26,630,000.

A floating bridge design was selected because the Canal is over 300 feet deep and has a tidal variation of over 16 feet, ruling out the use of a fixed bridge. The overall bridge length is 7,869 feet (approximately 1.5 miles). It has a center draw-opening of 600 feet. During inclement weather, the draw span is retracted (closing the bridge to vehicle traffic) when winds of 40 miles per hour or more are sustained for 15 minutes. The Hood Canal Bridge was the third concrete pontoon floating bridge constructed on Washington's highway system. It is one of the world's few floating bridges in a salt-water environment.

In February 13, 1979, a 100 year storm destroyed the western half of the Hood Canal Bridge-the principal highway link from Seattle to the Olympic Peninsula, see Figures 1 & 2. The storm wind gusts were reported to be 120 miles per hour with sustained winds of 85 miles per hour. The loss of this critical bridge link resulted in a 100-mile detour and activation of limited and costly emergency ferry service. The owner of the bridge, the Washington State Department of Transportation, determined that the structure should be replaced as a floating bridge but that the replacement would incorporate the considerable advances in the analysis of floating structures. The West Half replacement was completed in a two stage process in

October 1982. Costs for replacement of the West Half and rehabilitation of the East Half of the bridge was $143,000,000.

As part of the West Half design work, plans were also prepared for replacing the older East Half, but were not implemented based on a value engineering study that indicated the most prudent thing for the Department to do was to make use of the remaining 15 to 20 years of structural life.

More recently, in 1998, it was determined that the East-Half was to be replaced based on the 1984 plans. It was initially anticipated that minimal changes would be required. However, due to growth in the region as well as advances in bridge technology, a number of modifications were introduced, including widening the West Half roadway as average daily traffic across Hood Canal Bridge has increased to approximately 14,000 vehicles. Peak volumes reach 20,000 vehicles on summer weekends.

The East Half Replacement was advertised in the spring of 2003 and in July, 2003 a contract for approximately $204 Million was awarded to Kiewit - General to replace the East-Half and rehabilitate the West Half. Construction was initially scheduled to be completed in 2007 but there may be a one year delay due to the discovery of significant Indian artifacts at the site of the project's graving dock.

2. WEST HALF REPLACEMENT

To speed the restoration of highway service across the canal, the Department obtained Coast Guard approval to restrict the navigation channel during Stage I construction to the 300-foot width provided by the remaining half of the original 600-foot-wide twin draw spans, see Figure 3. In Stage II, a new draw span (on the West Half) replaced a portion of the Stage I construction, restoring the navigation opening to its full width. Stage III, the East Half replacement design was also completed at that time, see Figure 4. Based on a review of available wind speed records, the replacement bridge was designed to withstand sustained waves generated by 83-mph winds and wind pressure from 110-mph gusts. The canal is a deep natural waterway-up to 340 feet in spots-with strong currents and tidal variation of over 16 feet. Adding to design complexity, the bridge was designed for a seismic event and all construction materials were required to withstand a marine environment.

The replacement design was also a floating structure, consisting of continuously linked longitudinal concrete pontoons held in place by half-mile-long anchor cables attached to concrete anchors weighing 1,500 tons each. The prestressed concrete pontoons, anchors, and anchor cables are 2.5 times stronger than the original design. Each pontoon weighs 8,300 tons and contains 36 watertight cells. This compartmentalized design keeps water from migrating in the event of cell flooding and improves safety should a ship strike the pontoons. Special submarine-type, screw-down hatch covers provide access to each compartment to facilitate inspections. The pontoons - 10 feet wider and 4 feet deeper than the originals - support a two-lane roadway of 60-foot, precast, prestressed concrete AASHTO girder spans, see Figure 5. The roadway is supported on columns above the pontoons to keep it above storm waves and spray. The pontoons are post tensioned vertically, longitudinally, and transversely. The design allowed and detailed precast segments to speed construction. The contractor for the Unit 1 Contract, which had many common pontoon sections, elected to use precast elements for the pontoon walls and diaphragms. However the contractor for Unit 2, which had many different pontoon sections, utilized all cast in place pontoon construction.

