CHAPTER 2
Lock Operating Equipment

CHAPTER 2
Lock Operating Equipment

2.1 Miter Gate.

2.1.1 Description of Linkages and Applications. Four different types of miter gate operating machines have been frequently used. The Panama Canal Linkage, which has no angularity between the strut and sector arms at either the open or closed positions of the gate, is shown in Figure 2-1. The Ohio River Linkage, having angularity between the strut and sector arms at both the open and closed positions, is shown in Figure 2-2. The Modified Ohio River Linkage has angularity between the strut and sector arms at the open position and no angularity at the closed position. This linkage is shown in Figure 2-3. The direct connected linkage, which does not use strut arms or sector arms, transmits hydraulic cylinder force (thrust) directly to the gate. This linkage is shown in Figure 2-4.

2.1.1.1 Panama Canal Linkage. The Panama Canal Linkage has been used primarily where electric motor operation was feasible, that is, at locations where high water will not overtop the lockwall. The operating machinery for this linkage generally consists of a high torque, high slip A.C. motor driving the gate through two enclosed speed reducers, bull gear, sector arm and spring type strut. This linkage will permit the gate to be uniformly accelerated from rest to the mid point of its travel and then uniformly decelerated through the remainder of its travel, thus eliminating the need for elaborate motor speed control. This is accomplished by locating the operating arm and strut on "dead center" when the gate leaf is in both the open and closed positions. The strut must be located at a higher elevation than the sector arm in order to pass over the arm and become aligned for "dead center" position when the gate is fully open. Special consideration should be given to the design of this eccentric connection between the strut and sector arm. An assembly layout of the Panama type linkage is shown on Plate B-1.

2.1.1.2 Ohio River Linkage. The Ohio River Linkage consists of either a hydraulic cylinder and rack gear, or an electric motor and gear reducer, driving a sector gear/sector arm assembly. A strut arm, which usually includes a buffer spring, connects the gate leaf and sector arm. A typical machine is shown on Plate B-3.

2.1.1.3 Modified Ohio River Linkage. The Modified Ohio River Linkage is similar to the Panama type except that the "dead center" alignment is attained only when the gate is in the mitered (fully closed) position. With the Modified Ohio Linkage, the strut and sector gear are located at the same elevation, thus eliminating the eccentric strut connection but preventing the linkage from attaining the "dead center" position with the gate recessed. The operating machinery for this linkage has been built either for electric motor drive as with the Panama Canal machine or hydraulically operated as with the Ohio River machine. An assembly layout of the Modified Ohio River Linkage with electric motor drive is shown on Plate B-2. Special consideration should be given to the strut length and cylinder stroke which become critical at the gate closed position. Generally, some means of adjusting strut length should be provided in order to ensure that the gate's leaves are fully mitered when the sector and strut arms go straight. If the gates do not miter completely at the straight position, any additional travel provided by the cylinder or motor will only pull the gates further apart.

2.1.1.4 Direct Connected Linkage. The Direct Connected Linkage consists of a hydraulic cylinder with its shell (or body) supported in the miter gate machinery recess by a trunnion/cardan ring assembly (or gimbal) and its rod connected directly to the miter gate with a spherical bearing type clevis. Its linkage kinematics is such that it is necessary to control the acceleration of the gate by use of a variable volume pumping unit instead of relying on the mechanical advantage of the linkage. The size of the piston rod is determined by the bending/buckling load criteria. Since the piston rod is used as the strut, it is generally a little larger in diameter than the rod of the Ohio River type machine. This larger rod also increases the ratio of time of opening to time of closing, since the net effective cylinder volume on the rod end is smaller relative to the volume of the cap end. This variation in opening and closing times can be easily eliminated by using adjustable flow control valves or a regenerative circuit in the hydraulic system. Experience has shown that the direct connected machine costs approximately 30 percent less than the conventional Ohio River type machine. A direct connected machine is shown on Plate B-4. See Chapter 5 for a discussion on hydraulic system design.

2.1.1.5 Recommended Linkage. The Ohio River or Direct Connected linkages are probably the most satisfactory types to use with hydraulic cylinder operation. Load analysis for all components is possible for both linkages. Overloads due to surges or obstructions are carried through the piston and converted to oil pressure which is released through a relief valve. In this way, all machinery component loads can be determined based on the relief valve setting. This is also true for the Modified Ohio linkage except at the mitered position. As this linkage approaches the mitered position, the sector arm and strut approach the "dead center" position. Should an obstruction be encountered at this time, the force in the strut becomes indeterminate. Although this linkage provides restraint against conditions of reverse head in the "dead center" position, it must be designed with an easily repaired "weak link" to limit the maximum loads that can be placed on the machinery components. The Modified Ohio River Linkages on some locks has yielded unsatisfactory results, and these have been converted to Ohio River Linkages. The Ohio River Linkage offers several obvious advantages due to its unique geometric configuration relating to the acceleration and deceleration of the miter gates. The disadvantages of this system are wear, bearing forces, and mechanical inefficiencies associated with the geared rack, sector gear, sector arm and strut. Ohio River linkages have recorded a service life of more than 50 years on many locks, with good reliability and a minimum of maintenance. But as compared to the direct connected, the Ohio River linkage requires increased greasing and adjustment. The direct connected cylinder arrangement, when properly designed, is the simplest to maintain, repair and replace. The Direct Connected Linkage is very common in Europe and is becoming more common in the U.S., where it is now being used on several 17.1 meter (56 feet) wide, 25.6 meter (84 feet), and 33.5 meter (110 feet) wide locks.

2.1.1.6 Operating Struts. Two types of struts have been used for the above machines. One type utilizes several nests of helical coil springs installed into a cartridge and attached to a wide flange structural steel fabricated member. The springs, when compressed, act as a shock absorber to soften the loads transmitted to the operating machinery. In the case of electric motor operated machines, the compression in the springs permits the operation of a limit switch to cut off current to the motor when the gates are mitered or recessed. The switch also serves as a limit switch to protect the machinery against the possibility of extremely high loads which might occur if an obstruction is encountered when the strut approaches dead center in either direction. The limit switch is set to open the motor circuit at a point immediately preceding the maximum spring compression in the strut. This type of strut is shown on Plate B-5. Another type of strut uses a spring cartridge housing and tubular steel strut. Ring springs are used in the spring cartridge to provide the necessary deflection. Excessive maintenance and repair costs have occurred with the use of this type of strut. In addition, ring springs are available only from one manufacturer. Use of the ring spring type strut is not recommended. Recently, Belleville springs have been utilized in struts and appear to function satisfactorily. The Belleville spring strut is shown on Plates B-6 and B-7. But there have also been several failures reported for the Belleville spring design. This design should consider the extreme loading conditions and necessity for proper lubrication and sealing.

2.1.1.7 Sector Gear Anchorage. The sector gear support and anchorage is one of the more critical items to be considered in the design of miter gate machinery. For proper machine operation and long component life, the sector gear must be maintained in rigid and proper alignment. The recommended arrangement consists of a sector base anchorage, sector base support and a sector base. The sector base anchorage is a welded steel frame imbedded deep in the concrete which provides anchorage and alignment for post tension rods. The sector base support is a heavy, rigid, welded steel member which is anchored to the concrete by the post tension rods. The sector base is a heavy steel casting which is bolted to the sector base support and contains the sector pin on which the sector gear turns. The sector gear pin should be restrained to prevent rotation in the sector base. The design is such that the final post tension rod force is enough to resist the horizontal sector pin load by friction between the concrete and sector base support. Another important feature is the bearing choice and lubrication design for the bearings that allow the sector gear to rotate around the pin. In addition, compression blocks are welded to the bottom of the sector base support to provide additional resistance to horizontal motion. Details of this anchorage are shown on Plate B-3.

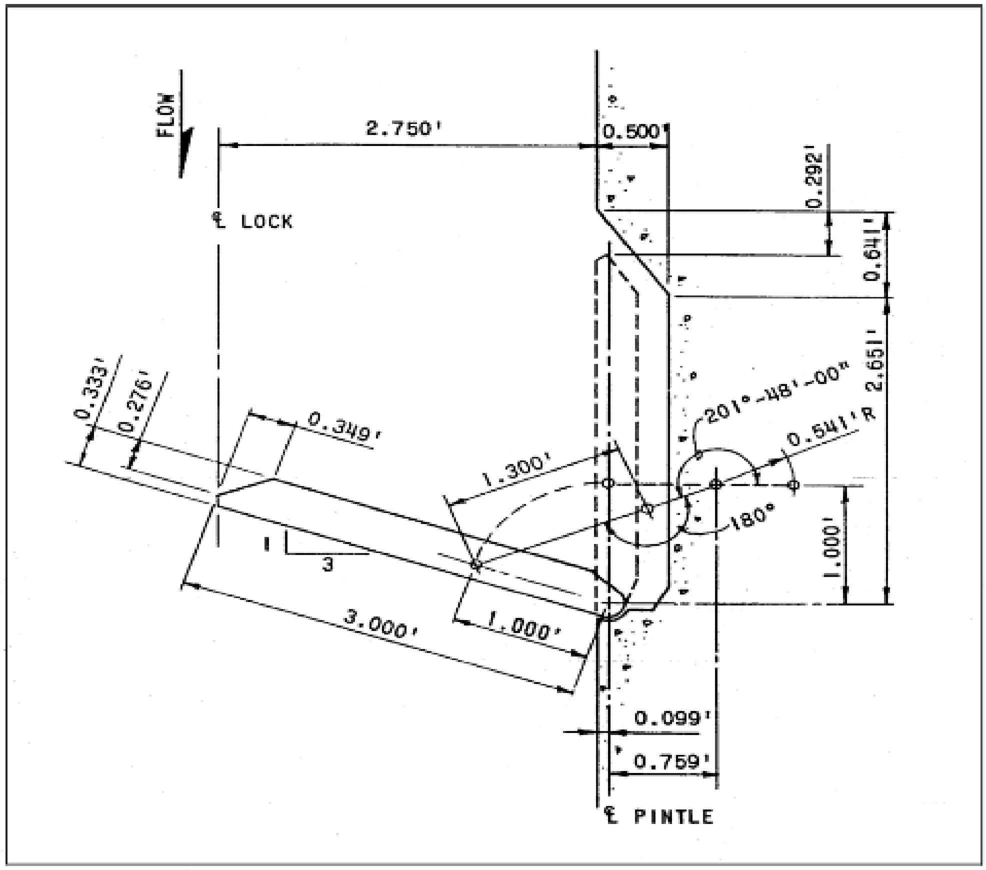
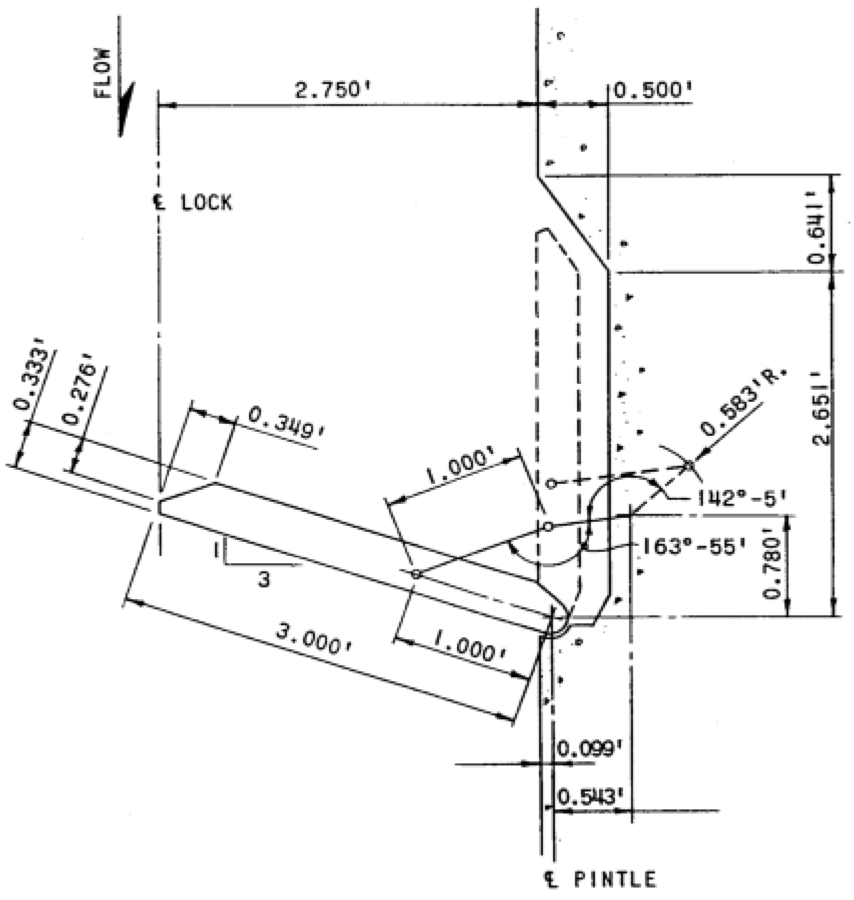


Figure 2-1. Panama Canal Linkage
Note: Dimensions shown are dimensions used in WES model tests



NOTE:
DIMENSIONS SHOWN ARE DIMENSIONS USED IN WES MODEL TESTS.

