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"HYDRAULIC LIFTING SYSTEM FOR KINGSTON FERRY TERMINAL PASSENGER LOADING RAMP"

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HYDRAULIC LIFTING SYSTEM

FOR KINGSTON FERRY TERMINAL PASSENGER LOADING RAMP

Kingston, WA

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1.0 INTRODUCTION

The Kingston Ferry Terminal, operated by the Washington State Department of Transportation (WSDOT), forms a marine highway link between Edmonds and Kingston, Washington. The new passenger Loading Ramp was open for service in October, 1993. At the heart of the system, is a single movable support column, guided within a concrete "supercolumn", with no counterweights, towers or other neighborhood view obstructions.

After evaluating many alternatives, Hamilton Engineering's final concept was to position the 420,000 pound passenger loading ramp over the 23 foot vertical range by means of a single 16 inch bore hydraulic cylinder. This was accomplished by a support mechanism which included a 44 inch square movable column sliding inside a large outer support bearing.

The square movable column, together with the support bearing, provides simple lateral support and guidance for the passenger ramp. The movable column was designed to carry all dead and live loads, as well as projected wind, snow and earthquake forces. The 16 inch hydraulic cylinder provides vertical positioning only, and has large radius spherical ends machined on the rod and body to prevent lateral loading of the cylinder. The large outer bearing was imbedded inside the single concrete column, cast on site.
This innovative design provides engineers with a simple and inexpensive alternative for lifting large structures (like ferry passenger loading ramps) relatively large distances (23 feet and more). The lift system elements are machined with a close tolerance for longer life and the whole system was fit and tested in the shop for easy final assembly in the field. This method reduces field erection problems and is less expensive than the common, field erected rope and tower type mechanisms.

The design of the lifting mechanism is original and unique. It provides key advantages over rope type lifting systems: elimination of view obstruction support tower, smaller footprint, simplicity (fewer moving parts), and improved safety.

This paper discusses this unique hydraulic lifting system from its initial concept stages to the final design, manufacturer, installation and operation at the ferry terminal.

2.0 PROJECT DESCRIPTION

The Kingston Passenger Loading Ramp concept required a lift mechanism that would provide support and guidance for the 420,000 pound structure over a vertical range of 23 feet. Several major technological challenges and environmental concerns had to be addressed and solved, including:

- The WSDOT requirement for a low, non-view obstructing loading facility.
- The standard tower and rope type lifting system was not acceptable because of concerns about view obstruction, as well as the high construction and maintenance costs.
- Complicated control and hydraulic systems would be required if multiple hydraulic cylinders were utilized to raise and lower the passenger cab.
- Economics dictated a single column support design versus the use of a concrete pile cap with support piles.

The Kingston Passenger Loading Ramp is shown on Figure 1. The system consists of Passenger Cab, Passenger Cab Lifting Cylinder, Movable Column and two Aprons. The Passenger Cab can be moved up or down by the Lifting Cylinder and stopped at any position in between. Lateral support and guidance of the Passenger Cab is provided by the Movable Column. The extra wide final loading ramps, or Aprons, can be adjusted horizontally (swing and extend) and also vertically for comfortable passenger access to all ferries at all tidal conditions.

3.0 THE LIFTING MECHANISM

After evaluating many alternatives, Hamilton Engineering's final concept proposal was to position the 420,000 pound Passenger Cab over the 23 foot vertical range by means of a single 16 inch bore hydraulic cylinder. This was accomplished by a support mechanism which included a 44 inch square movable column sliding inside a large outer support bearing (see Figure 2). The square movable column, together with the support bearing, provides simple lateral support and guidance for the Passenger Cab. The movable column was designed to carry all dead and live loads, as well as projected wind, snow and earthquake forces. The 16 inch hydraulic cylinder provides vertical positioning only, and has large radius spherical ends machined on the rod and body to prevent lateral loading of the cylinder. The large outer bearing was imbedded inside the single concrete column, cast on site.

The design of the lifting mechanism is original and unique to this Passenger Loading Ramp. It provides key advantages over rope type lifting systems:

- Elimination of the support tower view obstruction, a constant complaint from neighboring residents.

- Unobtrusive and functional design blends with a variety of architectural designs.

- Smaller footprint allows the main loading ramp to come closer to the ferry wing wall, thus shortening the size of the end ramp aprons.

- Simplicity of design--the system uses few moving parts, and most of the parts are machined and fit in the shop for easy field assembly, resulting in a design that is low maintenance and low cost.

