Chapter 5
Special Hydraulic Study Topics

Section I
Introduction

5-1. Baseline Analysis

The hydraulic analyses of lock filling and lock emptying require an unsteady flow formulation that includes the decreasing head caused by the rise or fall of the chamber water surface. The objective is to determine, as a function of time, three basic quantities:

a. Chamber water-surface elevation.

b. Flow rate exiting (filling) or entering (emptying) each of the chamber manifolds.

c. Hydraulic grade line from the reservoir intakes to the lock chamber (filling) or from the lock chamber to the outlets (emptying). The grade lines include valve wells and other attached flow passages.

5-2. Baseline Constraints

Conditions normally imposed on the analysis are chamber, approach, and system geometries and hydraulic characteristics; initial upper, lower, and chamber water-surface elevations; valve geometry, opening pattern, and hydraulic characteristics; type of valving (commonly two synchronous valves or single valve); and type of operation (filling, emptying, or steady flow). Nonroutine conditions, such as instantaneous valving and bulkhead failures, may also require consideration during hydraulic design. The analysis, excluding mathematical considerations, varies in precision from lock to lock due to the following factors.

a. Stubby culverts. Lock culverts are short and contain elements (manifolds, valves, bends, transitions, etc.) in proximity. Published hydraulic coefficients as tested for individual elements are in error when directly applied to the composite system. Best results are obtained when culvert system coefficients are derived from a geometrically similar model or prototype.

b. Unusual shapes. The intake, chamber, and outlet manifolds, particularly, are function specific. Published data for nonlock manifolds are useful in concept but rarely in detail for the shapes used for lock design. Other unusual shapes and combinations of elements are not uncommon. Useful data, when available for these unusual geometries, generally come from previous lock hydraulic model or prototype tests.

c. Flow acceleration. Analysis, based on incompressible unsteady flow, is similar to established procedures (surge tank design, for example). However, specific information regarding the significance of wells, branches, junctions, ports, etc., is very limited. These information gaps are resolved, to the extent possible during design, by comparison with solutions for similar locks.

5-3. Analysis Results

The baseline analysis (paragraph 5-1) provides the basic quantities required as input for the design of individual flow passage elements. Conventional hydraulic practice applies to the design details.

Section II
Steady Flow in Lock Culverts

5-4. Discharge

For constant valve opening and fixed pool levels, the flow rate is given by an orifice discharge equation:

$$Q = CA\sqrt{2gH} \tag{5-1}$$

in which

Q =discharge per culvert, cubic feet per second (cfs)

C = discharge coefficient (referenced to area A)

A = reference cross-sectional orifice area, square feet (ft)

g = gravitational acceleration, 32.2 ft/second (sec)^2

H = difference in pool levels (head), ft. The difference is upper pool to chamber for filling and chamber to lower pool for emptying

The value of C, a measure of the efficiency of the design, depends on:

a. Reference area. The accepted practice is to use the cross-sectional area A_c at the culvert immediately downstream of the valve as the reference area A in Equation 5-1. Consequently, systems having small valves (relative to total efflux area) in culverts with streamlined contractions and expansions have large C values; systems with large valves having essentially the same Q and H relationship erroneously appear less efficient because of low C values.

b. Exit port geometry. Streamlining the efflux ports tends to increase efficiency (i.e., increasing Q for unchanged H corresponding to a larger C value). Similarly, increasing the total port area A_p tends to increase efficiency. However, observations indicate that when A_p exceeds about 1.1 times the manifold section area, no additional increase of Q is attained.

c. Energy loss. Head losses occur throughout the flow passage. Systems with streamlined transitions, smooth and short culverts, few boundary changes, and efficient manifolds have high C values.

5-5. Energy Loss Coefficient

The overall energy loss coefficient k_t is defined and compared to the discharge coefficient C (Equation 5-1) as:

$$k_t = \frac{H}{V^2/2g} = \frac{1}{C^2} \tag{5-2}$$

where

$V = Q/A_c$ = mean velocity at the reference section, fps. A range in C values from 0.5 to 0.9 corresponds to k_t values from 4 to 1.2; this range includes nearly all existing CE lock designs for either filling or emptying.

5-6. Individual Losses

The sum of individual loss contributions, boundary losses plus losses due to numerous form changes, as calculated using published friction and form loss coefficient values exceeds losses observed for lock filling-and-emptying systems. This difference is attributed to having stubby culverts (i.e., inadequate spacing so that established flow is not reached between identifiable boundary changes). Such summations are avoided in analysis by using model and prototype test data reduced to the form shown schematically in Figure 5-1.

5-7. Reynolds Number

Higher flow rates occur in prototype lock culverts than are predicted from model observations. This difference is attributed to a decrease in loss coefficient values corresponding to the much larger Reynolds number R for prototype flows. Reynold's number is defined as

$$R = VD_h / \upsilon \tag{5-3}$$

where

D_h = hydraulic diameter; $D_h = A_c/P_c$ where P_c, ft, is the culvert perimeter at the reference section

υ = kinematic viscosity (for example, υ = 1.05 H 10^{-5} ft^2/sec for water at 70 EF and atmospheric pressure)

For a 1:25-scale model (common size, see Chapter 6) the difference in Reynolds number is 125-fold due to geometry alone. The Darcy-Weisbach friction factor is defined as

$$f = \frac{D_h}{L} \frac{H_L}{V^2/2g} \tag{5-4}$$

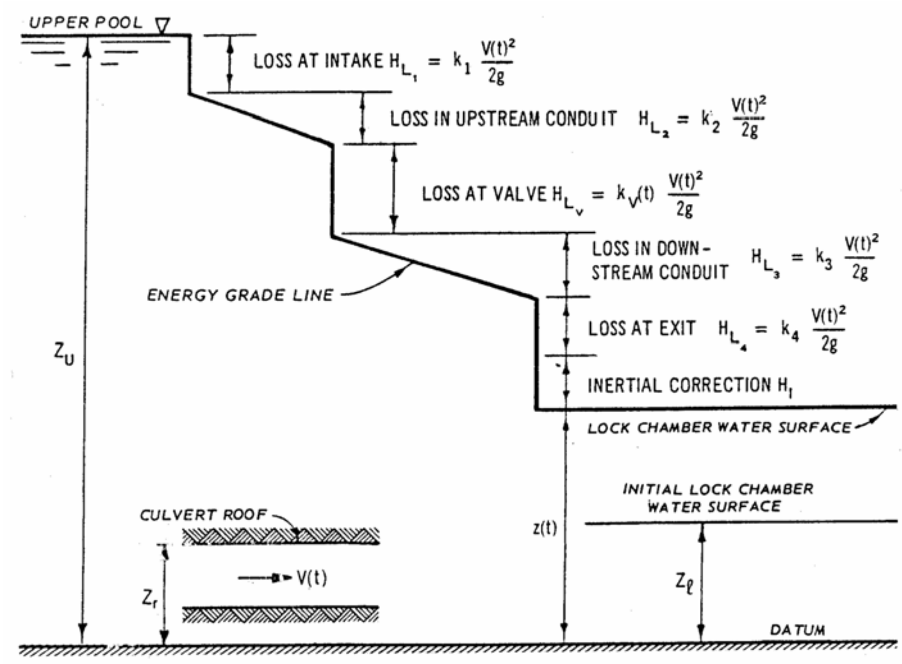
where

H_L = energy loss, in ft, over a length L in ft, of uniform conduit. For smooth boundaries, the reduction in f from a peak model R (say 10^5) to a peak prototype R (say 1.25×10^7) is from 0.018 to 0.008.