Figure 2-2. Ohio River Linkage

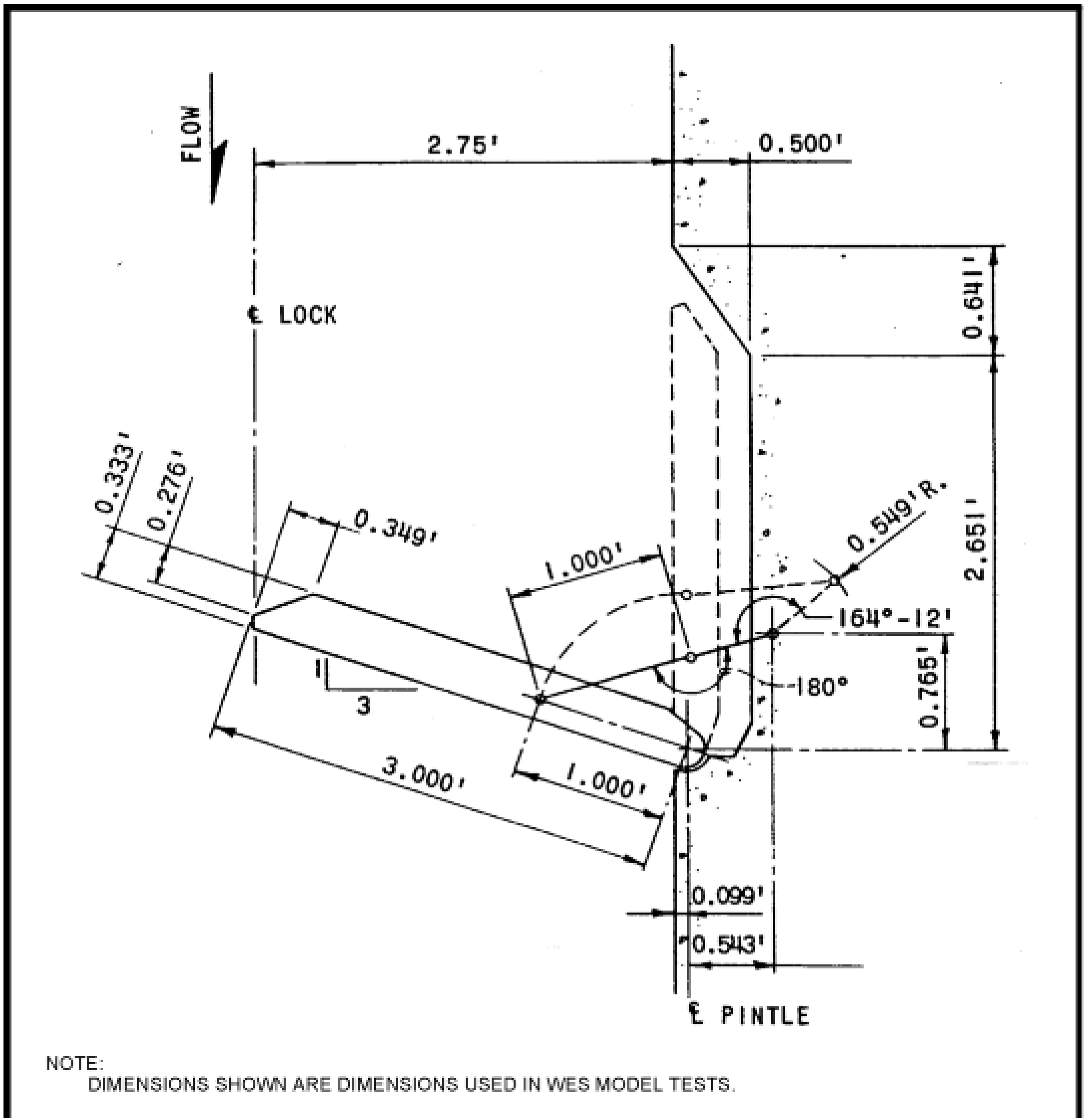


Figure 2-3. Modified Ohio River Linkage

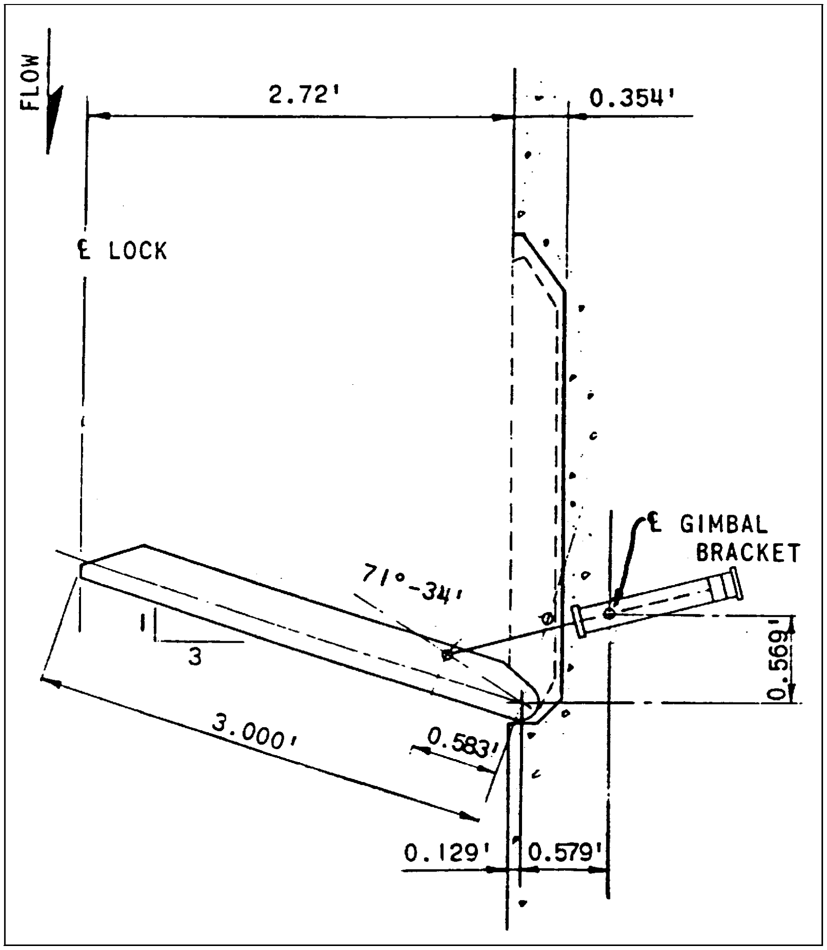


Figure 2-4. Direct Connected Linkage

2.1.2 Design Criteria.

2.1.2.1 Normal Loads. Gate operating machinery should normally be designed to conform to the following criteria: Operating loads on the miter gate machinery should be derived by hydraulic similarity from test data obtained from model studies. The model study available for design is included in U.S. Army Corps of Engineers Waterways Experiment Station (W.E.S.) Technical Report No. 2-651 "Operating Forces on Miter Type Lock Gates", June 1964, Vicksburg, Mississippi. (This was the last study made by W.E.S. on this subject.) This report includes data on the Ohio River, Modified Ohio River, and Panama Canal type linkage. The study contains necessary data for conversion to prototype torque for all three of the different types of linkages. For direct connected type machines, prototype tests were made at Claiborne

Locks and results of the tests are included herein for the determination of gate torque for any proposed direct connected lock machine of similar proportions. A curve of gate torque plotted against percentage of gate closure has been included so that torque at any other submergence or time of operation can be computed by application of Froude's Law, adjusting the submergence and time to suit the new conditions.

2.1.2.2 Temporal Loads. In addition to the above normal loads, the miter gate machinery should be designed to withstand the forces produced by a 0.38 meter (1.25 feet) (exceeding 30 second duration) surge load acting on the submerged portion of the miter gate. For this case, the machinery must be designed to maintain control over the miter gate when the gate is in the miter position. See Plate B-25 for a sample computation. In the recess position, control of the gate may be accomplished by automatically latching the gate in the recess. Normal machinery operating loads govern the machinery design for the intermediate positions.

2.1.2.3 Operating Time. A time of operation should be selected and should be based on the size of gate. For smaller gates, 25.6 meter (84 feet) locks, an average time of 1.5 minutes should be used and for the larger gates, 33.5 meter (110 feet) locks, an average time of 2 minutes would be suitable. Any decision to increase the operating time from 1.5 to 2 minutes for smaller gates, or 2 to 3 minutes for larger gates should be made only after considering the economic impact of the increased time required to transit the lock.

2.1.2.4 Submergence. The design of the gate operating machinery should be based on the submergence of the upper or lower gate, whichever is greater. The design should be the same for all four gate machines since there would be no savings in designing and building two different size machines. The increased design cost, and additional spare parts inventory would offset the reduced cost of the material used in constructing the smaller machine.

2.1.2.4.1 The submergence of the gate is the difference in elevation of the tailwater on the gate and the elevation of the bottom of the lower seal protruding below the gate. A submergence selected for design of the gate machinery should be the tailwater on the gate that would not be exceeded more than 15 to 20 percent of the time.

2.1.2.4.2 The operating cylinder size should be selected to provide a force to operate the gate under these conditions utilizing approximately 6-20 Mpa (900-3000 psi) effective pressure where a central pumping system is used. If higher than 7 Mpa (1000 psi) is selected for the operating pressure, then measures to eliminate hydraulic shock should be considered because of the long hydraulic lines. Where local or integral pumping units are used, an operating pressure of 10-20 Mpa (1500-3000 psi) will be satisfactory.

2.1.2.4.3 The time of gate operation will automatically be lengthened when the required gate torque exceeds the available gate torque. This condition may occur during starting peaks or periods of higher submergence. This condition causes the pressure in the hydraulic cylinder to rise above the relief valve setting, which in turn reduces oil flow to the cylinder slowing down the gate and reducing the required pintle torque. This increases the total time of operation; however, this slower operation will be experienced for only 15 to 20 percent of the lock total yearly operating time.

2.1.2.4.4 Peak torque can be reduced by non-synchronous operation of the gate leaves. A considerable reduction in peak torque can be obtained by having one leaf lead the other by approximately 12.5 percent of the operating time. The time of opening would be increased by the amount of time one gate leads the other. It has been found that in actual practice very few gates are operated in this manner.

2.1.2.5 Under Gate Clearance. Model tests revealed an increase in gate torque values as the bottom clearance decreased, regardless of the length of operating time. When using model similarity to compute gate loads, an adjustment should be made in accordance with model experience. Normally 0.76 to 1.0 meters (2.5 to 3.5 feet) clearance under the gate should be satisfactory.

2.1.2.6 Machine Components. General design criteria applicable to the various machine components is presented in Chapter 5. Allowable stresses may be increased one-third for temporal loading conditions.

2.1.3 Load Analysis.

2.1.3.1 Normal Loads. Normal operating hydraulic loads on miter gates are primarily caused by submergence, speed of gate and clearance under gate. For additional information and explanation the designer should review the W.E.S. Report 2-651.

2.1.3.1.1 For the Ohio River Linkage, W.E.S. Report 2-651 indicates that the maximum torque recorded as the gate leaves entered the mitered position (closing) varies as the 1.5 power of the submergence; and the maximum torque recorded as the gate leaves left the mitered position (opening) varies as the 2.1 power of the submergence.

2.1.3.1.2 For the Modified Ohio River Linkage, W.E.S. Report 2-651 indicates that the maximum torque recorded as the gate leaves entered the mitered position (closing) varied as the 1.9 power of the submergence; and the maximum torque recorded as the gate leaves left the mitered position (opening) varied as the 2.2 power of the submergence.

2.1.3.1.3 For the Panama Canal Linkage, W.E.S. Report 2-651 indicates that the maximum torque recorded as the gate leaves entered the mitered position (closing) varied as the 1.5 power of the submergence; and the maximum torque recorded as the leaves left the mitered position (opening) varied as the 1.7 power of the submergence.

2.1.3.1.4 For the Ohio River Linkage, W.E.S. Report indicates that the maximum torque recorded decreased as the 1.0 power of the operating time for both the closing and opening cycles.

2.1.3.1.5 For the Modified Ohio River Linkage, W.E.S. Report 2-651 indicates that the maximum torque recorded decreased as the 1.1 power of the operating time for the closing cycle and as the 1.5 power for the opening cycle.

2.1.3.1.6 The report indicates for the Panama Canal Linkage that the torque decreased as the 1.1 power of the operating time for closing cycle and as the 1.3 power for opening cycle.

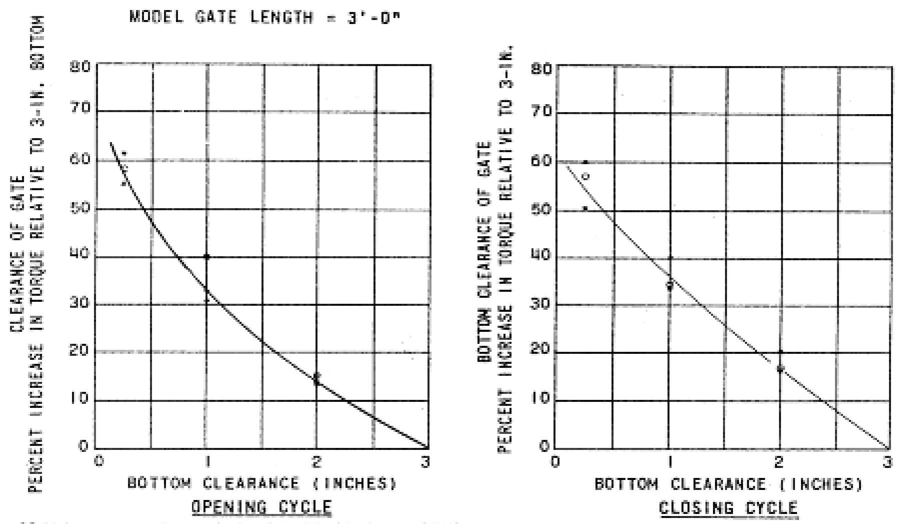
2.1.3.1.7 Tests reveal that an increase in gate torque occurs when the clearance under the gate leaf is decreased regardless of the length of operating time. Data from these tests are presented in Figure 2-5 and indicate the percentage increase in model torque for various bottom clearances relative to the torque observed with a 76 mm (3 inch) bottom clearance. These data can be used to adjust the observed torque values determined for a model bottom clearance of 76mm (3 inch) when gate length is 0.91 meters (3 feet).

