Hydraulic Design of Navigation Locks

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Navigation Systems Research Program

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US Army Corps of Engineers
BUILDING STRONG®

Tows Setting Up for Lock Operation

Check Posts

Line Hooks

Floating Mooring Bitts

USACE Lock Design Guidance

Hydraulic Design

- EM 1110-2-1604 "Hydraulic Design of Navigation Locks"
- EM 1110-2-1610 "Hydraulic Design of Lock Culvert Valves"

Planning

- EM 1110-2-2602 "Planning and Design of Navigation Locks"

General Discussion

- Davis, J. P. 1989. "Hydraulic Design of Navigation Locks" MP HL-89-5, Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station

TRANSIT TIME

7 different components:

1. Time required for a tow to move from an arrival point to the lock chamber
2. Time to enter the lock chamber
3. Time to close the gates
4. Time to raise or lower the lock surface (fill or empty)
5. Time to open the gates
6. Time for the tow to exit from the chamber
7. Time required for the tow to reach a clearance point so that another tow moving in the opposite direction can start toward the lock

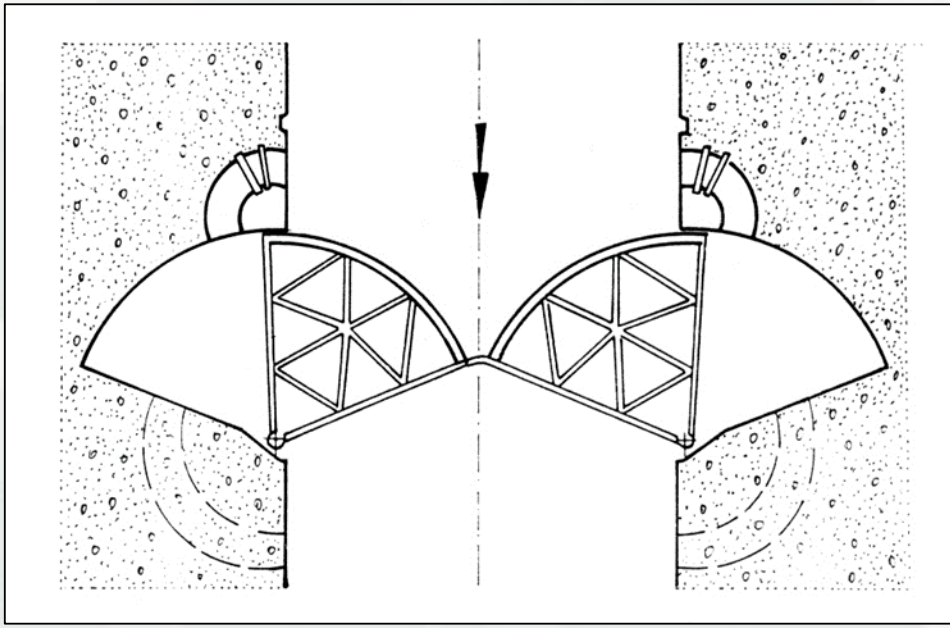
Lock Sizes

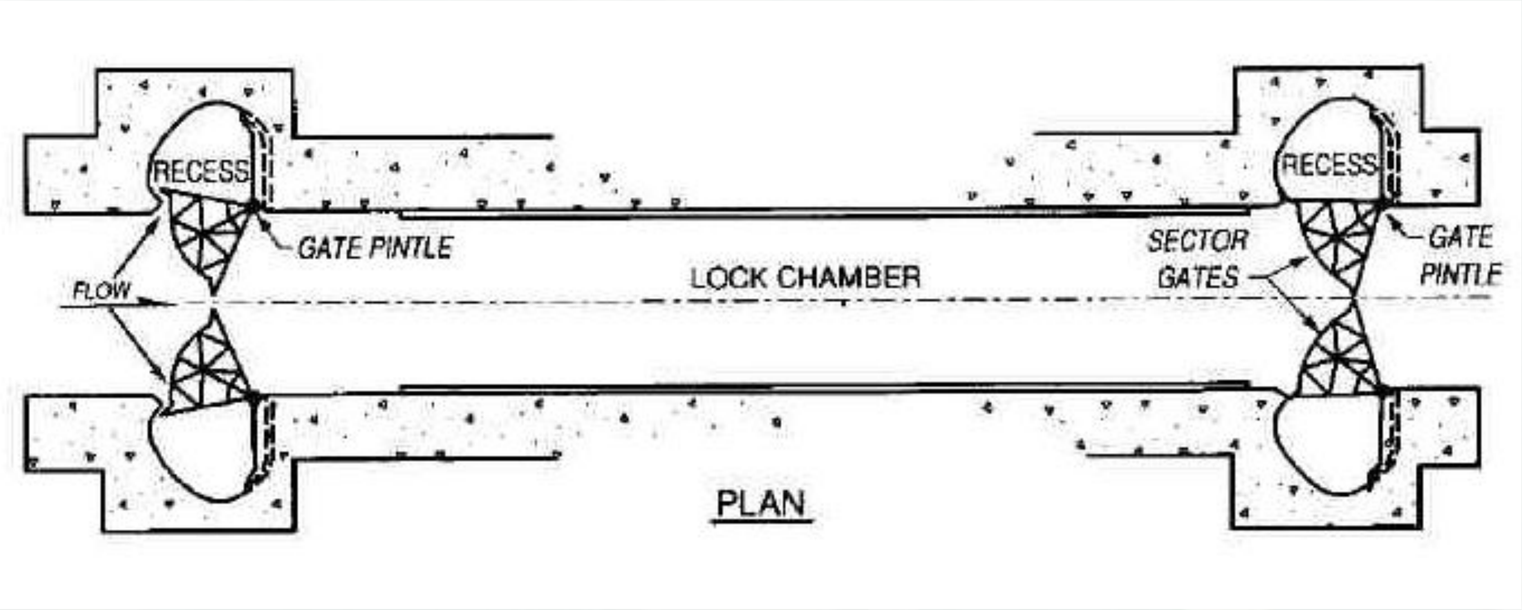
Lock Width, ft	Usable Lock Length, ft
84	400
84	600
84	720
84	1200
110	600
110	800
110	1200
86	675

Classification by Lift

Range of Maximum Design Lift	Project Classification	% of CoE Locks	Suitable Design Types
0 to 10 ft	Very Low Lift	25	End F&E (primarily sector gate)
10 to 30 (or 40)	Low Lift	60	Side-port system or Lateral w/ 1 Culvert
30 (or 40) to 100	High Lift	15	Longitudinal Manifold System
100 to ? (not yet determined)	Very High Lift	0	John Day is the exception w/ design lift of 107 ft

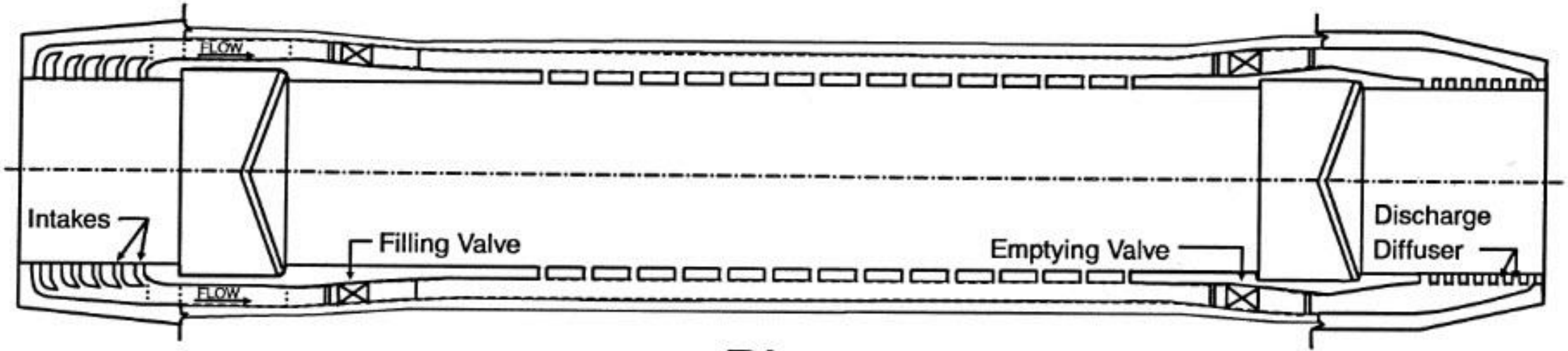
End Filling System, Sector Gates



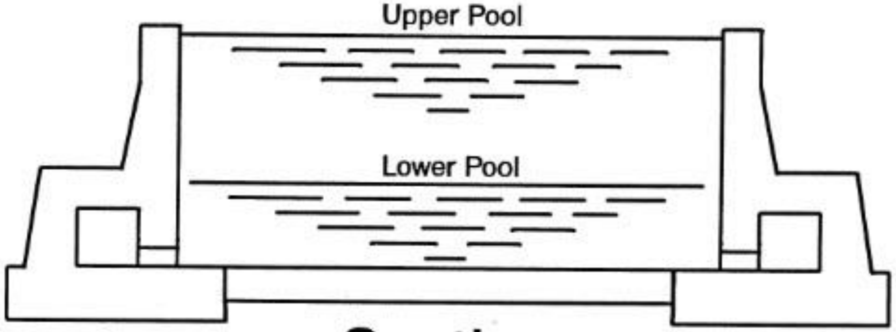


Sidewall Port System

Sidewall Port



Plan



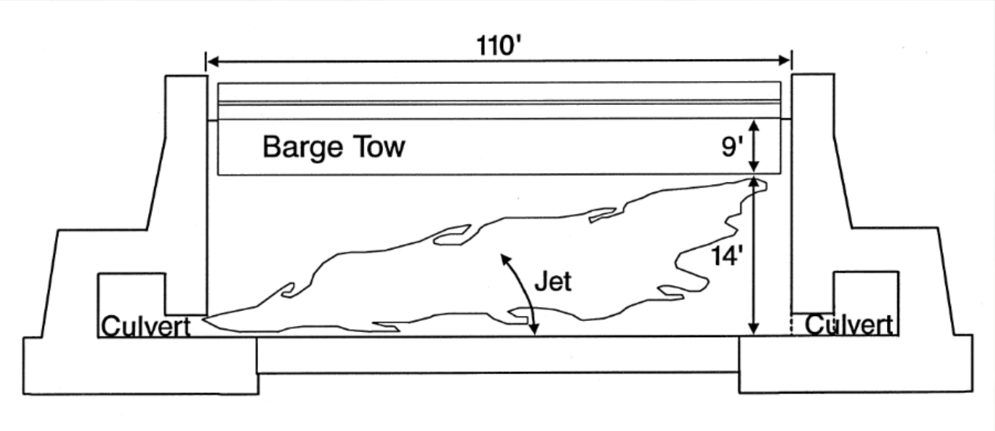
Section

Sidewall Port System

Most widely used (in US) for locks up to 1200’ by 110’ with lift up to about 30’

