HEAVY MOVABLE STRUCTURES, INC.

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# "Frame Mounted Hydrostatic Drive System for the Whitehair Bridge"

by Jeffery S. Flanders, P.E.
E. C. Driver & Associates, Inc.

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Jeffrey S. Flanders, P.E.
E.C. Driver and Associates, Inc.
500 North Westshore Blvd. #700
Tampa, Florida
Phone: (813) 282-9886
Fax: (813) 282-9873

INTRODUCTION

The Whitehair Bridge, located over a navigable portion of the Saint Johns River in Volusia County, is a traditional double leaf, Hopkins trunnion type bascule bridge. The bridge, shown in Figure 1, provides vehicle passages for east and west bound traffic on State Road 44 and provides 17 feet of vertical and 90 feet of horizontal clearance for marine traffic in the closed position. In the open position, the, vertical clearance is unlimited between the fenders.

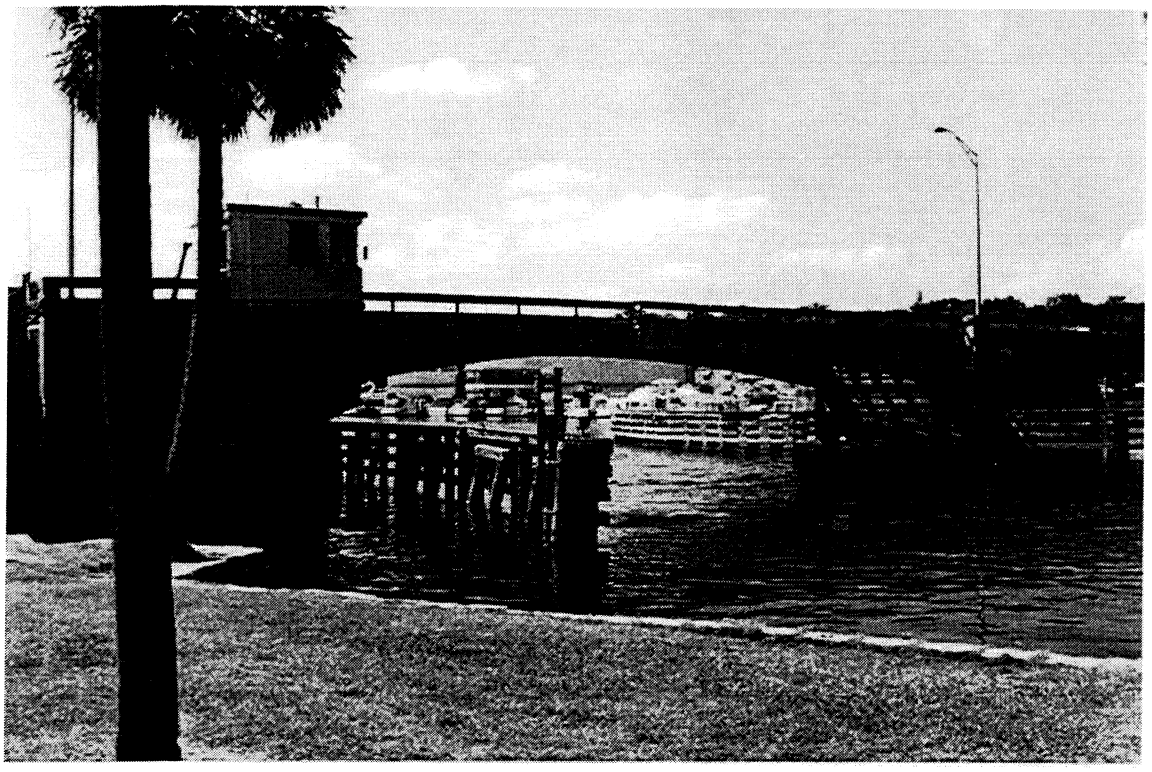


**Figure 1**

**The Whitehair Bascule Bridge**

After many years of service, primarily for the passage of fuel barges to a nearby electric power generation plant, it was determined that repairs would be required to maintain the structures mechanical reliability. In 1996, the bridge owner, the Florida Department of Transportation, requested assistance from E.C. Driver and Associates, Inc., in a drive replacement study. E.C. Driver was later awarded the design contract for the bridge rehabilitation. The general scope of this contract would involve the replacement of the bridge drive and control systems along with various architectural modifications.

EXISTING EQUIPMENT

Built in 1955, the leaves of the Whitehair Bridge were originally driven by Hopkins frame mounted machinery, typical of the era. Each leaf contained a drive frame consisting of a single 15 horsepower wound rotor motor and a single reducer driving two rack and pinion sets. During construction of the original structure, installation of this type of frame mounted machinery became very popular. Particularly, this configuration permitted installation of a complete drive system in the confined machinery area of a typical bascule pier as constructed in the 1950's and 1960's. Therefore, this bridge adapted well to the use of a Hopkins frame, but limited the designer's options during retrofitting. Figure 2 shows a view of the near bascule pier of the Whitehair Bridge, illustrating the limited machinery area.