2.1.3.1.8 Non-synchronous operation of miter gates results in slightly lower forces on the leading leaf. Forces on the lagging gate leaf are greater during most of the closing cycle and less during the opening cycle than similar forces recorded for synchronous operation of the gate leaves. The greatest reduction in torque appears to be when one gate is leading the other by approximately 12.5 percent of the total operating time.

2.1.3.1.9 Barges in the lock chambers are found to have negligible effect on gate operating forces.

2.1.3.1.10 Chamber length does affect gate torque in that the longer the chamber the less the torque. As the length of time is increased, the less the chamber length effects the gate torque. Insufficient data is available to set up any definite adjustment factors for correcting for chamber length

2.1.3.1.11 Torque caused by gate pintle friction is of small magnitude and should not be considered in load calculations.



OPERATING TIME TORQUE, LB-FT (3-IN. BOTTOM CLEARANCE)

SEC.	OPENING CYCLE	CLOSING CYCLE	SYMBOL
13.4	40	35	○
20.1	29	20	△
26.8	18	12	▼

Figure 2-5. Relative Effect of Gate Bottom Clearance on Torque, 1.2 Meter (4 feet) Submergence

2.1.3.1.12 When computing operating torque for a "Direct Connected" type miter gate drive, the curves shown on Plates B-8 and B-9 may be used. The curves are results of prototype tests made on Claiborne Lock and show gate torque plotted against percentage "closed". The torque from these curves may be adjusted to suit new conditions by the application of Froude's Law as described in detail in Paragraph 2.1.4 below. Since the curves were based on the use of a three speed pump to slow the gate travel at beginning and end of cycle, it will be necessary to make similar assumptions on the proposed lock. Assuming a fast delivery rate of the pump at 1.0, the medium delivery rate should be 0.8 and the slow rate adjusted to 0.3 of the fast rate. A normal cycle would be to operate 10 percent of the gate angular travel at 0.3 capacity, 10 percent at 0.8 capacity, 60 percent at 1.0 capacity, 10 percent at 0.8 capacity and 10 percent at 0.3 capacity. A comparison study made between this type of operation and the Panama type linkage indicates that the direct connected machine, if operated as stated above, will compare favorably with the Panama machine in angular gate velocity (degrees per second) at all positions. Assuming that the angular velocities compare with the Panama type machine, the maximum torque will vary as the 1.5 power of the submergence (closing) and 1.7 power of the submergence (opening). The operating time should vary as the 1.1 power for closing and the 1.3 power for opening cycle.

2.1.3.2 Temporal Loads. Temporal hydraulic loads or surges are temporary changes in water level resulting in a differential water level on opposite sides of a lock gate. These surges or differential heads may be caused by overtravel of water in the valve culvert during filling or emptying, wind waves, ship waves, propeller wash, etc. Depending on the circumstances, this differential has been observed to vary from 0.3 to 0.6 meters (1 to 2 feet). These forces do not affect the machinery power requirements, but they do affect the design of the gate machine components when the gate is at the recess or mitered position. These forces have been known to fracture gate struts and shear sector pins. See paragraph 2.1.2 for the description of these loads.

2.1.4 Determination of Machinery Loads.

2.1.4.1 Normal Loads. Normal miter gate operating machinery loads are difficult to determine and should, whenever possible, be determined from model or prototype tests. Data compiled by the Special Engineering Division of the Panama Canal Zone taken from tests made on the existing locks and a model for the third locks and model studies included in W.E.S. Technical Report No. 2-651, appear to be the most reliable sources for obtaining miter gate machinery loads available at this time. When using data from the model tests, it will be necessary to adjust the data on the basis of the scalar ratio between the model and the proposed lock. The length of the gate leaf is normally used for determining the scalar ratio. From the scalar ratio, Froude's Law comparing prototype to model would be as follows:

$$\text{Scalar Ratio} = \frac{\text{Length of Prototype Leaf}}{\text{Length of Model Leaf}} = L_R$$

Volume, weight and Force = $(L_R)^3$:1

Time and velocity = L_R:1

Torque = $(L_R)^4$:1

When using machines having the Ohio Linkage, the Modified Ohio Linkage, or the Panama Canal Linkage, the forces on any size miter gate may be obtained from curves shown on Plates B-10 through B-13 which are plotted from the results of the W.E.S. and Panama Canal

Model Tests. Readings from the curves must be factored according to Froude's Law for submergence, time of operation and clearance under gate. Curves are based on lock chamber lengths of 183 meters (600 feet) or greater. Forces for shorter lock chambers would be slightly greater. This should be considered when replacing the miter gate machinery on 17.1 meter (56 feet) wide locks, which usually have 109.8 meter (360 feet) chamber lengths.

2.1.4.1.1 Computation of Pintle Torque for Panama Canal and Ohio Type Linkage. If the proposed lock gate is in the same scalar ratio with respect to length of gate, submergence and time of operation as shown on curves and the type of linkage is the same, the pintle torque would equal the pintle torque at each position indicated on the curves multiplied by the ratio of gate leaf lengths to the 4th power.

$$P_1 = P(L_1 / L)^4$$

Where

P_1 = pintle torque of proposed lock gate at selected position

P = pintle torque shown on curve of model study at selected position

L_1 = leaf length, pintle to miter end, proposed lock gates

L = leaf length, pintle to miter end for curves that have been plotted on model study.

In the event the ratios of gate lengths L_1/L submergence S_1/S and the square of the time of operation T_1/T are not of the same scalar ratio, the formula should be expanded as follows:

$$P_1 = P(L_1 / L)^4 (S_1 / S_2)^x (T_2 / T_1)^y$$

where

P_1, P, L_1 and L = same as above

S_1 = submergence of proposed lock gate

S = actual submergence of model gate upon which curves are based

S_2 = adjusted submergence of model lock gate = $S(L_1 / L)$

T_1 = time of operation of proposed lock gate (See arc of travel adjustment below)

T = actual time of operation of model gate upon which curves are based

T_2 = adjusted time of operation of model lock gate = $T\sqrt{L_1}\,/\,L$

X = power to which submergence must be raised, for particular type linkage

Y = power to which time must be raised, for particular type linkage

NOTE: If only one ratio for either submergence or the square of the operating time is not of the same ratio as gate leaf length L_1/L then only the ratio not in agreement with L_1/L need be considered in the formula.

If the arcs of gate travel differ from that shown on model curves, it will be necessary to adjust the operating time of the proposed lock T_1 to use in the above formula as follows:

Let T_A = adjusted operating time, or

$T_A = T_1$ (arc of travel, proposed lock)/(arc of travel, on model curves) $= T_1(K_1/K)$

T_A must be substituted in formula for T_1

Use of the above formula results in a pintle torque which makes no allowance for motor slip since all of the model curves were based on uniform speed of hydraulic cylinder or constant RPM of the motor. If a portion of the required gate torque curve overloads the motor, the resulting time of gate operation would be slower, which in turn would result in lower gate torque during this period. The same would occur when operating the gates with a hydraulic cylinder. Overloading the cylinder would result in some of the oil being bypassed through relief valves which in turn would slow down the gate during the overload period. When using the Ohio type linkages and torque data from W.E.S. Technical Report No. 2-651, the pintle torque P_1 should be adjusted for under gate clearance in addition to submergence and time. The percentage increase in torque can be obtained from Figure 2-5. Where a proposed lock is not subjected to flooding, electric motor operation with Panama type or Modified Ohio River type linkage may be considered. A high torque, high slip motor should be used and should be selected so that the normal full load torque available would not be exceeded by the required torque of the machine more than 15 to 20 percent of the time. Peak torque during the overload period should not exceed 150 percent of full load torque. This can be determined by plotting the required torque based on curves computed from model tests described above and by plotting available motor torque curves at various degrees of slip and superimposing these curves over the required curves. Typical calculations for determining loads using the Ohio River type linkage (hydraulic operation) are shown on Plates B-14 through B-25. Calculations for determining loads using the

Panama Canal type linkage (electric motor operation) for the same design conditions are shown on Plates B-26 through B-38.

2.1.4.1.2 Computation of Pintle Torque for Direct Connected Linkages. The kinematics of this type of machine would be developed so as to provide the shortest practicable piston stroke. This will require the gate pin connection to be located out from the pintle a distance of 20 - 25 percent of the gate length, and the centerline of the cylinder gimbal bracket to be located so as to give the best effective operating arm about the pintle at each position throughout the entire stroke of the piston. With use of this linkage and a uniform traveling piston, gate angular velocity will be greatest at the extreme closed or open position of the gate. Uniform travel of the piston is therefore undesirable, and it will be necessary to slow down the speed of the piston near the closed and open positions by use of a variable volume pump in the oil circuit. By slowing the travel near open or closed position of the gate, angular travel rates will be comparable with the Panama Canal linkage. Figure 2-6 shows comparison curves for angular velocity of gate plotted against percent "closed" for Panama Canal Third Locks linkage and for Claiborne Lock direct connected linkage with and without variable speed control. Time of operation should be selected for the proposed lock that will give angular gate velocities approximately equal to the velocities shown on the curve for Panama Canal. Gate pintle torque should then be taken from the prototype curves shown on Plates B-41 and B-43, and adjusted by means of Froude's Law of Similarity to the submergence and time requirements of the proposed lock using the same exponents as used for the Panama Canal linkage. Load computations for a direct connected machine are shown on Plates B-39 through B-48.

2.1.4.2 Temporal Loads. The resulting machinery loads for the case of temporal loading are based on a differential head, provided in paragraph 2.1.2.2, superimposed on the normal gate submergence. These loads are considered applicable only when the gate is in the mitered or recessed positions. These forces are resisted by a load brake for mechanical drives or a high pressure relief valve for hydraulic drives. For this load condition, a 33.33 percent overstress is allowed for component design. An automatic gate latching device may also be used in the recess position. Only the sample computations for the Ohio River type machine shown on Plates B-14 through B-25 includes the temporal load computations.

2.1.5 Operating Machinery Control.

2.1.5.1 Hydraulically Operated Machines. A complete description of the two basic types of hydraulic systems for locks along with pertinent hydraulic system design criteria is presented in Chapter 5. Several types of control schemes have been used for these systems, including manual, solenoid or servo operated control valves, and variable frequency drives.

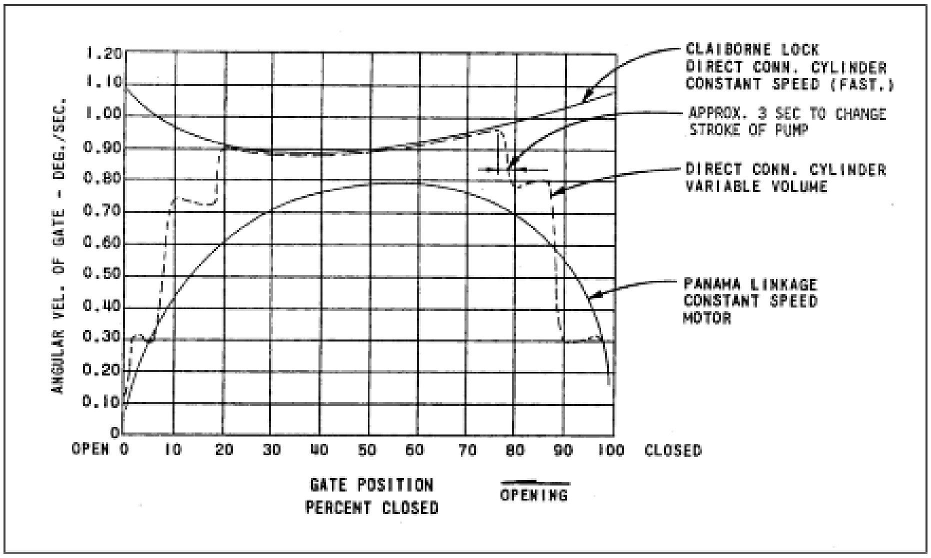


Figure 2-6. Gate Velocity Comparison Curves

2.1.5.1.1 Manual controls for conventional hydraulic systems utilize lever operated control valves to control the flow of oil to the cylinders. These levers are usually located on a lock wall near each set of gates.

2.1.5.1.2 Electrical controls for conventional hydraulic systems utilize solenoid or servo operated four-way valves to control the flow of oil to the cylinders. This makes the system more flexible and enables the inclusion of an electrical interlock between the miter gates and lock culvert valves so that the lock chamber water level cannot be changed before all gates are closed. Changing the water level in the lock chamber before the gates are closed creates a differential head on the partially closed gates which could cause them to slam shut damaging the gate and/or gate machinery. This type of control is recommended over manual control. A schematic hydraulic system diagram of this control system is shown on Plates B-49 and B-50.

