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"Applications of Hydraulic Jacks to Move Heavy Structures Including Heavy Movable Structures"

by

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APPLICATIONS OF HYDRAULIC JACKING SYSTEMS

OR

HOW TO MOVE HEAVY STRUCTURES
INCLUDING
HEAVY MOVABLE STRUCTURES

Presented To:

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PREFACE

The construction and operation of portable hydraulic jacking systems is covered in the American National Standard: ASME B30.1, JACKS. The introduction to that standard includes the following statement: "The use of cableways, cranes, derricks, hoists, hooks, jacks, and slings is subject to certain hazards that cannot be met by mechanical means but only by the exercise of intelligence, care, and common sense."

INTRODUCTION

What do a failing roof truss over a paper machine and a fixed span truss bridge on a shattered pier have in common with an operationally-challenged swing bridge? All needed to be repaired. And all utilized hydraulic jacking systems to enable those repairs.

The scope of this paper is limited to simple portable hydraulic jacking systems used commonly by the civil/structural construction industry. This paper opens with an overview of the components which comprise hydraulic jacking systems: pumps, fluid delivery systems and jacking cylinders. A suggested approach for system selection, installation and operation follows. The paper closes with examples of typical applications of civil/structural hydraulic jacking systems. A caution about the information in this paper, things have a habit of being available at one time or place and then not being available at another time or in another place. If the reader plans a jacking project, verify availability of components before committing to a course of action and reread the preface to this paper.

PUMPS

What is referred to as a "pump" is itself an assembly of components: a pressure creating means (a pump), a fluid reservoir and a control system. The pump can be hand powered or motor powered, with motors driven by electricity (115 VAC, 230 VAC, 460 VAC, or 24 VDC), gasoline or compressed air.

Fluid reservoirs can vary in capacity from 0.1 gallons (20 cubic inches) to 18 gallons or more.

The control system will have a system gauge and a control valve. The system gauge is normally a *pressure* gauge calibrated from 0 to 10,000 psi, although a specific pump/cylinder combination may come with a *force* gauge matched to the cylinder supplied, and calibrated in pounds or tons.

Control valves can offer one-, two-, three-, or four-way flow control. One-way control valves, integrally mounted on hand pumps, control flow from the jack cylinder back into the reservoir. They are closed when the pump is used to deliver pressure to a jack cylinder and opened to depressurize the cylinder and allow the hydraulic fluid to flow back into the reservoir. Other one way valves (shut off and check) used in hydraulic jacking systems, but not usually mounted on the pump, are discussed below in the paragraph on fluid delivery systems. Two-way control valves, called "two-position, two-way" valves, are used to control single-acting jack cylinders. The phrase "two position" refers to the control handle positions available, "advance" and "retract". The "advance" position connects the jack cylinder supply hose to the pressure side of the pump, while the "retract" position connects the supply hose to the reservoir side of the pump. Three-way control valves, called "three-position, three-way" valves, are the same as two-position valves except that a third control handle position, "hold", is included which closes off the supply hose from both sides of the pump. Four-way control valves, called "three-position, four-way" valves, look much the same as three-way valves. The four-way control handle has the same three positions, "advance", "hold" and "retract" as the three-way. The difference between the two is that the four-way valve has two jack cylinder supply ports, where the three-way has one. The two jack cylinder supply ports are coordinated so that when the control handle is in the "advance" position, one supply port is connected to the pressure side of the pump and the other is connected to the reservoir side of the pump. The "hold" position shuts off both supply ports from both the pressure side and the reservoir side of the pump. The "retract" control handle position reverses the "advance" supply port connections. Four-way control valves are needed to control double-acting jack cylinders which are discussed in the paragraph on jack cylinders below. Four-way control valves can operate single-acting jack cylinders by utilizing only one of the jack cylinder supply ports.

FLUID DELIVERY SYSTEMS

The hydraulic fluid delivery system connects the pump to the jack cylinder. This may be just a single hose or it may include multiple hoses, connectors, manifolds, gauges, and valves.

Hydraulic hose generally is supplied in one color, black, and in lengths of from ten to fifty feet in ten foot increments. When working a single system with multiple jack cylinders, especially double-acting cylinders which have two hoses each, coding of the ends of each hose with a distinctive marking makes set-up of the system easier. Coding can easily be accomplished with various combinations of colored tape, such that, for instance, both ends of one hose have red tape, another hose green tape, etc. Color coding greatly reduces the chances of misconnecting hoses initially and speeds the confirmation checking of a newly set-up system.

There are several different styles of component or hose connectors, most of which are referred to as quick disconnect connectors (QDC). This is a big reason for avoiding mixing parts and pieces from more than one source. Renting a pump from one source and using the hoses and cylinders from your attic may prove frustrating when the quick disconnect connectors won't connect. Even when using a single supplier it is good practice to check ahead of time that all the connectors will mate as expected.