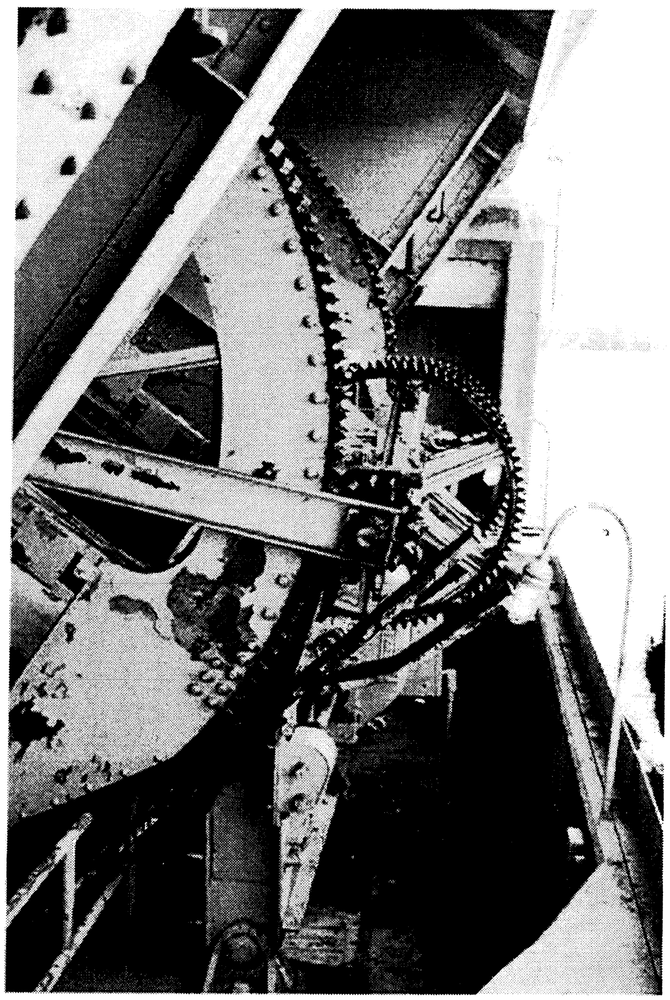


**Figure 2**

**Existing Hopkins Drive Machinery And Limited Machinery Floor Space**

Another benefit to the frame mounted machinery is ease of fabrication and installation. The drive machinery (i.e., motor, brake, reducer, external gearing, couplings, and auxiliary drive) can be assembled off-site at a fabrication shop, allowing a better environment for aligning all components. The complete assembly can then be easily attached to the machinery floor through a pinned connection and connected at the top with link arms to a rack center shaft located at the center of leaf rotation.

An in-depth inspection of the existing machinery took place in November of 1996. During this inspection, an evaluation of the drive machinery revealed evidence of wear common to this type of drive frame. The frame exhibited worn gearing and bearings. Additionally, the vertical uplift exerted on the frame during normal operation had caused failure of the clevis bases, which had subsequently been field repaired. This lifting force had also resulted in elongation of the clevis pin holes, creating unacceptable vertical movement of the frame during operation.

## MECHANICAL DESIGN CONSIDERATIONS FOR A NEW DRIVE SYSTEM

The new drive for the Whitehair Bridge would focus the use of a rack and pinion system. For this, further design investigation would involve determining suitable motors, reducers, and external gearing, which would meet the criteria as mandated by the owner and applicable AASHTO codes. Consideration would also be given to disruption of both vehicular and marine traffic in the area. With a highway detour of approximately 60 miles, bridge closure durations would have to be limited. However, with the requirements of the local fuel barges to the electric generation plant, long-term closures to marine traffic also would not be permitted. These issues dictated that a drive replacement would not interrupt bridge operation for any period greater that 15 minutes, but single leaf operation would be allowed as necessary. To overcome these restrictions, the Contractor would later employ a temporary hydraulic cylinder drive system to facilitate uninterrupted operation of the bridge.

As discussed above, machinery areas in the bascule piers were very limited by design. The use of floor mounted drive machinery would be difficult to install and almost impossible to maintain in the space allowed. This caused the design focus to move toward another frame mounted drive solution.

The Sea Breeze Bridge, also in Volusia County, has been successfully retrofitted in the past with a frame mounted hydraulic drive system consisting of two hydraulic motors coupled to independent planetary reducers. With the Sea Breeze Bridge replacement occurring near the time of the Whitehair Bridge rehabilitation, consideration was given to reusing this equipment. However, it was determined that new equipment would be used for the project.

Deciding to use a frame mounted drive system, the type of prime mover would next have to be considered. This created two options, a variable speed electric motor drive system or a hydraulic motor drive system. Either prime mover technology selected would have two motors, each driving an independent speed reducer on either side of the drive frame. The speed reducers would have to be planetary type, providing a greater power rating per volume compared to parallel type reduction boxes.

