Appendix H
In-Chamber Longitudinal Culvert System Design

H-1. Description

An In-chamber Longitudinal Culvert System (ILCS) for lock filling and emptying was developed to reduce construction costs associated with large concrete gravity walls. The longitudinal culverts are located within the chamber with the ILCS design allowing less costly, thin structural type lock walls. Conventional intake and outlet designs can be used with the ILCS as well as designs with intakes and outlets at the miter sills. The design philosophy for the ILCS was to develop a system that performed almost as efficiently as the side-port system. Some sacrifice in hydraulic performance is expected due to the flow entering the culverts from the upstream end and the short port lengths. The designs of the culverts and ports within the chamber are provided in this appendix.

H-2. Culvert

The culvert size is estimated based on the lock filling or emptying time requirements. Knowing this operation time, Equation 5-5 can be rearranged to compute the culvert size necessary to provide this operation time. Section 5-12 provides estimates for the valve coefficient. The overall lock coefficient, C_L, for filling with the ILCS determined from model studies is 0.64 and for emptying is 0.57. A good estimate for the over travel, d_f , is 1 ft. Two culvert longitudinal systems are the preferred design and most of the research summarized in this appendix was conducted for this configuration. The longitudinal center line of each culvert in a two-culvert system should be located on the lock chamber cross section quarter point as shown in Figure H-1. This location is more practical for construction and the hydraulic performance is not significantly affected. This may not be the optimum location for spreading of the jet discharging from the ports during filling. However, since these jets are not large and the opposing culvert walls inside the chamber help deflect and dissipate the energy of these jets, excessive turbulence (water surface roughness) in the chamber does not occur.