Each draw span combines a 300-foot-long steel deck and a floating draw span. To open a span, the deck is lifted hydraulically to create an open well into which the draw span is retracted beneath the deck. In addition to being more economical, the lift-draw design allows a safer and more efficient traffic flow than was possible on the original bridge, which required a sharply curved, split roadway to leave room for draw-span retraction.

After the deck is raised the draw-span can be retracted into the U-shaped flanking pontoon structure. When the draw-span is extended, the deck is hydraulically lowered to roadway level. The draw-span is operated by a rack and pinion mechanism with twin 432 foot-long racks. Both east and west draw-spans are electronically controlled from a single control house.

The bridge construction also included a special hinged pontoon joint and flexible deck section. When dynamic analysis simulating storm forces showed high torsional moments about the pontoon joint at the draw span, the answer was a structural hinge: an 8-foot-diameter, steel-lined, concrete cylinder sliding on teflon-coated neoprene bearings within a steel-lined can-a "wrist" held together by cable. Across this joint, a flexible superstructure span of steel stringers with partially filled grating deck can twist with the pontoons yet maintain a smooth roadway.

The control tower and storage building superstructure used fiberglass-reinforced concrete panels to provide an attractive, lightweight, and durable surface. The building panels and concrete surfaces were coated to provide a uniform color, as well as improved durability.

Early in the design, consideration was given to designing the bridge so that it could be widened in the future to carry 4 lanes of traffic. But since the work was being federally funded as an emergency replacement, the funding restrictions would only allow for a replacement in kind. Thus the roadway width had to be fixed at 30 feet to match the original structure roadway width. Fortunately, the layout of the buildings and lift spans was set so a wider superstructure could be accommodated.

3. EAST HALF REPLACEMENT

The East Half of the bridge, which was constructed in 1961, is nearing the end of its structural life. A severe marine climate, accelerating deterioration, draw span unreliability and a desire to bring the bridge up to higher design standards made the replacement of the East Half one of the Department's highest priority bridges for replacement. In December 1998, work began to update the East Half Replacement plans and specifications to complete the work begun 20 years ago. The update has incorporated current standards, lessons learned since the replacement of the West Half, and revisions due to changes in available equipment.

When the design update began in 1998 it was anticipated that the effort would focus on revising the plans and specifications to bring the East and West Half machinery, power and controls up to current standards, and to revise the East Half Control Tower and Shop to meet the operating requirements of the maintenance staff. But once work began, the Department's traffic studies indicated that it would be highly desirable to widen the roadway on both the existing West Half and future East Half to accommodate a 40 foot wide roadway now and then a 60 foot roadway in the future. The 40 foot wide roadway will allow for 8 foot wide shoulders, matching those on all the approach roadways in the area. Thus the scope of the project was increased to include revising the superstructure design on the East Half to use a 40 foot wide roadway. On the West Half, the existing superstructure roadway is being widened 10 feet to 40 feet by adding a line of girders and deck. The wider roadway not only affected the pontoon superstructure but the fixed approach spans and hinged transition spans as well. As the spans only carried a 30 foot wide roadway, it was necessary to replace them as well. But as there is a possibility of further widening the roadway to 60 feet in the future, allowing two lanes of traffic in each direction, the widening design was detailed so as to allow a 60 foot roadway. On the pontoon spans widening to 60 feet will require complete replacement of the superstructure with a steel superstructure to avoid further weight increases and loss of buoyancy.

The project scope was also increased to include a fixed graving dock at Port Angeles, Washington. All of the new pontoons will be fabricated at this location and floated approximately 60 miles to the Hood Canal Bridge. The Department plans to utilize this graving dock for a future floating bridge project, the replacement of the Route 520 Bridge, some time after completion of the Hood Canal project. Once construction began in the fall of 2003, it was discovered that the site contained important Indian artifacts and this slowed construction of the graving dock until the area could be explored and the issue resolved.