The differences between any electric motor drive and hydraulic drive are clear. Typically, an electric motor will provide higher shaft speeds with a lower torque. This increases the need for gear reduction, either through a gearbox or external gearing, subsequently increasing the cost of installed machinery. However, a cost benefit comes in the form of a less expensive Variable Speed Drive (VSD) controller as compared to the Hydraulic Power Unit (HPU) of a hydraulic drive system.

Opposite of the electric motor is the Low Speed, High Torque (LSHT) hydraulic motor. As their name implies, this motor provides a low shaft speed at a high torque. These motors also deliver much greater power per volume that any traditional electric motor, providing more flexible design options. This high output torque further allows for a decrease in gear reduction and, therefore, a lower installed machinery cost. However, as mentioned above, the drive for these (i.e., the HPU) will generally cost slightly more per horsepower than a comparable VSD.

A further advantage to using hydraulic motors involves the common issue of drive system torque sharing. A definitive criterion of the new drive system would require identical torque to be applied to each output pinion to allow for even distribution of machinery loads. This is typically accomplished through the use of a differential type gearbox. However, to maintain total redundancy in the drive train, two independent reducers would be required for each leaf. By using two independent units, the design would eliminate any mechanical linkage between the drive motors other than the bascule leaf. Therefore, torque sharing would have to be accomplished at the prime movers, a function inherent to hydraulic motors, but complicated with VSD's.

After making the above comparisons, including a detailed cost analysis, the owner and designer decided to implement the new drive system using LSHT motors. Two of these motors would be installed, along with two planetary type gear reducers, on each drive frame. The output side of the reducer units would be coupled to the drive pinion. This provided a complete system, which could be shop fabricated to reduce installation time and provided solutions for space limitations. The decision to use hydraulic motors further aided in satisfying the requirements of drive torque sharing, as these motors can be hydraulically connected in parallel for matched load sharing.

## CONTROL DESIGN CONSIDERATIONS FOR A NEW DRIVE SYSTEM

As mentioned, one of the primary reasons for rehabilitation of the Whitehair Bridge was determined to be degradation of the drive machinery, particularly, the drive machinery frame. Although reports focusing on similar frames identified undersized components as a major cause of failure, cyclic action on the complete drive train, due to the motor control system, is also a large contributor. Motor controls installed around the time of the Whitehair Bridge construction generally consisted of nothing more than drum controllers for acceleration and speed control of each leaf. This placed all control for leaf movement in the hands of the bridge operator, allowing the operator to accelerate, move, and seat the bridge leaves with as much or little stress as he dictated. On this and other similar drive systems, the results manifested in failure of various components of the leaf drive trains.

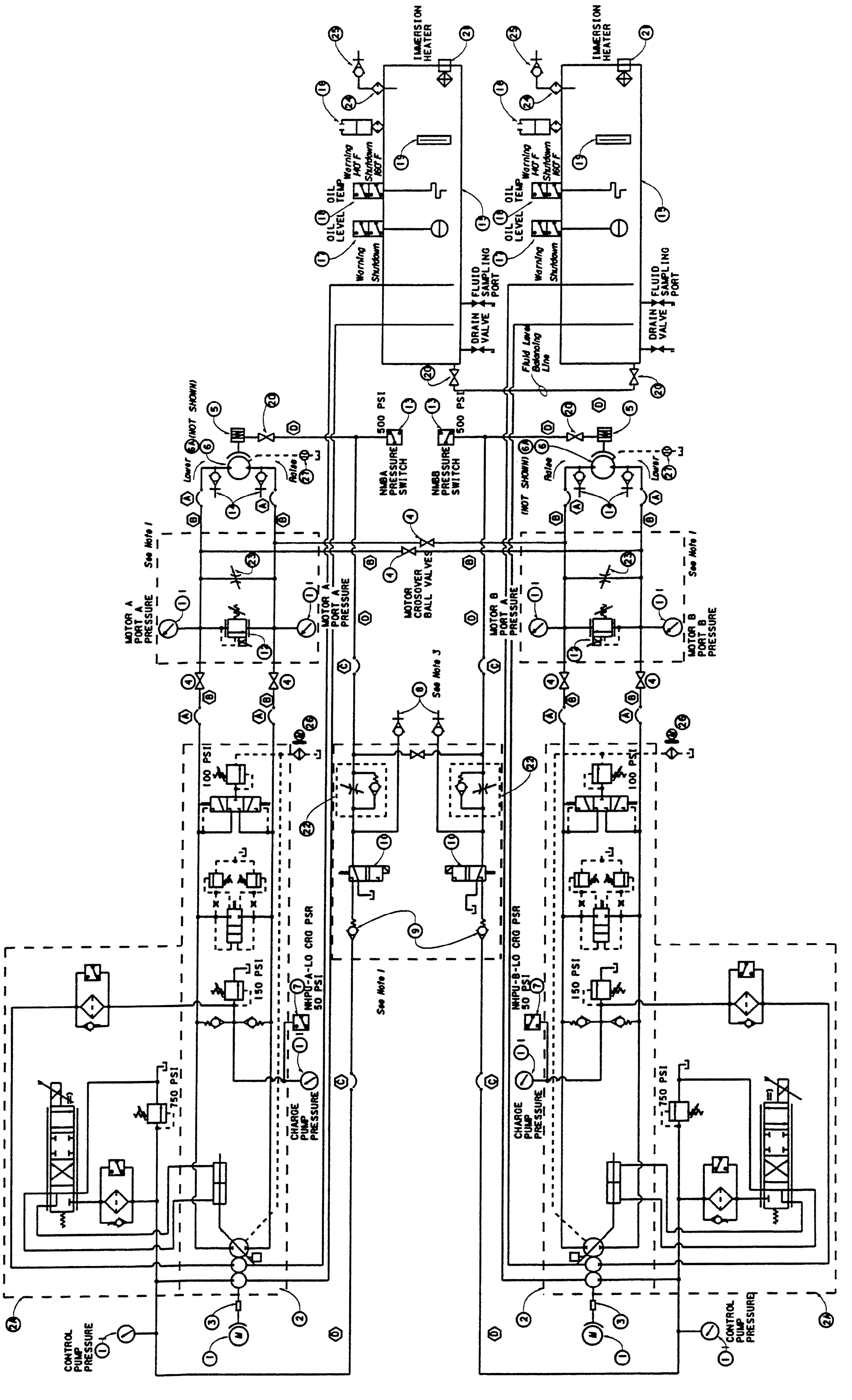
The new drive system for this rehabilitation project would be required to provide better motion control that the existing system. This could be performed through a variety of drive technologies including both hydraulic and electrical motor options. For simplicity, acceleration and speed control for the drive design would be accomplished with proximity type limit switches and analog valve control cards. This eliminated any need for additional controllers in the Hydraulic Power Unit Control Panel (HPUCP).