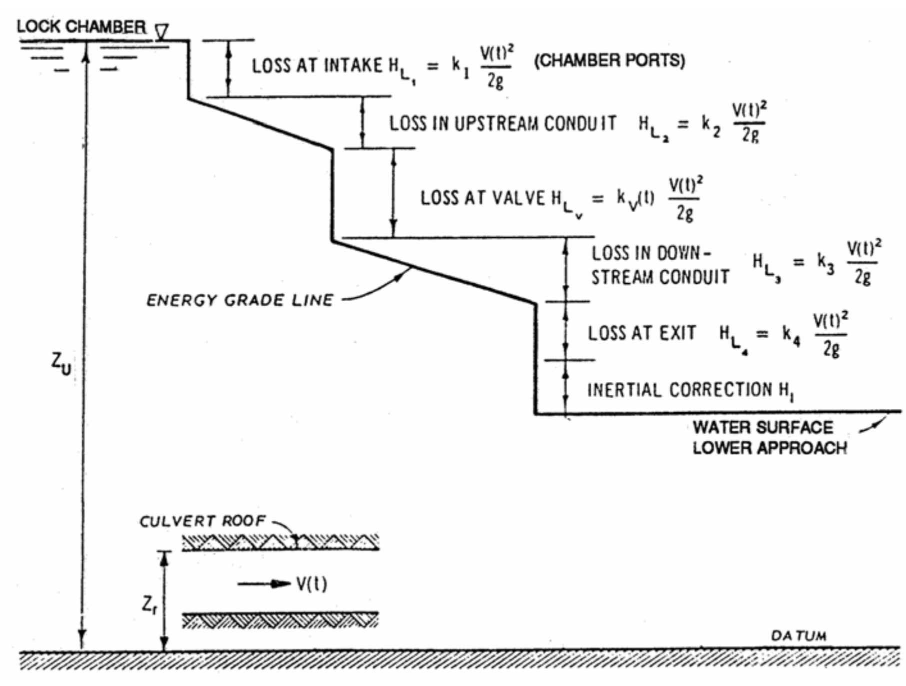
5-8. Energy-Loss Coefficient Values

This illustration uses Lower Granite Lock model test data reduced to the form shown in Figure 5-1 as listed in Tables 5-1, filling, and 5-2, emptying. Data are for two valves fully opened and steady flow.

a. Inflow (filling). Typically, the intake is a highly efficient combining-flow manifold, and the point of measurement (Table 5-1) is upstream of the region within which the velocity profile is restructured to culvert flow. Consequently the k_1 value is low, ranging from near 0.05 to about 0.15. Higher values may occur with a small total port area, trashrack blockage, or inefficient approach conditions.



a. Filling (valve full open)



b. Emptying (valve full open)

Figure 5-1. Hydraulic grade line determination. The schematics show common measurement locations and coefficients determinable from most model and prototype experimental studies. Steady flow conditions apply. Symbols are defined in Appendix J.

Table 5-1
Filling Culvert Loss Coefficient Example; Two Valves Full Open With Steady Flow (Lower Granite Lock, Item 79: BHL, TR No. 126-1, Table J)

Symbol[a]	Location	Coefficient with Reference Area = 168 ft.^{2}
k_1	Intake	0.08
k_2	US culvert	0.25
$k_{v,100}$	Valve	0.045
k_3	DS culvert	0.07
k_4	Chamber	1.19

Notes:
[a] Notation is described in Figure 5-1*a*.
[b] k_t = 0.08 + 0.25 + 0.045 + 0.07 + 1.19 = 1.635

Table 5-2
Emptying Culvert Loss Coefficient Example; Two Valves Full Open With Steady Flow (Lower Granite Lock Item 79: BHL TR No. 126-1, Table M)

Symbol[a]	Location	Coefficient with Reference Area = 168 ft.^{2}
k_1	Chamber	1.40
k_2	US culvert	0.24
$k_{v,100}$	Valve	0.045
k_3	DS culvert	0.16
k_4	Outlet	0.79

Notes:
[a] Notation is described in Figure 5-1*b*.
[b] k_t = 1.40 + 0.24 + 0.045 + 0.16 + 0.79 = 2.635

b. Upstream culvert (filling). This segment of a filling culvert is commonly convergent; vertical and horizontal bends and other changes in form and alignment vary significantly between projects. The k_2 value, 0.25 in Table 5-1, includes losses incurred at the intake as well as boundary and form effects on the flow within the culvert upstream from the filling valve.

c. Valve (filling). Valve loss coefficients, as determined from experimental data for valves in long culverts, are used (see Section IV). For valves located in a nonexpanding culvert the $k_{v,100}$ value is 0.045 as shown in Tables 5-1 and 5-2.

d. Downstream culvert (filling). This segment is commonly of constant section although variations occur (for example, Lower Granite is highly divergent). The determination as to whether the expansion affects valve loss (i.e., nearer to the valve than at Lower Granite) is described in Section IV. A low value, k_3 equals 0.07 in Table 5-1, is common particularly when effects of the more complex geometrical features are included in the chamber outlet loss.

e. Efflux (filling). The chamber manifold ports are orifice-type controls during filling. The value of k_4 decreases toward a minimum expected value of about 1.2 as the total port-to-manifold section area ratio increases to unity. Further increase in port area tends to cause little or no decrease in exit loss coefficient values. The value k_4 equals 1.19 in Table 5-1 includes effects due to the long and complex crossover geometry combined with a ratio equal to 0.84. More efficient filling (and emptying) would be expected with a ratio nearer to unity.

f. Overall loss (filling). Using reference-area values from Table 5-1, the filling loss, k_t = 1.64, corresponds to a discharge coefficient value, $C = \sqrt{1/k_t} = 78$. Typically C filling values range from about 0.5 for inefficient systems, to 0.90 for highly efficient systems, although choice of reference area (valve sizing) can distort these values in a misleading manner.

g. Inflow (emptying). The chamber manifolds are inefficient intake devices (manifold loss coefficient k_m equal to 0.84 in Table 5-2), and when a complex culvert arrangement such as that at Lower Granite is included, a high k_1 value for emptying occurs.

h. Upstream culvert (emptying). The emptying culvert is commonly of constant section although variations occur (for example, Lower Granite is highly convergent). The k_2 value, 0.24 in Table 5-2, includes losses incurred upstream as well as boundary and form effects on the flow within the indicated culvert length.

i. Valve (emptying). Refer to *c* above.

j. Downstream culvert (emptying). This segment is commonly of constant section although variations occur. The losses occurring within this segment at Lower Granite are considered negligible; k_3 equals 0.16 in Table 5-2.

k. Efflux (emptying). The outlets are orifice-type control during emptying; a value of k_4 near unity is expected for an efflux-area-to-reference ratio of one. The low value, 0.79 in Table 5-2, depicts to an unknown extent a larger effective efflux area (due to sidewall flare in the basin).

l. Overall loss (emptying). From Table 5-2, the emptying loss k_t equals 2.64, corresponding to a discharge coefficient C of 0.62. Typically, emptying C values are similar in range to filling values. Distortions due to choice of reference area also occur and, for the same lock, a lower emptying than filling C value is not uncommon.

Section III
Lock Filling and Emptying

5-9. General Features

a. Filling. During a filling run, as sketched in Figure 5-2(a), valve movement is initiated at time t equals zero. The initial differential head H is the difference in elevation between the upper and lower pools (i.e., $H = Z_U - Z$). The rate of rise, dz/dt, of the lock water surface increases to a maximum at time t_m after which it decreases continuously, reaching zero at time t_f. The valve is fully open at time t_v. The operation time (or filling time) is designated as T. The inertia of the water in the filling system causes the lock water surface to rise the distance d_f, termed the overtravel (or overfill) above upper pool, which occurs at time t_f.

b. Emptying. Parameters describing an emptying run (Figure 5-2(b)) are analogous to those of a filling run. For example, during emptying, the water surface tends to lower the distance d_e termed overtravel (or overempty) below lower pool, which occurs at time t_e.