2.1.5.1.3. VFD controls for integral hydraulic systems, primarily used with self-contained actuators, utilize a bi-rotational hydraulic pump and reversible electric motor to control the flow of oil to the cylinder. The speed and direction of each actuator is controlled by a VFD, located in the motor control center, which controls the speed and direction of the electric motor.

2.1.5.1.4 The majority of locks using electrically operated control valves or variable frequency drives have two points of control, usually located in control shelters near each set of miter gates. Some locks utilize a single point of control, usually located in a centralized control building. Each control point consists of a console with all control functions associated with a normal lockage. These functions usually provide control for miter gates, culvert valvesl, bubbler system, lock lighting, navigational signals, alarms, etc. Control consoles located on the lock wall may become inundated during high water. Therefore these consoles should be designed so that they are located above the anticipated high water (by elevating the control shelters) or so that they can easily be removed. See Chapter 4 for more information on controls.

2.1.5.1.5 Electrical interlocks are used in the control circuit to produce the desired operating sequence. Limit switches are used to prevent the upstream culvert valve from being opened when the downstream gate and/or valves are open and vice versa. These interlocks are also used to prevent gates slamming or unintentional changes in chamber water level. A logic diagram for this system is shown on Figure 2-7. See Chapter 4 for more information on controls.

2.1.5.2 Electrically Operated Machines. At projects where flood waters will not overtop the lockwall or machinery recesses, a modified Ohio machine with electric motor drive may be economical and desirable. Control consoles similar to that described above for the hydraulic system are usually used. Electrical valve-gate interlock features should be similar to that described above for the hydraulic system.

2.1.6 Miscellaneous Equipment and Systems.

2.1.6.1 Machinery Stops. In order to deal with ordinary construction tolerances, a means must be provided to adjust the miter gate machinery linkage at installation. It is usually desirable to provide approximately 50 mm (2 in.) of overtravel at each end of the hydraulic cylinder to allow for adjustment. With the linkage connected and the miter and recess positions established for the gate, stops are installed and adjusted to limit the machinery motion to these extreme positions. For Ohio River type machines that are operated by hydraulic cylinders, one stop is placed so as to stop the rack when the gate is mitered; another is placed to stop the sector arm when the gate is recessed. Details of this arrangement are shown on Plate B-3.

2.1.6.2 Automatic Greasing. A system should be provided to automatically grease each miter gate pintle bushing and gudgeon pin as shown in Figure 2-8. The system should dispense a measured amount of grease to each location automatically during gate movement. An automatic grease system is available with a built-in programmable controller, which will allow variations in grease cycles, and quantity of grease provided. Since the grease systems have to be field tuned, for a particular lock application, the programmable controller should be a desirable option. The pintle bushing should be designed to permit the installation of an O-ring seal and a grease return line which can be monitored to insure grease delivery to the pintle bushing. The system should include automatic monitoring equipment to warn of a malfunction. Special consideration should be given to the layout and sizing of the grease lines to insure proper operation and minimum pressure loss. Grease lines should be stainless steel pipe of adequate wall thickness for the anticipated pressures. Grease lines should be located in areas of the gate that afford the greatest degree of protection from damage due to ice and drift. The pumping unit should be located near the gate to minimize grease line length. Provisions should be made to remove the pumping unit if flooding is likely. For pintle lubrication details, see Plate B-51.

Self-lubricated bushings can provide an alternative to greased bushings for the pintle and gudgeon pin, thus eliminating the need for an automatic greasing system. The Construction Engineering Research Lab evaluated field performance and conducted lab tests of commercially available self-lubricating materials used in lock and dam applications. Paragraph 5.1.3.4 provides additional information on the use of self-lubricating pintle bushings.

2.1.6.3 Automatic Gate Latches. Latches are normally provided for holding the gates in the recess. The latches should be designed to automatically latch the gate when it comes into recess. Release of the latches should be accomplished automatically each time a “gate close” function is initiated. Recess latch is shown on Plate B-52. The system should be provided with “latched” and “unlatched” position indication.

2.1.6.4 Maintain Pressure System. A maintain pressure system can be provided to hold miter gates closed with hydraulic pressure. The system is designed to hold the gate leaves together against wind loading or small water surges prior to changing the chamber water level. Maintain pressure is used for upstream gates during the emptying cycle and downstream gates used during filling cycle. This maintain pressure system is activated by the lock operator depressing a pushbutton on operator console. This system can be deactivated manually by the operator or is automatically deactivated when the gates under maintain pressure are opened or after the valves are opened for a predetermined time to allow an adequate head of water on the gates to keep them mitered. The maintain pressure system should utilize the valve slow or the lowest pumping rate available. The tandem center hydraulic system is not preferred, but if used, or if retrofitting a tandem center system, the maintain pressure system will provide pressure to the miter gate cylinder in the gate closed position through the use of standard bladder type accumulator. This accumulator, located in each miter gate machinery recess, will be charged and pressure maintained through a pilot-operated check valve installed in series with each miter gate cylinder. A pressure switch, sensing accumulator pressure, will insure adequate pressure through a time delay circuit. An indicator lamp on the control console will be illuminated when pressure in the maintain pressure system is adequate. At the same time the gate four-way valve will be automatically shifted from "close" to "neutral" position. An alternative to this system is specifying cylinders with "zero leakage" piston rings and rod seals and providing pilot operated check valves to lock the cylinder in the gate closed position.

2.1.6.5 Fire Protection System. EM 1110-2-2608 provides fire protection system requirements for navigation locks. In operation, this system provides a dense spray of water on the gate surface between the gate and barges which may be on fire in the lock chamber. This spray would keep the gates cool and minimize distortion in the event of a fire. This system consists of a series of water spray nozzles located along the top of each miter gate leaf discharging into the lock chamber. These spray nozzles are fed by high capacity raw water pumps. One pump is provided for each lock chamber. Control stations are located near each gate with controls for starting and stopping the raw water pump and also for opening and closing the motorized valve in the supply line to each set of gate nozzles. Many of the fire protection provisions presented in EM 1110-2-2608 apply to both miter and sector gate locks.

2.1.6.6 Overfill and Overempty Control System. The overfill and overempty system should be evaluated on a case by case basis and should be considered mainly on high lift locks or locks with long narrow approaches. A control system has been developed to eliminate overfilling and overemptying of the lock chamber. This system measures water levels by sensing the back pressure of compressed air constantly bubbling through tubes extending below the surface of the water. This system compares the level of water in the lock chamber with that of the upper pool when filling and the lower pool when emptying and at a predetermined time begins closing the fill or empty valves respectively. This action dissipates the energy of flowing water in the culverts, thereby eliminating lock overfill or overempty. Another system uses underwater pressure transducers installed in the lock chamber and upper and lower approaches. These transducers measure the static head pressure, which translates to the depth of water where they are located. By comparing the depth of water in the chamber with the upper and lower approaches, the system determines when the water level in the lock is equalized with the upper or lower pools.

2.1.7 Pintle Assembly. The pintle and related components support the dead weight of each leaf of the miter gate. The pintle assembly is made up of five major components, pintle socket, pintle, pintle shoe, pintle bushing, and pintle base. See Chapter 5 for pintle bushing information.

2.1.7.1 Pintle Socket. The pintle socket is made of cast steel and is connected to the bottom of the lower girder web of the miter gate with turned monel or stainless steel bolts. The bolts are to carry the gate leaf reaction in shear but as added safety factor a thrust plate should be welded to the underside of the bottom girder web, with a milled contact surface between the plate and pintle socket. The minimum plate size should be 31.75 mm (1.25 in.) in thickness and 0.3 meters (1 foot) with a length as required by the girder web. The socket encloses the bronze bushing which fits over the pintle ball. An allowable bearing stress of 10 Mpa (1500 psi) is desirable but

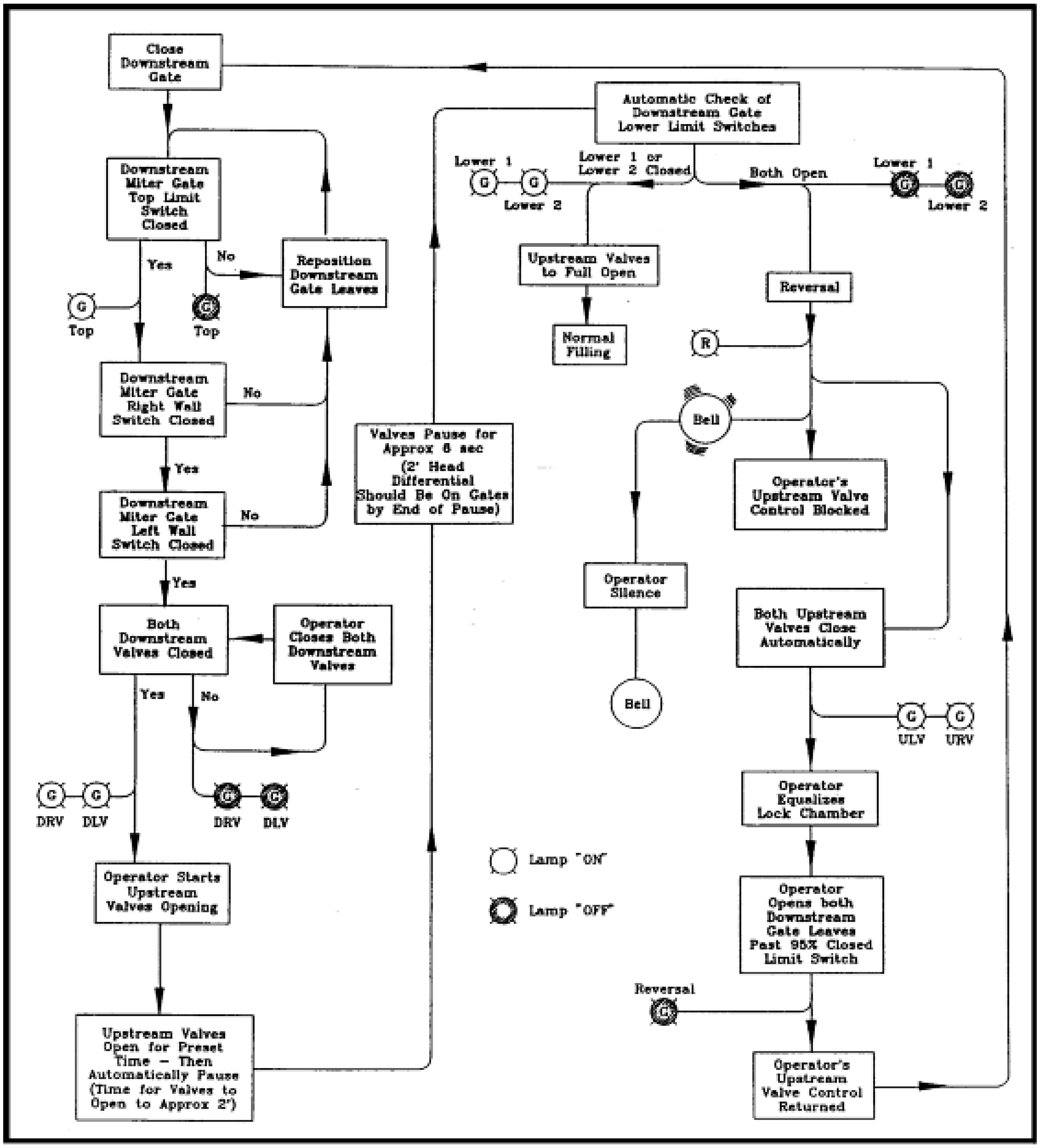


Figure 2-7. Lock Filling Sequence (Lock Emptying Sequence is Similar).

