Appendix D
Design of Side-port Systems

D-1. Description

A typical sidewall port filling-and-emptying system has a longitudinal culvert in each lock wall extending from the upper pool to the lower pool, with a streamlined intake at the upstream end and a diffusion device at the downstream end. Flow is distributed into and out of the lock chamber by short ports between the longitudinal culverts and the sides of the lock chamber. Two valves are required in each longitudinal culvert, one between the intake and the manifold of lock chamber ports to fill the lock and the other between the manifold of lock chamber ports and the discharge diffuser to release flow in the emptying operation. This discussion is concerned with design of that portion of the system between the filling and emptying valves.

D-2. Port Size

From data collected in model tests of an 84-ft-wide lock, three 110-ft-wide locks, and a 150-ft-wide lock, the desirable cross-sectional area for a port is plotted against lock width in Figure D-1. Studies have shown that the extent of the primary zone of diffusion of a submerged jet is a function of jet size and thus the optimum size port is dependent only on lock chamber width. Certainly the degree of surface turbulence in the lock chamber increases as the lift increases and/or as the submergence (difference in elevation between initial lower pool and the lock chamber floor) decreases, but distribution of turbulence across the chamber is independent of lift and submergence. For the 655-ft-long by 84-ft-wide Jonesville Lock, a 6.0-square-foot (sq-ft) port resulted in good distribution of turbulence and ports of other sizes were not tested. In the model study of the 670-ft-long by 110-ft-wide Arkansas River low-lift locks, ports with cross-sectional areas of 6.0, 8.9, 10.4, and 12.7 sq ft were tested. The 6.0-sq-ft ports definitely were too small as the jets from the ports were diffused prior to reaching the opposite side of the lock chamber. This resulted in boils with excess turbulence along the center of the lock chamber and caused large hawser forces on a moored tow. Conditions produced by the 8.9- and 10.4-sq-ft ports were rated as satisfactory. With the 12.7-sq-ft ports longer filling times were required for acceptable hawser forces than with either the 8.9- or 10.4-sq-ft ports. Also turbulence was considered excessive and it was concluded that this port was too large. In model tests for the