- Improved safety--the load is supported by the hydraulic cylinder rather than hanging from ropes, and close fabrication tolerances of the lifting column and the support bearing, assures long time dimensional stability.

4.0 THE HYDRAULIC LIFTING CYLINDER

The hydraulic lifting cylinder provides very simple and reliable means of moving the passenger ramp. It has several important safety features:

- The safety bulkhead inside the cylinder at the bottom will allow the passenger ramp to descend slowly in the event of a large cylinder head leak.

- Use of double large (3/4 inch cross-section) pistons and rod seals.

- An integral orifice in the piston retract port which will allow a slow descending speed in the event of a catastrophic failure of the hydraulic valves.

- Counterbalance valve in the piston retract port which hydraulically locks the cylinder and will prevent descent if a hydraulic line breaks.

- Overspeed valve in the piston retract port which will shut off the hydraulic flow and stop descent movement if the counterbalance valve fails.

- Design safety factor of over 7 : 1 based on maximum load induced pressure.

- Stainless steel, chrome plated rod.

5.0 HYDRAULIC SYSTEM

Pump, electric motor, and most other hydraulic components, except the pilot operated counterbalance valves, are mounted on the same frame as one self-contained unit for ease of fabrication, testing and field assembly. This hydraulic systems main component, Hydraulic Power Unit (HPU), is positioned below the Passenger Cab floor (see Figure 2). Such a configuration, close to the lifting cylinder, greatly simplifies the hydraulic piping and reduces hydraulic pressure losses. This arrangement is also environmentally safe because any possible leakage as a result of a HPU component failure, will be totally contained within the supercolumn.

The Hydraulic Power Unit contains a pressure compensated pump with 52 gpm maximum flow, with compensator pressure setting of about 2,600 psi (see Figure 3).

Hydraulic tank is mounted separately, also below the Passenger Cab floor.

All hydraulic cylinders in the system are activated by three position directional valves, solenoid operated, so each cylinder can be extended, retracted or stopped at any position when the valve's spool is centered.

The Passenger Cab lifting cylinder has the pilot operated counterbalance valve bolted directly to the cylinder's piston port. If the Passenger Cab is stopped in any raised span position, the pressure in the cylinder is held entirely by the counterbalance valve, not by the piping.

During the lifting phase, the hydraulic oil bypasses the counterbalance valve through the check valve. In case of a pipe or hydraulic hose break at that time, the lifting will stop automatically (by hydraulic means) as soon as the pressure drops and the weight will be held in place by the counterbalance valve.

During lowering of the Passenger Cab, the hydraulic system performs in the following sequence:

- the high pressure oil flows to the rod side of the cylinder;
- this high pressure signal is sensed by the counterbalance valve through the pilot line;
- the pilot line pressure together with the piston side pressure opens the counterbalance valve; and,
- it thus allows the Cab to be lowered.

If a return line from a cylinder breaks at this time, the lowering speed will not be affected because the counterbalance valve will control the cylinder pressure.

As explained above, the load is supported by the counterbalance valve all the time. If a limit switch or the operator activates the directional valve by shifting it to its neutral position, the down movement will also be stopped by the action of the counterbalance valve. In all of the above cases, the safety of the system is fully maintained, even if the hydraulic line breaks. The Passenger Cab up or down movement can be stopped at any time, by shifting the directional valve to its neutral position.

In order to further the safety of the system and to protect against a counterbalance valve malfunction (this occurrence might happen if the spool became stuck due to a piece of dirt, for instance) an overspeed valve is added to the system. This valve is wide open if the oil flow is not greater than the nominal (might be field adjustable), but it will close immediately if the flow increases above nominal flow. Overspeed valves are commonly used in hydraulic elevators to prevent free fall of the car in case of hydraulic line break.

The counterbalance valve and overspeed valve must be bolted together directly to the cylinder port. The connection will consist of SAE 4-bolt, 5,000 psi rated port for an extra safety margin. In this manner, the lift system will be protected not only from a hydraulic line break, but also against a valve failure.

The apron's cylinders for lift, swing, extend and retract motions, operate on the same principal solution of the counterbalance valve supporting the load all the time and locking the cylinder when the directional valve is centered. Additionally, the apron's lift cylinder has two-speed lowering capability. This is accomplished with two flow control valves, position for metering-in, field adjusted to desired speed. The solenoid three-way valve connected to the limit switch, changes the flow path, thus changing the apron's speed.