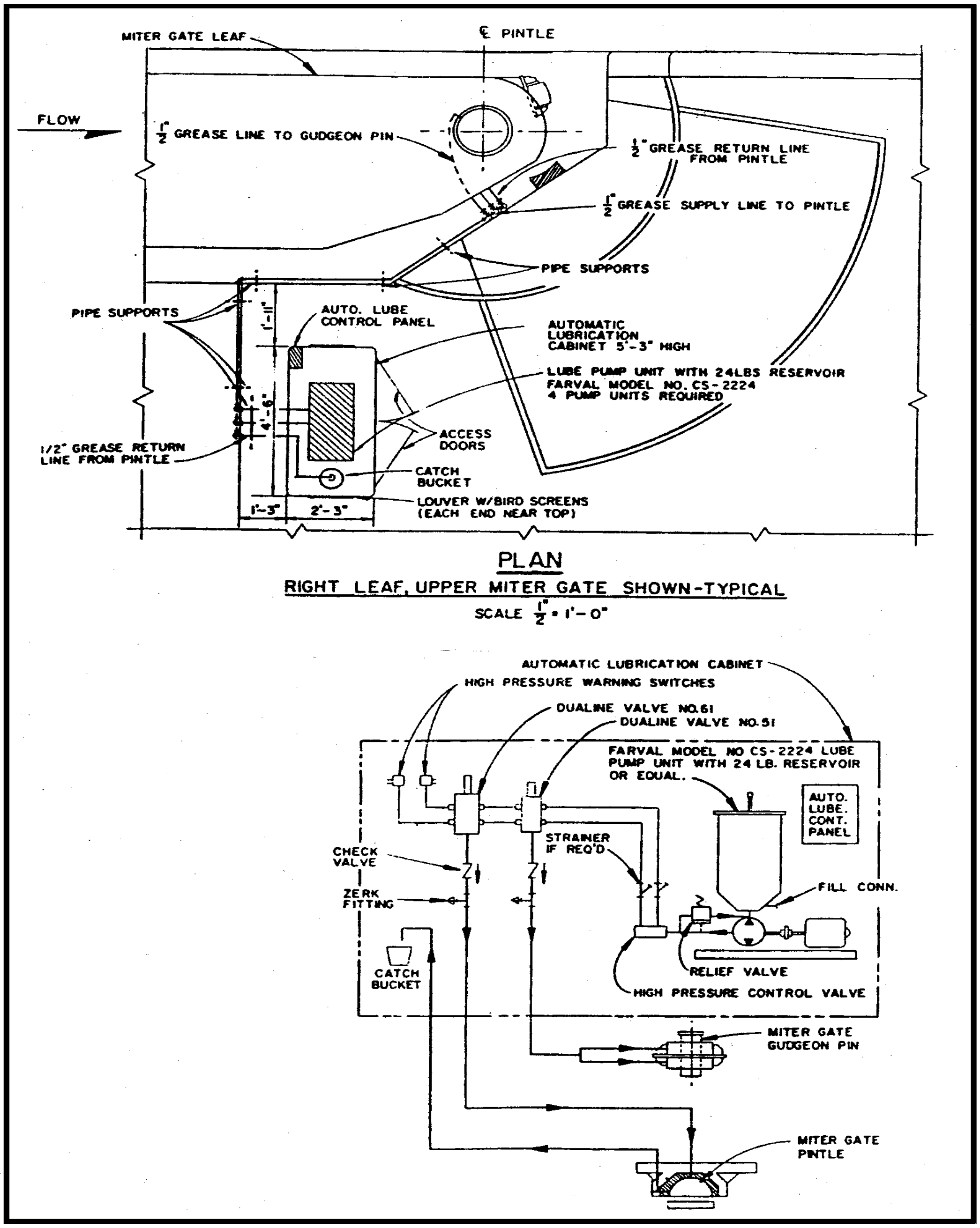


Figure 2-8. Automatic Lubrication System

may not always be practical. The automatic greasing system allows a higher bearing stress but should not exceed 17 Mpa (2500 psi). See Plate B-51 for additional information.

2.1.7.2 Pintle. The pintle generally made of cast alloy steel ASTM A148 GR 80-40 or ASTM A27 GR 70-40, usually 0.25 to 0.50 meters (10 to 20 inches) in diameter, with the top bearing surface in the shape of a half sphere and a cylindrical shaped bottom shaft. Pintles have also been produced with bearing surfaces of stainless steel deposited in weld passes to a thickness of not less than 4.8 mm (0.1875 inch) and machined to the required shape. Pintles for salt or brackish water locations should be forged alloy steel with the stainless steel bearing surface. The pintle ball and bushing are finished to a 16 microinch finish where the two come in contact.

2.1.7.3 Pintle Assemblies. Pintle assemblies used for horizontally framed miter gates are generally two types - floating and fixed.

2.1.7.3.1 The fixed pintle is recommended for new construction and major gate rehabilitation. The pintle fits into the pintle shoe, which is bolted to the embedded pintle base. The degree of fixity of the pintle depends on the shear capacity of the pintle shoe bolts. The pintle should be designed so that after relieving the load on the pintle by jacking, the pintle assembly is easily removable. See Plate B-53 for typical fixed pintle. The pintle base, made of cast steel, is embedded in concrete, with the shoe fitting into a curved section of the upper segment of the base. The curved section of the same radius as the pintle shoe is formed so that under normal operation the reaction between the shoe and base is perpendicular to a line tangent to the curve of both shoe and base at the point of reaction.

2.1.7.3.2 The floating pintle is not recommended for new construction. The pintle is fitted into a cast steel shoe, with a shear key provided to prevent the pintle from turning in the shoe. The shoe is not fastened to the base, allowing the gate leaf to move outward in case of debris between the quoin and wall quoin preventing the leaf from seating properly. See Plate B-54 for typical floating pintle. Damage to pintle bearing has occurred frequently with this type of pintle due to the relative movement between the pintle shoe and base. The movement can consist of the shoe sliding on the base during leaf operation from either the mitered or recessed position, until the leaf reaches approximately the mid-position, at which time the shoe slides back against the flange on the base. This type of movement is generally visually detectable and causes serious wear. However, an alternative to the floating circular shoe is to make the shoe three sided with one corner having the same radius as the circular shoe, and attach a steel keeper bar to the embedded base in front of the shoe. This would prevent the shoe from rotating on the embedded base and prevent the pintle from moving out of pocket. Again, the degree of fixity would depend on the shear capacity of the bolts in the keeper bar. This alternative will meet the requirements of the fixed pintle as well as the capacity to minimize damage in case of emergency.

2.1.7.4 Pintle Base. The pintle base is designed so that there will be a compressive force under all parts of the base. The value of the compressive force on the concrete will vary from a maximum on one edge to a minimum on the opposite edge. Computations are based on that portion of the pintle above the point under consideration acting as a composite unit. The overturning moment can be found from the horizontal force on the pintle and will be resisted by the reaction on the section being investigated. The eccentricity of the vertical force can be determined by the angle the resultant makes with the horizontal and the distance between the horizontal force on the pintle and reaction on the pintle base.

2.1.7.5 Pintle Centerline. The centerline of the pintle (vertical axis of rotation) is located eccentric (upstream) relative to the center of curvature of the bearing face of the quoin contact block. This center of curvature is on the thrust line. The centerline of pintle should be located on the point of intersection of the bisector of the angle formed by the mitered and recessed gate leaf work lines and the perpendicular line from the bisector to the quoin contact point resulting in an offset of approximately 180 mm (7 inch). Studies and experience show that eccentricities arrived at by the above described method will reduce the contact time between the fixed wall quoin and the contact block of the moving gate leaf sufficiently to minimize interference and binding between the bearing blocks. The 180 mm (7 inch) offset will be exact and constant for all gates with the same miter angle and distance from the face of lock chamber to the recessed work line (0.37 meters [1.2 feet]).

2.2 Sector Gate.

2.2.1 General Description.

2.2.1.1 Wire Rope and Drum. Sector gates have traditionally been driven by either a wire rope and drum mechanisms, shown on Plate B-55 or by rack and pinion, shown on Plate B-56. The wire rope and drum mechanism was designed to be an inexpensive method of operating infrequently used gates, such as floodgates. A disadvantage of the wire rope and drum mechanism is that the wire ropes tends to lose tension with use, thereby requiring periodic retensioning and replacement. Also, because the wire rope drum position does not accurately correlate to the gate position, limit switches must be located on the gate or in the gate recess, potentially exposing them to damage.

2.2.1.2 Rack and Pinion. The rack and pinion mechanism, are mainly used on lock gates or gates that have a high frequency of use. Once the rack and pinion is aligned there are no further adjustments or readjustments. In addition, the gate drive pinion gear accurately correlates to gate position thereby permitting the use of limit switches which can be located to operate directly from the machinery. A disadvantage with the rack and pinion mechanism is that wear in the gate's hinge and pintle eventually manifest itself in a tightening of the gear mesh, however, by this time it is usually wise to either replace or rotate the gate bushings. The rack and pinion gears should have a diametrical pitch of 1 or more to minimize the effects of changes in gear clearance resulting from the relative radial movement of the gate rack and pinion gears.

2.2.1.3 Direct Acting Hydraulic Cylinder. A third design uses a direct acting hydraulic cylinder as shown on Plate B-57. The direct acting hydraulic cylinder has been around for a number of years, but is not in wide-spread use. To reduce the cylinder's stroke length, the cylinder's rod end is attached to the gate's top frame near the hinge and at an operating radius that is approximately 1/5 that of either the rack and pinion or cable and drum mechanisms. The short operating radius imposes higher stresses on the gate and machinery then the previous two designs. The advantages of the direct operating cylinder are fewer machinery components, the cylinder is self-aligning with the gate, and limit switches can be built directly into the cylinder where they are not easily damaged.

2.2.1.4 Power Transmission. Mechanical and hydraulic are the two types of transmissions that provide power to the three gate operating mechanisms described above. The hydraulic transmission usually consists of an electric motor driven hydraulic pump, control valves and, except for the direct acting hydraulic cylinder machine, a hydraulic motor. Hydraulic transmissions are inexpensive and provide flexibility in control and physical layout. The control flexibility of the hydraulic transmission is particularly suitable for lock gates. The mechanical transmission usually consists of an electric motor, motor brake and multiple shaft speed reducer. Mechanical transmissions are dependable and require little maintenance which makes them suitable for flood gates.

2.2.2 Design Considerations and Criteria.

2.2.2.1 General. Hydraulic loading on sector gates are produced from direct heads and reverse heads. A direct head is a head differential across the gate with the highest water elevation on the convex side of the skinplate. A reverse head is a head differential across the gate with the highest water surface on the concave side of the skinplate. Operating forces from direct heads are friction from the pintle and hinge, hydraulic forces on the seal bracket, and bottom seal friction. Operating forces from reverse heads are hinge and pintle friction, hydraulic forces on the seal brackets, hydraulic forces on the vertical steel members near the nose of the gate, and friction from reverse head seals. Unpredictable forces such as those caused by silt, debris, wear, and construction inaccuracies should be accounted for by applying a 1.5 application factor to the calculated loads. Ice loading should be calculated separately and then added to all other calculated loads. Sample calculations for determining closing loads with a reverse head are shown in Appendix C.

2.2.2.2 Hydraulic Loads. Difficulty was experienced in the design of the first sector gates when operated with reverse heads. Prototype tests showed that hydrodynamics forces on the vertical steel member near the nose of the gate created much greater loads than anticipated during design. As a result, extensive tests were made to obtain operating hydraulic forces on sector gates and to account for the hydrodynamics forces. These tests made by Waterways Experiment Station (WES) are published in the following reports.

- Technical Report No. H-70-2, titled "Operating forces on Sector Gates Under Reverse Heads and "Appendix A."
- Technical Report No. H-71-4, titled "Calcasieu Saltwater Barrier prototype Sector Gate Tests".
- Technical Report No. 2-309, titled "Filling Characteristics, Algiers Lock Intracoastal Waterway, Gulf Section, Louisiana" and Appendix. The appendix covers gate operating forces and modifications to reduce operating forces.
- Technical Report No. CHL-TR-03-3, titled "Filling and Emptying System for Inner Harbor Navigation Canal Lock Replacement, Louisiana".

The third and fourth reports are for a tests conducted on models of modified sector gates referred to as ear sector gates. In plan view an ear sector gate resembles a traditional sector gate with the addition of two protruding radial members at each end of the gate called ears. Ear sector gates are designed to pass water through the center of the lock and through the gates recesses as the gates opens. This enables the lock chamber to fill and empty at a faster rate and with less turbulence, since not all the water is entering or leaving the lock chamber through the center opening as is done with non eared gates. This feature is of greater importance with increase in lock lift. The design also prevents siltation in the gates' recesses. Algiers Lock, located on the Intracoastal Waterway and the Mississippi River at New Orleans has ear sector gates designed for a differential head of 5.6 meters (18.5 feet), about 3.6 meters (12 feet) higher than what would be practicable with non eared gates.

2.2.2.3 Hinge and Pintle Friction. Hinge and pintle frictional torque is the torque generated at the bearing surfaces between the stationary part of the bearing and the movable part. The bearing load is the load resulting from the gate weight, hydrostatic loads and reaction loads generated by the operating machinery. Based on using self aligning hinge and pintle, a bearing frictional factor of 0.25 for steel on bronze should be used. If either a cylindrical hinge or pintle is used the designer should anticipate much higher frictional loads resulting from possible construction misalignment. WES has found that cylindrical hinge and pintle friction for Calcasieu Saltwater Barrier sector gates were 4.5 times the calculated value.

2.2.2.4 Bottom Seal Friction. Bottom seal friction is caused by the differential hydrostatic head across the seal and force of precompressing the seal 6.4 mm (0.25 in.). A coefficient of friction of 1.0 should be used even for Teflon coated rubber seals. Initially the seals on a sector gate are set with approximately 0 to 0.8 mm (0 to 1/32 in.) of clearance. The 6.4 mm (0.25 in.) precompression accounts for gate sag, hinge and pintle wear and variations in gate temperature between submerged members and non-submerged members.

2.2.2.5 Contingencies. After the gate loads are calculated, an application factor of 1.5 should be applied to the combined friction and hydraulic loads. The application factor accounts for transient and unpredictable forces such as those resulting from silt, debris, hinge and pintle wear and construction inaccuracies.

2.2.3 Operating Procedure/Controls

2.2.3.1 Low Head Locks. Low head locks are locks that have a lift of 1.5 meters (5 feet) or less. To fill and empty a low head sector gated lock chamber the operator opens the filling or emptying sector gates from 0.3 to 0.9 meters (1 to 3 feet). The gates are then held in this position until the differential water level across the gates is within 150 mm (0.5 foot). At this time the gates are then fully opened. A single operating speed of between 20 to 35 degrees of gate rotation per minute with cushioned gate start and stop has been found to be satisfactory. With a hydraulic transmission, cushioned gate start and stop can be incorporated into the hydraulic system using ramp proportional valves or other flow control devices. Machinery brakes should also have cushioned movement.