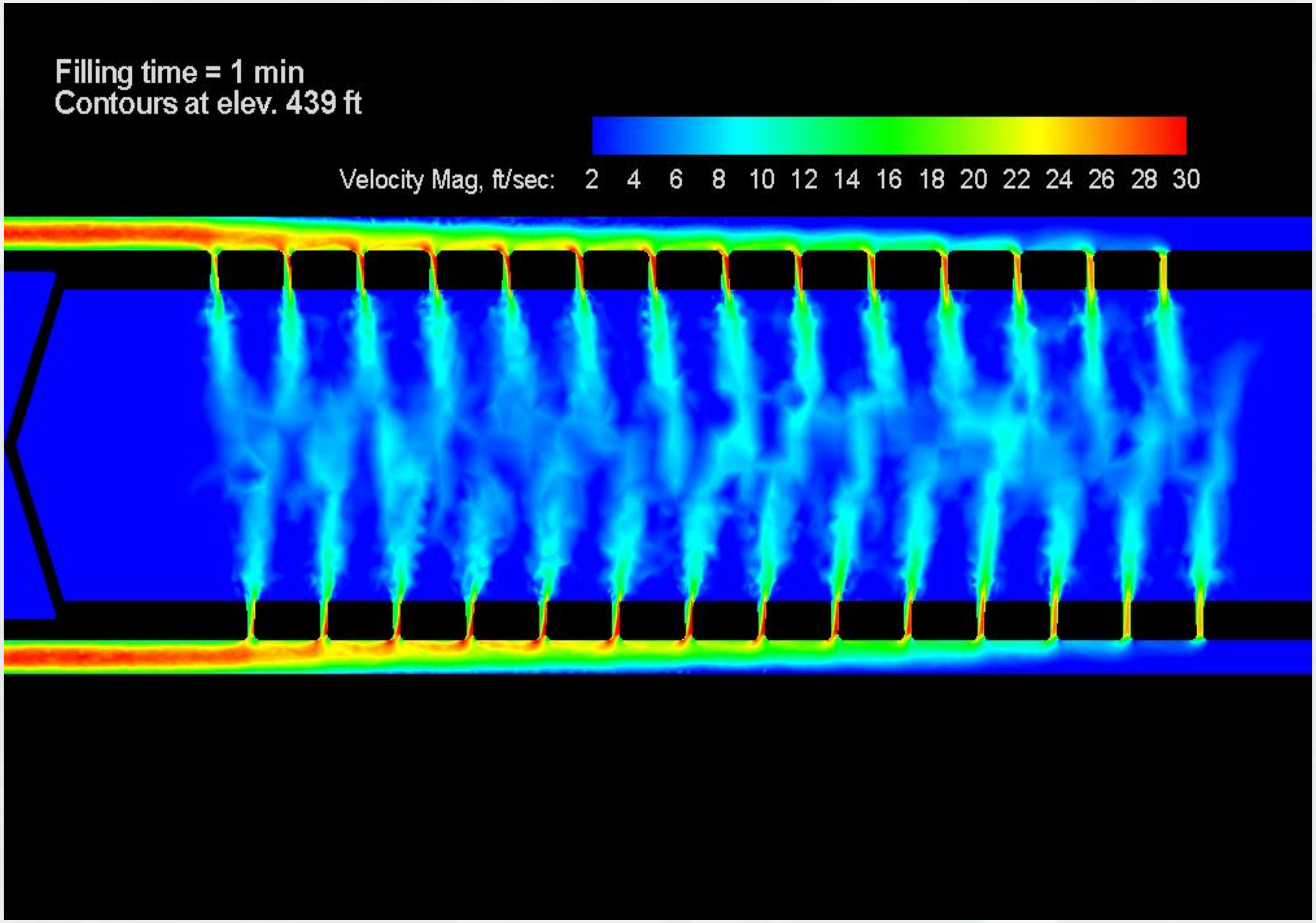
Features

- **Multiport intakes**
- **Ports in each wall are staggered**
- **Reverse tainter valves**
- **Problem: flow from upstream ports occurs first**