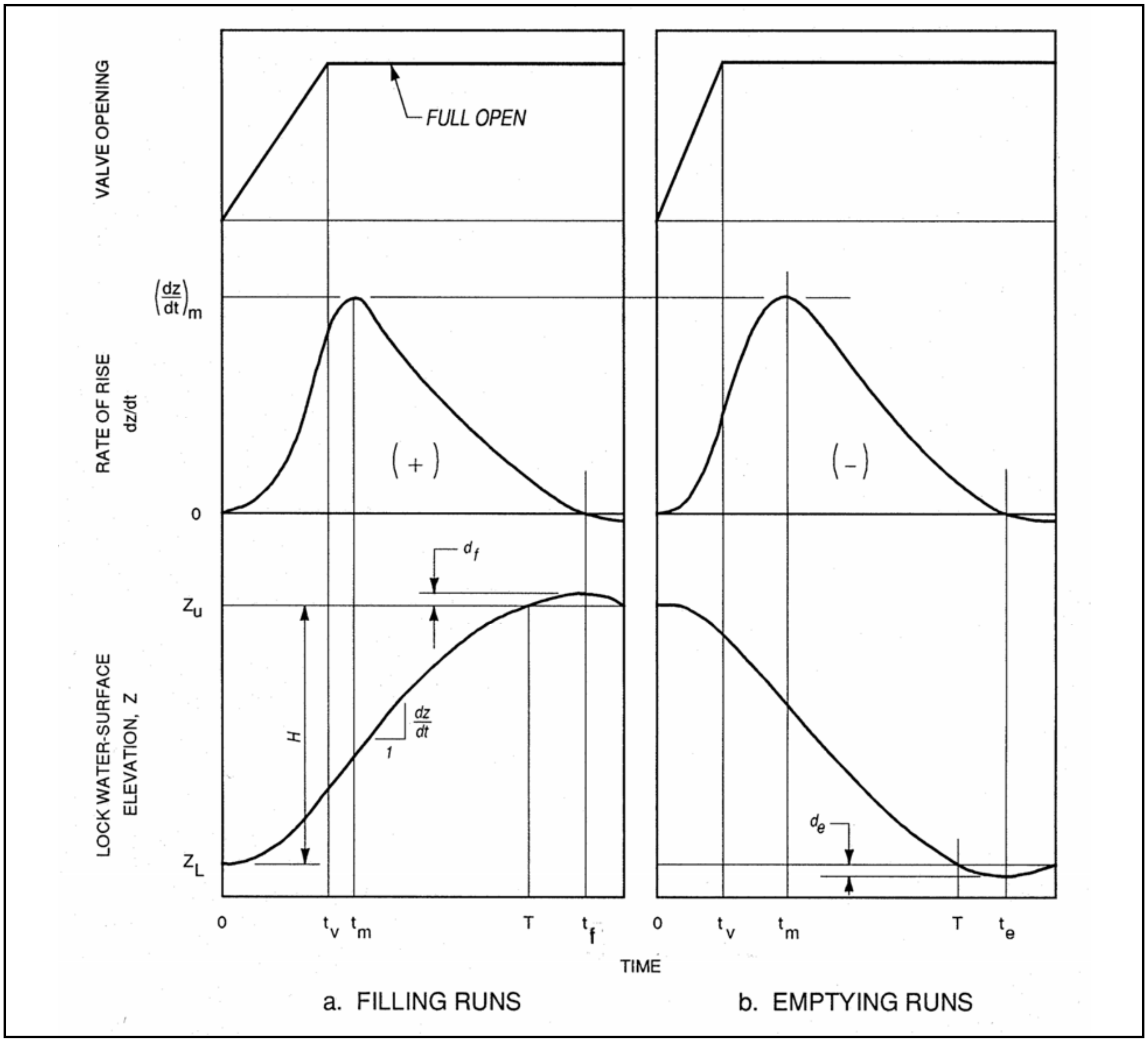


Figure 5-2. Lock filling and emptying (definition sketch)

5-10. Valve Operation

As noted in Figure 5-2, the valve hoist and linkage mechanism normally result in a nonlinear relationship between relative valve opening (*b/B*) and opening time (t/t_v) where *b* is the vertical gate opening, *B* is culvert height, *t* is time, and t_v is the valve operating time period. The pattern sag varies depending on the valve and linkage geometry and on the operating mechanism. The sag, when t/t_v is equal to 0.5, varies between 0.4 (large sag) and 0.1 (small sag). The following are variations in valve operation (applicable to either filling or emptying):

a. Normal two-valve (synchronous). Flow is through two culverts; the valves' operating mechanisms are identical and mechanically and electrically synchronized so that identical valve patterns are obtained. This is the type of valving preferred for normal lock operation.

b. Single valve. Filling or emptying with one valve (in a two-valve system) may be required for emergency or operation and maintenance reasons. Satisfactory chamber performance using one-valve operation is needed although longer operation times are usually acceptable.

c. Nonsynchronous valves. For this two-valve operation, either or both start time and opening rate differ between valves. This is not general design practice. However, prototype mechanisms and operating procedures contain many examples of designs deteriorated from synchronous into some form of non-synchronous valving.

d. Stepped valves. The valves are opened to a particular value (commonly about one-fourth open), maintained in that position for some delay time period, then opened to full open. Stepped valving is not usually a design choice. However, certain postconstruction requirements for raising culvert pressures or reducing chamber oscillations have been resolved by means of stepped valves.

e. Special valve patterns. Smoothed (but essentially stepped) patterns are obtained using cams in the valve hoist mechanism for purposes similar to stepped valving. Variable-speed valve operations are capable with automated control, and model tests of the McAlpine Lock Addition (item 96) showed that this type of operation could speed up the safe filling time versus the normal two-valve synchronous operation. The IHNC lock model (item 102) demonstrated that since the sector gates were used due to large reverse head conditions in conjunction with the side port filling and emptying system, these two systems could be operated together during a filling operation to reduce the safe filling time.

f. Overtravel control. The extent of overtravel (d_f or d_e in Figure 5-2) is reduced by initiating valve closure prior to the normal lock operating time. Valve closure for many existing locks is initiated automatically using a differential water-surface-level sensor.

g. Valve opening time. Rapid valve times (near 1 min) are an existing design goal. The slow valving (8 min or greater) that is used at certain locks should be unnecessary for new lock designs.

Lock valve operations have been investigated as a means to lower the upper pool in an emergency situation for Lock 1 on the Upper Mississippi River (item 97). Valve operations were also investigated for the Whitten (formerly Bay Springs) Lock (item 100) to determine if these operations were contributing to culvert damage.

5-11. Lock Coefficient

The continuity relationship between culvert flow and chamber rate-of-rise when combined with steady-flow discharge coefficient (Equation 5-1) is the basis for the traditional empirical lock design equation (item P4). The solution is modified to include effects due to flow acceleration and valve opening pattern

$$T - Kt_v = \frac{2\,A_L\left[(H + d_f)^{1/2} - d_f^{1/2}\right]}{nA_cC_L\ \sqrt{2g}} \qquad (5\text{-}5)$$

where

T = lock filling time, sec

K = overall valve coefficient (not a loss coefficient)

t_v = valve opening time, sec

A_L = chamber surface area, ft^2

H = initial head (i.e., lift), ft

d_f = overtravel, ft

n = number of valves used, 1 or 2

A = culvert area at the valves, ft^2

C_L = overall lock coefficient

g = acceleration of gravity, 32.2 ft/sec^2

Equation 5-5 is adequate for preliminary study purposes only. A full hydraulic analysis requires numerical completed simulation of the system.