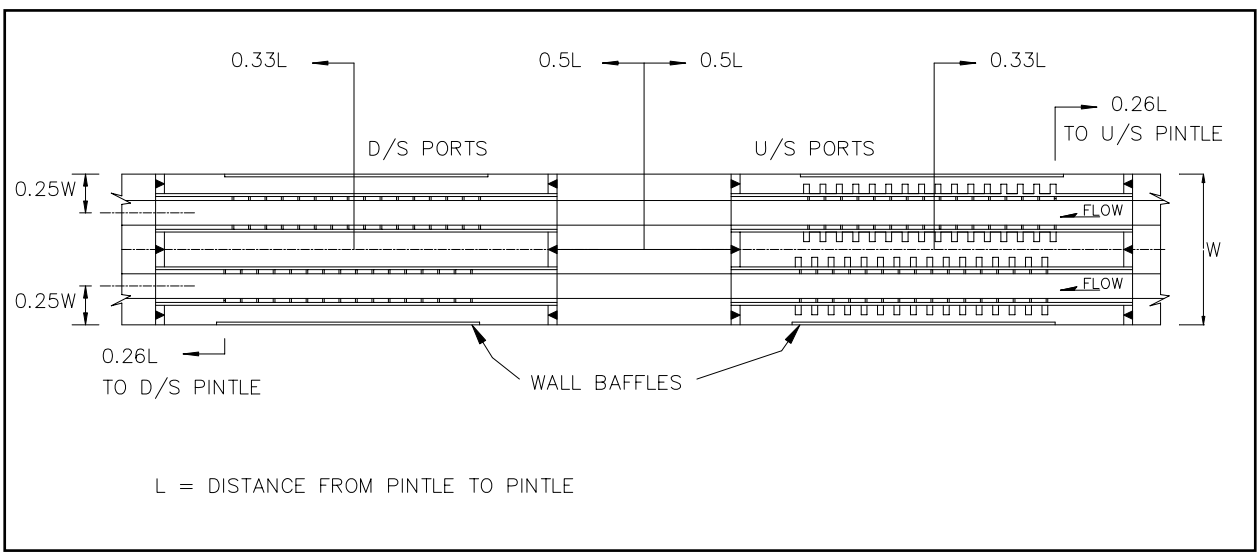

Figure H-1. Recommended port location

H-3. Port Size

The port size was developed based on the smallest practical sizes currently in use for Corps projects with bottom lateral systems and the size needed for a person to enter the culvert for inspection and maintenance (item 92). A large port was not desired due to the difficulty of achieving adequate energy dissipation during filling. The individual port cross-sectional area, A_{pi}, for these laterals in the bottom longitudinal systems generally varied from 3.78 to 4.84 ft^2. A practical port size was found to be 4.375 ft^2, 1.25 ft wide by 3.50 ft high. This port size performed well for both McAlpine lock models, the Marmet lock model, and the ILCS research model. The lock width proposed for the McAlpine and Marmet projects are 110 ft.

H-4. Number of Ports

The number of ports recommended for the two culvert ILCS system depends on the culvert area. Similar to the side-port design, the sum of the port areas in the culvert, sum of A_{pi}, should be equal to or slightly less than the area of the culvert, A_c. The preferred ratio of port area to culvert area for the ILCS is between 0.95 and 0.97. This provides flow control at the ports for normal valve operations (excluding long valve times) and helps reduce flow instabilities.

H-5. Port Location

Similar to the 1,200-ft-long side-port lock, the ports were located so that at least 50 percent of the chamber was covered. Hawser forces for tows less than full size that moor in the ends of the chamber are less with the ports located in this manner. The recommended port location places the upstream port grouping at a distance equivalent to 0.26 the pintle-to-pintle length of the chamber from the upstream pintle as shown in Figure H-1. The downstream port in the downstream port grouping should also be located between 0.26 and 0.27 the pintle-to-pintle length of the chamber from the downstream pintle. The center of the port grouping should be located at nearly the one-third points of the chamber. It is important that the distance from the upstream port to the downstream port be approximately 50 percent of the chamber length to avoid large hawsers for a tow that does not occupy the entire chamber. A schematic showing a plan view of the port location is shown in Figure H-1. Ports on the inside wall of one culvert should be staggered with respect to the ports on the inside wall of the other culvert. The ports on the outside wall of the culvert should be located at the same longitudinal station as the inside ports. The location of the port groupings in the chamber will affect the port spacing as discussed below. For foundations where the culverts are excavated, it may be less expensive to locate the ports at the top of the culvert, which allows the lock floor to be at the port invert.

H-6. Port Spacing

The ports should be spread over at least 50 percent of the lock chamber length and maintain as even a distribution of port flow along the culvert as possible. Port spacing along with port size determine the flow distribution and turbulence intensity within the chamber. The ports in opposite culverts should be staggered; therefore, the jet impact distance for the inner ports is the distance between the culverts. The jet impact distance for the outer ports is the distance from the culvert to the lock wall.

Ideally, port spacing is such that jet interaction between opposite manifolds would not produce bulking of the water surface and the energy dissipation would take place uniformly throughout the chamber. The recommended spacing for the side-port system with the 110-ft-wide chamber is 28 ft from center to center. This distance was based on the expansion of jets issuing from individual ports. At this spacing, the jets discharging into the chamber during filling did not interact to cause boils near the center of the lock. Using the ratio 28/110 from the side-port system, the port spacing for ILCS can be checked from

$$\frac{S}{L_w} = \frac{28}{110} \tag{H-1}$$

where S = port spacing for the ILCS and L_w = distance between inner walls of the culverts. This distance is considered the minimum spacing, and the actual spacing determined from the port location guidelines suggested previously will usually be larger.