2.2.3.2 Flood Control Gates. Single speed operation of between 5 to 7 degrees of gate rotation per minute has been found to be satisfactory. At this low speed of operation, cushion gate start and stop are not required.

2.2.3.3 Medium to High Lift Gates. Medium to high lift locks are locks with lifts of over 1.5 meters (5 feet). For medium to high lift locks, where the gates are used to fill and empty the chamber, a two-speed operating system is required with a slow initial opening speed. The slower speed enables the lock operator to accurately set the gate opening in order to prevent excess chamber turbulence. The slow speed should be field adjustable with a range of from 1.5 to 5 degrees of gate rotation per minute. A higher speed of 20 to 35 degrees of gate rotation per minute can be used once the differential head across the gate is within 150 mm (0.5 foot). Starts, stops and changes in gate speed should be cushioned.

2.2.4 Special Design Consideration. The gate operating machinery is crucial to the operation of a lock or floodgate structure. Reasonable means should be made to incorporate into the design a high degree of reliability and serviceability.

2.2.4.1 Auxiliary Drives. For most hydraulically driven gates an auxiliary drive has proven valuable. The auxiliary drive should be basic and provide an operating speed that is 1/3 to 1/4 that of the primary drive. The auxiliary drive should consist of a pump and motor connected permanently to the gate's hydraulic system. Other hydraulic system components, such as valves, solenoids and hoses should be accessible and easily replaceable. Mechanically operated gates do not normally require an auxiliary drive. However, flood control gates with mechanical drives should have auxiliary power sources, such as auxiliary generator, hand crank or air motor with air storage.

2.2.4.2 Hydraulic System Contamination. Water in the hydraulic system is one of the primary reason for hydraulic component failures. Water usually infiltrates the system from the moisture in the air that is exchanged in the reservoir through the breathers. To eliminate this source of contamination the hydraulic reservoir should be located in a room with dehumidification and/or be equipped with a bladder that prevents direct exchange with outside air. A bladder is an elastomeric air chamber that is connected to the reservoir. The bladder expands and contracts as the air volume changes in the reservoir, eliminating the need for a breather. Reservoirs using bladders should be pressure tested and equipped with relief valves. Contamination can also be eliminated by using integral power units, that have sealed reservoirs. These units combine a hydraulic power with a hydraulic cylinder to form a self-contained actuator that is completely sealed and submersible. Self-contained actuators are now used for miter gate machinery on several locks. See Chapter 5 for additional information.

2.2.4.3 Material Selection. When practicable, machinery components that are potentially subject to damage, should be constructed from field weldable materials. This is especially important for items requiring a long lead time to acquire or would take a substantial effort to replace, such as gear racks, drive pinions and machinery bases.

2.3 Vertical Lift Gates (Locks).

2.3.1 General Description and Application. Vertical lift gates can be used as upstream lock operating gates, emergency gates, auxiliary gates, and ATide@ or AHurricane@ gates. Vertical lift gates are often used when the lock has a design criterion, which requires operation under heavy ice or debris conditions. Emergency gates are used to close off a lock chamber under flowing water conditions with the main operating gates damaged. Vertical lift gates are used as auxiliary lock gates, in tandem with miter gates, on some locks. When used as auxiliary gates, the vertical lift gate provides more efficient performance during ice and debris conditions than a miter gate. Vertical lift gates are also used as tidal barriers or AHurricane@ gates in coastal areas. A typical lift gate leaf consists of a number of large horizontal steel girders, intercostal web girders, an upstream skinplate and end framing. Downstream skinplates may also be added, for strength and debris control, when adequate access is provided for inspection and maintenance.

Lift gate systems of one to three leaves have been used for lock operations. Lift gate leaves designed for unbalanced head operation often have upstream and/or downstream reaction rollers to reduce friction and improve vertical stability. Design of vertical lift gate leaves is detailed in EM 1110-2-2701. The only major disadvantage to the use of vertical lift gates is a significantly higher construction cost.

2.3.1.1 Upstream Lock Gates. Most upstream lock lift gates are multiple leaf gate systems. The use of multiple leaves permits operation at high river levels by using the upstream, or lower, leaf as a movable sill. The upstream leaf can also serve as the primary operating leaf, at normal pool levels, until a damaged operating leaf can be repaired. The downstream leaf is generally designed with an overflow nappe section to allow ice and debris to be passed over the gate while submerged under head. This overflow feature is one of the primary reasons for use of this type of gate. This gate design is particularly useful for locations that operate all winter with floe ice conditions. Each gate leaf is operated by a separate hoist connected to each end of the leaf. The hoists, which each have their own electric motor, are electrically, or electronically, synchronized to insure that the ends of the leaf remain relatively level at all elevations. Most upstream lock lift gates are operated by an electric motor driven, geared hoist system with a counterweight system to reduce operating power requirements. Two typical systems are found on the Mississippi River. These systems are used as sole upstream lock operating gates on the two heaviest usage locks on the Mississippi River. Typical gate arrangements are shown on Plates B-58 and B-59.

2.3.1.1.1 Three Leaf Lift Gate Hoist. This hoist uses two sets of round wire ropes at the end of each gate leaf. One set of cables passes over two sets of sheaves to connect to a steel counterweight container, filled with removable lead weights, which travels in a shaft in the lock wall. The other set of cables is connected to a spiral-wound steel drum attached to a large spur gear. The pinion, which drives the spur gear/drum assembly, is coupled to a parallel shaft reducer. The parallel shaft reducer input shaft is connected to a DC motor on one side and an electric shoe holding brake on the other side. This hoist is located within the lock walls, at one of two separate levels at the existing installation, but could be located above the lock wall. A typical design is shown on Plates B-60 and B-61.

2.3.1.1.2 Two Leaf Lift Gate Hoist. One typical two leaf gate system uses a machine, which consists of a roller chain connected to the each end of the gate leaf, which travels over idler sprockets and a drive sprocket to connect to a concrete counterweight inside a shaft in the lock wall. Two slightly different hoist machines, located within the lock walls, drive the upstream and downstream leaves. The downstream leaf drive sprocket is powered by a series of spur gears, a parallel shaft reducer and an electric motor controlled by a Variable Frequency

Drive (VFD) system. A holding brake is mounted adjacent to the electric motor. The upstream leaf, which is basically a moveable sill, operates much slower than the downstream leaf due to an additional 9 to 1 ratio worm reducer, located between the motor and the parallel shaft reducer. A typical design is shown on Plates B-62 and B-63.

2.3.1.2 Emergency and Auxiliary Lock Gates. These gates are not the primary operating gates for the lock. The gates are used when failure of the miter gates occurs, or if it is necessary to pass floe ice or debris. Under ice or debris conditions, the miter gates are secured in the open position with the lift gate closed. The lift gates are lowered to allow ice or debris to pass through an open lock chamber past both sets of miter gates, which are retracted in their recesses. These types of gates typically consist of two leaves, one upstream or lower leaf, and one downstream or upper leaf. The downstream leaf is equipped with wheels to facilitate raising in flowing water. The upstream gate should be designed to be raised only under balanced head or a swell head of one foot or less. The upstream leaf is normally operated in steps as shown in the operating procedures on Plate B-64.

2.3.1.2.1 Reeved Lift Gate Hoist. One typical hoist system uses a double grooved hoist drum driven by open spur gears, a parallel shaft reducer, a shoe-type holding brake and an electric motor. The rope drum is designed to wrap several layers of round wire rope. One wire rope attaches to each end of a gate leaf through a multi-part reeving system with sheaves attached to the end of the gate leaf. One of the wire ropes must pass through a tunnel beneath the lock chamber to additional idler sheaves on top of the opposite lock wall from the drum. This machinery is mounted above maximum high water on top of the lock wall. A typical design is shown on Plate B-65.

2.3.1.2.2 Alternative Design. A hoist system similar to the arrangements in Upstream Lock Gates above could be used for this type of gate. Since this would not be a principal operating gate, the size of the machinery could be reduced to reflect actual operating procedures for reduction of the construction costs. Option 2.3.1.1.2 would be less advantageous, past roller chain design tended to become troublesome when not properly designed, operated and lubricated regularly. See paragraph 3.1.5 for roller chain design information.

2.3.1.3 ATide@ or AHurricane@ Gates. This type of vertical lift gate is generally a single leaf gate, which can be used at either end of a lock in coastal areas. This type of gate is raised when not in use, permitting normal traffic to pass underneath the gate leaf.

2.3.1.3.1 Tide Gate Machinery. A typical tide gate machine has tandem, dual drums driven by a single pinion connected to a parallel shaft reducer. The reducer is driven by an electric motor, with dual drive shaft extensions, through an electric holding brake. The extra motor shaft extension permits connection of a hydraulic Aemergency@ lowering mechanism.

The electric motor has two speeds. The low speed is used to start and stop the gate. The two drums wind both ends of a continuous wire rope, which lifts the gate through a series of sheaves. One dual drum serves each end of the gate leaf. Two of the sheaves mounted on the gate leaf serve as equalizing sheaves to even the line pull if one drum winds slightly more wire rope than the other. Each drum is precision grooved so that it winds the same amount of wire rope on each layer. A typical hoist arrangement is shown on Plate B-66.

2.3.1.3.2 Emergency Lowering Mechanism. The emergency lowering mechanism consists of a radial piston-type hydraulic pump connected to the electric motor shaft extension and associated controls. The controls include a flow control valve, check valve, tubular-type oil cooler, piping and a reservoir. When the gate is lowered without electric power, the weight of the gate turns the hydraulic pump, through the wire rope and gears. The oil, from the pump, is circulated through the flow control valve, which restricts the flow to control speed and transmit heat to the oil to be removed by the oil cooler.

2.3.2 Design Criteria.

2.3.2.1 Upstream Lock Gates. There are four typical design criteria to investigate for normal operation of multi-leaf vertical lift gate machinery for upstream lock gates. The first condition is normal operation with balanced head on each side of each leaf. This condition occurs when the gates are opened to allow the tow into the chamber. The second condition is holding the gate against an unbalanced head. This condition occurs when the tow is in the chamber at tailwater prior to opening the downstream gates. The third condition is ice or debris flushing operation, where the machinery holds the gate against an unbalanced head with flow over the downstream leaf. The fourth condition is ice or debris flushing operation, where the downstream leaf machinery must raise the leaf to block the flowing water. The first three conditions are applicable to upstream and middle leaf machinery.

2.3.2.1.1 Gate Operating Speeds. Upstream leaves, used as moveable sills, are often designed for 5 to 25 mm per second (1 to 5 feet per minute) operating speed. Since these leaves are usually designed to compensate for overall increased pool conditions, high speed is not an important requirement. An upstream leaf that is used as a main operating leaf should probably have an operating speed similar to the middle leaf requirements. Middle leafs, which are often used during normal operation, can be designed for an operating speed in the range of 25 to 50 mm per second (5 to 10 feet per minute). Middle leaf speeds are often determined by an effort to minimize overall operating time by having the middle leaf complete its travel slightly before the downstream leaf. Downstream leaves are usually designed for dual, or multi-, speed operation with maximums of 50 to 60 mm per second (10 to 12 feet per minute). Minimum speeds for downstream leaves are determined by the torque requirements for raising the gate in flowing water conditions.

2.3.2.1.2 Hoist Drive Motors. While dual speed operation can be accomplished with a two speed electric motor, the original design for the two leaf lift gate hoist used two separate motors, one high speed and one low speed, with a ASynchro-tie@ system for Askew@ correction. These motors were eventually replaced with a single motor controlled by a Variable Frequency Drive (VFD). Modern technology has provided the DC drive and the VFD, which provide widely variable speed and torque at a competitive cost. The three leaf lift gate hoist uses a DC drive for each leaf, which provides infinitely variable speed between 400 and 1200 revolutions per minute (rpm) of the motor with constant horsepower. This system allows ice flushing at low rpm and high torque, while normal, balanced head operation can occur at high rpm and low torque.

2.3.2.2 Emergency and Auxiliary Lock Gates. Load cases similar to Upstream Lock Gates paragraph, above, must be evaluated for emergency and auxiliary lock gates which will be used as primary operating gates for the lock.

2.3.2.2.1 Gate Operating Speeds. Upstream leaves, used as moveable sills, are often designed for 5 to 25 mm per second (1 to 5 feet per minute) operating speed. Since these leaves are usually designed to compensate for overall increased pool conditions, high speed is not an important requirement. Downstream leaves are usually designed for two speed operation with maximums of 25 to 50 mm per second (5 to 10 feet per minute). Minimum speeds for downstream leaves are determined by the torque requirements for raising the gate in flowing water conditions. Actual speed requirements will be determined by frequency of use, impact to traffic and benefit/cost analysis.

2.3.2.2.2 Hoist Drive Motors. While dual speed operation can be accomplished with a two speed electric motor, there may be some cost and operational benefits to using a variable frequency drive system. The VFD would be particularly useful for gates that require operation under unbalanced head. For more detailed information see Chapter 4.

2.3.2.3 ATide@ or AHurricane@ Gate Machinery. This machinery must be designed for raising and lowering against differential head, as well as additional wind load on the exposed portion of the gate leaf. The gate machinery must be designed to lift the gate leaf above the highest elevation necessary to clear traffic beneath the gate. The machinery must be raised above the maximum high water elevation in an environmental enclosure. Where cable fleet angles, approaching the drums, exceed 1.5 degrees, a fleet angle compensator should be provided.