A separate float system allows the apron to be lifted and slewed by the ferry boat, when the boat changes its position due to change in tide, boat weight (live load change) and also when the boat is pushed sideways by strong winds. The float system is activated by the solenoid valve, by-passing the counterbalance and directional valves (oil is pushed or sucked directly to or from the tank).

6.0 CONSTRUCTION

The concrete, steel reinforced supercolumn was cast on site. All other steel structural portions of the system were fabricated, assembled and tested (if possible) in the shop.

Perhaps the most complex machined part, was the lifting shaft. It was machined on a large mill with 40 feet of horizontal travel to close geometric tolerances.

The hydraulic lifting cylinder (16 inch bore, 23 feet stroke) was manufactured and tested in the shop by Atlas Cylinders. The cylinder was installed in the field through the opening in the Passenger Cab roof.

6.1 HYDRAULIC POWER UNIT SHOP TESTING

The hydraulic power unit, together with the hydraulic tank, was assembled and tested in the Contractor's shop prior to installation in the field.

During the shop test, the systems operational loads were simulated by using the relief valves. All pumps and valves were sequenced through their full operating ranges to ensure satisfactory operation of the components.

All major components were tested to their maximum specified operational pressure and flow. Pumps were run for a minimum of 5 hours at 2000 psi.

Thorough hydraulic power unit shop testing paid off later during system field testing, because fewer adjustments were needed.

6.2 HYDRAULIC SYSTEM TESTING

Hydraulic system testing was relatively simple because all components were previously tested in the shop. The initial chattering of the apron during the lowering phase was gone after thorough air bleeding from the cylinder. Similar vibration of the Passenger Cab during the lowering phase disappeared after air bleeding and after lubrication of the sliding race of the lifting shaft.

Perhaps the most difficult problem was the hydraulic fuse valve malfunction in the main cylinder. The initial design included two fuse valves, one in each end of the cylinder. The idea was to stop the abnormally increased flow, not only in the piston side port (e.g. in case of piping and counterbalance valve failure), but also in the rod side port in case of the catastrophic failure of the piston seals or internal piping on the rod side of the cylinder. In reality, the two opposite oriented fuse valves created a potential hydraulic "trap" for the cylinder. In case of occasional activation (closing) of one fuse valve (e.g. cased by thick oil at low temperatures), the other fuse valve would close without apparent cause and the cylinder was jammed. The only solution was to manually "crack" one of the cylinder port fittings and release pressure trapped inside, thus resetting both fuse valves. After thorough analysis, it was found that the system dynamics (pressure pulsation) caused the other fuse valve to close shut and the only solution was to remove the rod side fuse valve. The safety system did not suffer, because the possibility of simultaneously catastrophic failure of the piston seals and piping is very remote.

7.0 RECOMMENDATIONS

7.1 HYDRAULIC SYSTEM PRESSURE SELECTION

The maximum pressure in the hydraulic system was selected as 3,000 psi, maximum working pressure as 2,600 psi, maximum load induced pressure as 2,100 psi. These pressures are higher than the AASHTO recommended pressure of 1,000 psi for hydraulic systems for highway movable bridges.

Today, the majority of industrial hydraulic components are rated to operate continuously at 3,000 psi or above. Even 5,000 psi systems are becoming more and more popular. The AASHTO pressure specification of 1,000 psi or less is well below the industrial components' rating. The reduction in pressure (below rating of the component) does not bring the proportional increase in reliability of the system. For a given flow rate, any reduction in pressure below 2,500 psi, is estimated by engineers to have a negligible effect on the system reliability of operation and frequency of the maintenance. On the other hand, for a given power demand, higher flow required by reduced pressure, increases system cost, complexity, and maintainability. This is particularly noticeable in larger, high power systems. Therefore, the theoretical benefits gained by following the conservative AASHTO specifications, do not match the losses of handling the large flow.

Based on current experience with modern industrial hydraulics, it is felt that heavy movable structure designers should not be governed by detailed pressure limitations dictated without regard to flow and power considerations. It is in the public interest that the selection of both pressure and flow in hydraulic systems, be left to the designers and component manufacturers.

If maximum pressure limitations are to be specified, however, they should be updated to reflect the current state-of-the-art of hydraulic components.

7.2 FUSE VALVES IN THE SYSTEM

Fuse valves are often specified in the hydraulic systems for safety or for control of the oil leakage. Based on my experience with hydraulic systems for civil application, the use of fuse valves shall be minimal and only in cases when sudden shut-off of the line does not cause operational problems. The hydraulic fuse valve is not a precision type device, and sudden valve activation without apparent cause is quite common, especially when rating of the valve is only slightly higher than the nominal flow. Rating of 150% of the nominal flow shall be the minimum.