H-7. Port Extensions

The ILCS design includes port extensions on the upstream port to direct the jet flow normal to the lock center line. This helps distribute the flow more evenly in the upper end of the chamber and provides a more balanced flow over the entire length of the chamber during filling. Inertia effects during filling cause flow to enter the chamber initially through the most upstream ports. This flow enters the chamber primarily in the downstream direction rather than entering normal to the lock center line. The port throat lengths for the ILCS depend on the culvert wall thickness, and therefore the port throat length is rather short. The culvert wall thickness for an ILCS will probably be from 2 to 3 ft, and this port thickness will cause the jet to have a larger downstream component than desired when discharging from the port during filling. Port extensions on the upper ports direct the flow toward the center of the chamber and normal to the lock walls. The port extensions effectively increase the port throat length. A port extension length equal to 0.5 times the culvert width (C_w) is recommended. An 8-ft port thickness is recommended for the side-port system. A sectional view of the port extension recommended for the upper ports is shown in Figure H-2.

H-8. Roof Overhang

A roof overhang on top of the culvert of at least 2.00 ft is recommended for ports located at the top of the culverts. This length is included in the port extension length for those requiring extensions. The jets discharging from ports located at the top of the culvert sides have a vertical component. The roof overhang helps redirect this jet horizontally. A sectional view of the roof overhang is shown in Figure H-2.

H-9. Wall Baffles

A wall baffle is recommended for the ILCS to help diffuse the port jets near the lock floor and reduce upwelling along the lock walls. The baffle is simply a horizontal shelf that cantilevers from the lock walls along the port areas as shown in Figure H-2. A 2.0- to 3.0-ft-wide baffle is recommended and should be placed at the same elevation as the top of the longitudinal culvert. Vertical baffles underneath the wall baffles are also recommended to aid in the energy dissipation and are beneficial in the structural support of the wall baffle. The vertical baffles should be located along the lock walls halfway between the ports and at a distance of one-half the port spacing upstream and downstream from the first and last ports, respectively.

H-10. Valve Operations

Acceptable filling times and chamber performance for the ILCS have been achieved with normal valve speeds ranging from 4 to 8 min. The performance of the ILCS is sensitive to valve operation, and valve speeds faster than 4 min are not desirable especially for lifts over 15 ft. Fast valve operations cause excessive downstream hawser forces shortly after the valve is opened. This high downstream hawser force is caused by the water surface in the upper end of the lock being higher than that in the lower end. This is inherent in a longitudinal culvert system where flow enters at the upstream end of the chamber.