Manifolds allow the connecting of gauges in-line with hoses and allow multiple cylinders to be connected to a single supply or return port.

Gauges, as described in the section on pumps above, may be calibrated to read either pressure (psi) or force (lbs, kips, or tons). Gauges are usually supplied reading pressure and may not be available reading force for a particular cylinder. A gauge reading force units may have multiple scales on its dial which requires the use of the correct scale for the force in the cylinder being used to be read correctly.

There are many kinds of valves, used in-line, available for hydraulic jacking systems. The simple jacking systems encompassed by this paper however usually use only two kinds: shut-off valves and manually operated check valves. Shut-off valves, (SOV) also called needle or needle-type valves should be provided for each cylinder used in a jacking system. Even if the anticipated use of the system does not require a SOV for each cylinder, good practice is to provide one in case the unexpected happens during the actual use of the system. Manually operated check valves, also called load lowering or load holding valves (LHV), are also items to include in all jacking systems on a good practice basis. Use of a LHV reduces the possibility of accidentally releasing the system pressure by inadvertently turning the control valve handle in the wrong direction or by some other mis-step. LHV's are often installed in-line immediately after the pump, but are sometimes also installed immediately before each cylinder.

JACKING CYLINDERS

Cylinders for jacking systems are available in various capacities and in different styles depending on the purpose for which it is to be used. Key terms used to describe cylinders are: single-acting, flat-jack, locking-collar, double-acting, and hollow-cylinder.

Single-acting cylinders are available in capacities from 5 to 1500 tons and with a variety of stroke extension lengths. Stroke extension directly affects overall height of the cylinder and selection of the right cylinder for an application usually requires a consideration of both items. A category of single acting cylinders called low-height or flat-jacks are available in up to 150 ton capacities for extremely low height applications, but come with an extremely limited stroke of less than 1 inch. These "flat-jacks" should not be confused with "pancake" or Freyssinet jacks which are also sometimes called flat jacks. Freyssinet jacks, distributed by PSC Heavy Lift, Inc. are another category of hydraulic jack not covered by this paper.

Single-acting cylinders are available with threaded rams and locknuts, called "locking collar" cylinders. These are appropriate for situations where the load must be held immobile for an extended period of time, where loss of hydraulic pressure could have catastrophic results.

Double-acting cylinders are configured to allow the ram to be extended by hydraulic pressure as with a single-acting cylinder, and also retracted with hydraulic pressure. This allows faster cycling of the ram in and out, as single-acting rams either are spring return or gravity return, which can be a slow process. If a ram is used in a horizontal position a single acting ram might not retract well at all. Double-acting rams are available in up to 500 ton capacities in the push direction with half of that or less in the pull direction.

Cylinders are available with hollow rams, sometimes called "center-hole" or simply "hollow" cylinders. A hollow ram allows a rod or assembly of rods or strands to pass through the body of the cylinder This allows a ram to be positioned over the object to be lifted. These are generally available up to 200 ton capacity, although one of the projects featured at the end of this paper used 494 ton hollow cylinders.

A consideration is the material from which cylinders are made. Single-acting aluminum cylinders are available in up to 100 ton capacities. A steel 50 ton cylinder with a 6 inch stroke weighs 60 lbs. An aluminum one weighs 24 lbs. If a system must be set-up and taken-down repeatedly, weight may be important.

JACKING SYSTEM DESIGN

The first task when given an assignment requiring the use of hydraulic jacks is to go to the site and observe. Taking photographs for later reference provides good reminders of what was seen and may provide an opportunity to detect problems not perceived during the site visit. Look for obstructions that may prevent setting cylinders in a desired location. Electrical, piping or other items not shown on drawings may impact desired locations.

Hunt down drawings of the existing construction. Compare what is shown on the drawings with the photographs. The drawings may be obsolete. Often old drawings will have a wealth of dimensional and load information which provides an excellent basis for preliminary design of the system. Remember to verify load assumptions from old drawings. Field check dimensions taken from old drawings

Analyze structure for deflection due to actual loads and anticipated jack cylinder location. Use loads that match existing conditions as closely as possible so that predicted forces and deflections will be meaningful. Overestimating loads and deflections can be as troublesome as underestimating them. Deflected behavior may be critical if flat-jack cylinders must be used due to height limitations.