## NEW DRIVE SYSTEM DESIGN-MECHANICAL

Continuing to pursue the most efficient use of the limited pier space, it was decided to base the hydraulic system on a closed loop, hydrostatic drive. Hydrostatic drive technology has been used for many years, primarily in the mobile hydraulics industry. Advantages include a smaller reservoir size and a reduction in safety valuing generally required in open loop type bridge hydraulic circuit. Additional features included in this circuit design were cross port relief valves to limit output torque to machinery, seating relief valves to provide reduced force during live load shoe contact in the lowering cycle, and flushing valves to aid in oil filtration and heat removal. Diagnostic features included system pressure switches, clogged filter indicators, and temperature sensors. The complete closed loop hydraulic circuit system is shown in Figure 3.

Heat removal in closed loop systems becomes an obvious concern when accounting for the low volume of oil within the system loop. Because of this low volume, it is necessary to divert a percentage of oil from the system loop during operation and provide cooling before returning to the reservoir. Otherwise, heat generation through pressure losses would quickly overcome the oil, sending the temperature to unacceptable levels. For the Whitehair Bridge drive, a fan driven oil-to-air heat exchanger was specified. This unit is designed to provide cooling for all oil from flushing valves and losses in system relief valves, thereby keeping loop oil at acceptable levels.

Regardless of drive system type, good bridge drive design always draws attention to redundancy. In the event of major component failure of a drive or control element, it is important to maintain operation of the structure in a temporary or emergency mode while repairs are executed. It is for this reason each bridge leaf drive was designed with complete redundancy. That is, bridge operation could continue with the loss of one drive motor, reducer, rack, pinion, or a complete HPU. The process of switching to single unit operation would include valuing off the suspect unit and switching the HPUCP to the appropriate setting. During normal operation, motor piping crossover valves were designed to remain in the open position, allowing both motors to be hydraulically linked. This allows equalization of drive pressures at both motors ports resulting in even torque output at each drive pinion. Evidence of this torque sharing is shown in Figures 4A, 4B, 4C, and 4D. In these graphs, torque curves are nearly overlapped. A mathematical analysis of recorded values indicted torque sharing to be greater than 99% at steady state operation.