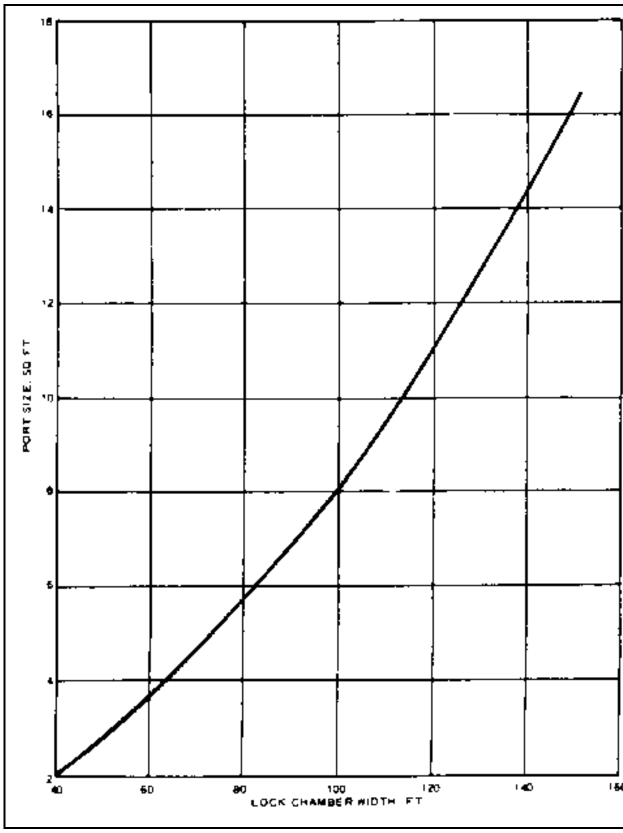

Figure D-1. Recommended port size

1,270-ft-long by 110-ft-wide Cannelton Lock, ports 8.4 and 11.2 sq ft in cross-sectional area were observed. For equal filling times more favorable hawser forces resulted with the 11.2-sq-ft ports. Upon completion of the tests for the Cannelton Lock and the Arkansas River low-lift locks, engineers involved in both studies agreed that the 8.9- and 10.4-sq-ft ports tested in the Arkansas model resulted in more favorable turbulence conditions across the lock chamber than did the 11.2-sq-ft port tested for Cannelton Lock. These engineers are of the opinion that a slightly better design for the filling system for Cannelton Lock could have been developed if a port 9.0 to 10.0 sq ft in cross-sectional area had been used. For the 1,265-ft-long by 110-ft-wide New Cumberland Lock, a port 9.5 sq ft in cross-sectional area was selected. In the model of the 1,290-ft-long by 150-ft-wide Mississippi River-Gulf Outlet Ship Lock, a port 16.2 sq ft in cross-sectional area results in good distribution of turbulence across the lock chamber. Ports of other sizes have not been tested. Obviously a variation in port size of about 5 percent to either side of that recommended is acceptable.

D-3. Port Spacing

a. Ports in one wall should be staggered with respect to the ports in the other wall so that the jets issuing from one culvert will pass between jets from the other culvert. If ports are spaced too close together, the jets from the opposite walls will meet; and boils will form near the center of the lock, resulting in large hawser forces. If spacing between the ports is too great, the port jets will tend to stray, resulting in some areas of essentially no turbulence and other areas of excess turbulence.

b. Again the areas of excess turbulence will cause large hawser forces. Recommended spacing for the ports in a lock wall is given in Figure D-2. In a 110-ft-wide lock, a spacing of 28 ft center to center for the ports in each wall has been found to be optimum in several model studies. For locks of other widths there are few significant data. In an 84-ft-wide lock, spacings of 22 and 20 ft were tested, and the 20-ft spacing was preferred although a 21.5-ft spacing is indicated in Figure D-2. In a 150-ft-wide lock, only a spacing of 38 ft has been observed and this appears to give satisfactory conditions. Certainly spacing is not so critical that variation of 1 ft on either side of that recommended would result in a noticeable change in conditions.

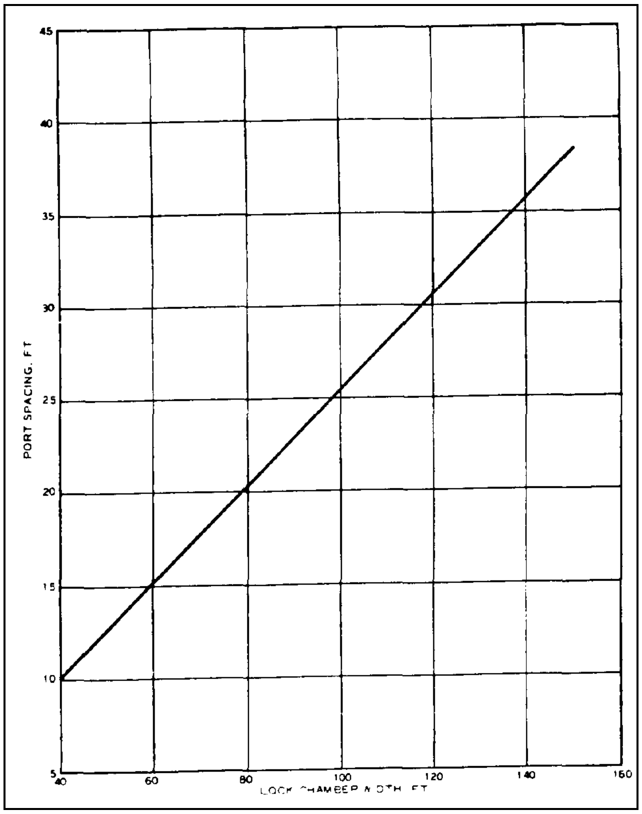

Figure D-2. Recommended port spacing

D-4. Number of Ports

Following selection of port size and spacing, the next consideration is the number of ports that is feasible for the particular lock. In this connection the port group must be centered with respect to the length of the lock chamber, and it must extend over at least 50 percent of the lock chamber length. If the port group does not extend over at least 50 percent of the chamber length, hawser forces on a tow in either the upstream or downstream half of the lock chamber will be greater than those on a tow that occupies the entire lock chamber. The greater the extent of the port group the better, but usually structural considerations will limit the port group to about 60 percent of the lock chamber length.