5-12. Operation Time Estimates

Equation 5-5 provides an acceptable estimate of lock operation time subject to the following observations.

a. The valve coefficient K is normally set equal to 0.5, but a variation from 0.4 to 0.6 occurs in practice. Equation 5-5 is therefore more reliable for rapid (instantaneous for model tests) valving.

b. The lock coefficient C_L for existing locks ranges from about 0.45 (relatively slow operation) to about 0.90 (rapid operation). However, since reference area A_c varies due to culvert roof expansions between otherwise similar locks, comparisons based solely on C_L may be misleading. The discharge coefficient C differs from C_L due to factors (Reynolds number, flow acceleration, valve pattern, etc.) not adequately incorporated into Equation 5-5.

c. The overtravel d_f is normally unknown (ranging from near 1 ft for short inefficient culverts to greater than 4 ft for long efficient systems). The relative insensitivity of filling time to overtravel value causes rough estimates to be within acceptable accuracy.

5-13. Basis For Numerical Simulations

The extent of hydraulic detail required in design calculations varies. Higher velocity systems (high lifts) require more detailed grade line elevation and velocity histograms so that energy losses, local velocities and pressures, air entrainment characteristics, surface and form cavitation potential, etc., can be evaluated. These evaluations should use references such as Hydraulic Design Criteria (HDC), EM 1110-2-1602, and other closed conduit flow guidance documents to supplement the hydraulic calculations described in *a* - *e* below.

a. The following summary of equations is an intermediate approach relating to lock filling which applies to emptying provided appropriate sign changes are included. “The overall head loss in the system is assumed to be made up of the five components listed below. Figure 5-3 shows an example of how the pressure gradient and the lock water surface (an indicator of overall head losses) vary with filling time.”

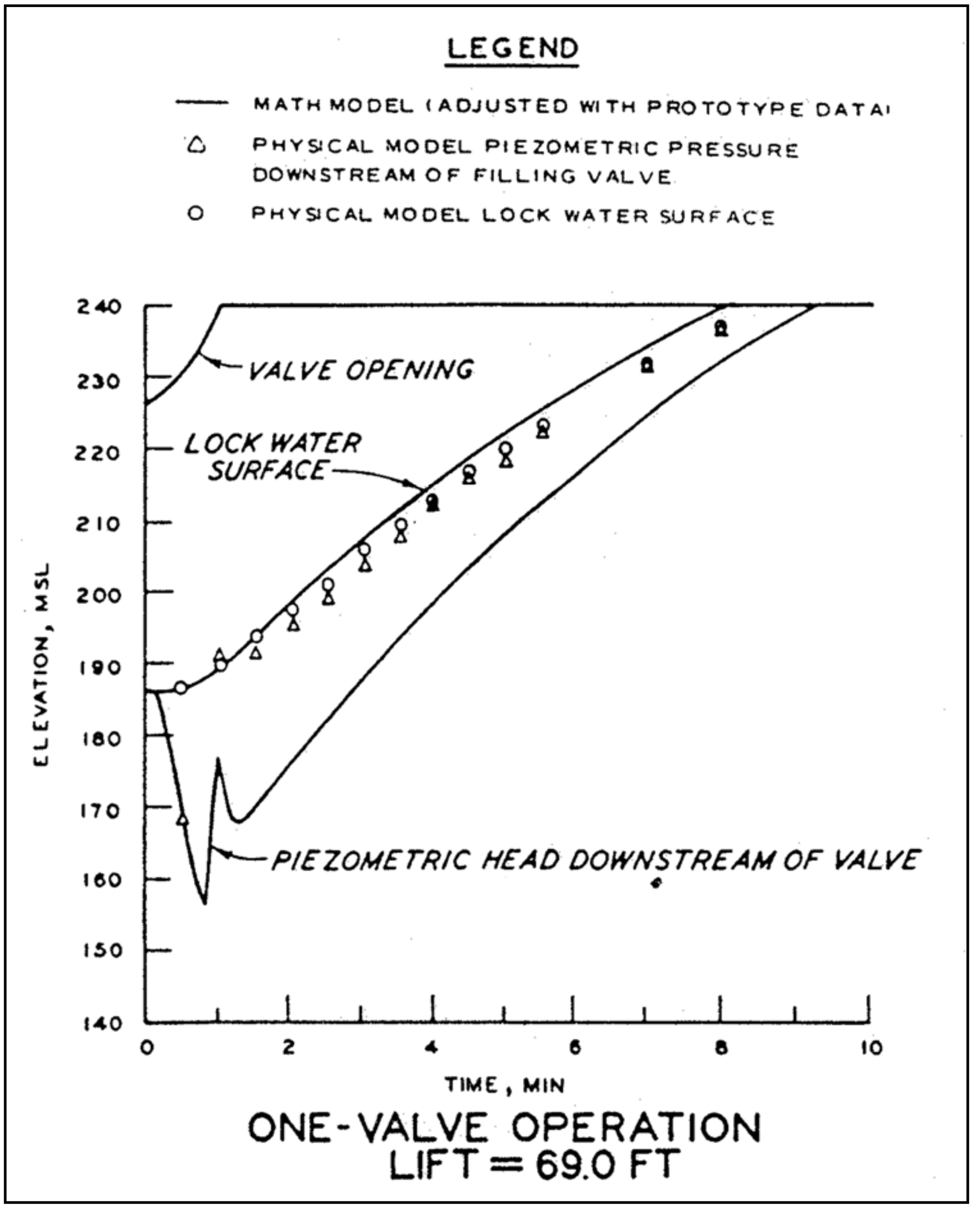


Figure 5-3. Schematic of the lock chamber (filling)

(1) Intake

$$H_{LI} = k_1 \frac{V^2}{2g} \tag{5-6}$$

(2) Upstream conduit

$$H_L 2 = \frac{k_2 V^2}{2g} \tag{5-7}$$

(3) Valve and valve well

$$H_{Lv} = \frac{k_v V^2}{2g} \tag{5-8}$$

(4) Downstream conduit

$$H_L 3 = \frac{k_3 V^2}{2g} \tag{5-9}$$

(5) Outlet

$$H_L 4 = \frac{k_4 V^2}{2g} \tag{5-10}$$

The overall loss H_{Lt} is

$$H_{Lt} = (k_1 + k_2 + k_v + k_3 + k_4)\frac{V^2}{2g} \tag{5-11}$$

or

$$H_{Lt} = \frac{k_t V^2}{2g} \tag{5-12}$$

Coefficients k_1, k_v, and k_4 are taken to be essentially form-dependent; coefficients k_2 and k_3 are not only affected by form but also by Reynolds number and relative roughness. However, in view of the Astubby@ conduits and the dominance of form effects in a lock system, the conduit coefficients k_2 and k_3 can reasonably be assumed constant for either model or prototype, bearing in mind that significant differences may exist between the model and the prototype values.

b. Since the flow is incompressible, the inertial effect is treated as a lumped quantity, that is

$$H_m = \frac{L_m}{g}\frac{dV}{dt} \tag{5-13}$$

where

H_m = overall inertial effect

L_m = inertial length coefficient

$$L_m = A_c \sum_{i=1}^{m} \frac{L_i \alpha_i}{A_i} \tag{5-14}$$

for a conduit made up of m sections of lengths L_i, areas A_i, and flow ratios α_i (i.e., $\alpha_i = Q_i/Q$ where Q_i is the flow through the i^{th} section).

c. The water-surface differential, Z_U - z in Figure 5-2, is the sum of the inertial effect (Equation 5-13) and the energy losses (Equation 5-5) or

$$\frac{k_t V^2}{2g} = (Z_U - z) - \frac{L_m}{g}\frac{dV}{dt} \tag{5-15}$$

d. Continuity applies to the culvert flow (nA_cV) and the rate-of-rise, $A_L\ dz/dt$, of the lock chamber water surface

$$V = \frac{A_L}{nA_c}\frac{dz}{dt} \tag{5-16}$$

and

$$\frac{dV}{dt} = \frac{A_L}{nA_c}\frac{d^2z}{dt^2} \tag{5-17}$$

e. Integration of Equation 5-15 (with k_t = constant and for reasonably high lifts)

$$\frac{dV}{dt} = \frac{-gnA_c}{k_t A_L} \tag{5-18}$$

$$k_t = \frac{-g\,\dfrac{nA_c{}^2}{A_L}}{\dfrac{d^2z}{dt^2}} \tag{5-19}$$

f. Similarly, for overtravel,

$$d_f = \frac{L_m\, nA_c}{k_t A_L} \tag{5-20}$$

or

$$L_m = \frac{d_f\, k_t\, A_L}{nA_c} \tag{5-21}$$

Since the possible measurement error for d_f is always large, Equation 5-21 is not an appropriate means of evaluating L_m.