Construction was initially expected to be completed in 4 1/2 years, by the end of 2007. However, the unearthing of the remains of the village known as Tse-whit-sen, which was home to the ancestors of the existing Lower Elwha Klallam Tribe, has caused a delay of four months or more. This time is being used to collect archeological data from the 22-acre graving dock site, prior to re-commencing construction work there.

There will be an 8 week shut down of the bridge in May / June 2006 or 2007, at which time alternative passenger only ferry service with busses serving the ferry terminals will be provided.

Three bids were received and opened June 18, 2003. With a bid of $204 million, Kiewit - General of Poulsbo, Washington was the low bidder. HS Bridge Constructors of Longmont, Colorado, bid $253.86 million. Hood Canal Bridge Constructors of Watsonville, California, bid $258.5 million. The engineer's estimate was $191.75 million. The existing East-Half pontoons had already been sold to various parties and will be delivered in 2006 or 2007, being removed from service.

The archeological work at the graving dock site is estimated at $4.5 million. WSDOT will pay the Lower Elwha Klallam Tribe $3.4 million for mitigation costs. The additional cost to Kiewit-General for the extended project schedule will be negotiated.

4. BRIDGE MACHINERY

Lift Deck Machinery

Each set of lift deck machinery consists of one Hydraulic Power Unit (HPU) and four hydraulic cylinders, one lifting each corner of the deck, see Figure 8. The HPU's contain a flow divider that is used to equally proportion the fluid to the cylinders. The three HPU's for each half of the bridge are contained in a single pontoon cell. Stainless steel hydraulic piping runs from the HPU's through the pontoon cells to each cylinder and back. The cylinders are 12 inches in diameter with a 9-foor-long stroke. The lift spans operate sequentially, after one starts to move the next unit follows. The entire operation is controlled from the control house.

The 1982 (Unit II) design used 75hp@1200 rpm motors and 120gpm (~400cc) pumps. Each deck took about 75 seconds to rise. Each cylinder was equipped with a "Bear Loc" to hold the cylinder rod in case of a loss of fluid pressure. The "Bear Loc" is a patented device that utilizes a hydraulically expanded sleeve around the piston rod. In order to control the lowering of the span, a counterbalance valve in the HPU was used.

In 1998 a hydraulic rehabilitation was performed. The work involved replacing the cylinders, the pumps, and the directional control valve. The "Bear Loc" on the original cylinders proved to be difficult to maintain. Therefore, the replacement cylinders used a cylinder mounted load holding valve instead. The original fixed displacement pumps were replaced with more sophisticated 500cc (~150gpm) variable displacement axial piston pumps with pressure compensating control. The hydraulic rehabilitation proved troublesome because the new pumps were poorly suited to the low pressure and flowrate associated with the 30-foot-wide roadway and 75 hp motor, resulting in a low pump efficiency of 73%. Subsequent to the rehabilitation the lifting times dropped to 90 seconds and the motors continue to have problems with overloading and tripping out the circuits. The new directional control valve caused additional troubles, as it requires the pumps to start against the system relief valve until enough pilot pressure is built up to operate the valve. Further problems were encountered with the cylinders that were supplied in the metric size of 320mm (12.598”) diameter, instead of 12”. The larger size contributed to the slower lift times and reduced pump efficiency. On half of the locations, the cylinder manifold also interfered with the adjacent concrete guide columns, requiring the columns to be chipped out to make room. The load holding valves (Rexroth DZ) were not effective in this application and allowed the lift decks to slowly drift down during bridge operation. These valves were replaced with SUN CWIA-LHN valves, which proved effective.

For the 2003 (Unit III) design the roadway was to be widened from 30 to 40 feet, hence the weight of the lift decks increased. Therefore considerable effort was placed in selecting the appropriate pump and motor combination. The selection was made somewhat more challenging as the design needed to not only suit the 40-foot-wide roadway, but also be suitable (with minor modifications) for the future 60-foot-wide roadway. The final decision was to use the same pumps as were installed during the 1998 rehabilitation and to increase the motor size from 75hp to 150hp. The increased pressure, due to the widening, and the increased flow, made possible by the larger motor, bring the existing pumps into the range for which they where designed. A proportional relief valve was also added to the HPU’s to allow the motors a soft start. The anticipated lift times are 60 seconds for the 40-foot roadway and 75 seconds for the 60-foot roadway.