D-5. Culvert Size

After the number of ports that can be accommodated is fixed, then the desirable size for the culverts in the lock walls can be determined. In each culvert the ratio of the total cross-sectional area of the ports to the cross-sectional area of culvert should be about 0.95. If the cross-sectional area of the ports is as large as or larger than the cross-sectional area of the culvert, poor distribution of flow from the port manifold will result to the extent that during peak discharge of a filling operation, flow is likely to be drawn from the lock chamber by the upstream ports. On the other hand if the port-to-culvert area ratio is too small filling time will be sacrificed without a noticeable improvement in conditions in the lock chamber.

D-6. Culvert Shape

A culvert square in cross section allows for easy forming of the culvert and port and results in good hydraulic efficiency. However, forming advantages can be maintained with a rectangular cross section and as long as the minimum dimension is at least two thirds of the maximum dimension there will be very little loss in hydraulic efficiency. Frequently wall stability and valve design are simplified by making the height of the culvert greater than the width.

D-7. Port Shape

There is an advantage in a rectangular port with the width equal to about two thirds of the height. With a narrow port there is less downstream component in the jet issuing from the port due to the velocity of the flow passing the port in the wall culvert. On the other hand, turbulence in the lock chamber is better distributed with a square port rather than with a long, narrow port. Long, narrow ports result in unstable jets with severe concentrations of turbulence. A port in which the width is about two thirds of the height is as narrow as is feasible without the risk of unstable jets. Also it has been found to be beneficial to flare the sides of the port by as much as, but never more than, 3 degrees. The length of a port should never be less than three times its width and a length of about four times the width is desirable. A port suitable for a 110-ft-wide lock is shown in Figure D-3.

D-8. Port Deflectors

Even with properly designed ports there is likely to be a downstream component in the jets issuing from the upstream ports in the manifold where velocity of flow past the ports is quite high. Triangular deflectors that tend to counteract this downstream component are beneficial at the upstream one-third of the ports in the manifold. These deflectors reduce the peak upstream hawser force and allow about a 5 percent decrease in permissible filling time. (Permissible filling or emptying time is the time required to fill or empty the lock without causing hawser forces on a rigidly moored tow in a model to exceed the equivalent of 5 tons prototype.) Unfortunately, general rules for design of deflectors for various size ports have not been developed. Satisfactory conditions in a 110-ft-wide lock were obtained with a deflector as shown in Figure D-4. This deflector can be formed by a wall on the lock floor or by a recess in the lock floor. If a recess-type deflector is used, then recesses probably will be desirable at all ports. In this case triangular recesses are suggested for the half of the ports in the upstream end of the lock chamber and rectangular recesses for the ports in the downstream end of the chamber.

D-9. Angled Ports

There are data from tests in which ports were angled upstream in attempts to gain the same benefits as those gained with deflectors. In all cases conditions resulting with angled ports were not as favorable as those obtained with deflectors.

D-10. Required Submergence

Submergence is defined in paragraph D-2 as the difference in elevation between the lower pool and the lock chamber floor. The greater the submergence the faster is the permissible filling time. However, in many cases each foot of submergence provided is quite costly and the designer needs to know the minimum submergence at which satisfactory operation can be expected. Data from various width locks indicate that the jets from the ports expand in an upward direction at the same rate as they expand horizontally. Thus a clear space between the bottom of the vessel using the lock and the floor of the lock chamber equal to one-half of the port spacing is required to prevent direct action of the port jets against the bottom of the vessel. In a 110-ft-wide lock designed for tows of 9-ft draft, a submergence of 23 ft should be provided (9 ft, draft of tow, plus 14 ft clear under tow, one-half of 28-ft port spacing). If a greater submergence than that suggested is provided, then permissible filling times will be shorter; but an increase in clear space under the tow of 100 percent will allow a decrease in permissible filling time of only 10 percent. On the other hand, a decrease in the suggested clear space under the tow of only 20 percent will require a 20 percent increase in permissible filling time.