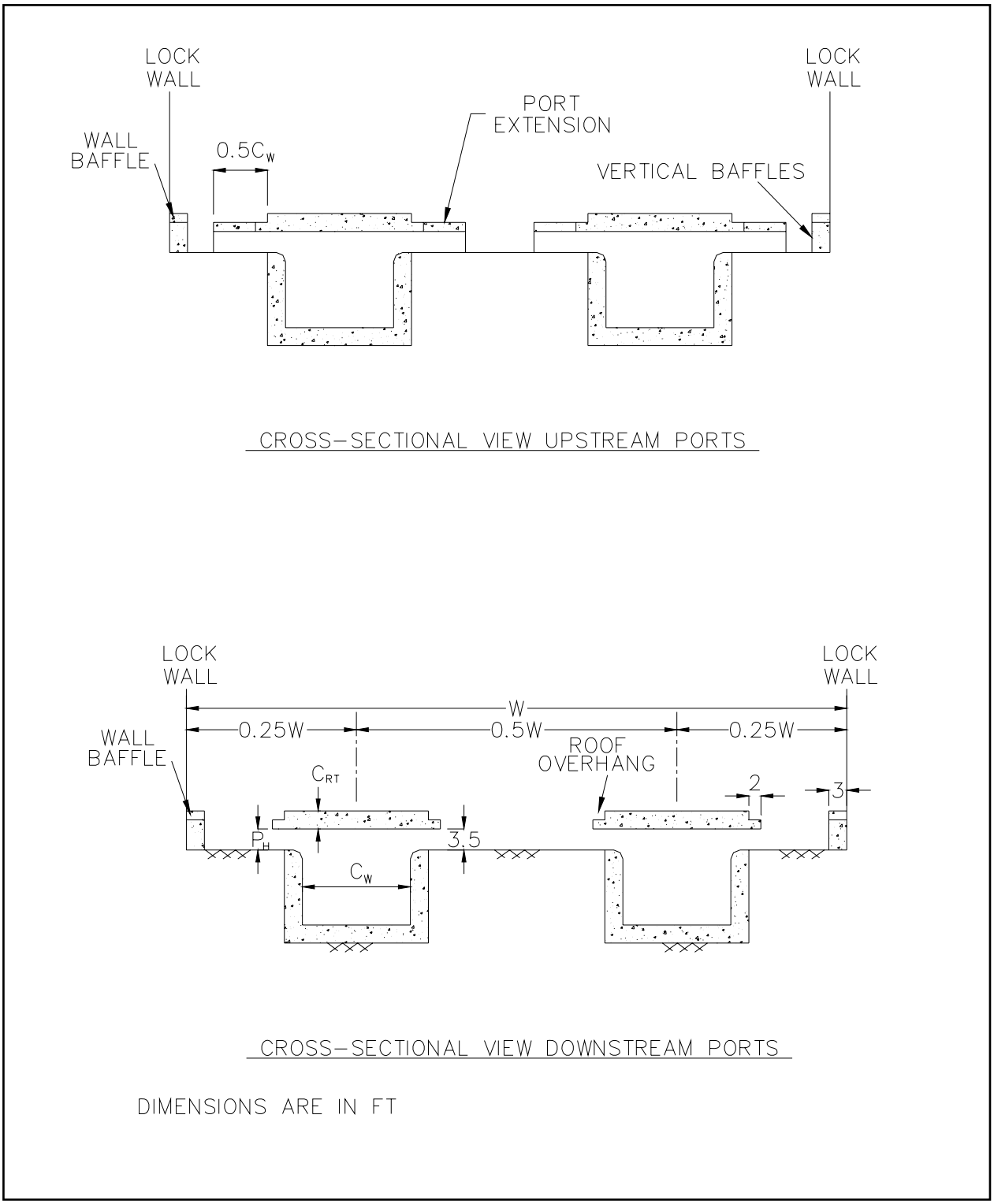

Figure H-2. Cross-sectional view of ILCS ports

Model experiments have been performed with three types of valves—butterfly, vertical lift, and reverse tainter valves—and satisfactory chamber performance was achieved for all three types. Each of these valves has slightly different operating characteristics. Valve selection will probably depend on project requirements and economics. Variable speed valve operations performed with the reverse tainter valves were found to reduce permissible filling times slightly from normal type valve operations. A slower valve speed during the initial lock filling reduces the hawser forces; and once a cushion of water is in the chamber, the valve speed can be increased. This type of operation is not recommended for higher lift projects where cavitation might occur.

H-11. Lock Filling

Acceptable filling performance based on the hawser force criteria was measured for lifts between 10.0 and 40 ft and submergence conditions between 19.0 and 29 ft for different normal valve schedules in model studies. The submergence for the ILCS is the depth from the water surface to the top of the port. The filling time (and associated normal valve time) that resulted in an average maximum hawser force of 5 tons or less for the lift and submergence condition evaluated was considered the permissible filling time. Figure H-3 provides the permissible filling times based on the 5-ton hawser force criteria. This filling time represents the fastest allowable filling time to maintain hawser forces of 5 tons or less for the lift and submergence conditions evaluated with normal valve operations. For example, for a project being designed for a 20.0-ft lift with a 24.0-ft submergence, the fastest acceptable filling time is 8.1 min. Single valve operations with a two-culvert system require much slower times to prevent high transverse hawser forces.