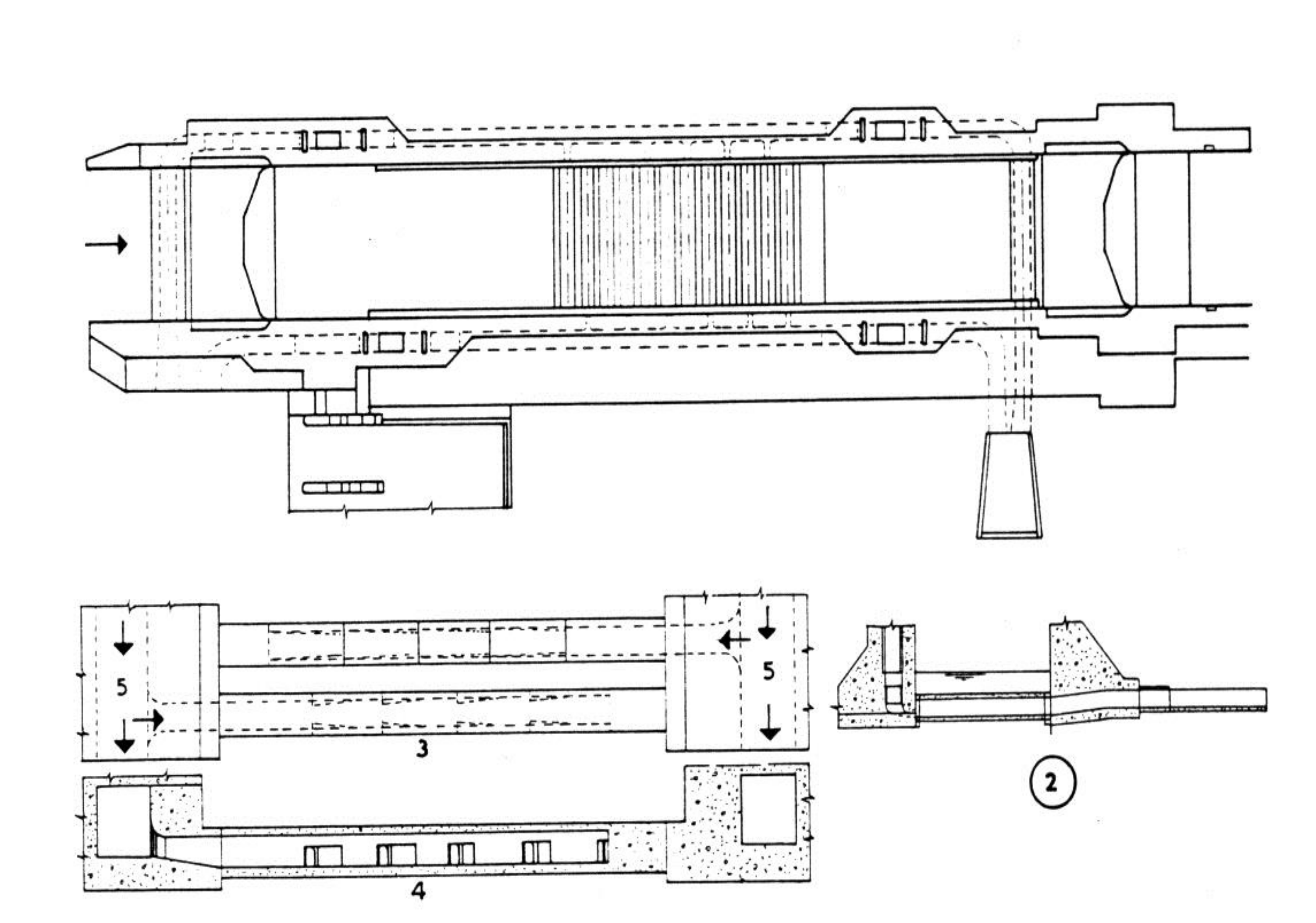


Section View of Sidewall Port System

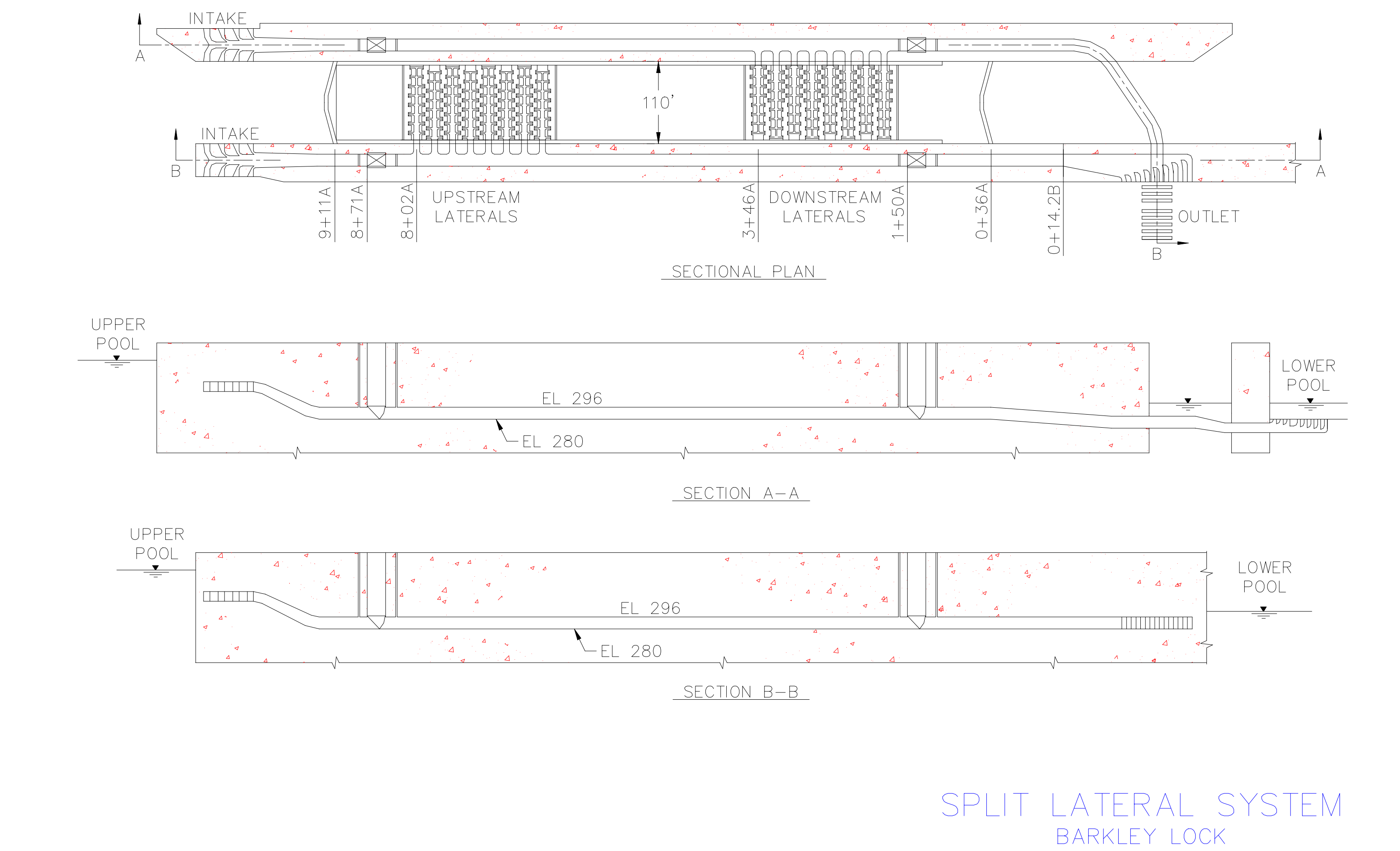
Surface Velocities during Lock Filling, Jets Issuing from Sidewall Manifolds



Interlaced Lateral System



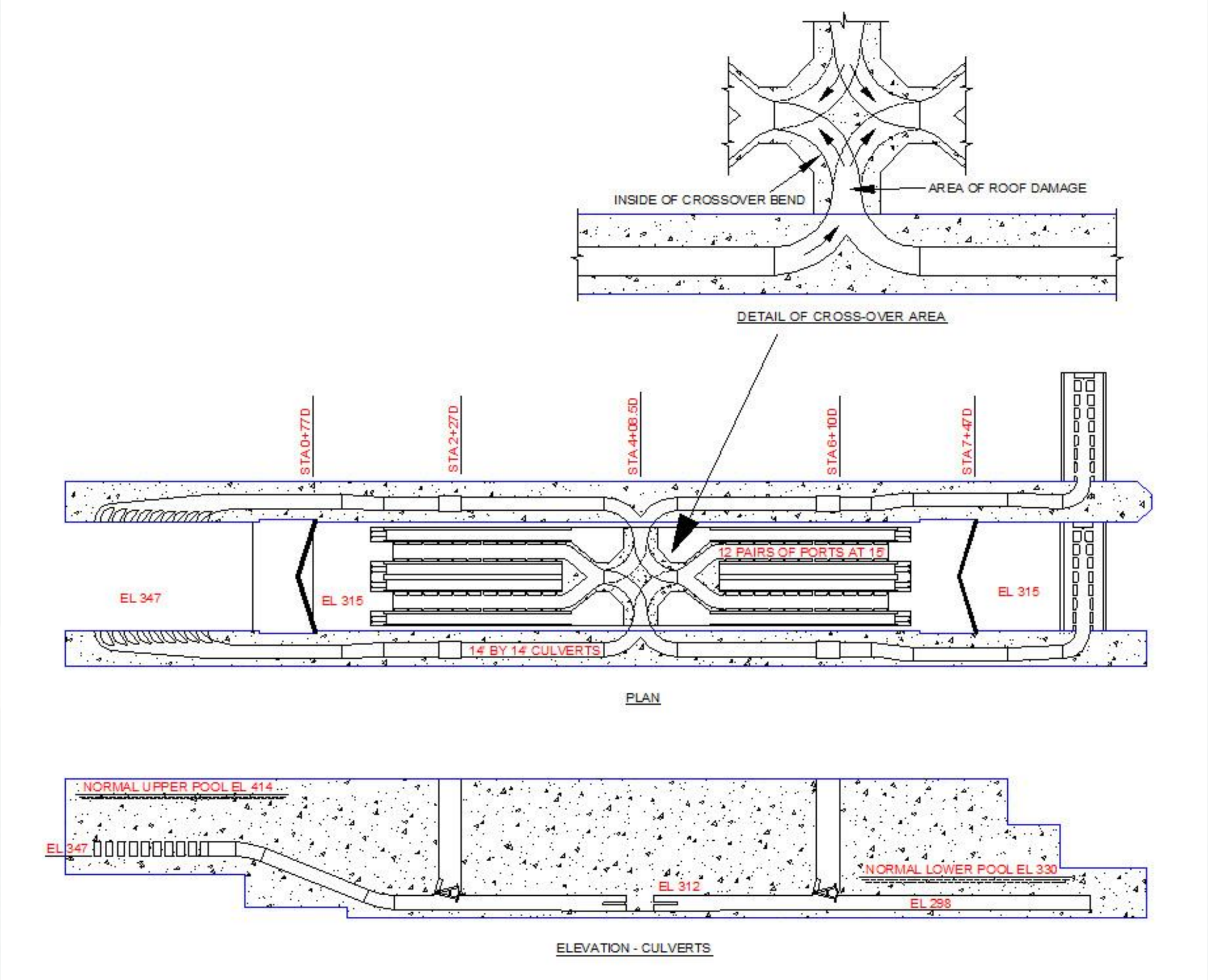
Split Lateral System



Single "H" System

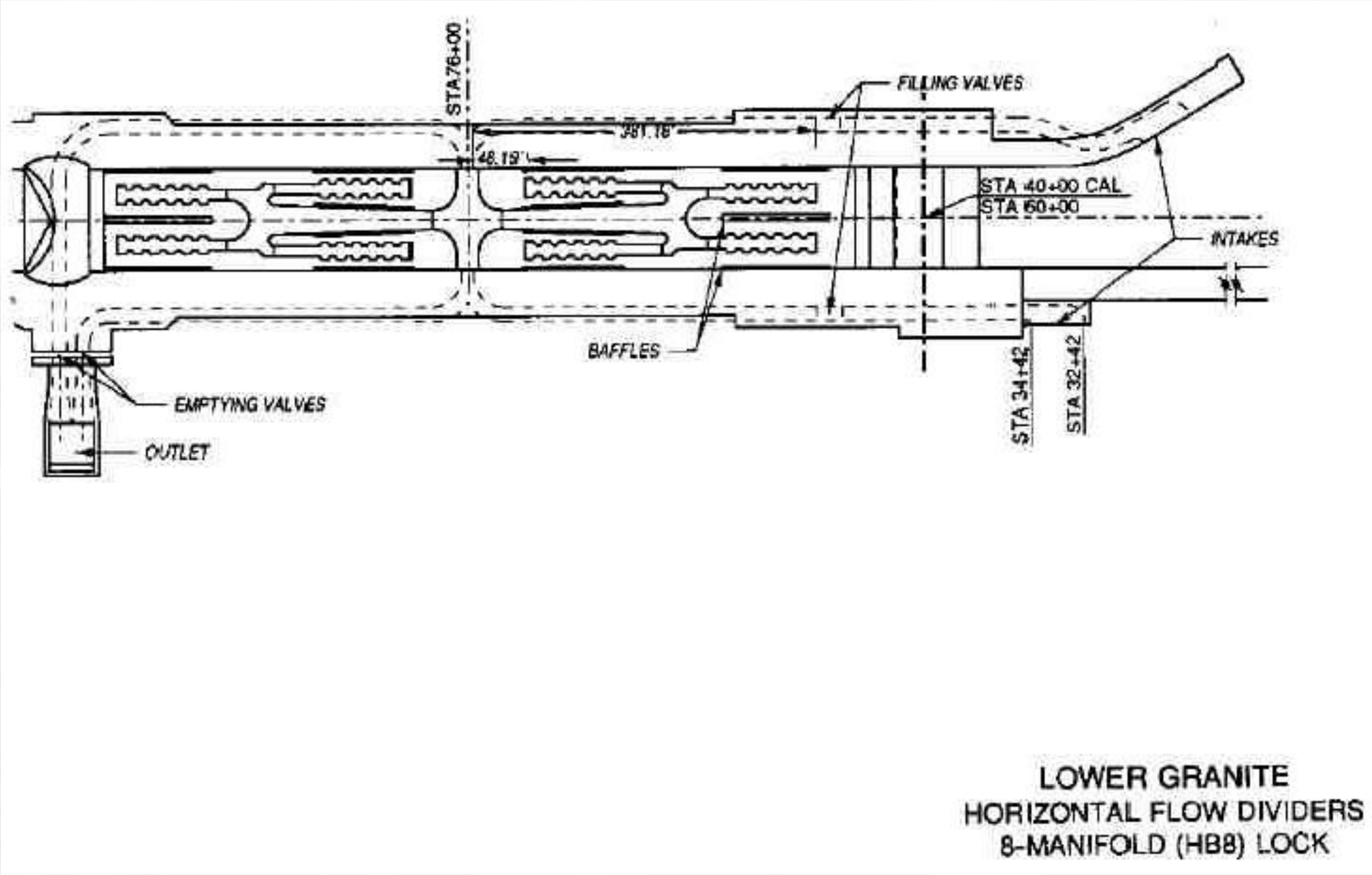
Whitten Lock
Tennessee-Tombigbee Waterway