At the time of this writing (July 2004), it has become apparent that the contractor will widen one side of the lift decks of the existing West Half prior to performing the hydraulic rehabilitation work of the 2003 design. Therefore it has been necessary to find a solution so that the existing hydraulic system will be able to operate the heavier and temporarily lopsided lift decks. The solution currently being pursued is to increase the pressure settings of the load holding valves, pressure relief valves, and the pump compensator. The pump flow will be reduced from 50% to 30% of maximum. This will raise the anticipated lift time to 145 seconds, until the hydraulic rehabilitation is performed. In order that the cylinders all be at equal pressure, even if only half of a lift deck is widened for a time, water filled Jersey barriers could be placed on the lift deck to serve as ballast.

Draw Machinery

During the 1982 design process, some consideration was given to using a wire rope system to open and close the drawspan. However, the rack and pinion drive used by the 1962 design had proved to be effective with no major maintenance problems.

For the 1982 design 4 drivetrains were provided per drawspan, two on either side of the span. The drivetrains engage a 432-foot-long rack that is mounted on each side of the drawspan. Each drive train consists of one 75 hp @ 900 rpm motor, thrustor brake, a right angle reducer, and a pinion and idler open gearing; see Figure 10. Under normal conditions, the drawspan moves 309 feet in three minutes.

The drawspan machinery has functioned well and few changes are being made for the current work. There were some problems with the vertical couplings joining the reducer to the pinion; the existing couplings are not appropriate for vertical applications and are being replaced. The machinery supports are also being replaced to improve access to the pinion and idler gear assembly.

Pontoon Guide Machinery

The pontoon guides are mounted on the fixed flanking pontoons, see Figure 9. While opening the drawspan they serve to guide the draw pontoon such that the mesh between the rack and pinion is maintained, with a maximum allowable gap between the rollers and their track of 1/8”. While the span is closed the guides function to transfer loads between the drawspan and the fixed spans. To minimize impact, the maximum allowable gap at these rollers is 1/16”.

The rollers are designed to withstand a one-year storm with the drawspan extended (span closed). For larger storms, the span must be opened and the bridge closed to traffic. There are seven guide roller assemblies per side. These assemblies are doubled at the fully extended position due to the greater loads at this location.

During the 1982 design, various guide schemes were considered including using nests of many small rollers. In order to prevent or dampen the impact due to wave action, methods of spring-loading or buffering the guides were considered.

The final 1982 configuration incorporates sets of two 4-foot-diameter rollers that are joined by an equalizer frame, see Figure 6. As shown in Figure 7, the guide rollers are oriented at 45 degrees to a horizontal plane. This arrangement permits the guide rollers to be mounted in a way that does not penetrate the pontoon walls and, at the same time, allows the rollers to be out of the water to facilitate adjustment or replacement.

The 1982 design used high strength weathering steel (T1) weldments for the equalizer frame and its supports; these items were hot dip galvanized and painted. Plain bronze bearings ran on shafts forged from Inconel 625, which is a Nickel based alloy. At the connection between the rollers supports and the flanking pontoons a ½” thick neoprene pad was used as a method of decreasing impact loads.

This roller design did not fair well in the aggressively corrosive marine splash zone. Despite the use of the weathering steel plus galvanizing and painting, corrosion was a persistent problem. The neoprene pad also subjected the bolts to bending loads, making snapped bolts a problem which was addressed by adding restraining lugs.

As part of the 1998 design update an alternate design was created. This design utilized a skid instead of rollers. The skid consisted of a steel weldment, with a thick reinforced neoprene bearing and Teflon sliding surface. A single prototype was fabricated and installed. Tests, however, indicated that there was an increase in friction over the rollers, as demonstrated by greater power demands on the draw span machinery.