5-14. Mathematical Aids

a. Computer programs are available for most of the complex problems associated with lock operation. The four programs listed in Table 5-3 are applicable.

b. Database contents, H5300, are outlined in Appendix C. Computer input and output examples, H5310 and H5320, are included in Appendix F.

Table 5-3
CORPS Computer Programs for Lock Operation

Program	Brief Title	Description
H5300	Database-Lock Studies	Reports (86) are being arranged in a database so that description (251 items) and measurement types can be printed. Database is being filled.
H5310	Surge in Canals	Surge characteristics (idealized as presented in EM 1110-2-1606) are evaluated. Program is fully operational.
H5320	Symmetrical Systems	Hydraulic characteristics (idealized as described in Item H2 are evaluated. Program is fully operational.
H5322	Symmetrical Systems (R2)	H5320 revised to accommodate distributed flow acceleration and hydraulic friction and roof expansions. Program is operational off CORPS.

Section IV
Culvert Features

5-15. Goals

The importance of providing efficient hydraulic shapes for entrances, bends, expansions, contractions, etc., cannot be overemphasized. This is particularly important for components of hydraulic systems for locks with high lifts. Many existing locks have been designed without proper regard to efficient and smooth filling operations. However, modernization of obsolete projects introduces opportunities to design faster and more efficient system. In order to reduce the time required for lockage and still maintain safe operating conditions, the filling system is designed to provide equal distribution of flow into and out of chamber ports, to reduce surging and vortex action, and to provide culverts that are as hydraulically efficient as possible. The degree of refinement in the design of various units of the hydraulic system must be balanced by construction costs.

5-16. Improved Performance

Reduced operation time is achieved by streamlining the shape of the culverts and ports to reduce energy loss. Energy losses are reduced by having hydraulically smooth flow passages and rounded entrance corners on ports and conduits. Other aspects of improved performance also exist but are more difficult to evaluate. For example, proper distribution of the flow between manifold ports facilitates the dispersion and dissipation of jets issuing into the lock chamber or lower lock approach. In high-lift locks, streamlining for the elimination of excessive localized negative pressures and cavitation becomes increasingly important. Streamlining of the intake ports effects better flow distribution and reduces vortex action of the intake.

5-17. Evaluation

Although general criteria for the type and degree of streamlining that should be used for a given condition is not available, numerous examples can be found in model and prototype studies (Appendix C) that can be used for comparison. Corners should be sufficiently rounded to prevent separation of the flow from the boundaries. The angle of divergence in venturi-shaped ports should be small to avoid separation at the boundary.

Section V
Valve Hydraulic Characteristics

5-18. Design Concerns

Valve characteristics are provided in EM 1110-2-1610. Items of particular concern for reverse tainter valves as addressed in EM 1110-2-1610 are

a. Valve hoist loads.

b. Valve siting (including submergence and air venting alternatives).

c. Cavitation parameter evaluation.

d. Valve shape and structural description.

e. Valve lip details.

f. Valve loss coefficients.

g. Culvert roof pressure downstream from valves.

5-19. Valves With Expansions Downstream

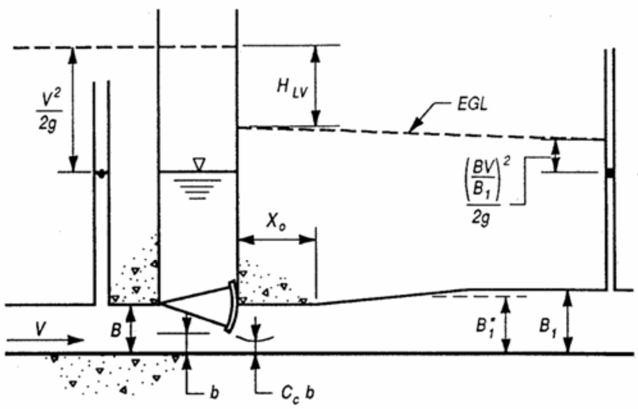
a. Recent concerns (item 83) with the change in energy loss due to a roof expansion immediately downstream from the valve are summarized in Plates 5-1 through 5-3. The roof expands from a value B (Figure 5-4) to a value B_1. The valve loss coefficient is equivalent to an abrupt expansion from a maximum jet contraction, $C_c b$ to an intermediate roof elevation B_1^*. The energy loss is greater with the expansion than with a horizontal roof. When the roof expansion begins more than 4.5 B downstream from the valve, the valve and expansion are treated as separate form loss items.

b. For equal flow rates the pressure drop coefficient defined in Figure 5-5 is not measurably influenced by downstream expansion.

Section VI
Low Pressure Effects

5-20. General Concerns

Subatmospheric pressure permits air to enter the flow (see Section VII). The abrupt release of air into the chamber or valve wells can cause unsatisfactory lock operation. Vapor pressure, which is the extreme lower limit of subatmospheric pressure, is a major concern for high-lift locks. A separation zone (sharp bends, abrupt expansions, joints, etc.) will develop local cavitation for sufficiently high velocities and sufficiently low approach pressures. Incipient cavitation criteria are available for surface finishes, control devices, and flow passage variations (see HDC and items B1, B2, B3, B10, C1, M10, N1, and R7). Criteria based on data from alternate hydraulic structures, such as outlet works, are applicable to locks provided approach velocities and pressures are correctly evaluated.



ENERGY LOSS

VALVE LOSS COEFFICIENT:

$$k_v = \frac{H_{LV}}{V^2/2g}$$

PRESSURE DROP COEFFICIENT:

$$E = \frac{\Delta h}{V^2/2g}$$

AND

$$E = (B/C_c b)^2 - 1.0$$

TERMINOLOGY

b = VALVE OPENING (FT)
B = CULVERT HEIGHT (FT) AT VALVE
B_1 = CULVERT HEIGHT (FT) DOWNSTREAM
B_1^* = EFFECTIVE CULVERT HEIGHT (FT) DOWNSTREAM
C_c = CONTRACTION COEFFICIENT
E = PRESSURE-DROP COEFFICIENT
EGL = ENERGY GRADE LINE; GRADIENT AND ELEVATION BASED ON DOWNSTREAM CONDITIONS
g = ACCELERATION DUE TO GRAVITY (32.2 FT/SEC^2)
h_R = MINIMUM PIEZOMETRIC HEAD (FT) ON CULVERT ROOF REFERENCED TO DATUM AT THE CONTRACTED JET
h_v = VELOCITY HEAD (FT); $h_v = V^2/2g$ AND IS NOT SHOWN
h_{vp} = VAPOR PRESSURE (NOT SHOWN; h_{vp} = -33.5 FT FOR WATER AT 50 °F)
Δh = DIFFERENCE IN PIEZOMETRIC HEAD (FT)
H_{LV} = ENERGY LOSS (FT) ATTRIBUTED TO LOCAL GEOMETRY, VALVE, AND ROOF EXPANSION (FT)
HGL = HYDRAULIC GRADE LINE: PIEZOMETERS ALONG CENTER LINE OF CULVERT ROOF
k_v = VALVE LOSS COEFFICIENT
P_R = MINIMUM PRESSURE (FT) ALONG THE CULVERT ROOF
Q = FLOW RATE (CFS); STEADY FLOW
V = VELOCITY (FT/SEC); $V = Q/BW$
W = CULVERT WIDTH (FT); W IS CONSTANT AND IS NOT SHOWN
X_o = EXPANSION OFFSET DISTANCE (FT)
σ = CAVITATION PARAMETER