Single "H" System

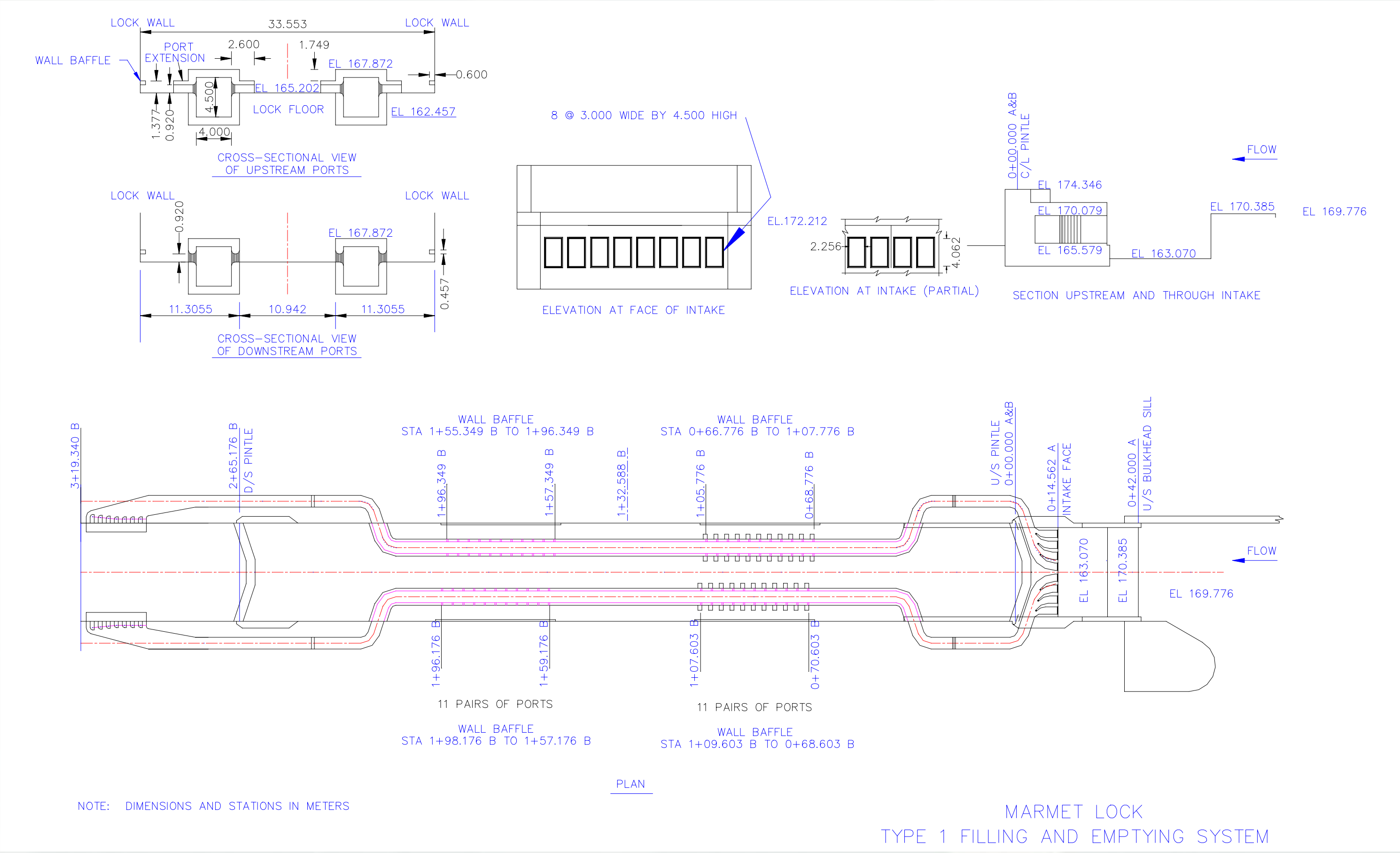


Whitten Lock

Double "H" System

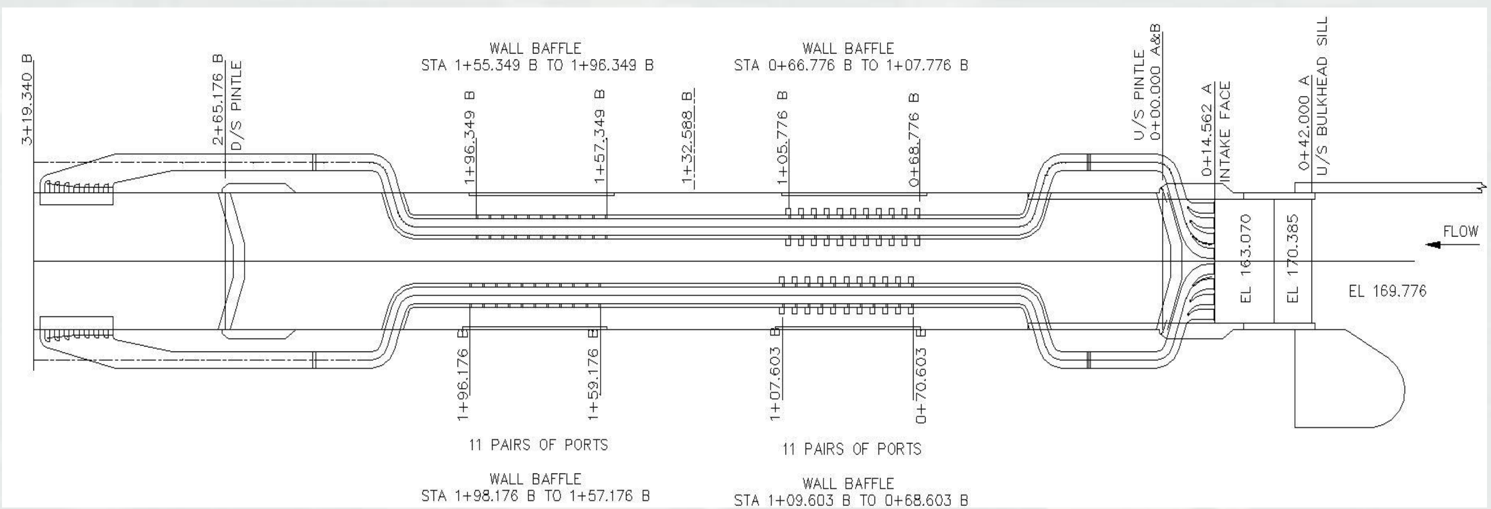


In-Chamber Longitudinal Culvert System (ILCS)



ILCS Design Philosophy

- **Develop a system nearly as efficient as the side-port filling and emptying system**
- **Culverts in the chamber walls are replaced by culverts in the chamber floor**



Marmet Lock

In-chamber Longitudinal Culvert System (ILCS)

Marmet

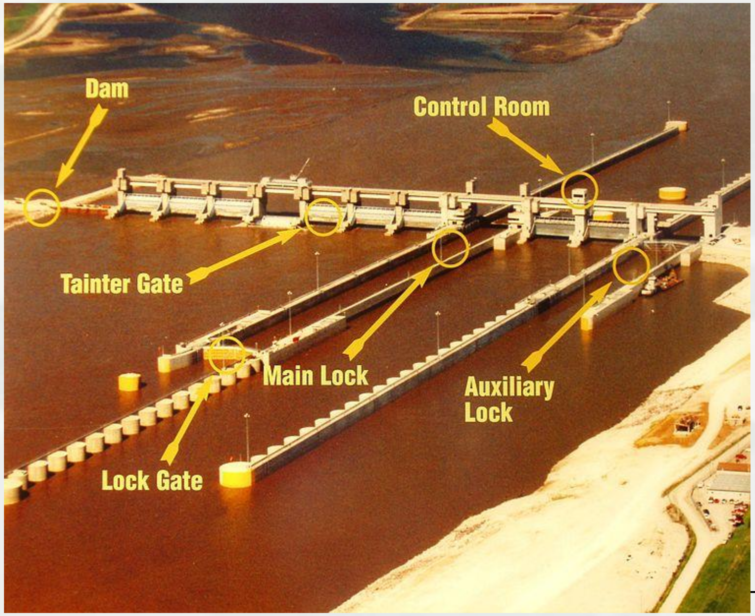
McAlpine

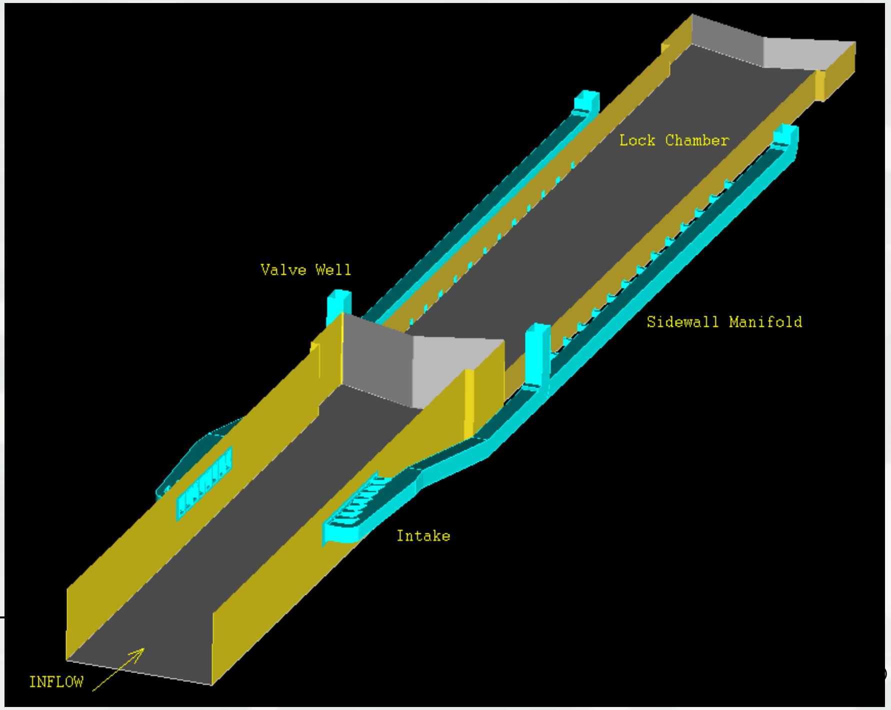
Features of Locks

Guide Walls – essentially continuations of a lock wall- placed at each end to aid towboat pilot in aligning the tow for entry into the lock chamber – used to guide tow into chamber.