D-11. Ports Above Chamber Floor

It may be structurally desirable to have the ports enter the lock chamber at an elevation higher than the lock chamber floor. If this is the case then the ports should be angled down so that the jets are directed at the base of the opposite chamber wall such as was done at the Eisenhower and Snell Locks. Of course the ports never should enter the chamber at an elevation that will result in jets impacting directly on a vessel using the lock.

D-12. Valve Position

During opening of the filling valves there are depressions in the pressure gradients in the culverts that extend from each valve to a section about 6.5 times the culvert height downstream from the valve. Thus it would be expected that there would be a deficiency in flow from ports placed in this zone. However it is during the valve opening period that the discharge from the upstream ports is likely to be in excess of that desired. In a series of tests for Newburgh Lock it was found that, “with the port manifold placed in positions that resulted in the first two and the first four ports being within the low pressure zone downstream from the valve no differences in filling time or hawser forces could be detected from those obtained with the manifold placed so that all ports were outside of the low pressure zone.”

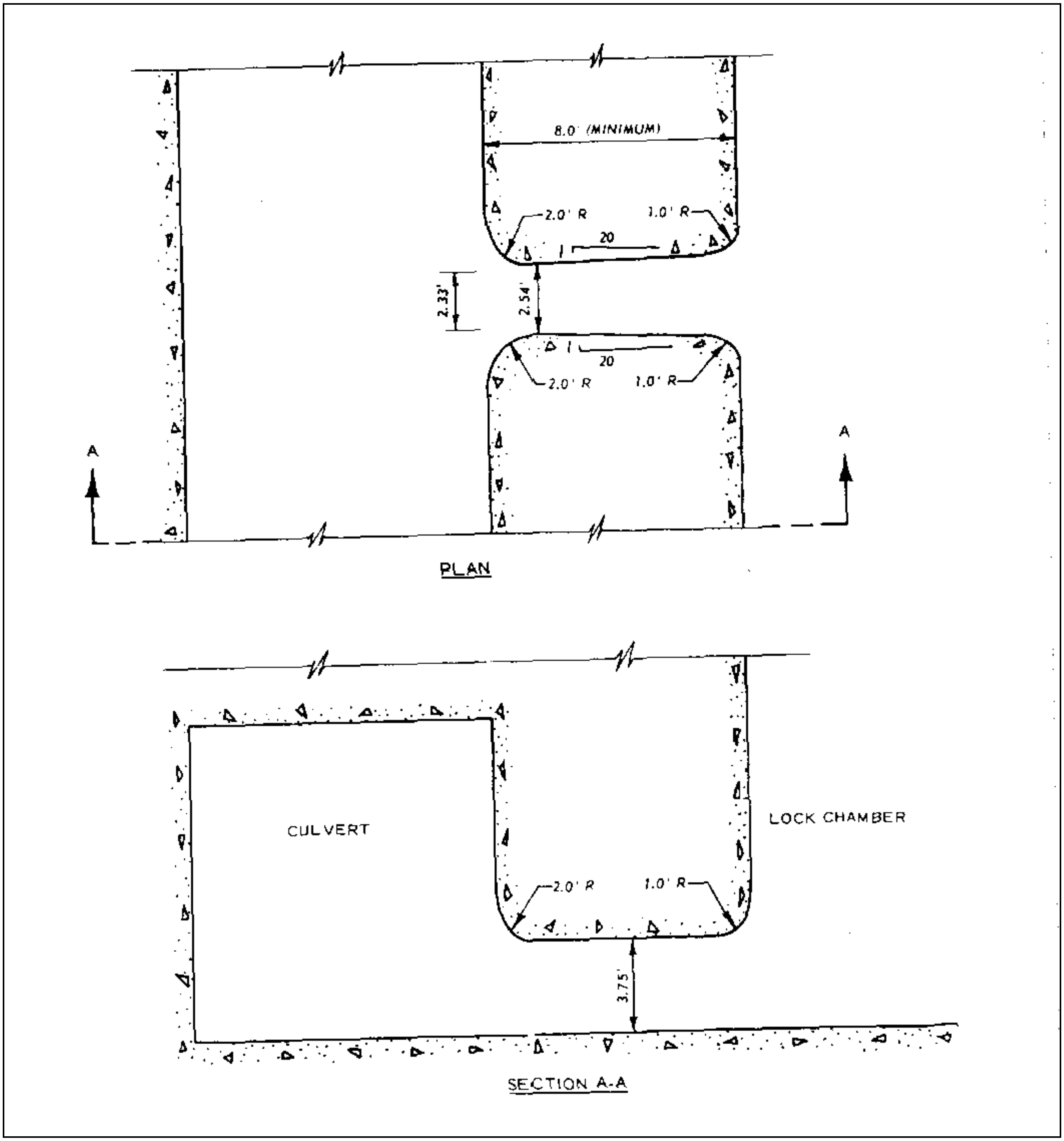

Figure D-3. Port for 110-ft-wide lock

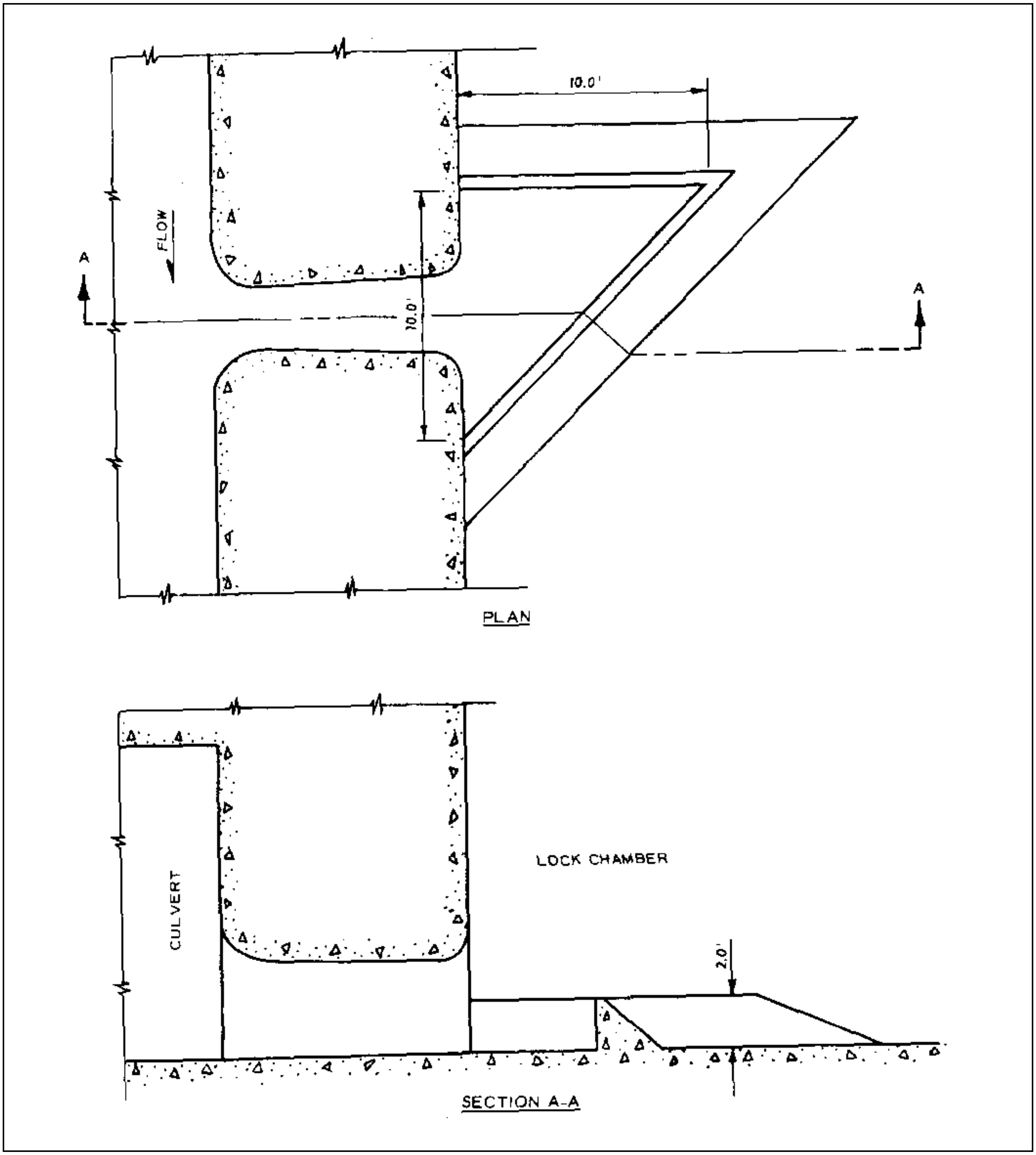

Figure D-4. Port deflector for 110-ft-wide lock

D-13. Culvert Transitions