NEAR LEAF HYDRAULIC SYSTEM

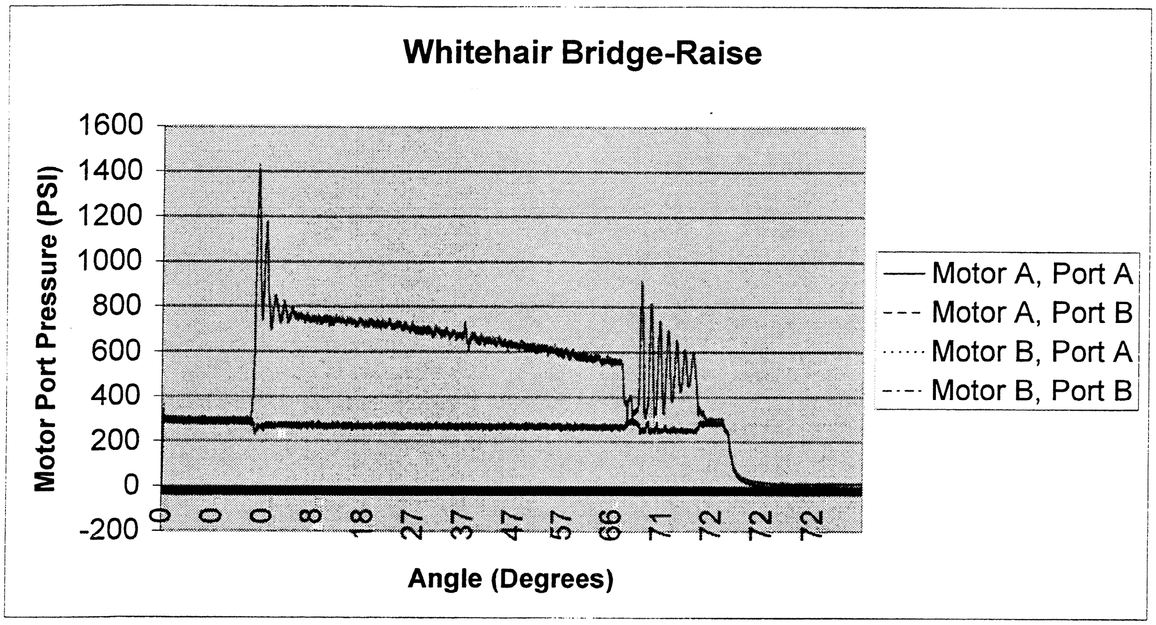



Figure 4A

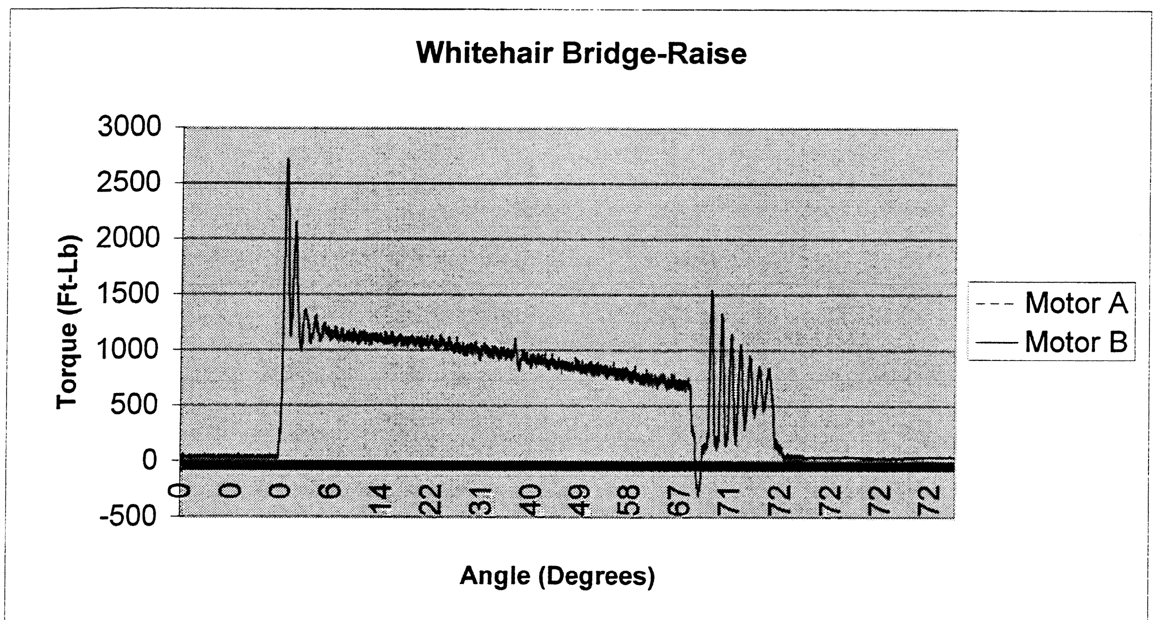



Figure 4B

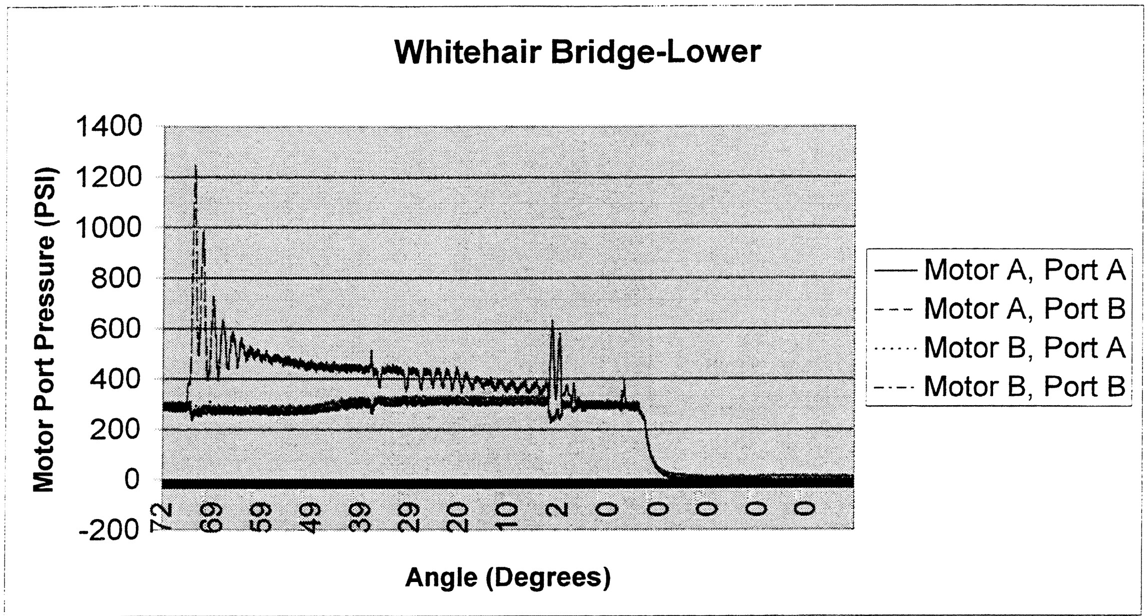



**Figure 4C**

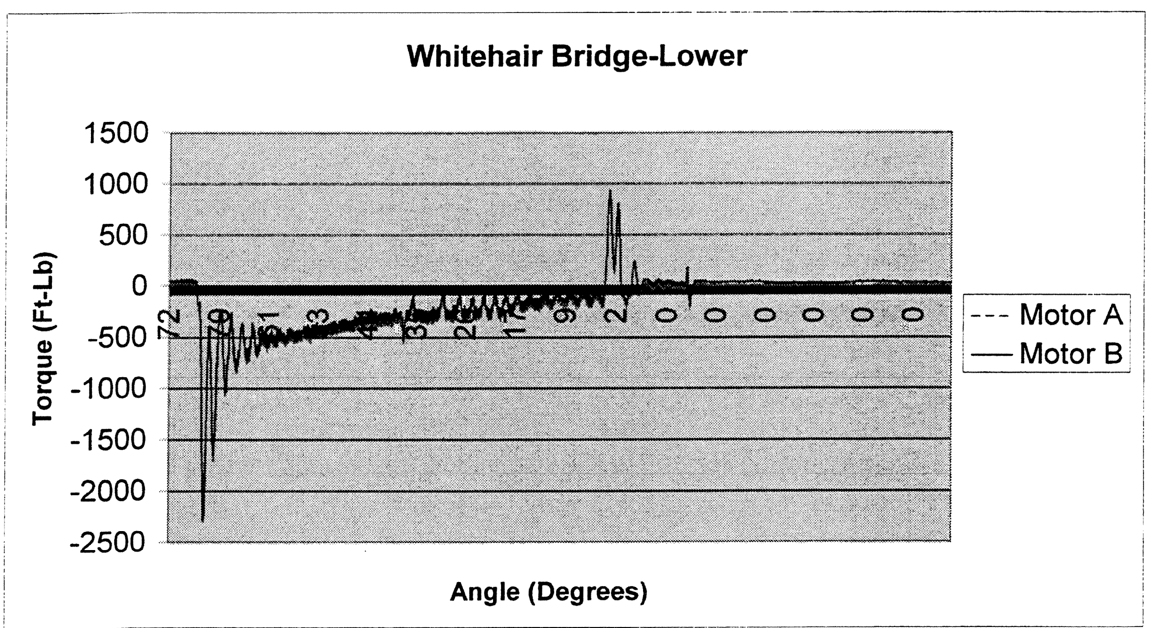



**Figure 4D**

AASHTO design specifications were used in determining required hydraulic flows, pressures, and horsepower. An analysis trunnion friction, unbalance, inertia, and wind loads on the bascule leaves yielded the following estimated values for the proposed hydraulic design:

| | |
|---|---|
| Flow Rate per Unit (Normal Speed)= | 11 GPM |
| Pressure at each Unit (AASHTO Condition "A") | 960 PSI |
| Pressure at each Unit (AASHTO Condition "C") | 2000 PSI |
| Pump Motor Power at each Unit | 2 X 10 HP |

Actual recorded drive pressures appeared lower than the above-calculated values. This was primarily due to the conservative nature of the AASHTO specifications.

Figure 5 provides the basic machinery layout employing the frame mounted hydraulic motors and reducers as installed.