Guard Walls – placed at each end of a lock on the opposite side from the guide walls

- **When 2 parallel locks are built adjacent to spillway, a guard wall may be long or longer than a guide wall**
- **Serves as a guard between the navigation channel and the spillway**

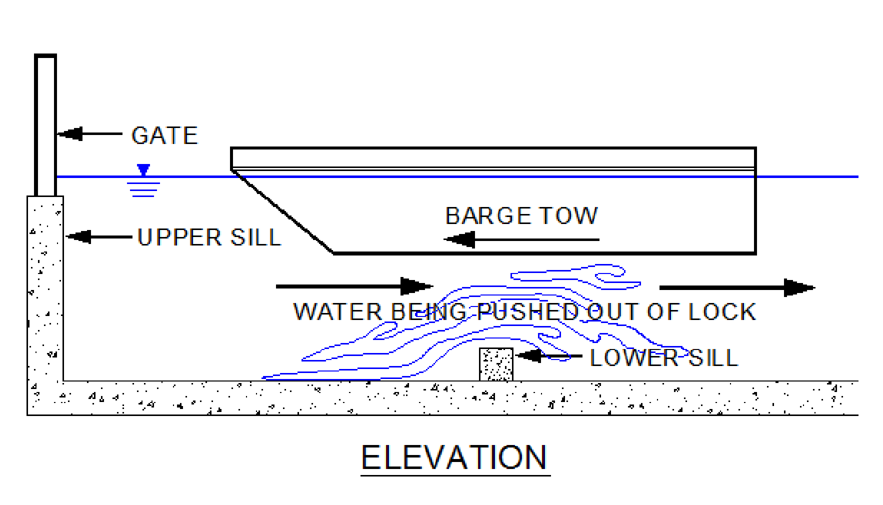




Features of Locks

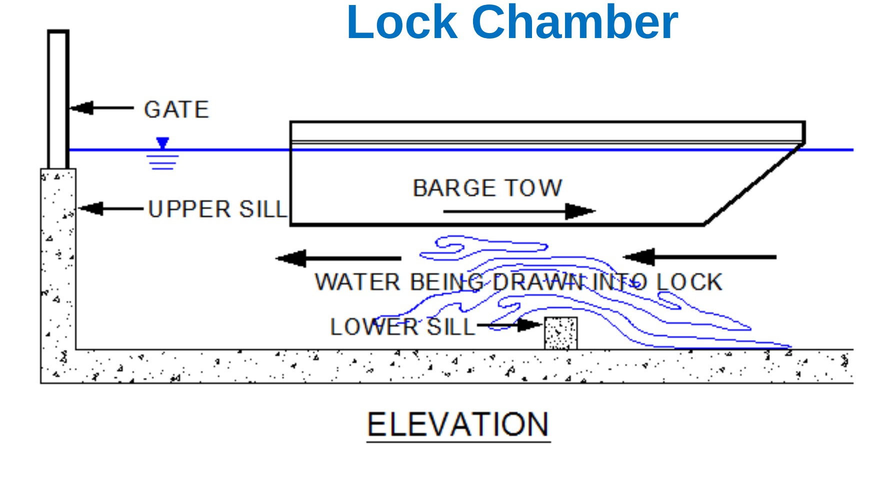
Lock Sills – structure on the bottom across the lock that the gates contact when they are closed.

- **Sill elevation affects the transit time**



Upbound Tow Entering Lock Chamber

Downbound Tow Leaving Lock Chamber



Features of Locks

Lock Gates

Miter Gate – Do not operate under head and can not withstand very much reverse head

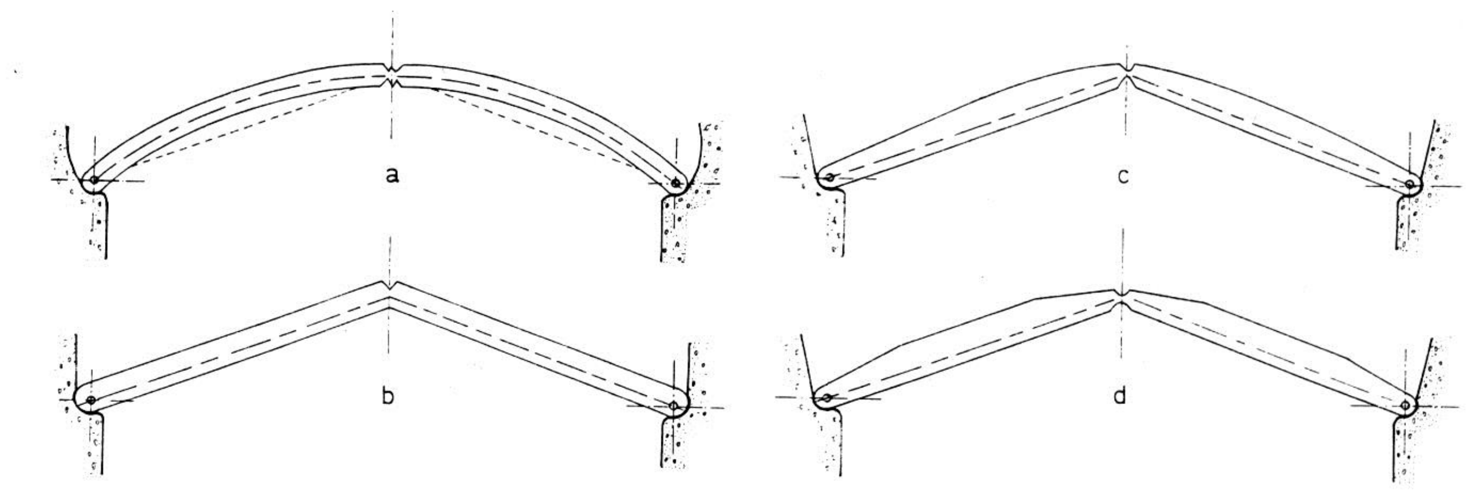


Fig. 14 - Mitre gates; types of construction

Lock Gates

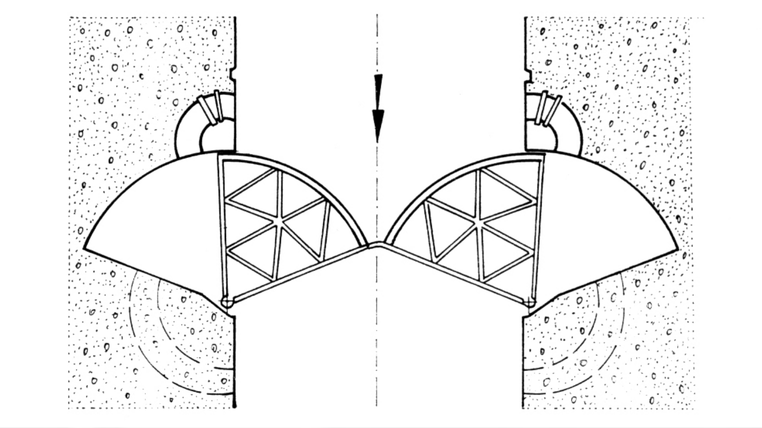
Submergible Vertical-Lift Gate – fit nicely in high-head locks where the recess can be in the upper sill

Overhead Vertical-Lift Gate – used at the downstream gate at high-head projects – less maintenance than submergible gates

Submergible tainter gate

Vertical axis sector gate – like miter gate, these have 2 gates at each end of the chamber – somewhat like tainter gates mounted on vertical axis

- **They are used as end filling in very low lift locks**
- **Can be designed to withstand head from either side so they are ideal for tidal situations that result in reverse head**



Lock Gates

Rolling gate – rolls horizontally across the chamber floor

- **Not used any longer by new USACE designs**
- **Still used on large locks in Europe**
- **Is the design selected for the Panama Canal 3rd Lane Locks**

Tumbler gate – hinged on the lock floor – when open, it lies flat on the chamber floor

Rising sector gate – relatively new gate design horizontal axis trunnion

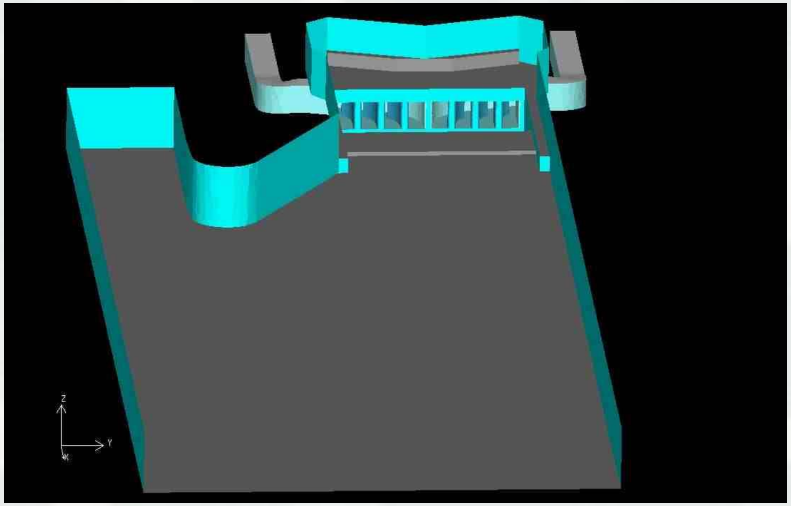
Debris Accumulation

Hydraulic Concerns:

- Develop an operational procedure to flush floating material over the upper sill, through the chamber, and out of the lower approach
- Design of trash bars and trash racks at the intakes to keep submerged material from entering the culvert system
- Gate and sill designs that provide reliable operation in the presence of both submerged and floating debris
- Identify locations along the flow passage boundaries that might require close inspection and major maintenance