If there are transitions in the culverts downstream from the filling valves or upstream from the emptying valves, all ports should be outside of the transition zones as pressures in these zones will be modified even after the valves are fully open. Expansions downstream from the filling valves and contractions upstream from the emptying valves can be used to provide the optimum size culvert through the reach of the port manifold with smaller and thus less costly valves and bulkheads. Of course this will result in greater losses through the contracted reaches of the culvert and somewhat longer filling and emptying times.

D-14. Suggested Designs

a. A good design for a 670- by 110-ft lock would have 15 ports, as shown in Figure D-3, from each of two 150-sq-ft culverts (minimum dimension at least two-thirds of maximum dimension) and deflectors as shown in Figure D-4 on the five upstream ports in each culvert. If designed for tows of 9-ft draft, minimum lower pool would be 23 ft above the lock chamber floor.

b. Similarly a 1,270- by 110-ft lock would have 28 ports, as shown in Figure D-3, from each of two 280-sq-ft culverts, with deflectors as shown in Figure D-4 on the nine upstream ports in each culvert. Again for tows of 9-ft draft, minimum lower pool would be 23 ft above the lock chamber floor.

c. A 655- by 84-ft lock would require 18 ports, each with a throat area of 6 sq ft, from each of two 115-sq-ft culverts. Deflectors similar to that shown in Figure D-4 would be installed on the six upstream ports in each culvert. If designed for tows of 9-ft draft, minimum lower pool would be 19.5 ft above the lock chamber floor.

D-15. Valve Times, Filling