For the 2003 design the decision was made to improve on the 1982 guide roller design. WSDOT had a positive experience with uncoated castings of the corrosion resistant martensitic Iron-Chromium-Nickel alloy AASHTO M163 Ca6nm on their SR520 Evergreen Point pontoon bridge, which crosses Lake Washington. Ca6nm is a common high strength alloy that is available from multiple foundries. In addition to being high strength it also has excellent ductility and impact resistance. It can be produced without excessive weld repair before final heat treatment. Another advantage is that the heat treatment requires no quench; the alloy is air hardening. Quenching would risk causing the long, thin equalizer frame to warp.

While Ca6nm does not corrode in the lake environment of SR520, the marine splash zone of the Hood Canal is much more corrosive. Ca6nm is commonly used in the propellers of ocean going ships, however these ships are cathodically protected. After some investigation it was determined that uncoated Ca6nm would corrode in this application.

The alloy ASTM A890 grades 1b and 5a were also investigated. Uncoated these alloys would not corrode in a marine splash zone. They are of similar strength as Ca6nm and have even better ductility and impact resistance, with grade 5a superior on all accounts. However, there are few foundries capable of producing these castings and quenching is required during heat treatment. Castings from grades 1b and 5a would cost 20% and 30%, respectively, more than Ca6nm.

J.M. Dwight, welding engineer retained by WSDOT, proposed applying a "Twin Arc Spray" of Inconel 625 to the Ca6nm castings. This coating is expected to provide 25 years or more of corrosion protection. Paint will be applied over the arc spray coating. This solution was estimated to save $500k and $800k when compared with ASTM A 890 grade 1b and 5a respectively, and was adopted.

In addition to re-detailing the guide roller supports from weldments to castings, the 2003 design also addressed the problems with bolts breaking by replacing the neoprene shim with stainless steel shims.

Centering and Lock Machinery

Centering pyramids, longitudinal locks, and shear bumpers are provided at the ends of the drawspan pontoons. The centering pyramids allow the initial alignment and the locks and shear bumpers hold the spans closed.

The two 6' high by 4' wide centering pyramids are located at mid-channel on the West Half draw pontoon with mating yokes on the East Half draw pontoon. 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. Once the pontoons are mated, they are held together with the two hydraulically actuated longitudinal lock bars. The longitudinal lock bars automatically reach out and capture the mating pontoons. An automatic control then maintains a constant pull between the two 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. The 2003 design of the above components remains the same as the 1982 design.

Transverse locks are provided in machinery houses with the drawspan machinery. The 1982 design actuated the lockbars with a rack and pinion mechanical drive. However, due to the overhung load on the reducer, this arrangement proved flexible and unsatisfactory. The 2003 design replaces the mechanical drive with hydraulic cylinder actuation. Improved lubrication features were added to the lockbar guides. Otherwise the lockbar and guide designs remain unchanged.

5. CREDITS

The 1982 design was completed by a joint venture of Parsons Brinckerhoff/Raymond Technical Facilities, New York. The current design was developed by the Washington State Department of Transportation. Parsons Brinckerhoff Quade & Douglas, Inc. prepared the machinery, power, control and building structure design revisions. Streeter and Associates, Seattle Washington, was the architectural subconsultant on the East Half Building revisions and Norton Corrosion, Woodinville, Washington, the sub consultant of the East Half cathodic protection system revisions. The graving dock design was prepared by KPFF, Seattle, Washington.

6. ACKNOWLEDGEMENTS

The project has involved a close working relationship with the Washington State Department of Transportation and in particular Patrick Clarke, Project Manager; Duane Stone, Mechanical; and Tim Benson and Charlie Collins, Electrical.