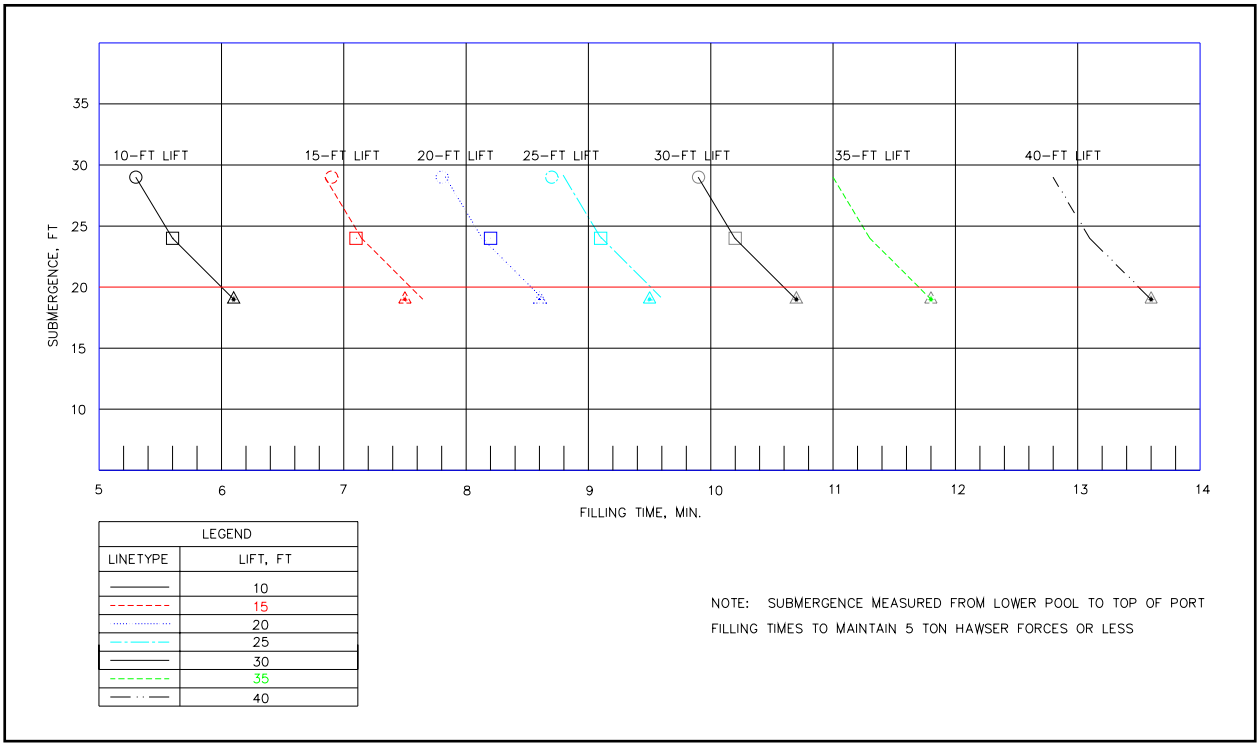

Figure H-3. Permissible filling times determined from ILCS models

H-12. Lock Emptying

Acceptable emptying performance was determined from model studies in a similar manner to that for filling. The average maximum emptying times for lifts between 10.0 and 40 ft with submergences of 19.0, 24.0 and 29.0 ft were determined. The acceptable emptying times were based on the longitudinal hawser forces, and the transverse hawser forces for all conditions observed were much less than 5.0 tons. This guidance developed for emptying is shown in Figure H-4. For a 20.0-ft lift and 24.0-ft submergence, the fastest emptying time to maintain hawser forces of 5.0 tons or less was determined to be 8.7 min.