Figure 5-4. Valve loss coefficient (definition sketch)

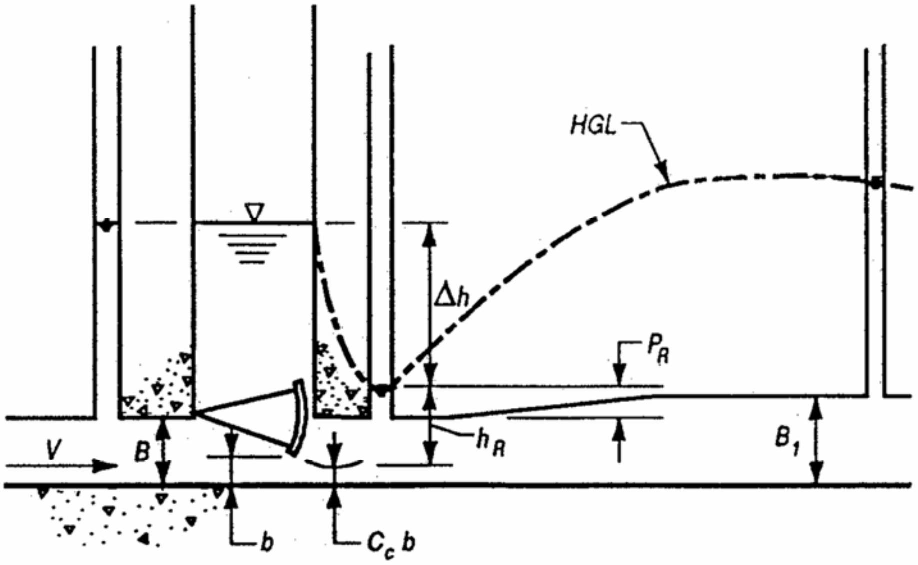
5-21. Reverse Tainter Valves

EM 1110-2-1610 addresses cavitation near reverse tainter valves at high-lift locks. Criteria for the assessment of cavitation potential is presented in Plate 5-4.

Section VII
Air Inflow and Outflow Devices

5-22. High-Lift Lock Air Vents

Valves for high-lift locks are commonly vented to preclude cavitation damage. Air vent design is presented in EM 1110-2-1610, EM 1110-2-1602, and HDC charts. Because of the potential adverse impact of air flow on chamber performance in the prototype lock and concerns regarding the minimum acceptable pressure below the operating valve, design practice is generally to oversize the air vent and establish a satisfactory orifice or air-valve setting to limit air flow. The orifice sizing or valve setting is established by observation in the prototype.



LOW-PRESSURE CONDITIONS

CAVITATION PARAMETER:

$$\sigma = \frac{h_R - h_{vp}}{\left[\frac{BV}{C_c b}\right]^2 / 2g}$$

Figure 5-5. Definition sketch. Calculation of pressure at the culvert roof immediately downstream from the filling valve

5-23. Low-Lift Lock Air Vents

Older low-lift locks with high culverts and normal tainter valves have required air release vents between valve and chamber. Occurrences in which large disruptive air bubbles entered these low-lift chambers have been noted. For high-velocity flows (high lifts) the air entering the chamber tends to be frothy and not disruptive to lock performance. For any design (or modification) requiring air outflow vents, the rising pressure gradient along a manifold culvert (items M5 and M10) and air flow characteristics (item F1) are of concern.

Section VIII
Vorticity at Intakes

5-24. General

An intake manifold will operate at its maximum efficiency only when the approach flow is free of turbulence and vortexes. Vortex formation lowers the efficiency of the manifold by diminishing the effective area of the openings and by introducing a component of velocity perpendicular to the direction of flow. Basic design procedures that will ensure vortex-free approach flow are not known, but model tests on intake manifolds have indicated methods of improving approach flow conditions. In model tests on intake manifolds located in the top of the upper sill, with the series of ports parallel to the upstream gate, vortex action was reduced by decreasing the distance between the manifold and the upper gate; increasing the space between ports; increasing the port area at the sill face; and increasing the port submergence. Vortexes are less likely to occur during the accelerating flow of the valve opening period than in decelerating or steady flow. Vorticity is highly affected by local structures and channel geometries. Although precise scaling rules have not been established for these types of vortices, general guidance is to consider a surface swirl as acceptable whereas a depression (> 1/8 in. in the model) becomes questionable.

5-25. Evaluation

A larger entrance reduces intake losses, reduces the tendency to draw air into the intake, and reduces the chance of drift or ice damaging the racks by impact. By using several small intake openings instead of one large one, the flow is spread over a wide area; hence, the tendency for the formation of vortices and the suction of air into the culvert is further reduced. Enlargement of the intake and locating the top of the intake well below the minimum upper pool level ensures that the pressure gradient will be above the roof of the intake making it difficult to draw air into the culvert. The use of several small intake openings is also better structurally when the openings are located in a lock wall. Trashracks can also be kept to a reasonable size by the use of several small openings. When the intakes are located near to the upper pool level where floating drift or ice can easily reach them, the gross intake velocity is usually limited to 8 or 10 fps to avoid damage to the racks by impact.

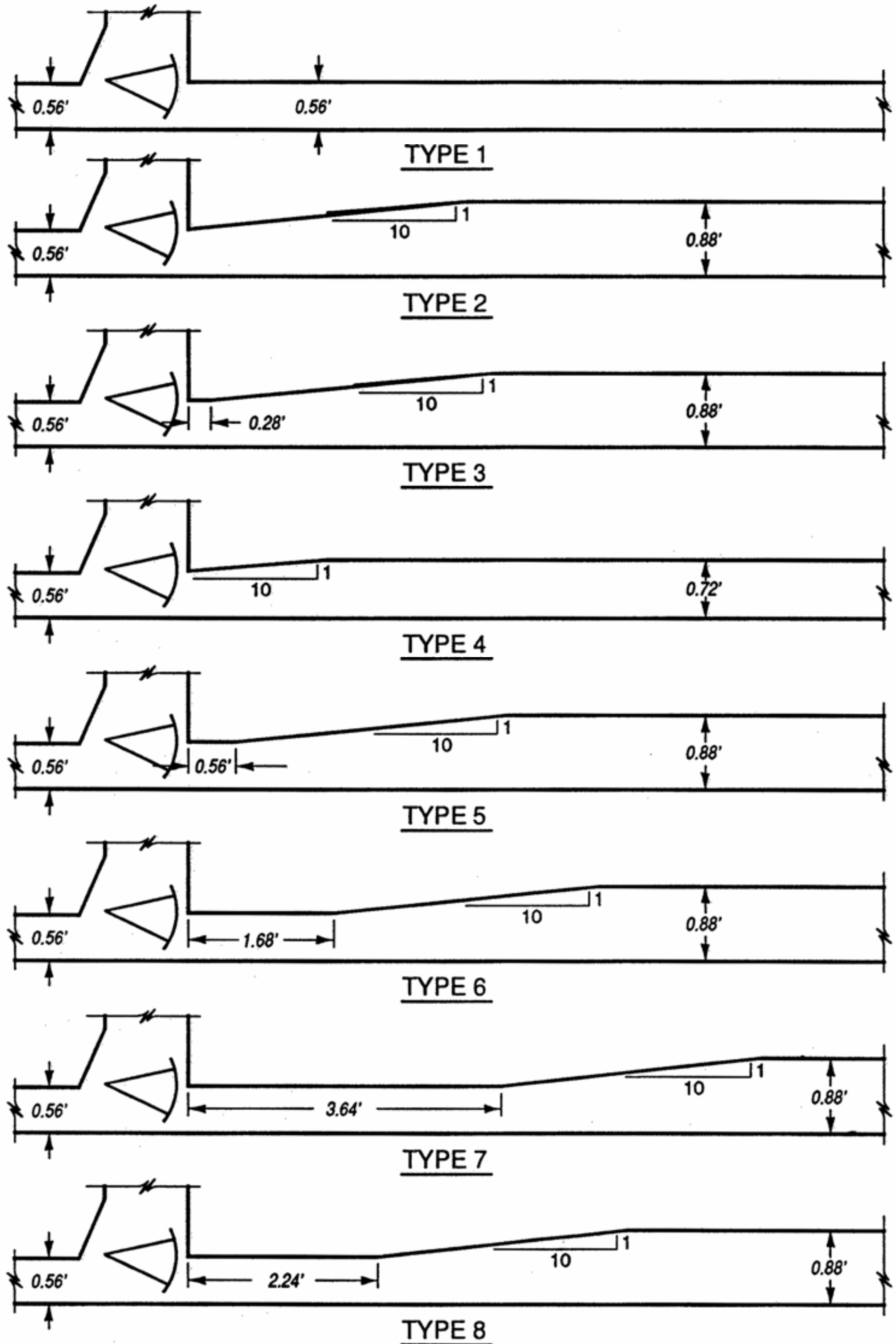
Section IX
Energy Dissipation at Outlets