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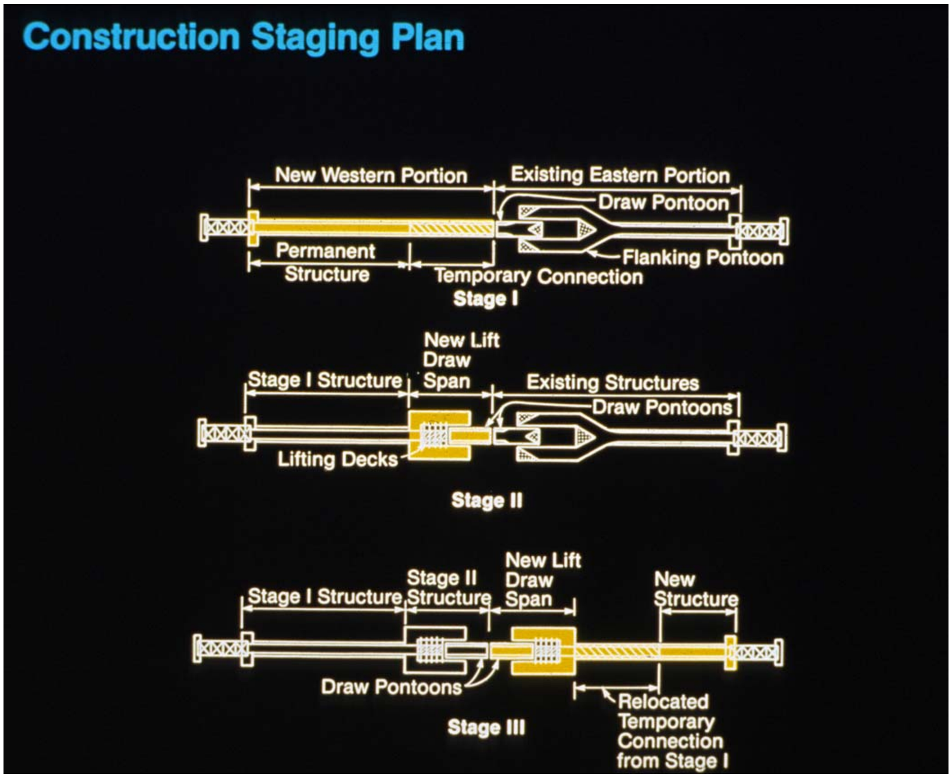
FIGURES

Figure 1 – Aerial Photo Showing Existing East Half (1958 Design) and Sunken West Half.

Figure 2 – East Half Sunk During 100 Year Storm

Figure 3 – Aerial Photo Showing Existing East Half (Near) and New West Half During Stage 1



Construction Staging Plan

New Western Portion
Existing Eastern Portion
Draw Pontoon
Permanent Structure
Flanking Pontoon
Temporary Connection
Stage I

New Lift Draw Span
Stage I Structure
Existing Structures
Draw Pontoons
Lifting Decks
Stage II

New Lift Draw Span
Stage II Structure
Stage I Structure
New Structure
Draw Pontoons
Relocated Temporary Connection from Stage I
Stage III