One reason for inadvertent fuse valve actuation is changed in viscosity of the hydraulic oil caused by low temperature. Most often, at least part of the hydraulic system is positioned outdoors or is not in a heated room. In the cold winter climate, oil in the cylinders and piping is thick. Fuse valves are not a viscosity compensated device and in presence of thick oil, the valve will actuate at much lower flow than it is rated.

Another reason is a high pressure surge caused by the dynamics of the system. High pressure surge and perhaps local surge in flow, is common for hydraulic systems for heavy machinery especially with high velocity movements. High pressure surge can cause the fuse valve to shut-off.

Perhaps one more argument against fuse valve is that the valve is adding complexity to the system, as the valve represents one more element potentially subject to fail. I witnessed the situation, when a small counter nut got loose from the fuse valve, it flowed with the oil stream and jammed the directional valve, causing the system to be inoperative and a great deal of confusion.

8.0 SUMMARY

This innovative design provides engineers with a simple and inexpensive alternative for lifting large structures (like Ferry Passenger Loading Ramps) relatively large distances. The lift system elements are machined with close tolerance for longer life and the whole system is fit and tested in the shop for easy final assembly in the field. This method reduces field erection problems and is less complex and less expensive than the previously common, field erected rope and tower type mechanisms. The operation of the system is simple. Since the hydraulic lift cylinder is designed to support the live load, there is no need to activate locking pins after each ramp readjustment.