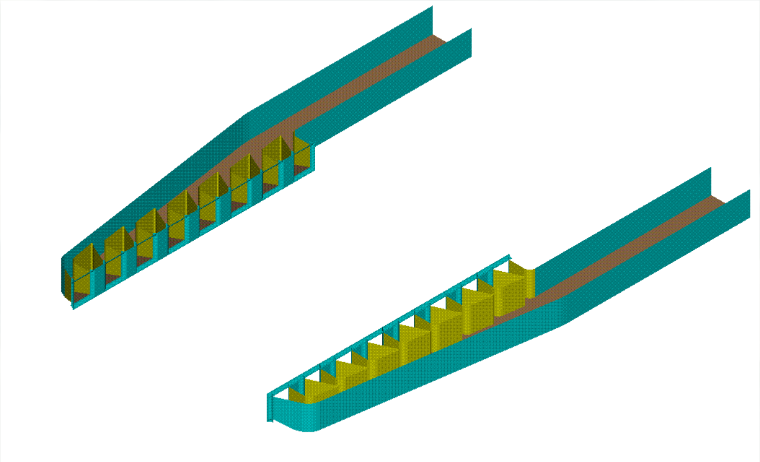
FILLING AND EMPTYING SYSTEM COMPONENTS

Intakes – manifolds designed as a combining flow manifold



Located in Gate Sill

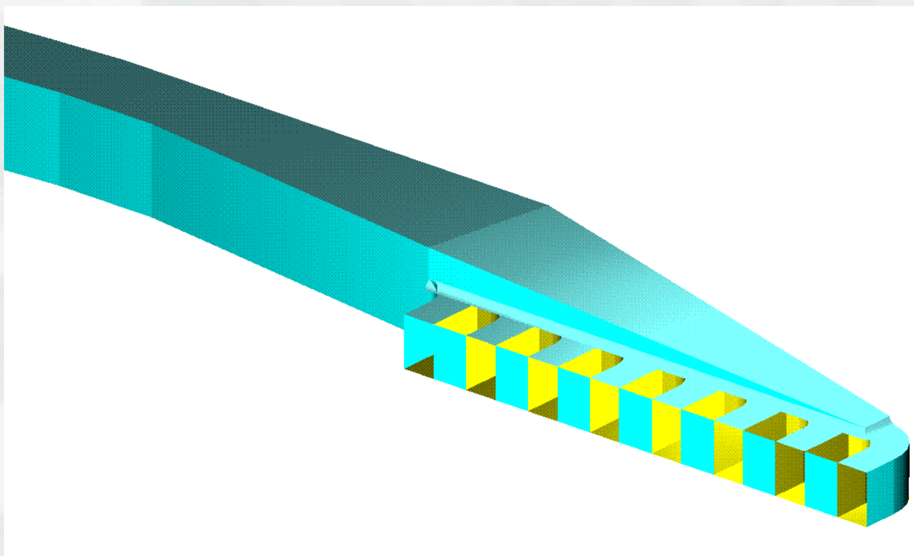
Located in Lock Walls

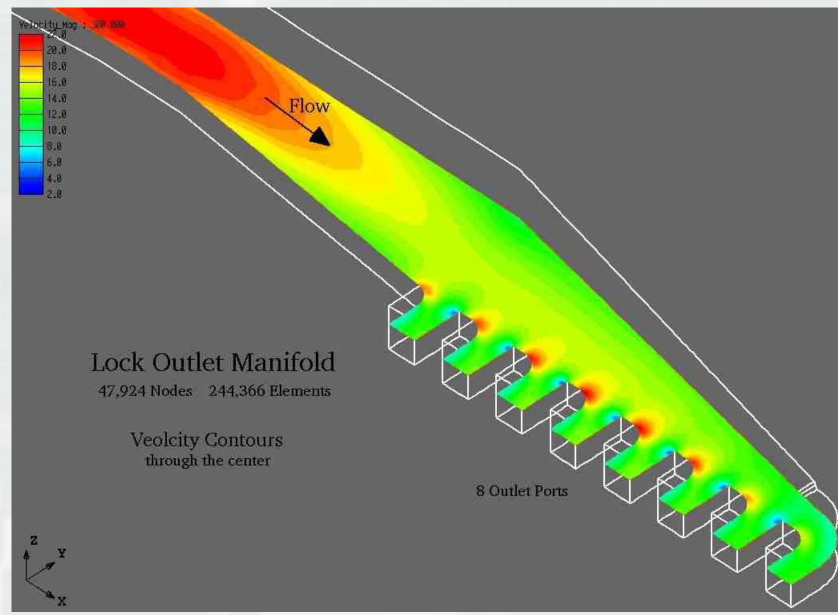


Filling and Emptying Manifolds

- $\Sigma A_p/A_c$ should equal 1.0 (0.95 for sidewall port)
- Round edges (2-way flow)
- Ports spaced according to the jet throw distance from the port face to the impact surface

Discharge Outlets – may be a ported manifold or a "bucket" or a basin with baffle blocks and an end sill