Design structural support system. Ideally the structural system should be as strong or stronger than the force the cylinders can exert. Follow the complete load path. Check load transfer from lifted element to cylinder. Adding stiffeners is almost always necessary and is always good practice. It is hard to guarantee that a cylinder will be perfectly located. Partial height stiffeners may provide adequate support. Assure that the cylinder bears squarely against the lifted load, so as to not edge load the ram and damage the cylinder or cause it to move unexpectedly. Consider the effect that thermal movement will have on the jacking set-up. Long structures can expand or contract considerably and induce significant horizontal forces where none were anticipated. Check load transfer into the supporting structure. Provide bearing stiffeners where cylinders are supported by structural steel and consider the effect that high bearing stresses may have on concrete, especially adjacent to free edges. Reinforcing may need to be added to keep supporting concrete from failing along a free edge..

Design the hydraulic jacking system. Select a cylinder package based on capacity, height, extension, single- or double-acting, if a hollow cylinder is needed, and if a locking-collar is needed. Anticipated loads on cylinders should be kept to below 80% of rated capacity and lower than 65% is preferable. Actual loads won't be known until the system is used for real and actual loads are sometimes higher than anticipated loads. Also, hydraulic systems are much less apt to leak at lower pressures. And a leaking system may not do the job. Cylinder travel needs to include an initial ram stick out from cylinder of 1/2" and provide for unanticipated extension requirements. Select a pump based on the power source that will be available when the work is performed. Remember that the normal electric service may be shut off when you go to do the work. Select a reservoir large enough to supply all cylinders over full travel range. There is a reason why the manufacturer puts that information in the catalog. Check weight of equipment. Will it have to be hand carried into place? Check to see if equipment is available for purchase or rental; availability of equipment is critical. Provide enough gauges and valves to job required. Create a schematic of the hydraulic system, one that conveys what you want and where. This does not need to follow ANSI or ISO graphic symbol conventions, but should be descriptive enough so that all the parties who will be involved can interpret it.

JACKING SYSTEM INSTALLATION AND OPERATION

Order system from a known reputable supplier. Double check items ordered, preferably using a written order. Discuss system with supplier. They have good ideas and lots of experience. Order an extra cylinder and hose. Consider hiring a representative from the supplier to supervise the installation and operate the system.

When the system is delivered open the box and check components against what the manifest shows. Mistakes happen. Make sure all cylinders, pumps, hoses, gauges, manifolds and valves are there. Find the instructions that came with system. Read them. Verify all connectors will mate as anticipated.

Assemble the system. Color coded hoses make multiple cylinder systems much easier to set up. Arrange valves on multiple cylinder systems so that the valve layout logically simulates the cylinder layout. If you need to shut off the cylinder closest to you quickly, you will save a valuable few seconds if the valve for that cylinder is the closest to you. Double check that all connectors are made up correctly and that safety locks if provided are set. Read the instructions that came with system. Do instructions make sense?. If there is a question about the operation of the equipment call the supplier. Dry run the system according to the instructions. Install monitoring equipment.

Get ready to operate the system. Review the operation plan with all personnel involved. Make them aware of safety issues regarding hydraulic system operation. Keep away from cylinder and hose connectors. Hoses have come off without warning. Be aware of pinch points. Get all involved to watch for and report unexpected behavior. Initiate lifting procedure. Record system behavior, lift pressures and movement amounts. Is load lifting when expected? Too soon can be as much a problem as not soon enough. Are pressures what they are supposed to be? How far off are they? Be prepared to trouble shoot a non-performing system. All should and most often does go well. Thorough preparation, appropriate system selection and attention to detail can make the operation of the system the easiest part of the job.

TYPICAL INSTALLATIONS

750 Ton Pile Load Test - Severn River Bridge - Annapolis, Maryland

The construction of the new Maryland Route 450 crossing of the Severn River required the static load testing of three of the 30" diameter, 250 ton design capacity piles. Test criteria required the piles to be loaded to three times their design capacity or loaded until the movement at the pile top exceeded the Davisson failure criteria, for these piles approximately 2 inches. A single-acting 1000 ton cylinder with a maximum stroke of 10 inches was selected to provide adequate capacity and enough stroke. Total stroke had to include the 2" pile movement, 3" of deflection of the structural steel reaction frame and an allowance for movement of the piles which provided the reaction for the applied test load. Fluid volume of the cylinder was 9 gallons, so a 20 gallon reservoir was provided. A 1000 ton digital readout loadcell was used to double check the hydraulic system gauge which was specially calibrated with the cylinder for this application. A 1500 ton capacity spherical bearing was used to prevent off center loading of the cylinder and load cell.