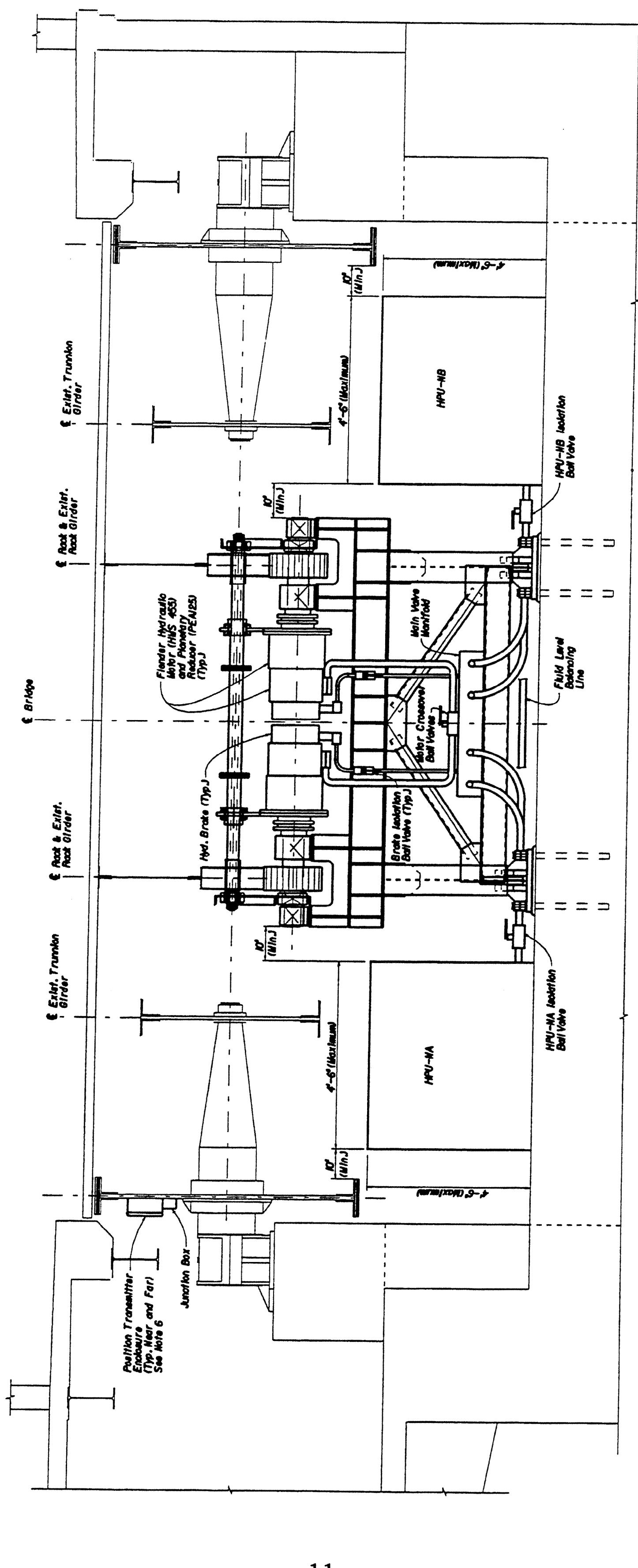
## NEW DRIVE SYSTEM DESIGN-ELECTRICAL CONTROLS

During operation, the drive HPUs were to be controlled by Hydraulic Power Unit Control Panels (HPUCPs), one for each leaf. The function of the HPUCP is to provide an interface between the primary bridge control system (i.e., the bridge control desk and PLC) and the HPU. This is accomplished through the use of simple relay contact closures for drive commands and feedback to and from the HPUCP. This technique also aids in construction by allowing different equipment suppliers to have standard interface connections between control panels.

The issues relating to damaged machinery due to operator control were also illuminated through the design of the HPUCP. This panel would provide smooth, repeatable acceleration, velocity, and deceleration throughout the complete bridge operating cycle, regardless of operator input. This control methodology allowed the designer to dictate acceleration times for bridge movement based on leaf inertia, which resulted in maintaining machinery loads to within design parameters.

## CONSTRUCTION

As with most Florida Department of Transportation projects, the Contractor initialized the construction process by submitting shop drawings to the project engineers for approval. During this time, the Contractor proposed a concept of using a temporary hydraulic cylinder drive system for the purpose of minimizing bridge downtime. Such a system would allow limited angle bridge openings during the demolition of the existing drive machinery. After review, this temporary drive was implemented using one HPU and two cylinders under each leaf in a "push-to-open" configuration. The maximum opening angle of approximately 45 degrees was found to be an acceptable temporary solution to the Coast Guard and local marine community. Figure 6 shows the bridge and the limited angle of operation.


ELEVATION OF DRIVE SYSTEM
℄ Exist. Trunnion Girder
℄ Rack & Exist. Rack Girder
℄ Bridge
℄ Rack & Exist. Rack Girder
℄ Exist. Trunnion Girder
Flender Hydraulic Motor (HMS 465) and Planetary Reducer (PEN125) (Typ.)
Hyd. Brake (Typ.)
Main Valve Manifold
Motor Crossover Ball Valves
Brake Isolation Ball Valve (Typ.)
Fluid Level Balancing Line
HPU-HB
HPU-HA
HPU-HB Isolation Ball Valve
HPU-HA Isolation Ball Valve
4'-6" (Maximum)
10" (Min.)
Position Transmitter Enclosure (Typ. Near and Far) See Note 6
Junction Box

The fabrication of the drive frames soon became a critical path item for the project. The frames and hydraulic drive machinery were fabricated at two different shops, with the intent of delivering the drive motors and reducers to the frame fabrication shop for final alignment after successful shop testing. Equipment shop testing covered operation of each HPU, motor, reducer unit, and HPUCP. After testing, the HPUs were shipped to the project site and the motors and reducers to the frame shop for installation.