2.3.2.3.1 Gate Operating Speed. Tide gates are typically operated at speeds between 25 and 50 mm per second (5 to 15 feet per minute), or the speed required to completely open in approximately 10 minutes.

2.3.2.3.2 Wind Load. The minimum wind load should be assumed as 0.9 kPa (20 pounds per square foot). Actual environmental data, which indicates greater loading, should be used whenever available.

2.3.2.4 General Machinery Component Design. The general design criteria for machinery components are indicated in Chapter 5. Other hoist specific design criteria are presented herein.

2.3.2.4.1 Hoist Load Distribution. The normal hoist load is considered to be equally divided between the two sides of the gate leaf. The main upstream lock gate, emergency and auxiliary lock gate machines use separate hoists or an equalizing arrangement to distribute load. Hoists should be designed to withstand the locked rotor torque of the motor, applied to a single end of the gate leaf, without damage to the hoist.

2.3.2.4.2 Wire Rope Design. Wire rope design should be in accordance with the provisions of EM 1110-2-3200. Wire rope design is a complex issue dependent upon the amounts and types of bending and connections involved in the design. In general vertical lift gate machines can not change wire ropes as often as the manufacturers recommend, therefore, conservative safety factors should be used in the design. Minimum factors of safety should be 5.0 applied to the maximum normal load with no rope exceeding 70 percent of the breaking strength for locked rotor torque of the motor. Wire rope lubrication is extremely important for installations with frequent bending of the wire ropes. There may be some benefit to the use of resin socketing material in lieu of the traditional zinc. Sockets used with the resin material must be designed with narrower tolerances to restrict rope bending at the socket, however they improve field installation, repair and corrosion protection.

2.3.2.4.3 Sheave Design. Sheaves should be a manufacturer=s standard design when used in a single rope, multiple reeving application. Custom sheave designs may be required for parallel multiple wire rope installations. Sheaves may have internal bronze bushings, permanently lubricated bushings or antifriction bearings according to their accessibility for maintenance. Sheave diameters are determined from the wire rope diameter in conjunction with common industry practice. The minimum recommended sheave to rope diameter ratios are provided in EM 1110-2-3200. Larger ratios are recommended for extended service and extensive reeving.

2.3.3 Controls. Control systems are discussed in Chapter 4.

2.3.4 Special Design Considerations. Special design considerations require coordination among the structural, hydraulic, mechanical and electrical designers to provide a proper operating system.

2.3.4.1 Upstream Lock Gates. These considerations are pertinent to two system examples indicated for principle lock operating gates.

2.3.4.1.1 Gate Cable Connection. The three leaf lift gate hoist uses multiple round wire ropes in parallel to lift the gate leaves. The original gate design must place the gate connection

at the horizontal center of gravity. This is essential to permit proper equal tension in each of the hoist and counterweight wire ropes. The structural engineer, who designs the gate leaf, must commit to this principle at the very beginning of his design. If this is not designed properly, the gate can tilt in the slot. A tilted gate may become Astuck@ in the slot, which could cause the wire ropes to continue to unwrap even though the gate is not moving. Such an event creates a dangerous and unsafe situation. The gate may fall from this "stuck@ position, which can damage the wire rope or anyone in the vicinity of the wire rope. It is also important that the cables be connected to the gate with a positive means of holding the sockets in contact with the gate. Bolts, pins or other devices, which provide proper tension adjustment, are required. Another beneficial design consideration would be a method, such as turnbuckles, located in a protected, but accessible, location, for individual wire rope tension adjustment. The top of the gate leaf is, in general, the most accessible location on the gate.

2.3.4.1.2 Slack Cable Safety Devices. Slack cable safety devices are an essential safety feature for wire rope operated lift gate hoists. The three leaf lift gate hoist uses three separate devices to stop the lift gate hoist motors in order to prevent unwrapping of the wire rope from the drum when the gate is not moving. The primary system is an encoder connected to a counterweight sheave. Since the counterweight is directly connected to the gate, it will only move when the gate moves. Therefore if the counterweight sheave is not rotating, the gate is probably not moving. When the encoder indicates no movement of the gate during movement of the hoist, it stops the hoist drive motor. The second safety device is a photoelectric cell, which is placed close to a vertical run of wire ropes from the hoist drum. When the cables go slack, indicating cable movement but no gate movement, the cell stops the hoist drive motor. The third level of safety devices is a simple limit switch which is activated by any sagging wire ropes in the horizontal run between the idler sheaves on the lock wall. For additional detailed information see Chapter 4.

2.3.4.1.3 Positional Encoders. Positional encoders, connected to the machinery, are essential to the operation of the lift gate machinery. Encoders are used to provide the elevation position indication and level control, or Askew@ correction, of the gate leaves. Encoders can be used to indicate speed, motion or actual angular position of various machinery components, which can be translated to gate leaf motion. For more detailed information see Chapter 4.

2.3.4.1.4 Chain Design. Roller chain assemblies for gate hoists are typically custom designed for the loads generated by the operating conditions. It is logical to design all operating chains for the lift gates to the maximum requirements, such that they are interchangeable for all gate leaves. The two leaf lift gate hoist chain was designed as two parallel chains connected by a clevis plate at each end. Each chain has two types of links; a fixed link, which connects two side bars using a steel pin, and a pivoting link, which uses a bushing between the two side bars and the steel pin. Both types of links are connected by the same steel pins, but the pivoting link side bars are inside of, and next to, the fixed link side bars. The pivoting link side bars are separated by a roller which revolves around the bushing on the inside radius and contacts the sprocket tooth on the outside radius. This design uses grease lubrication through the steel pins to reduce friction between the bushing, pin, roller and side bars. The two clevis plates have pivoting connections at the gate leaf and the counterweight to reduce chain bending and equalize the load between chain strands. A considerable amount of chain wear has been noted with this design. Several improvements to chain materials have had little effect upon the wear. Current investigations appear to indicate that machinery alignment, counterweight alignment or gate leaf alignment may be the cause of the apparent upstream movement of the chain against the drive and idler sprockets. See Chapter 3 for alternate roller chain design.

2.3.4.1.5 Sprocket Design. A typical sprocket is a high strength steel casting, similar to an ASTM A 148, Grade 120-95, with an overall hardness of 285-300 BHN. Tooth contact surfaces are surface hardened to a minimum of 450 BHN. A typical sprocket for a 305 mm (12 inch) pitch chain has eight teeth. Sprockets are keyed to the drive shafting for convenient removal.

2.3.4.1.6 Counterweight Design. The main design consideration for counterweights should be flexibility. The counterweight should have a method for convenient addition or subtraction of weight. The counterweight shaft, or enclosure, should be designed for convenient access for maintenance and inspection. Beams or hoists should be provided to allow handling of weights. A maintenance structure for suspending the counterweights will be needed while performing work on the gate leaves and hoists. Lead pig weights, installed in a structural steel container, were used for the three leaf lift gate hoist counterweight. The two leaf lift gate hoist uses a poured concrete counterweight with some additional steel weights added for adjustments.

2.3.4.1.7 Gate Girder Design. The structural engineer should be reminded that the operating machinery is not designed to force the gate leaf down. Since the gate leaf must lower due to its own weight, it is important that the structural designer compensate for any air trapped under the horizontal girders. Gate leaves, which are suspended completely, or partially, in air during unbalanced head, tend to trap large amounts of air beneath the girders. This trapped air has been known to make a 127 tonne (140 ton) gate leaf float. This problem was partially solved by boring large holes in the main girders and nappe section to release the air as the gate lowered under balanced head. It continues to be a problem with the existing gates. Additional holes have been drilled after several floating Aincidents@. It would be wise to eliminate lower flanges, which trap air, or include Aair-release@ provisions in the girder design, to prevent the need for compromising the structural girder design with retrofitted holes.

2.3.4.1.8 Gate Wheel Design. Gate wheel design should be coordinated with the gate structural design. It is important for all reaction rollers to have angular flexibility to adjust for the flexure of the gate. This can be accomplished with a crowned tread wheel, a spherical bearing or a combination of these items. The reaction rollers should be as large a diameter as practical to properly distribute load to the roller track. The roller track should be thick precipitation-hardened stainless steel, which can be easily replaced. Each wheel should be designed for loads generated if only one third of the wheels are actually in contact. This criterion will help to compensate for construction tolerances on the concrete gate recess and roller track installation tolerances. Upstream rollers are beneficial in maintaining gate leaf stability, as well as equal hoist tension. These rollers could be alternated in vertical location with the downstream rollers to encourage maximum bearing against the roller tracks, while providing maximum space for each roller.

2.3.4.1.9 Dogging Devices. The structural engineer should be encouraged to design a manual Adogging@ device which will permit supporting the gate leaf above the pool level near the top of the lock wall. This device would be essential to proper maintenance and inspection. This device should permit access to the gate end framing, wire rope or chain connection, reaction rollers, wheels, seals and other adjustable or maintainable equipment.

2.3.4.1.10 Nappe Breakers. Nappe breakers are additions to the nappe section of a downstream gate leaf that are designed to reduce vibrations transmitted to the machinery while water is flowing over the nappe. The three leaf lift gate design required a simple structural alteration to the nappe section to eliminate harmful vibrations.

2.3.4.1.11 Machinery Base Anchorage. It is essential for the structural engineer to design, detail, and specify minimum anchorage requirements for the machinery support base in accordance with the loads supplied by the machinery designer. The maximum holding load, against differential head, can often dictate the design of machinery support anchor bolts. The holding brake load, once exceeded, allows the gate to lower with the shoes still applying friction to the brake wheel to slow movement until it reaches the sill. Maximum locked rotor torque, and maximum normal motor load torque (as available for DC drive, Variable Frequency Drive, or standard electric motor) should be compared with the holding loads to determine the maximum force applicable to the anchor bolts. The holding brake load will control the loading during static, non-powered, conditions. The locked rotor torque generally applies as the maximum operating torque available on one end of the gate leaf while the motor is energized. Anchor bolts need to be detailed on the drawings, and clearly specified, to have bolt heads or hooks, to insure full development of strength. Overlapping concrete shear cone analysis needs to be part of any anchor bolt group design. Anchor bolt material, spacing and adjustment provisions should be clearly shown on the contract drawings and reviewed by the government during the shop drawing submittal process.

2.4 Culvert Tainter Valve.

2.4.1 General Description and Application. The most common type of filling and emptying system used in locks is a longitudinal culvert in the lock wall extending between the upper and lower pools. Each culvert has a streamlined intake at the upstream end and a diffusion exhaust at the downstream end. Culvert flow is distributed in and out of the lock chamber by wall ports or secondary culverts in the floor of the chamber. Each culvert has two valves; one for filling and one for emptying the chamber. The filling valve allows upstream pool to fill the chamber while the emptying valve remains closed. The emptying valve allows the chamber to drain to the downstream pool while the filling valve remains closed. The most common type of filling and emptying valve is the tainter valve. The tainter valve is constructed in a manner similar to the tainter gates typically used as spillway gates. Additional information on culvert valves is available in EM 1110-2-1610, ΑHydraulic Design of Lock Culvert Valves@.

2.4.1.1 Tainter Valve. Many of the navigation locks on the upper Mississippi River have conventional tainter gate type valves. The valve is oriented with the trunnions downstream of the skinplate causing the convex surface of the skinplate to face the flow and seal along the upstream end of the valve well. The hoist for this valve uses two stainless steel round wire ropes, one at each end of the valve. The wire rope is connected to the convex side of the tainter valve at the lower main girder near the side strut location. The valve should be designed to provide sufficient weight to close even under flowing water conditions, since the cable system is incapable of forcing the valve to close. The cables are connected to two grooved drum assemblies which are flanked by spherical roller bearing pillow blocks. The drum assemblies are connected to a quadruple reduction parallel shaft reducer by geared flexible couplings. The parallel shaft reducer has dual extended input shafts to connect to the electric drive motor and hoist holding brake. A rotary limit switch assembly is connected to the brake shaft extension. The holding brake is typically a solenoid operated shoe brake. The electric drive motor may be a custom two-speed constant torque motor or a variable frequency drive (VFD) motor system (for multi-speed operational requirements). Hardwired overtravel limit switches are also used to supplement the rotary limit switch assembly. A slack cable limit switch is provided to prevent unspooling of the cable when the gate is not moving. A typical design is shown on Plate B-67.

2.4.1.2 Reverse Tainter Valve. Many of the navigation locks on the Ohio River, as well as some of the newer ones on the Mississippi River, Red River and Arkansas River, have reverse tainter gate type valves. The valve is oriented with the trunnions upstream of the skinplate causing the convex surface of the skinplate to face downstream and seal along the downstream end of the valve well.

2.4.1.2.1 Hydraulic Operated Bellcrank Type Hoist. The typical hoist for the reverse tainter valve on large capacity locks consists of a trunnion mounted hydraulic cylinder, a bellcrank, a gate operating strut, a support base and bearings. The hydraulic cylinder has a center trunnion mounted on pillow block bearings. The cylinder rod is attached to one corner of a truss-type bellcrank made of steel pipe. The bellcrank has one corner, about which it pivots,

connected to a pair of pillow blocks. The other corners are connected to the hydraulic cylinder and the gate strut. The gate strut is a steel pipe assembly that contains clevis and eye end connections and a spring assembly. The gate strut connects the bellcrank to the tainter valve. All pivot connections are equipped with bushings and pins. Lubrication piping is routed to all bushings and pillow blocks. Lubrication piping can be routed inside struts and bellcrank tubes to reduce exposure to damage. A typical design is shown on Plate B-68.