Temporary Roof Support - Paper Mill - Versailles, Connecticut

Extreme environmental conditions over the dryer end of a paper machine caused extensive corrosion of the bottom chord of five 50' span trusses. The owner desired to have the trusses repaired without removing the roof and without interfering with a planned series of repairs to the paper machine. All work inside the building had to occur during a planned one week shut down of the paper machine. A temporary support system was required to hang the trusses from above. Prior to the shutdown steel beams were installed on the roof directly over the trusses and blocked through the roof to the main building columns. As soon as the machine was shut down, holes were drilled through the roof and the support hangers installed at three places along each truss. Jacking operations commenced at all three positions along the first truss simultaneously. A predetermined load was jacked at each location pulling the steel beam down and the truss up and into an unloaded state. The temporary hangers were locked off, the cylinders removed and advanced to the next truss and the operation repeated. After two trusses were temporarily supported repairs began on the first. Repairs required the total removal and replacement of the bottom chord of the trusses. Jacking operations continued without stopping until all trusses were supported. After each truss was repaired the temporary support system was detensioned, returning the roof load to the truss. This method safely supported the roof during repair operations and resulted in the repaired trusses maintaining their original camber profile, important for the prior roof drainage system to perform as originally designed. The hydraulic system for this work was comprised of three separate pump/control/cylinder set-ups. Two of the set-ups used two 20 ton single-acting hollow cylinders each and the third set-up used two 30 ton single-acting hollow cylinders. Although the load was only about four tons per cylinder, the 20 ton cylinder was picked because it was the smallest cylinder that the hanger hardware would fit through. The use of the 30 ton rams was dictated by the availability of equipment for this job which arose on short notice. The oversizing of the cylinders relative to the intended load was a cause for concern because of their ability to over lift the roof. Extra caution was applied to assure that only the intended load was induced into the hydraulic system.

<u>Truss Bridge Pier Repair - South Bridge - Lewiston, Maine</u>

A mid-river pier failed during February, 1995, causing complete loss of support to one bearing of a 235 foot single span through truss bridge. All load at this end of the bridge was held by the other bearing which precariously straddled another crack which passed under it. The side which failed completely dropped 14 inches before the torsional strength of the truss transferred load to the other bearing. A cantilevered jacking frame, anchored to the abutting undamaged span, was installed over the fallen span bearings. The jacking system was composed of two 500 ton, 12 inch stroke, double-acting hollow cylinder rams, each with its own control system and 440VAC electric pump. The cylinders weighed 1900 lbs each and the pumps 500 lbs each. At each side of the span, a hanger composed of 4 - 1 3/8" Ø Grade 160 Dywidag bars was threaded from a weldment placed under the truss, up through the truss end panel point, up through a jackstand, to the jack cylinder. The bridge was lifted approximately 16 inches to allow the pier to be repaired and the bearing seat dressed before the bridge was lowered 2 inches back onto the pier. Anticipated load per ram was 600 kips, actual load approached 750 kips. Extreme care was necessary when transferring load from the ram bearing plate to the fixed bearing plate located within the jackstand. The extreme care was required to assure that the nuts, which locked off the four bars against each bearing plate at each hanger, needed to be set at exactly the same height from the bearing plate so that when the load was applied to the bearing plate, all four rods took the load equally. Not doing this would cause one or more of the rods to try to take more load than anticipated, which would cause the associated nut to be overloaded and jam against the thread on the rod. Freeing the nut was an unpleasant experience. After the bridge failed, award of the repair contract took one week, design and detailing of the jacking system took one week, fabrication and installation of the jacking system took 2 weeks and the pier repairs took 2 weeks.

Pivot Bearing Repairs - South Capitol Street Bridge - Washington, D.C.

The rehabilitation of the South Capitol Street Bridge, a 386 foot long, five lane swing bridge over the Anacostia River, required the shimming of the pivot bearing to reduce the end wedge loads. This bridge appears to have been designed to be lifted, since four jacking points, complete with stiffeners were found to be optimally located for lifting the bridge. Through an extensive search of rental sources, a set of four 600 ton, 6 inch stroke, single-acting, locking collar rams were located. A 110 VAC electric pump complete with a 75 gallon reservoir and a four point shut off manifold completed the jacking package at the pivot bearing. The bridge was raised once with the bronze bearing disk fixed to the upper bearing casting so that the bearing wearing surface could be inspected, cleaned and re-oiled. After this operation the bridge was lowered, reseating the bearing halves together. The bolts holding the upper bearing casting to the bridge were removed and the bridge re-raised to permit the 1 inch shim to be installed. The shim was installed, the bridge lowered again and the bolts holding the bridge to the bearing re-installed. The bridge was estimated to weigh 2800 kips and lifted at 2749 kips., off by less than 2%. A copy of the hydraulic schematic is provided as an example of a technically correct schematic. Included for comparison is the hydraulic schematic provided with the procedure submitted for the jacking work. Although not technically correct, this second schematic, being more pictorial in nature, is adequate, if not preferable, for communicating the desired information with the target audience.

CONCLUSION

The preceding information is intended to indicate how a basic technology, hydraulic jacks, find widespread application in the civil/structural construction industry. As widespread as the applications are there is little available literature discussing their application and use. It is the hope of the author that this paper will be a starting place for those who wish to know more about the application of this technology.