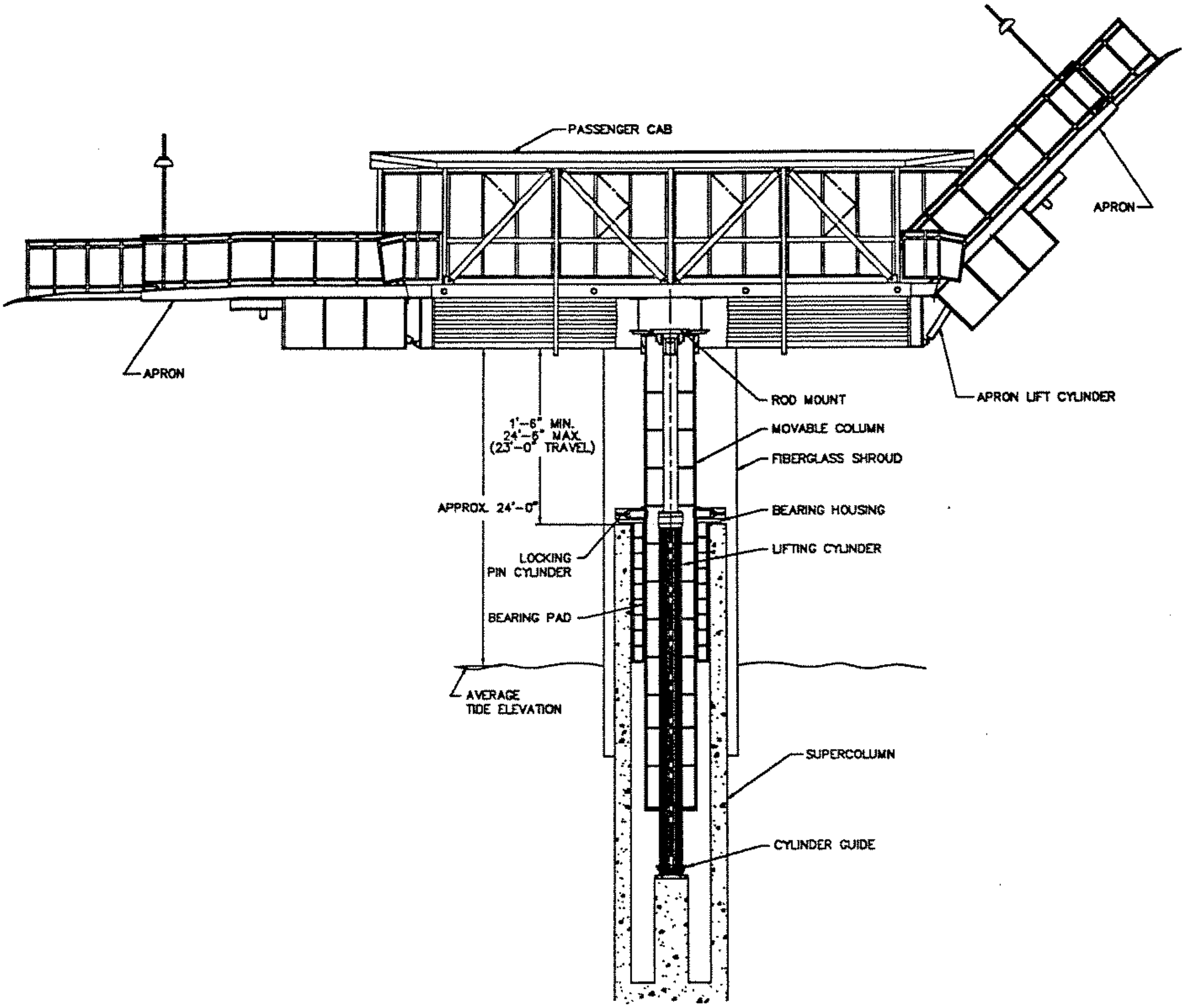

FIGURE 1 - PARTIAL CROSS-SECTION

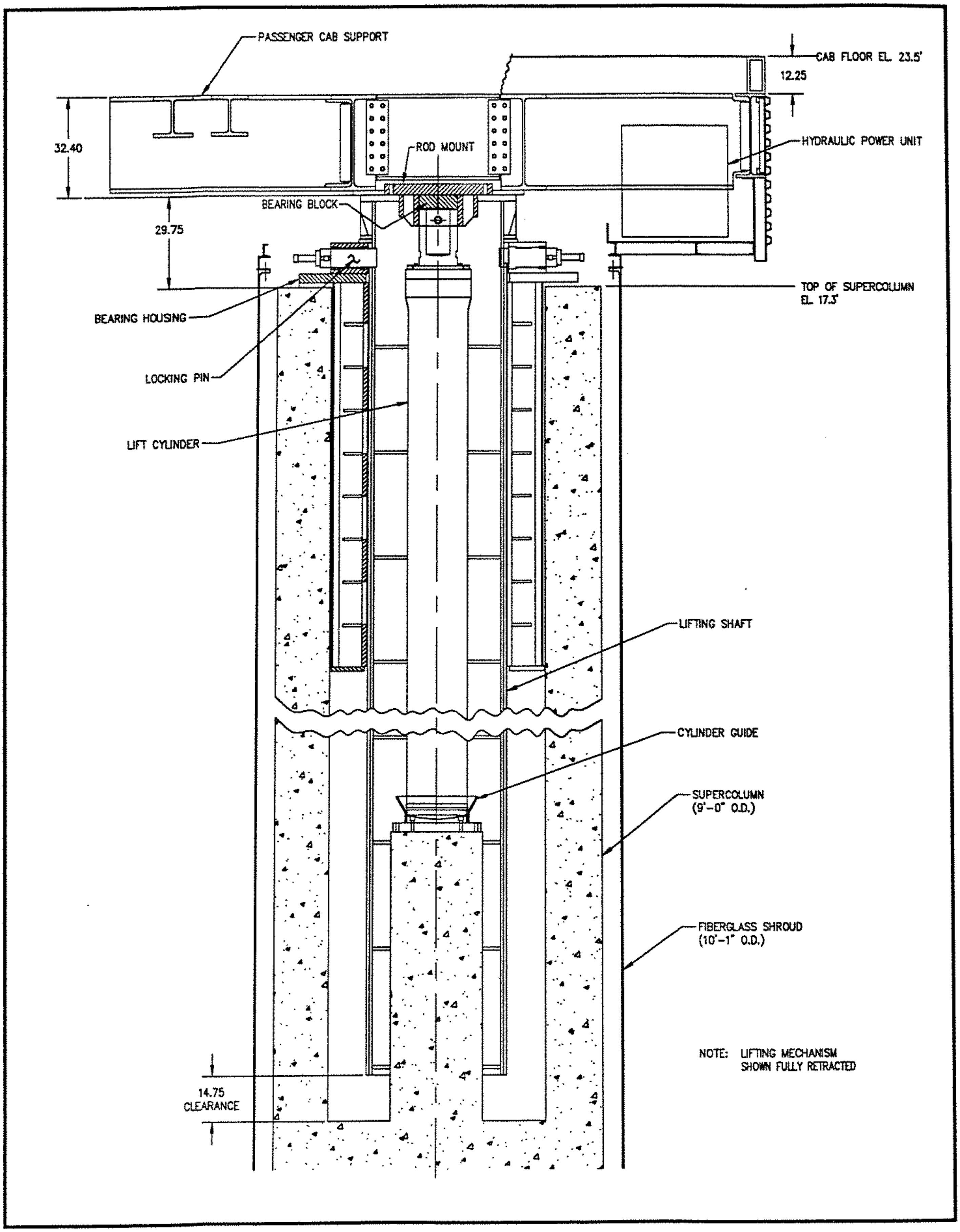