5-26. Conditions

Unfavorable navigation conditions, such as excessive turbulence and unusual velocity patterns, are the major problems to be considered when designing a discharge manifold in the lower approach. Scour near the outlet structure is an additional concern whenever the outlet is near an unprotected channel boundary. The discharge manifold is usually kept as short as possible to minimize cost. The cushion depth remains essentially the same throughout the locking operation.

5-27. Options

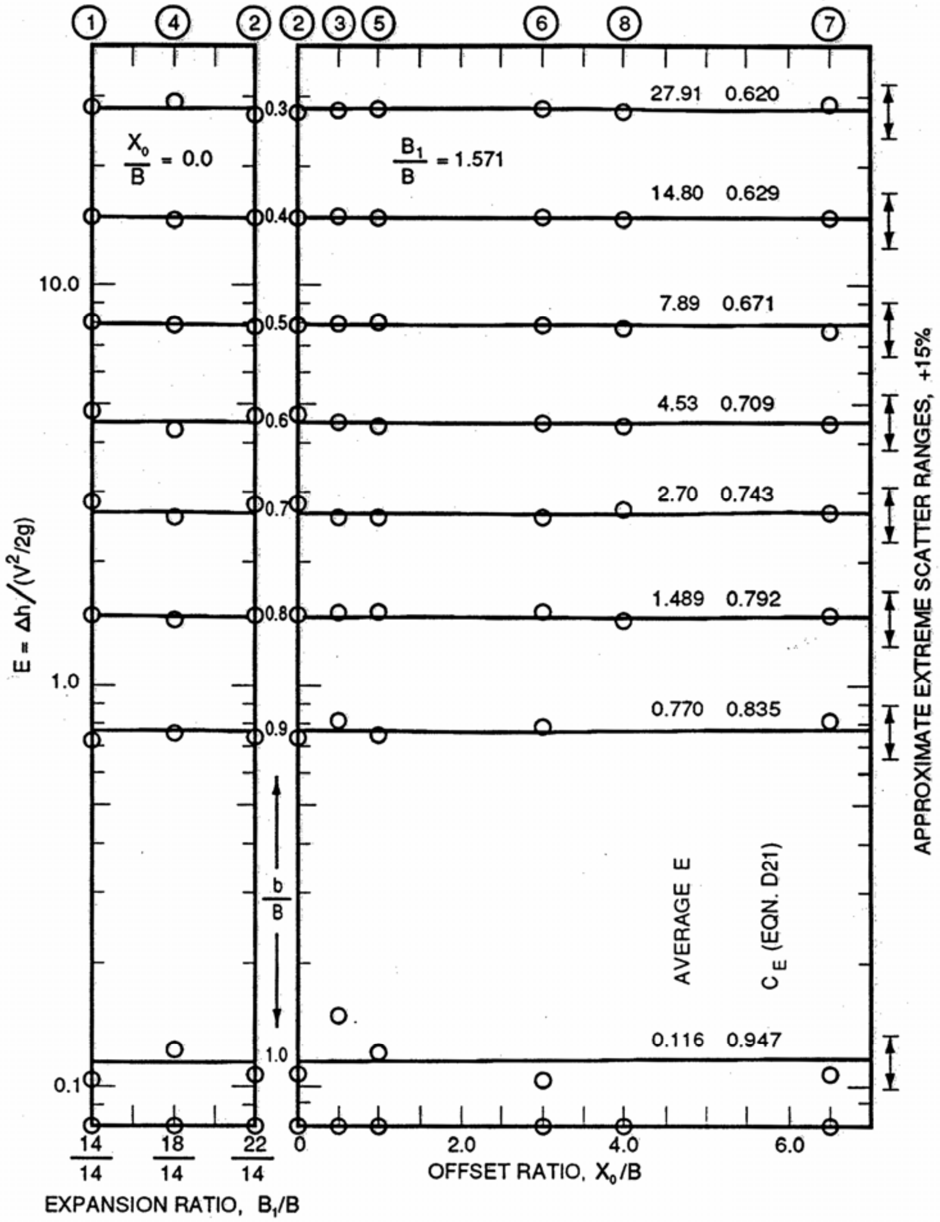
As discussed in paragraphs 4-19 and 4-20, discharge manifolds may empty all or part of the flow into the lower approach or into the river outside of the lower approach walls. When the total flow is discharged into the lower approach, the expansion in port area may have to be quite large to obtain low outlet velocities. The outlet location is normally not a factor (other than with regard to overfill and overempty) in chamber performance.