a. In Figure D-5 are plotted permissible filling times (hawser forces not in excess of the prototype equivalent of 5 tons in 1:25-scale models) for the designs described in paragraph D-14. In Figure D-6 are plotted the valve times required in the models for the permissible filling times shown in Figure D-5. Also in Figure D-6 are recommended valve times for use in prototype operation. Note that these valve times are essentially the same as were required in the models. It has been established from experience that a prototype lock will fill about 9 percent faster than will its 1:25-scale model but that conditions in the prototype will be satisfactory if the valves are operated at a rate no faster than was required to limit hawser forces to 5 tons in the model. Thus filling times in the prototype will be about 9 percent faster than those shown in Figure D-5.

b. Valve times required in the model for the 84-ft by 655-ft lock are not shown in Figure D-6 because the culverts used in the tests for the Jonesville Lock were 15 percent smaller than are considered optimum. Actually with the smaller culverts a valve time of about 2 min was satisfactory for all lifts, but with optimum size culverts the valve times recommended in Figure D-6 are considered more appropriate. These valve times were interpolated on the basis of the lock chamber length-to-width ratio. The greater the length-to-width ratio of the lock chamber the greater are the permissible filling times and valve times. For other length-to-width ratios valve times should be interpolated from those shown.

D-16. Valve Times, Emptying

For emptying, allowable valve times vary with the length-to-width ratio of the lock chamber, as in filling; but unlike in filling, allowable valve times are relatively independent of lift. In a 670- by 110-ft lock a valve time of 2 min is satisfactory for all lifts. A 1,270- by 110-ft lock requires a 4-min valve time for all lifts.