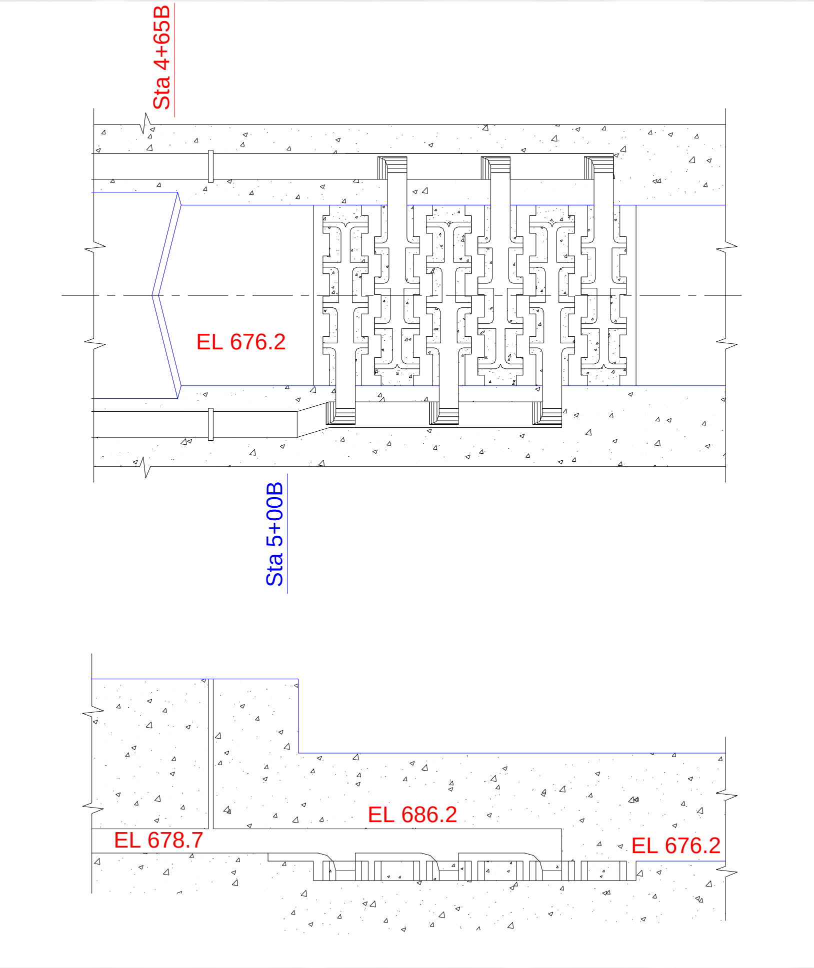




Sidewall manifold

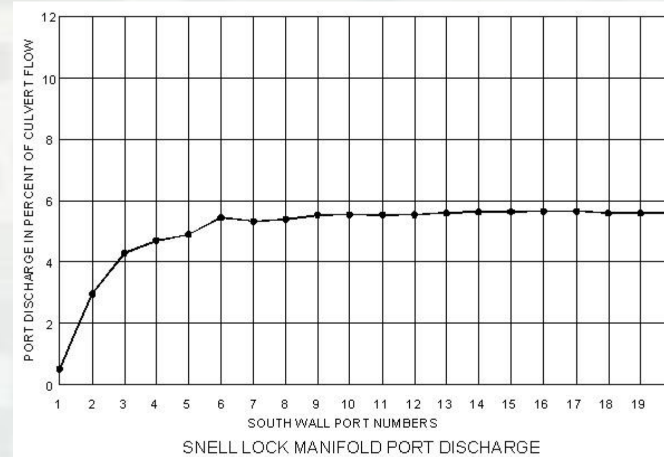
FILLING AND EMPTYING SYSTEM COMPONENTS

Discharge Outlets

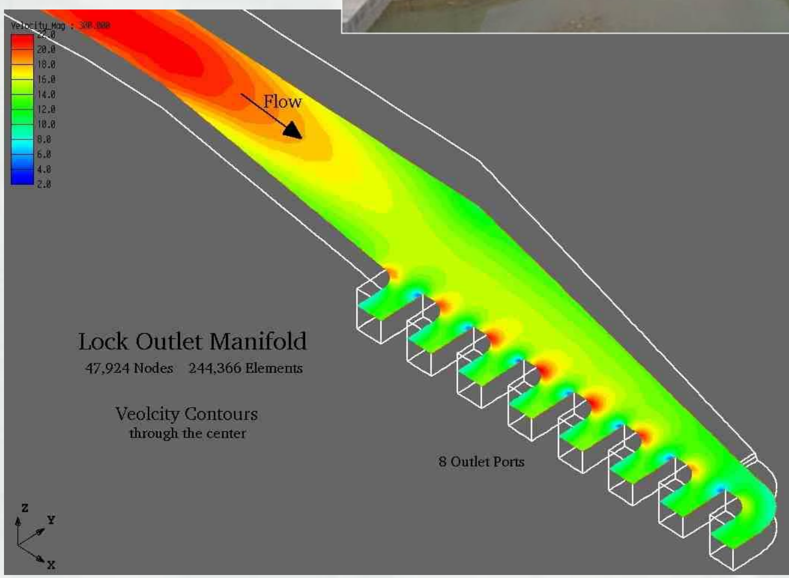


Interlaced Lateral Manifolds

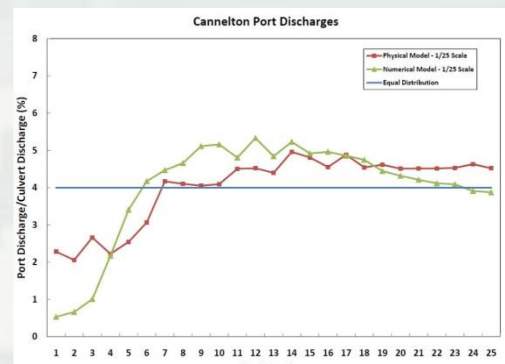
Computing Lock Manifold Flow



1-D Hydraulic Equations



3-D Navier-Stokes Equations



Evaluate performance with simple graph

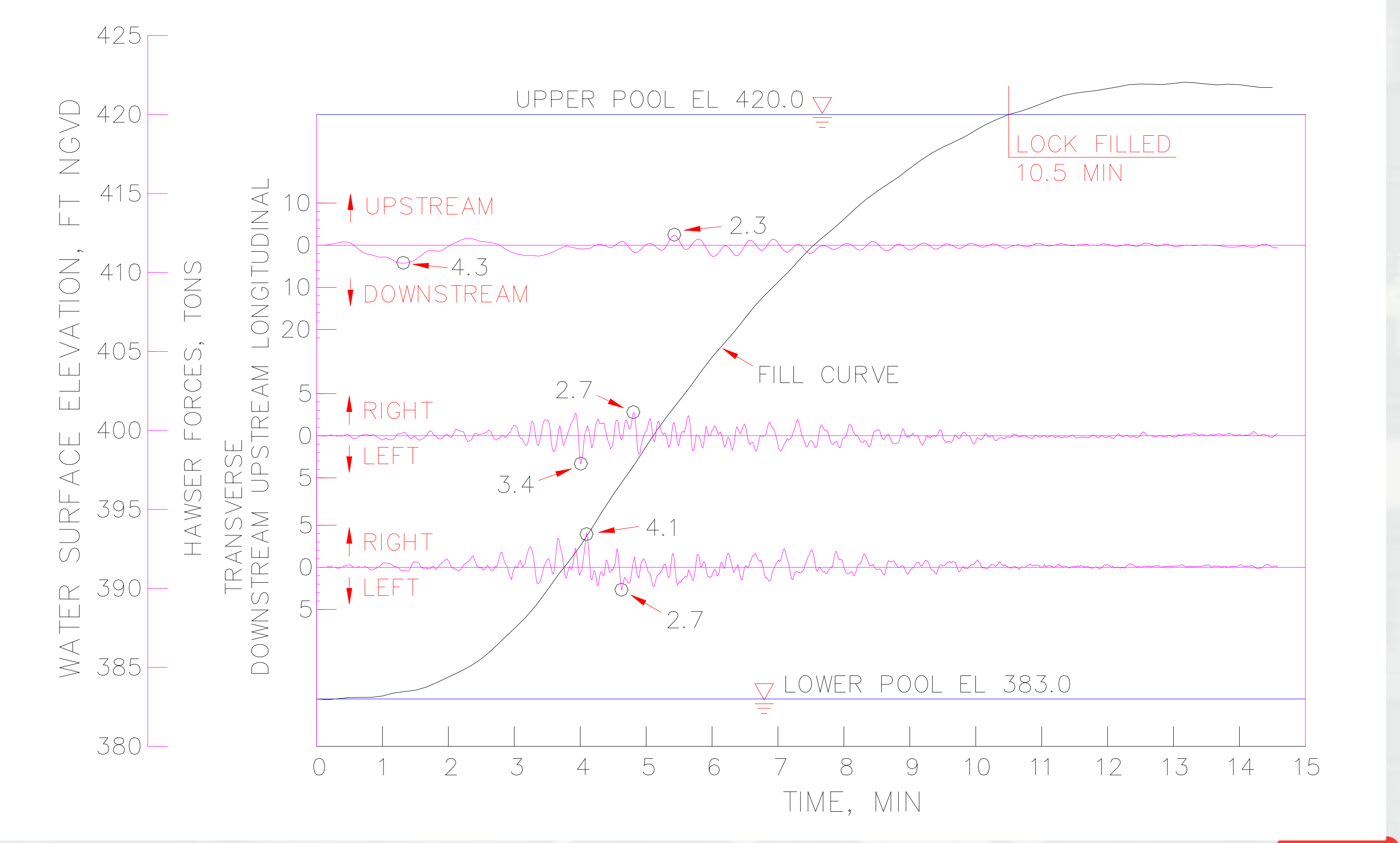
Chamber Performance

Typical model evaluations are based on:

- **Surface currents and turbulence – can not be hazardous to small craft**
- **Free tow drift**
- **Hawser forces – mooring line forces required to hold a vessel in place**

FILLING CHARACTERISTICS

5-min Valve



BUILDING STRONG®

Hydraulic Efficiency: Lock Coefficient

PILLSBURY EQUATION

$$T = \frac{2A_S}{C_L 2A_C \sqrt{2g}}\left(\sqrt{H+d} - \sqrt{d}\right) + Ut_v$$

Where:

T = operational time required to fill the lock
t_v = valve operation time
A_s = surface area of lock chamber
$2A_c$ = area of culverts at the valves (assuming 2 valves)
C_L = lock coefficient
H = head (or lift)
d = overfill or overempty
U = valve coefficient

HYDRAULIC COEFFICIENTS

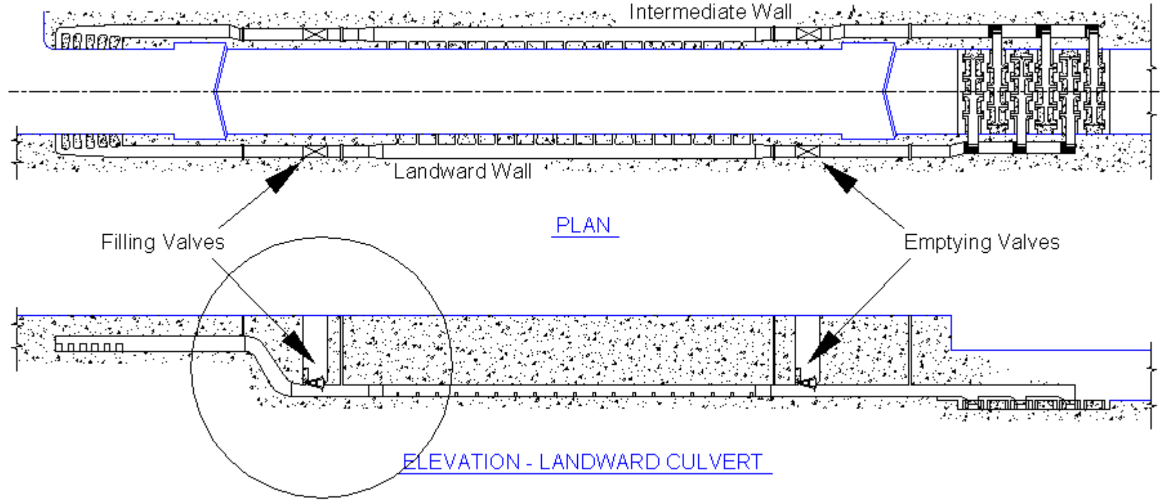
$$H_{L_i} = K_i \frac{V_i^2}{2g}$$

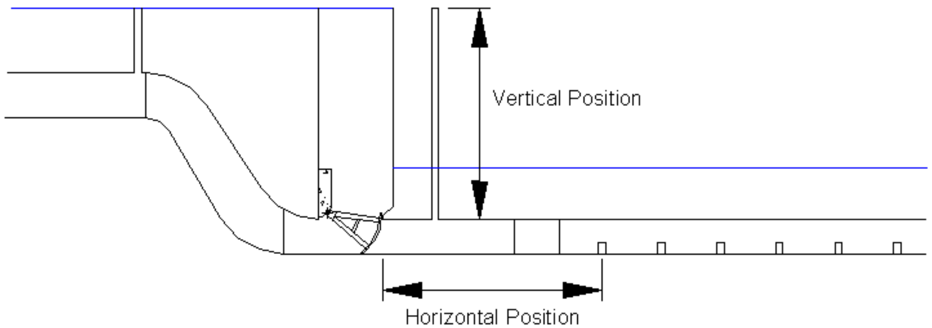
Published Coefficients often don’t apply to lock analysis because:

- **Lock culverts are short and stubby**
- **Elements are close to each other**

The velocity is computed using the Valve Area

Valve Position





Cavitation Index

$$\sigma = \frac{P + (P_a - P_v)}{V^2/2g}$$

Horizontal – Farrel and Ables (1968) found that first 2-4 ports can be located in valve's low pressure zone

Vertical – Cavitation Potential (Cavitation Index > 0.6)

- **Either high enough to draw air or**
- **Deep enough to ensure positive pressure**

PRESSURES DOWNSTREAM OF VALVES

Flow is controlled by the valves
Typically, reverse tainter valves
Low pressure zones are located in the area of contracted flow

$V = Q/A$ $A \downarrow$ at a contraction, so $V \uparrow$ and $P \downarrow$

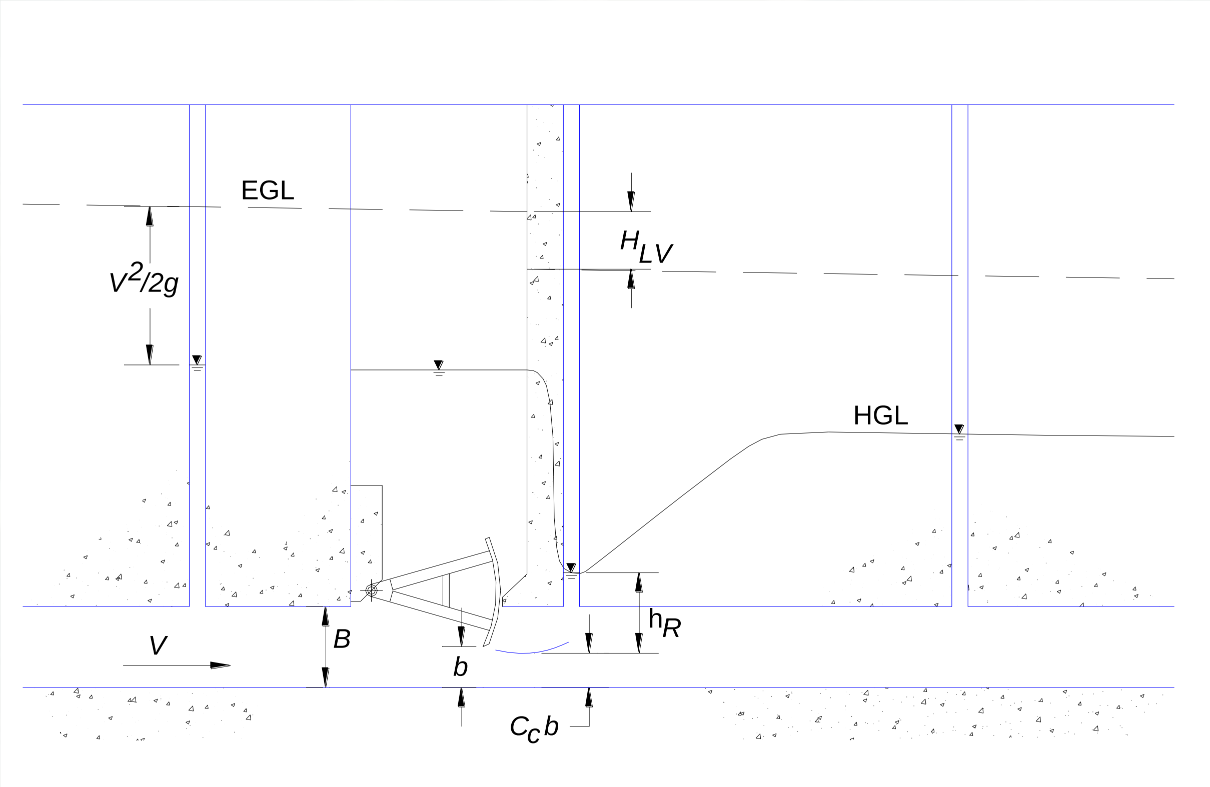
Where P = pressure at the contraction

- **Slower valve times result in longer periods of contracted flow**
- **Inertial effects suggest that high-head locks operate with fast valve openings, so that the concentrated flow period is small.**