Figure 4 – Construction Staging Plan

Figure 5 – Submarine Passing Through Open Bridge During Stage I

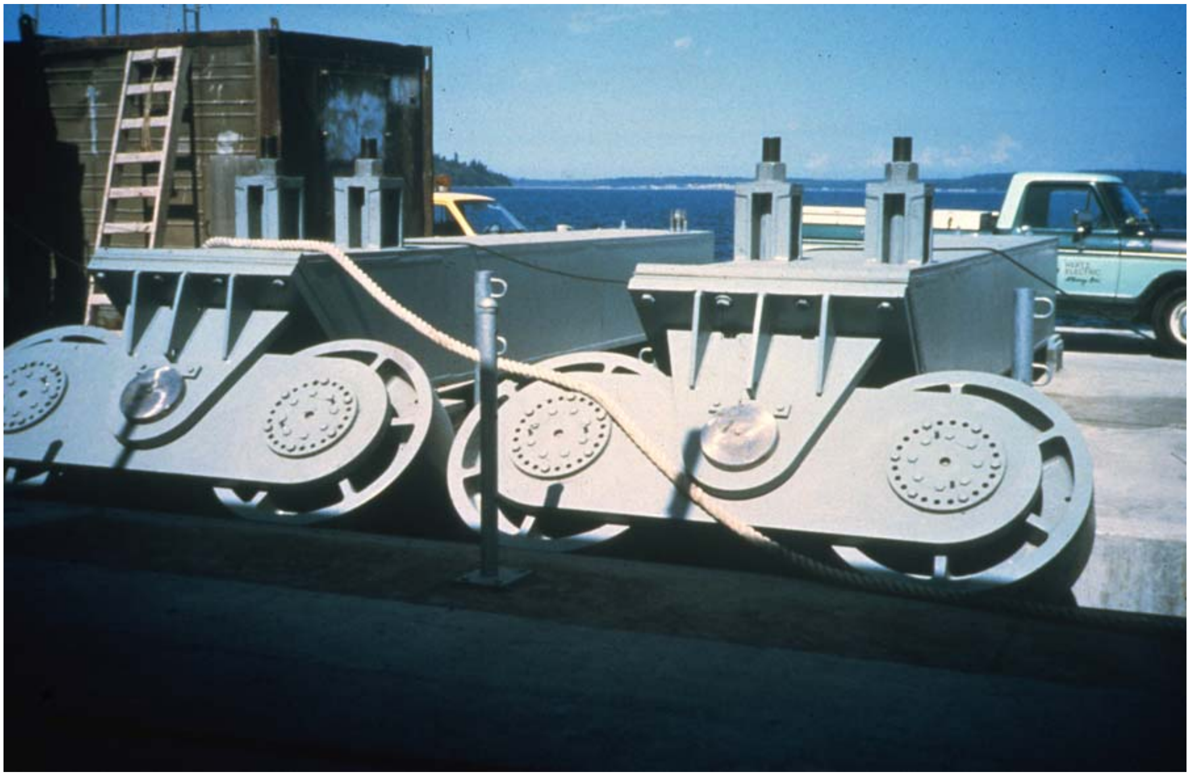


Figure 6 – 1982 Guide Rollers. Standing on Draw Pontoon Looking Transversely

Figure 7 – 1982 Guide Rollers. Standing on Flanking Pontoon Looking Longitudinally

Figure 8 – 1982 Hydraulic Cylinder for Lift Decks.
Replaced in 1998 Hydraulic Rehab