FIGURE 2 - LIFTING MECHANISM

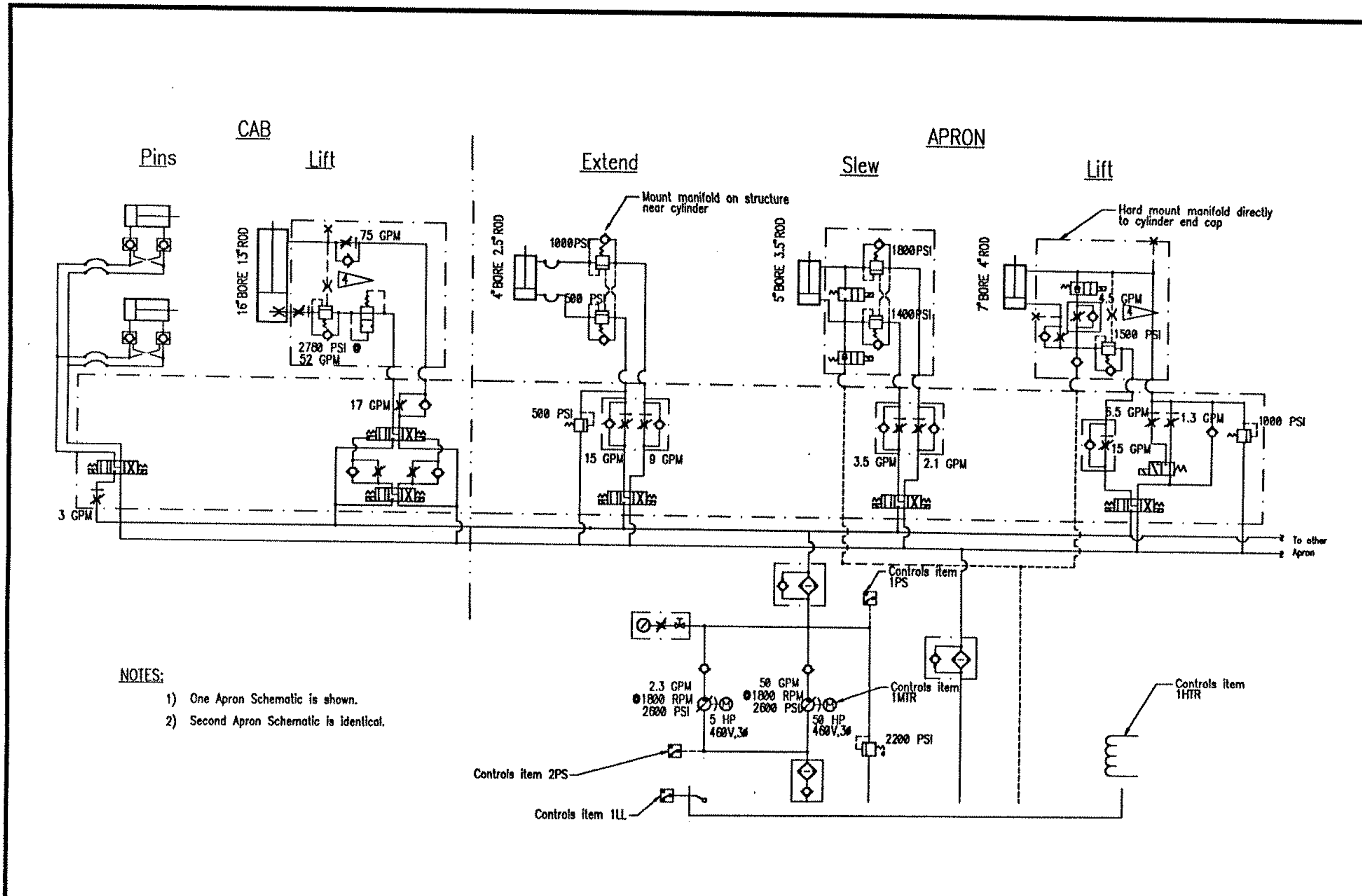

FIGURE 3 - HYDRAULIC SCHEMATIC