2.4.1.2.2 Alternative Design. Some locks use a vertically mounted hydraulic cylinder with a sealed bonnet around the cylinder rod end to exclude water from the valve well. The vertical cylinder does not pivot, but extends straight downward. The cylinder rod drives a pivoting gate operating strut that is connected to the gate. The connection between the cylinder and the strut is guided along the wall of the recess. A typical design is shown on Plate B-69.

2.4.1.2.3 Direct-Acting Cylinder Design. A direct-acting cylinder design, which pivots about a cap end trunnion with the rod connected directly to the tainter valve, has been used successfully. This system is submerged in operation. Some evidence of water leakage mixing with the hydraulic fluid does indicate sealing problems. This system might be applicable to locations where frequent inspection and maintenance of the cylinders is feasible. Extreme measures are required to protect and maintain seals and piping/hose from debris or ice. A typical design is shown on Plate B-70.

2.4.2 Design Criteria.

2.4.2.1 Tainter Valve. The tainter valve machinery must be designed to raise the valve under flowing water conditions at the full maximum head differential. Hydraulic design engineers should provide the gate operating speeds, including any pauses, to be used at the various head conditions planned for the specific lock location. Operating speeds are based upon specific flow conditions designed to safely fill or empty the lock chamber without producing unsafe hawser stresses, air entrainment or other operating conditions dangerous to the tows or their personnel. The tainter valve should be designed to provide sufficient weight to close even under flowing water conditions, since the cable system is incapable of forcing the valve to close. Closing under flowing water conditions may be required where ice or debris flushing operations are typical, especially at locks with upstream lift gates. It is customary to design all tainter valve machines identically for economy of fabrication.

2.4.2.1.1 Tainter Valve Hoist Loads. The hoist should be designed for the gate connection load due to flowing water under the valve, the buoyant (submerged) weight of the valve, the weight of the operating cable assemblies, the side seal friction, the trunnion bushing friction under maximum normal flowing water load, and the head differentials across the top seal of the valve. Evaluation of these loads is a mandatory minimum requirement for machinery design.

2.4.2.1.2 Valve Operating Speeds. Typical operating speeds for tainter valves should permit opening in approximately one to three minutes. Operating times as long as fifteen minutes have been used at the John Day Lock. Cavitation problems caused revision of the John Day Lock=s opening time to less than seven minutes, including a five minute pause at 30 percent open. Discharge conditions, such as scour, low water or temporary moorings, could also result in the need for slower valve operating speeds.

2.4.2.1.3 Hoist Drive Motors. Dual speed operation can be accomplished with a two speed electric motor. For multi-speed operation an electric motor controlled by a Variable Frequency Drive (VFD) would be more practical. Modern technology has provided the DC drive and the VFD, which provide widely variable speed and torque at a competitive cost. These devices can provide almost infinitely variable speed with constant horsepower. This system allows ice flushing at low rpm and high torque, while normal, balanced head operation can occur at high rpm and low torque. For more detailed information see Chapter 4.

2.4.2.2 Reverse Tainter Valve. The machinery must be designed to raise the valve under flowing water conditions at the full maximum head differential. Hydraulic design engineers should provide the gate operating speeds, including any pauses, to be used at the various head conditions planned for the specific lock location. Operating speeds are based upon specific flow conditions designed to safely fill or empty the lock chamber without producing unsafe hawser stresses, air entrainment or other operating conditions dangerous to the tows or their personnel. The tainter valve machinery should be designed to provide sufficient force to close even under flowing water conditions without causing damage by pushing the tainter valve against the sill in the culvert. Closing under flowing water conditions may be required where ice or debris flushing operations are typical, especially at locks with upstream lift gates. It is customary to design all tainter valve machines identically for economy of fabrication.

2.4.2.2.1 Tainter Valve Hoist Loads. The hoist should be designed for:

- The gate connection load due to flowing water under the valve,

- The buoyant (submerged) weight of the valve,
- The weight of the gate operating strut assemblies,
- The gate operating strut bushing friction,
- The side seal friction,
- The trunnion bushing friction under maximum normal flowing water load,
- The head differentials across the top seal of the valve,
- The bellcrank bushing friction, and
- The hydraulic cylinder trunnion bushing friction.

Evaluation of these loads is a mandatory minimum requirement for machinery design.

2.4.2.2.2 Valve Operating Speeds. See paragraph 2.4.2.1.2 for design criteria.

2.4.2.2.3 Hydraulic System Design. The tainter valve machinery control circuit for a conventional hydraulic system should include a solenoid or servo-controlled four-way directional control valve, an adjustable pressure relief valve for opening operations, an adjustable pressure relief valve for closing operations, and a remote pilot operated counterbalance valve. The directional valve should be designed with a blocked center or tandem center spool providing positive pump output to the cylinder in both directions of operation. Tainter valves should not be allowed to lower through the hydraulic control circuit by only their own weight. Such operation could lead to undesirable shock and vibration within the control circuit. The pressure relief valves are provided to protect the controls and cylinders from excessive pressure, which could lead to damage of the strut, bellcrank or associated bearings and pins. The counterbalance valve is the typical method to prevent an overrunning load, while providing a positive locking of the cylinder, at any valve position, until hydraulic pump pressure is applied to the cylinder for actual planned movement. The tainter valve machinery control circuit for a self-contained actuator, with integral hydraulic system, is similar except for directional control. Instead of a four-way valve, this system uses a bi-rotational hydraulic pump and reversible electric motor to control direction.

2.4.2.2.4 Instrumentation. The installation of pressure transducers, and pressure gauges, at strategic locations within the hydraulic circuit, would provide useful information in the adapting of the hydraulic system to actual lock operating conditions.

2.4.2.3 General Machinery Component Design. The general design criteria for machinery components are indicated in Chapter 5. Other hoist specific design criteria are presented herein.

2.4.2.3.1 Wire Rope Design. See paragraph 2.3.2.4.2 for design criteria.

2.4.2.3.2 Trunnion Mounted Hydraulic Cylinder. Trunnion mounted hydraulic cylinders, used for bellcrank type tainter valve machinery experience a kinematic motion that places large side loads on the upper half of the rod end seals. This usually leads to premature seal wear and Achatter@ marks on the cylinder rod. Special attention is necessary for the proper design of seals, bushings and rod material. Ceramic coated rods, in accordance with UFGS 15010A, and high quality synthetic bushings and seals can provide an excellent solution to this problem.

2.4.2.3.3 Bellcrank. The bellcrank must be specified with proper dimensional tolerances to insure that it rotates in a very accurate vertical plane. The assembly should have shop testing after fabrication to insure that all shaft pin holes are parallel and all arms are straight within maximum standard tolerances. There should be mandatory survey requirements through its entire range of motion after installation. Past installations, with poor Quality Control, have caused accelerated wear of bushings, clevises and eyes, leading to premature failure of machinery. Another important consideration is the protection of the shaft pin/bushing lubrication lines against damage by debris or ice. Lubrication piping can be placed inside the bellcrank tube arms except at the pivot joints. Other forms of guards should be provided to protect the hoses used at pivot joints.

2.4.2.3.4 Valve Operating Strut. The valve operating strut generally contains a spring assembly to assist in positive closure against the culvert sill. Several types of springs have been used, including coil springs, ring springs and, Belleville washer type springs. Coil springs appear to give superior performance because of their minimum lubrication requirements. Coil springs should be designed to not fully compress during normal operation. Since the ring and Belleville types are enclosed in the strut tube, there is no easy way to verify grease effectiveness without actual disassembly of the strut. Therefore performance can only be measured by failure. A number of failures have been observed with the shattering of ring springs and Belleville springs in normal service. Detailed inspections show that the components have not received sufficient lubricant on the essential rubbing surfaces to perform adequately.

2.4.2.3.5 Support Base. The tainter valve machinery support base is designed to properly align the trunnion mounted hydraulic cylinder and the bellcrank pivot trunnion bearings. This is essential to ensuring that the cylinder, bellcrank and strut operate in an accurate vertical plane. It is essential that the support base be inspected after fabrication to establish the relative positions of the machinery mounts to ensure the accurate vertical plane. The support base must installed level in order to allow a properly constructed bellcrank and trunnion support assembly to move in an accurate vertical plane.

2.4.2.3.6 Bushings. The largest cause of problems with bearings is misalignment of the system. The root cause is addressed in the previous paragraphs. However, additional problems have been noted due to improper lubrication. Lubrication piping to bushings is frequently damaged by ice or debris. Greaseless bushing have been tested at some locations and are a satisfactory alternative to lubricated bushings. CERL Technical Report 99/104, Greaseless Bushings for Hydropower Applications: Program, Testing, and Results, provides comparative information about these type of bearings.

2.4.2.3.7 Directional Control Valve. There is no benefit to designing a single-acting hydraulic cylinder system which does not have a four-way directional control valve to direct positive pump delivery to the cap end side of the hydraulic cylinder. Systems, which are designed to allow the weight of the reverse tainter valve to lower the valve, do not take advantage of the speed and force controlling features of a Apower-down@ control system. Locks, which have situations where closing the tainter valves against flowing water have some benefits, will most certainly need double-acting control.

2.4.2.3.8 Pressure Relief Valves. Pressure relief valves should be designed for the maximum pressure range which will not cause damage to the system. The smallest commercially available range that will meet system requirements should be used, since this will yield the maximum setting sensitivity. A pressure relief valve should be provided to prevent excessive pressure upon closing the tainter valve against the sill plate in the culvert. A pressure relief valve should be provided to prevent excessive pressure upon opening the tainter valve to the full open position.

2.4.2.3.9 Counterbalance Valve. A remote pilot-operated counterbalance valve is required to hold the tainter valve open, at any position that it is stopped, until positive pump pressure is applied to move the tainter valve.

2.4.3 Controls. Appropriate control devices are detailed in Chapter 4.

2.4.4 Special Design Considerations. Special design considerations require coordination among the structural, mechanical and electrical designers to provide a proper operating system.

2.4.4.1 Tainter Valve. These considerations are pertinent to conventional tainter gate type valves.

2.4.4.1.1 Slack Cable Safety Devices. Slack cable safety devices are an essential safety feature for wire rope operated tainter valve machinery. The tainter valve could seize against the valve chamber walls, or above the culvert floor, on debris or zebra mussels. The slack cable safety device will shut down the motor before too much cable is unspooled. This will prevent safety problems involved with guiding the wire rope back onto the drum properly.

2.4.4.1.2 Positional Encoders. Positional encoders, connected to the machinery, are essential to the operation of the tainter valve machinery and lock electrical control system. Encoders are used to provide the elevation position of the bottom of the tainter valve, which can control the filling, emptying and miter gate operation interlocks. Encoders can be used to indicate speed, motion or actual angular position of various machinery components, which can be translated to tainter valve motion. For more detailed information see Chapter 4.

2.4.4.1.3 Tainter Valve Design. The structural engineer should be reminded that the operating machinery is not designed to force the gate leaf down. Since the gate leaf must lower due to its own weight, it is important that the structural designer compensate for any uplift hydraulic loads. EM 1110-2-1610 has an extensive discussion of these uplift tendencies with respect to valve design and head conditions.

2.4.4.1.4 Limit Switches. Limit switch locations must be coordinated with the structural designer to prevent overtravel in the valve opening position.

2.4.4.2 Reverse Tainter Valve. These considerations are pertinent to reverse tainter gate type valves.

2.4.4.2.1 Positional Encoders. Positional encoders, connected to the machinery, are essential to the operation of the tainter valve machinery and lock electrical control system. Encoders are used to provide the elevation position of the bottom of the tainter valve, which can control the filling, emptying and miter gate operation interlocks. Encoders can be used to indicate speed, motion or actual angular position of various machinery components, which can be translated to tainter valve motion. For more detailed information see Chapter 4.

2.4.4.2.2 Limit Switches. Magnetic-operated limit switches are generally provided, which actuate on the arc of the bellcrank movement. These switches, and their electrical appurtenances, should be fully submersible.

2.4.4.2.3 Lubrication System. Where grease lubricated bearings, or permanently lubricated bearings with grease supplementary provisions, are provide for bellcranks and strut connections, the supply lines should be mounted inside the structural tubes. Flexible hose connections may be required to connect piping across pivoting joints. All exposed piping and hose should be provided with rigid structural steel guards designed to provide maximum protection against waterborne debris and ice.

2.4.5 Other options. Butterfly valves, vertical sluice gates and roller gates have been used with various culvert schemes to fill and empty locks. A rotary culvert valve system (basically a tainter valve on its side, similar to a sector gate design) has been extensively evaluated for filling/emptying duty. One butterfly valve plan uses submersible hydraulic cylinder operators, at a location in the upstream sill, to fill the lock chamber. Another "thru-the-sill" filling/emptying system, under development for new lock construction, will use bonneted slide valves and dry operating galleries located in the upper miter sill and lower river wall. Model testing of this system, conducted by the Waterways Experiment Station (WES), was successful. Thru-the-sill systems are desirable for new projects because they allow the use of more cost effective lock wall construction methods.