D-17. Filling and Emptying Computations

a. The usual formula for computing lock filling and emptying times is

$$T - Kt_v = \frac{2\,A_L\left(\sqrt{H + d_f} - \sqrt{d_f}\right)}{2C_L\,A_c\,\sqrt{2g}}$$

where

T = filling or emptying time, sec

K = a constant (value depends upon the valve opening pattern, usually about 0.50)

t_v = valve opening time, sec

A_L = area of lock chamber, sq ft

H = lift, ft

d_f, d_e = overfill or overempty, ft

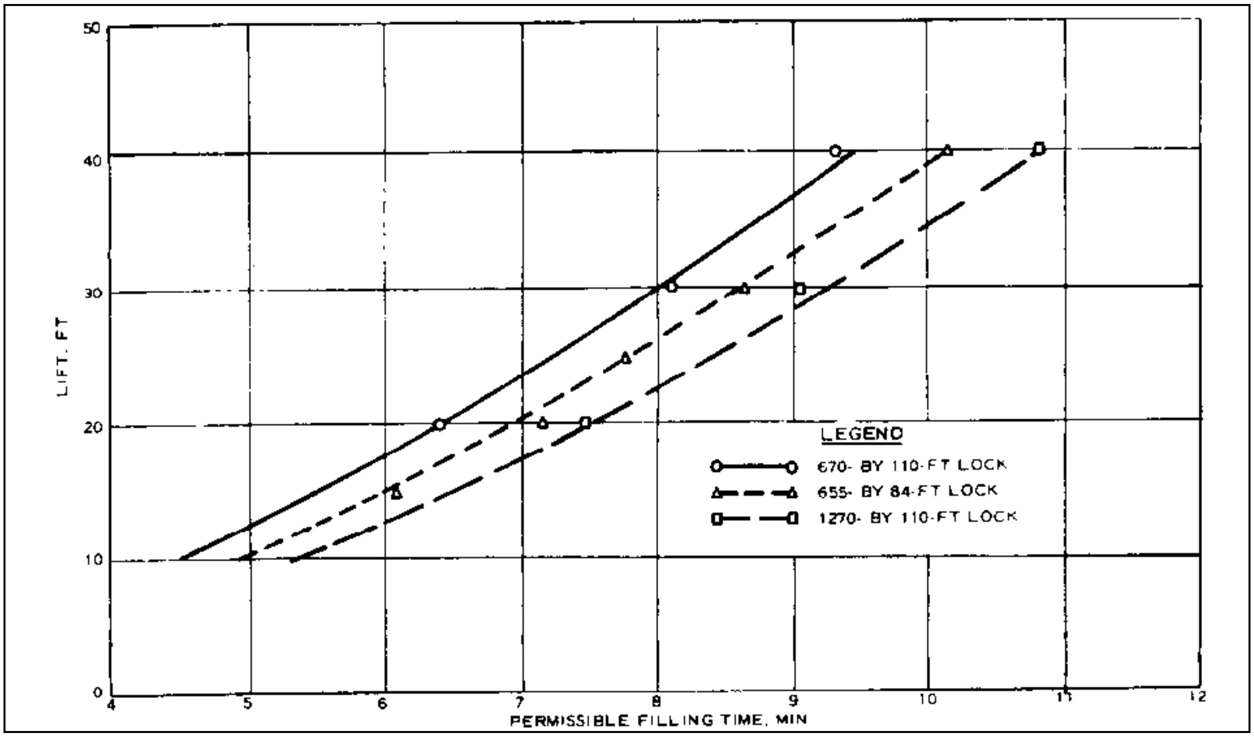

Figure D-5. Permissible filling times--models

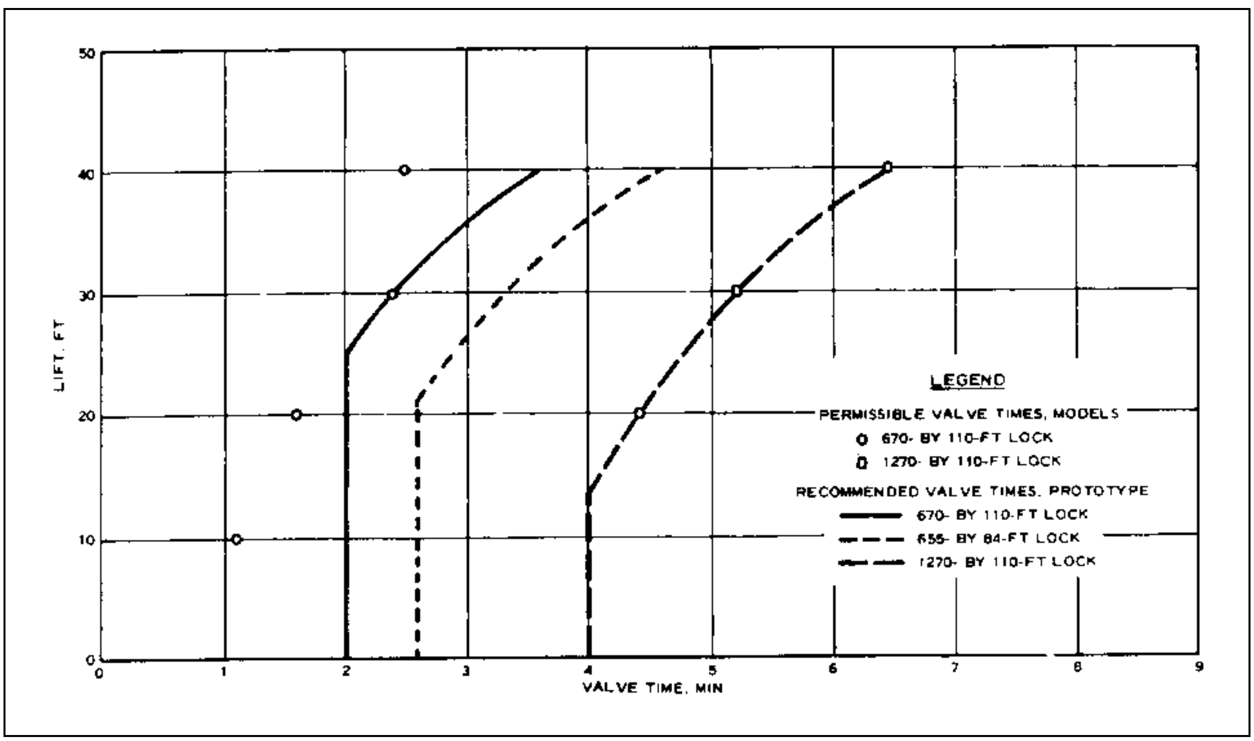

Figure D-6. Valve times--filling

C_L = a coefficient (value depends upon losses in system)

A_c = cross-sectional area of culvert, sq ft

g = acceleration of gravity, ft per sec^2

b. For the systems described in paragraph D-14 with intake and outlet structures essentially as shown in Plate 3-3, values for d and C_L are listed in Table D-1.

Table D-1
Lock Coefficients

Value	Fill	Empty
d_f, d_e, ft	1.00	0.90
C_L	0.80	0.72

These values of C_L are 9 percent greater than those determined in 1:25-scale models.

c. The total head loss through a filling-and-emptying system (H) is related to C_L thus:

$$H = \frac{1}{(C_L)^2} \times v^2/2g \qquad \text{(D-1)}$$

where

v = velocity in wall culverts through the full open valve, ft per sec

For the systems described in paragraph D-14, the total head loss is distributed as listed in Table D-2.

Table D-2
Distribution of Total Head Loss

Location	Total Head Loss, $v^2/2g$
Filling	
Upper pool to valve	0.45
Through open valve	0.10
Valve to lock chamber	1.05
Emptying	
Lock chamber to valve	0.93
Through open valve	0.10
Valve to lower pool	0.90

D-18. Discussion

a. The sidewall port filling-and-emptying system is an excellent system for low-lift locks. Although data are given herein for lifts as great as 40 ft, general use of the system for lifts of more than about 30 ft is not recommended. Improper operation or malfunction of the valves will create conditions that are undesirable at low lifts but become dangerous at lifts of more than about 30 ft.

b. Compared with the bottom longitudinal filling-and-emptying system, which is used for high-lift locks, the sidewall port system has favorable discharge coefficients. However when valve times of 4 min or slower are required for satisfactory operation of the sidewall port system, port system advantages of the more favorable discharge coefficients disappear as the bottom longitudinal system is relatively insensitive to valve speed and a fast valve time can be used at all lifts. Further, permissible filling-and-emptying times can be decreased by enlargement of the culverts in the bottom longitudinal system; this is not the case in the sidewall port system.