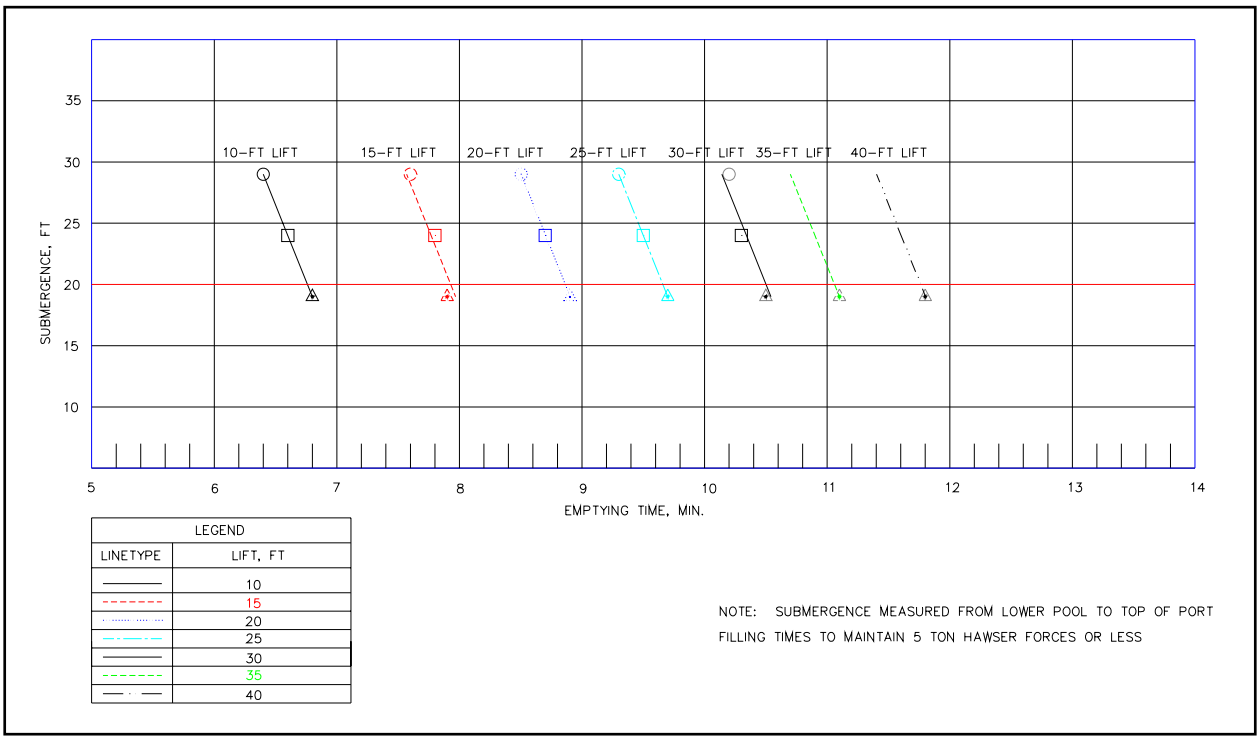

Figure H-4. Permissible emptying times determined from ILCS models

H-13. Design Example

a. Filling and emptying times are established from an economic analysis of the navigation project. Once these times are known, the culvert sizes can be determined. The system lock coefficient is used to determine the culvert size required to meet the target operation times. The port size, location, and spacing should be determined next. If unusual structural components, valving, or culvert geometry is required, a laboratory model is generally recommended to determine the chamber performance and verify the final design. The following example problem is provided to illustrate the steps above.

b. The first equation in Appendix D, section D-17, can be used to determine the culvert area. In this example, the lock dimensions are pintle-to-pintle length 1,270 ft and lock width 110.08 ft, and the project has a design lift of 15 ft. The target filling time determined from an economic analysis of 9 min and a 4-min valve operation is chosen for design purposes. Research results found that a lock coefficient of 0.64 is reasonable for the ILCS and a value of 0.5 was chosen as the valve constant, *K*. Assuming an overtravel, d_f, of 1.0 ft, the culvert area is 194 ft^2. A square culvert 14.0 ft wide by 14.0 ft in height and a port size of 4.375 ft^2 are selected. If each culvert contains 44 ports, then the ratio of the sum of the port areas to the sum of the culvert area is 0.98. Each culvert will have 44 ports, 22 in each half of the chamber