With all machinery alignment conducted in the fabrication shop, installation of the frames became a simple task. Similar to the traditional Hopkins drives, each hydraulic drive frame was easily fitted to the floor mounted clevises and link arms were attached to the rack center shaft. The only remaining field adjustment of the gear train was between each rack and pinion set. This was accomplished through a slotted connection between the two link arm halves. After proper alignment, additional holes were field drilled for the final connection between the two halves.

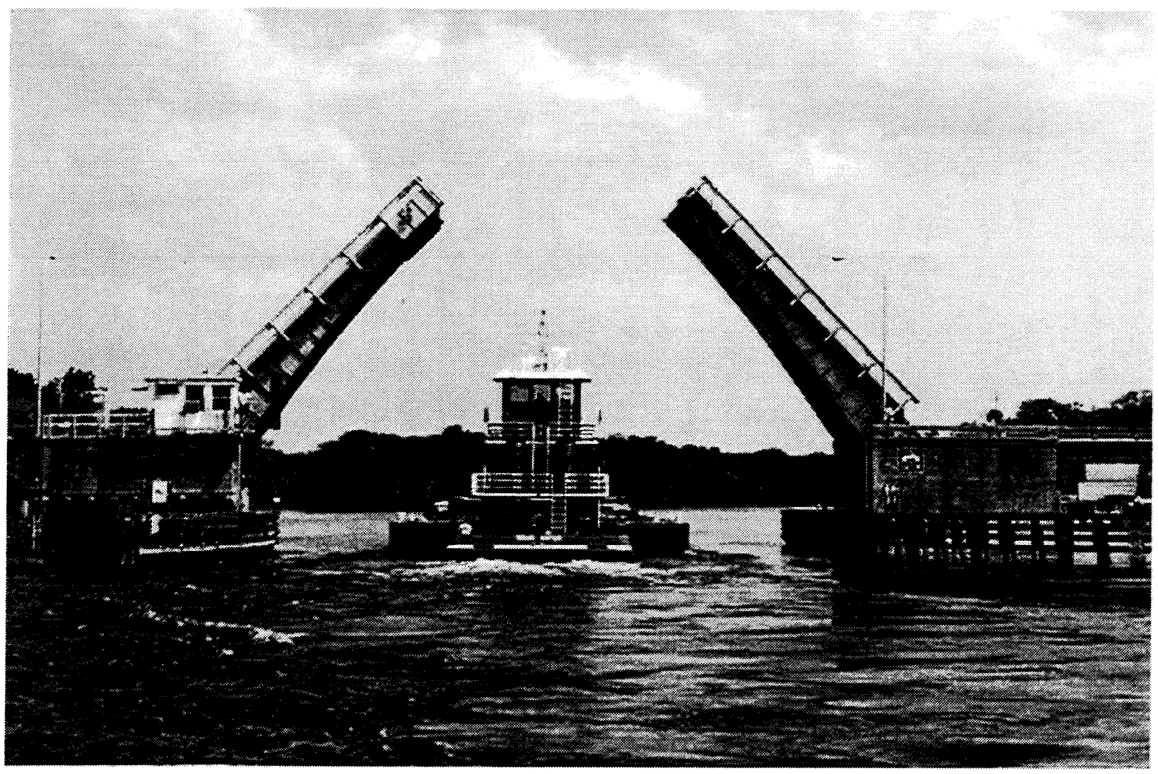


**Figure 6**

**Bridge a Reduced Angle of Opening**

The remaining construction issues after frame installation was the hydraulic installation and electrical interface. The hydraulic and electrical subcontractors accomplished these tasks and performed a series of "pre-functional" tests to verify compliance with the contract specifications for control and performance. After satisfactory operation, a complete functional test of the integrated bridge drive and control system was performed with the engineers, inspection team, and owners present for witnessing. This exercise was intended to demonstrate the functionality of the drive and control system in addition to testing of safety interlocks and emergency drive system operation.

## CONCLUSION

In retrofitting existing bridge structures with new mechanical and electrical equipment, options become governed by limits introduced in the original design of the structure. This is particularly true of movable bridges constructed in the building boom of the 1950s and 1960s. As with the Whitehair Bridge, many of these bridge piers were designed and constructed with machinery areas sized barely large enough for the Hopkins machinery than contained, making modern machinery design a challenge. By investigating the use of equipment with greater capacities per unit volume, design options become more open. The major components, which allowed the designers to overcome space limitations, were the hydraulic power units, hydraulic motors, planetary type gear reducers, and drive frame assemblies. Other options could have worked for this project, however, the final Whitehair Bridge drive design provided the best solution based on existing pier configurations and criteria for future maintainability.