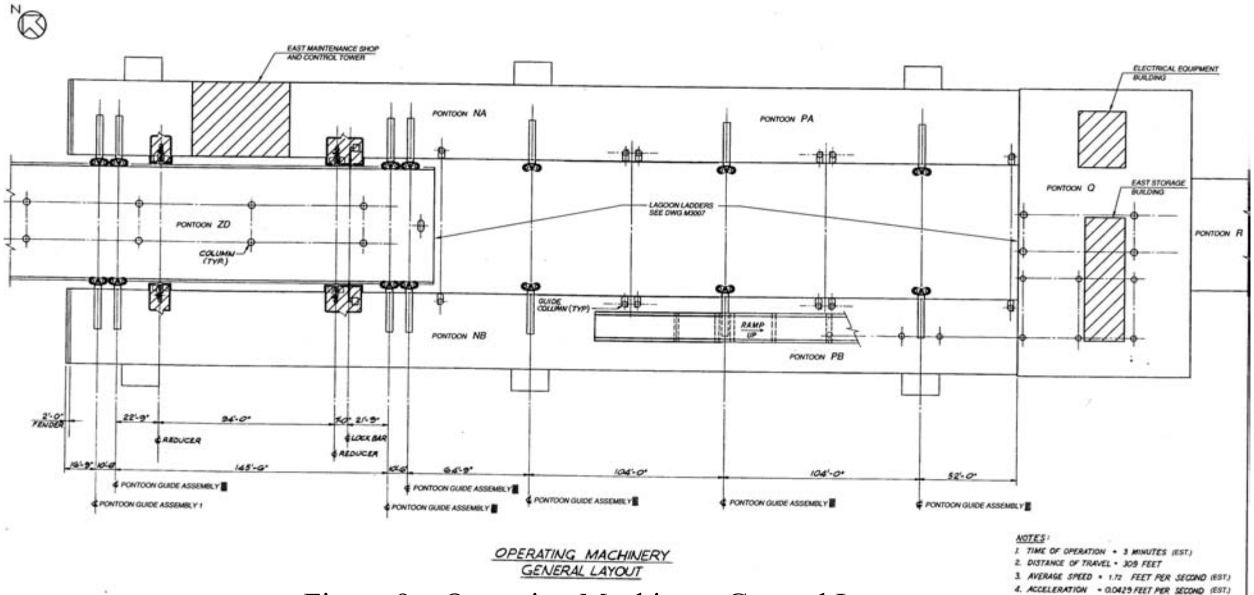


Figure 9 – Operating Machinery General Layout

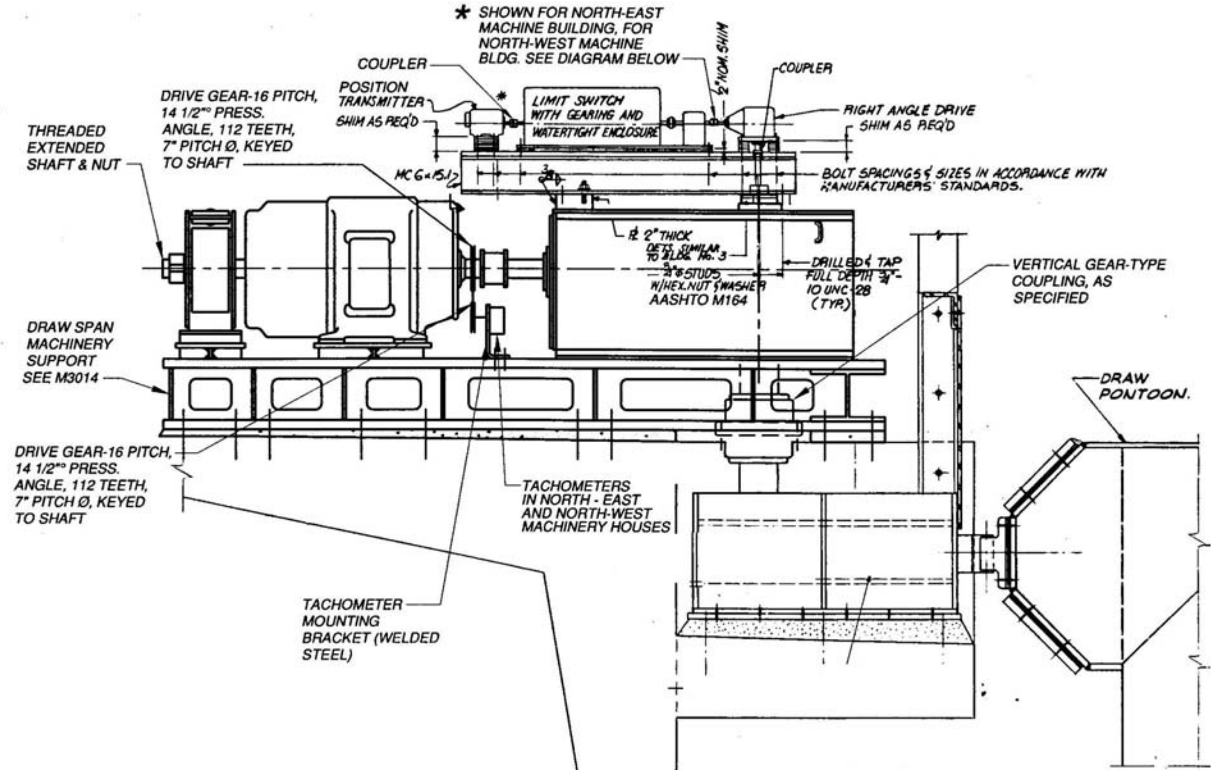


Figure 10 –Elevation of Draw Machinery