with 11 on each side of the culvert. The longitudinal stations for the one-third points are designated as sta 4+23.33 (upstream) and sta 8+46.67 (downstream). The upper pintle is designated sta 0+00. The center-line station for the middle port in the upper port group is sta 4+23.33. Based on the guidance given in Figure H-1, the center-line station for the most upstream port should be (1,270 ft × 0.26 ft) = sta 3+30.2. Therefore, the port spacing should be ((423.33 – 330.2)/5) = 18.63 ft from center to center. Port spacing from Equation H-1 gives 10.44 ft, so 18.63-ft spacing is ok. The port layout for this design example is shown in Figure H-5.

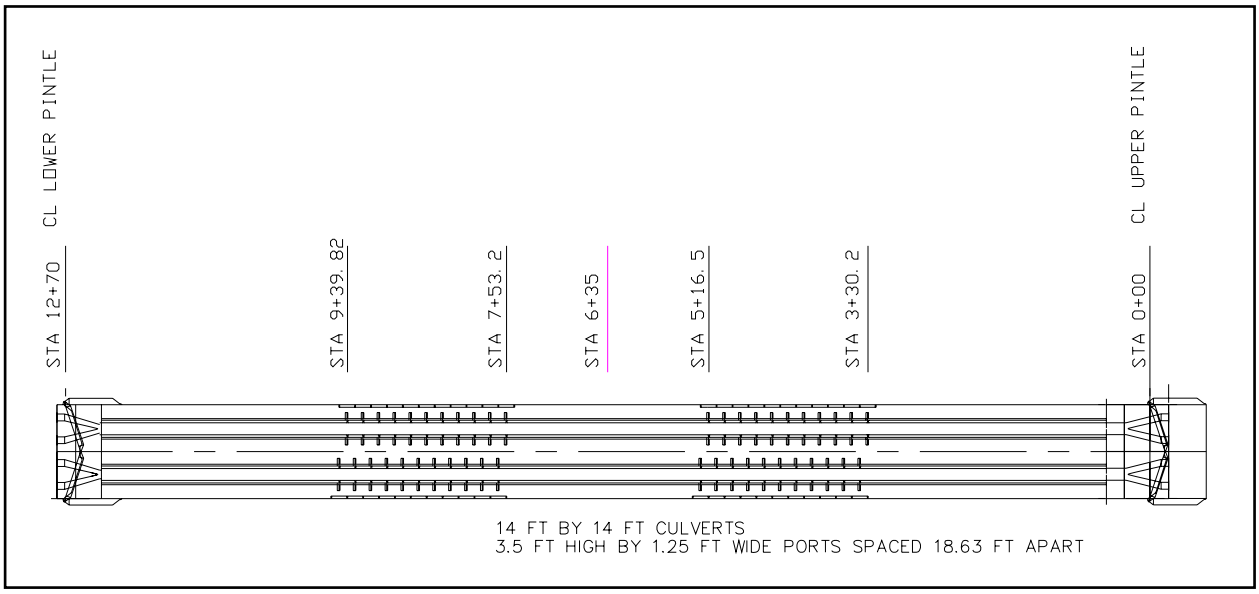

Figure H-5. Example ILCS lock design for 15-ft lift with 9-min filling time

H-14. Discussion

The ILCS is a feasible design from a hydraulic performance point of view and should be adaptable to innovative float-in and in-the-wet construction techniques. The system is not quite as efficient as the side-port filling and emptying system; however, the reduction in construction costs might make the system favorable over the project life. The system requires slightly deeper excavation where the culverts are located in the chamber and is probably better suited for rock foundations. Geotechnical evaluation is important to determine uplift pressures on the culverts for the various site conditions. A two-culvert system is preferable, and the center of the culverts should be on the widthwise quarter points. Valve operating characteristics are important to the chamber performance. Acceptable chamber performance should be achieved with normal valve operations between 4 and 8 min.