FROM ITEM 83

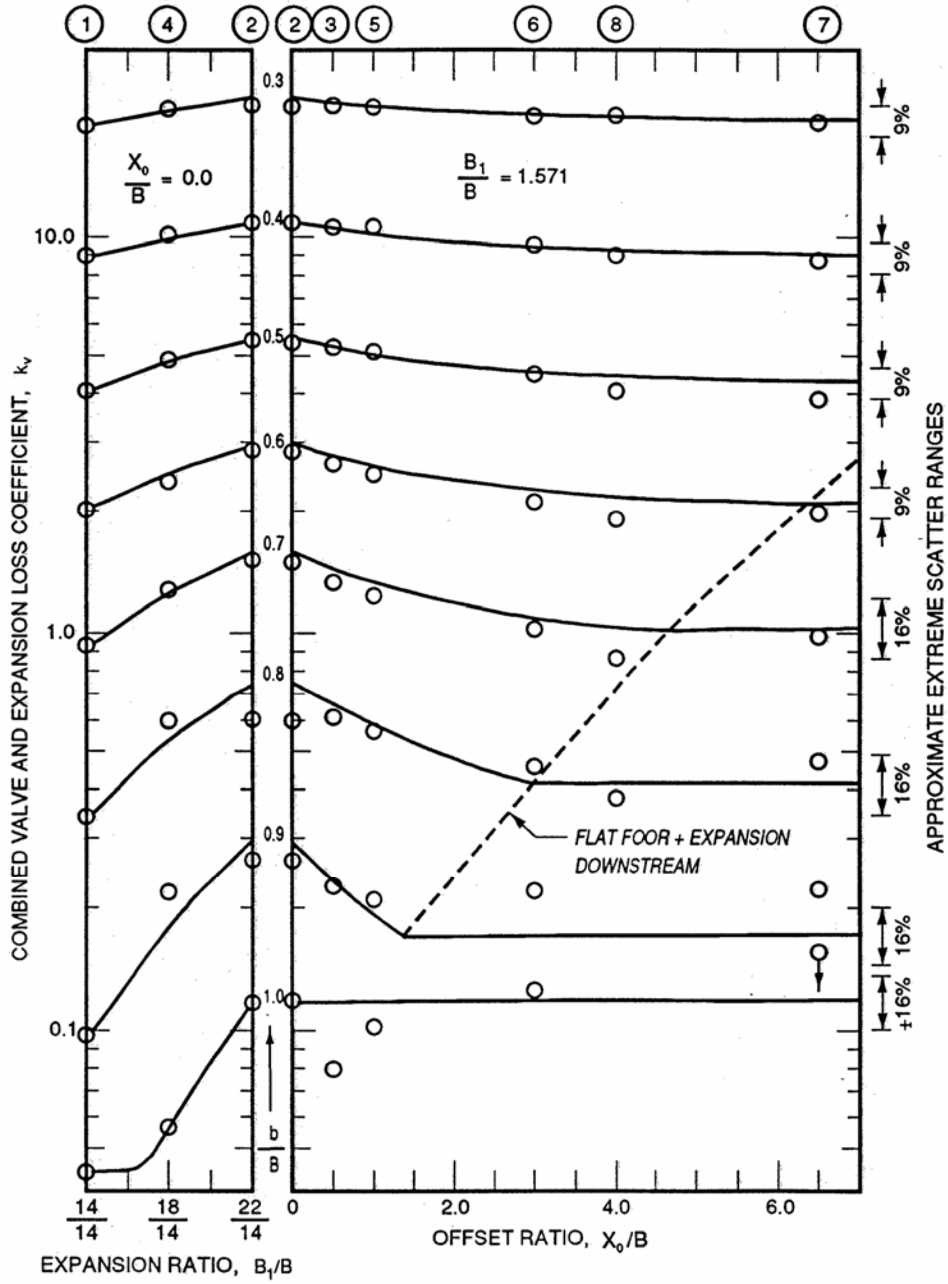
TYPE OF CULVERT ROOF EXPANSIONS USED IN LABORATORY STUDY

Plate 5-1



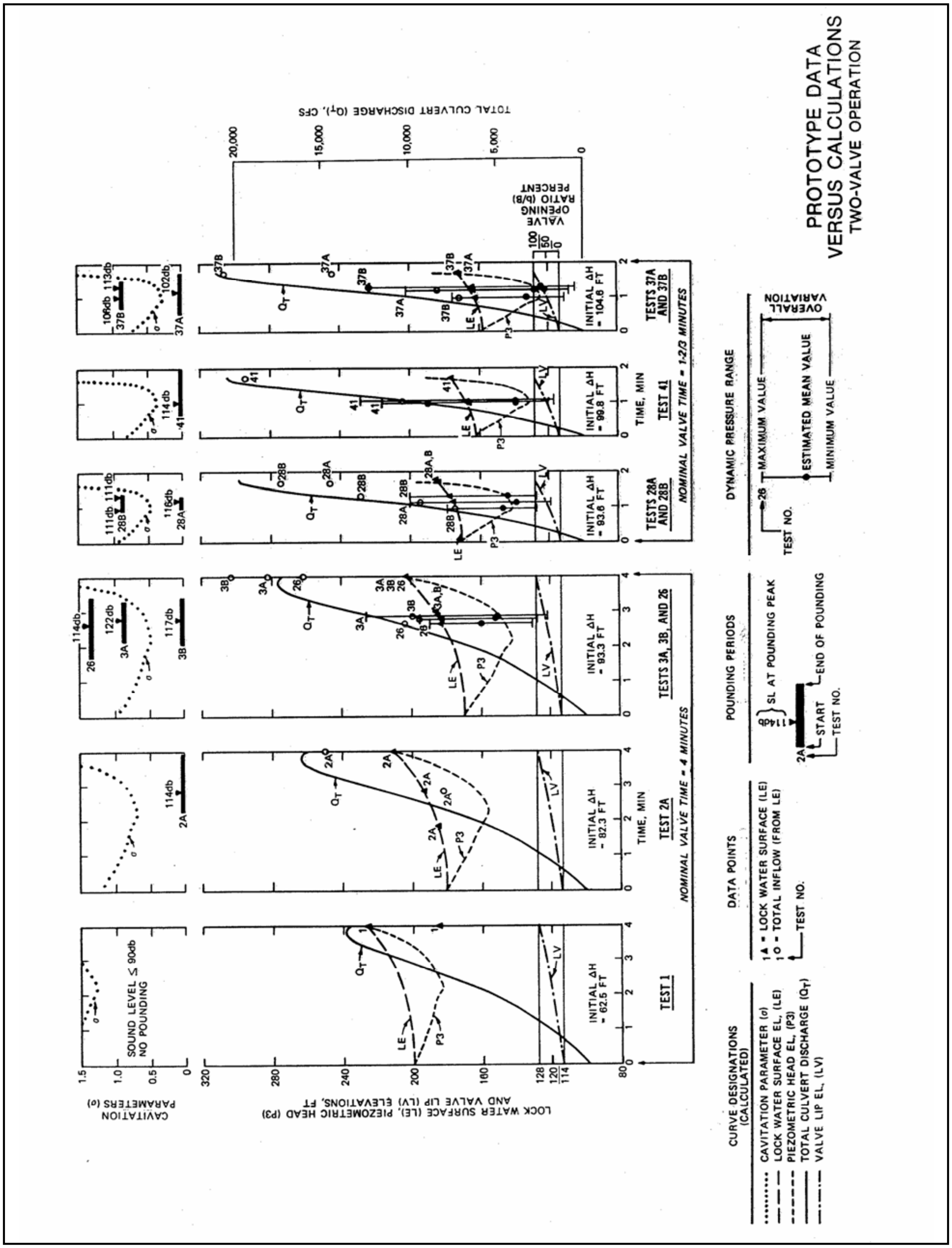
PRESSURE DROP COEFFICIENTS

Plate 5-2



FROM ITEM 83

VALVE-AND-EXPANSION
LOSS COEFFICIENT


PROTOTYPE DATA
VERSUS CALCULATIONS
TWO-VALVE OPERATION
TOTAL CULVERT DISCHARGE (QT), CFS
CAVITATION PARAMETERS (σ)
LOCK WATER SURFACE (LE), PIEZOMETRIC HEAD (P3) AND VALVE LIP (LV) ELEVATIONS, FT
VALVE OPENING RATIO (b/B) PERCENT
TEST 1
TEST 2A
TESTS 3A, 3B, AND 26
TESTS 28A AND 28B
TEST 41
TESTS 37A AND 37B
NOMINAL VALVE TIME = 4 MINUTES
NOMINAL VALVE TIME = 1-2/3 MINUTES
TIME, MIN
SOUND LEVEL ≤ 90db NO POUNDING
CURVE DESIGNATIONS (CALCULATED)
CAVITATION PARAMETER (σ)
LOCK WATER SURFACE EL, (LE)
PIEZOMETRIC HEAD EL, (P3)
TOTAL CULVERT DISCHARGE (QT)
VALVE LIP EL, (LV)
DATA POINTS
1▲ = LOCK WATER SURFACE (LE)
1○ = TOTAL INFLOW (FROM LE)
TEST NO.
POUNDING PERIODS
SL AT POUNDING PEAK
START
END OF POUNDING
DYNAMIC PRESSURE RANGE
MAXIMUM VALUE
ESTIMATED MEAN VALUE
MINIMUM VALUE
OVERALL VARIATION