PRESSURES DOWNSTREAM OF VALVES

Cavitation Index

$$\sigma = \frac{P + (P_a - P_v)}{V^2/2g}$$



Reverse Tainter Valve Schematic

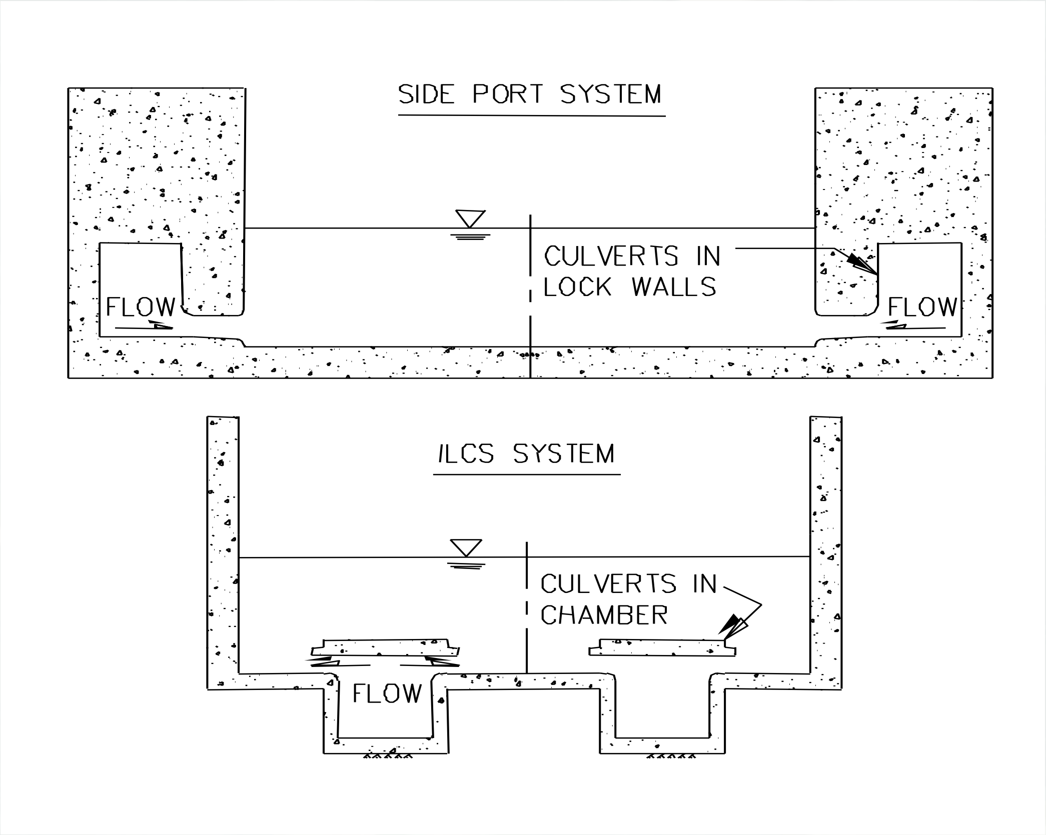
Recent Designs

In-Chamber Longitudinal Culvert System (ILCS)

- New lock designs have been developed to save construction, and operation and maintenance costs
- 2 newest locks have used ILCS designs
  - New McAlpine Lock, Ohio River (37' lift)
  - New Marmet Lock, Kanawha River (24' lift)

Completed Marmet Lock

ILCS Offers Potential Cost Savings in Wall Construction

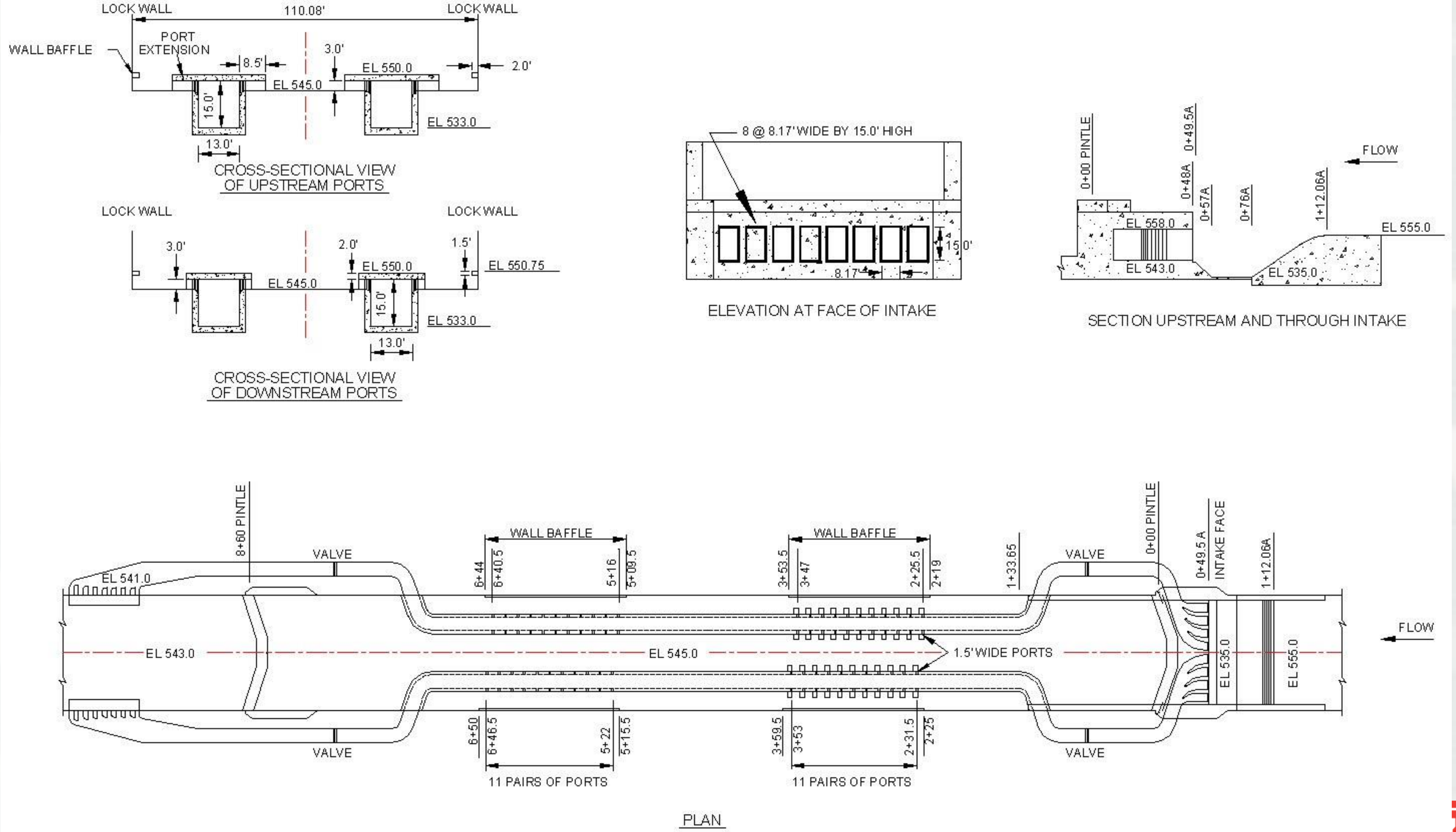


Culvert Locations for the Sidewall Port and ILCS Filling and Emptying Systems

Sidewall Port System

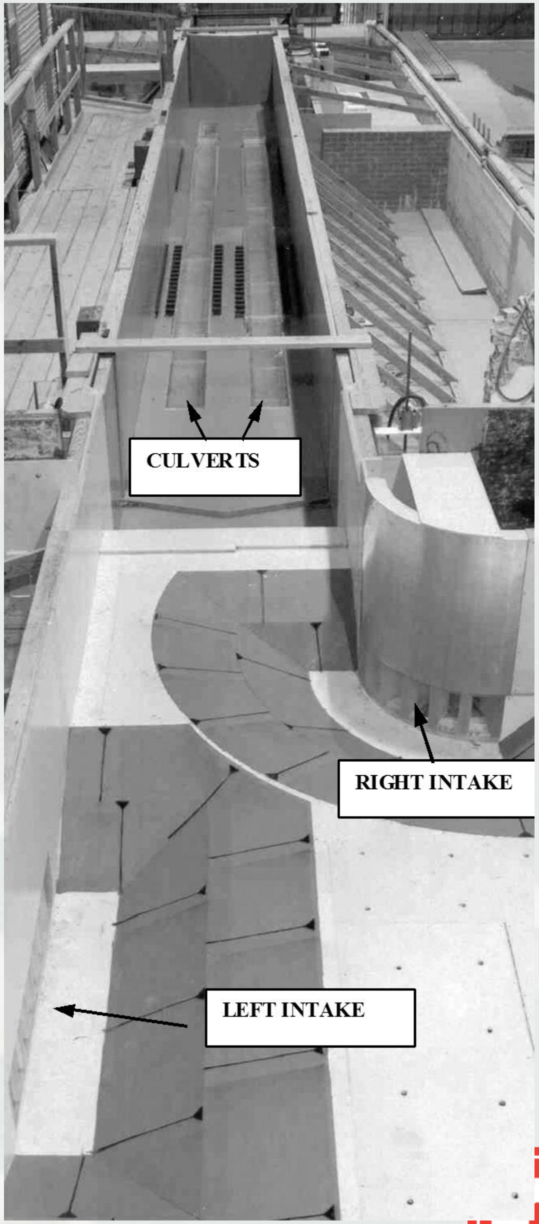
In-chamber Longitudinal Culvert System

In-chamber Longitudinal Culvert System (ILCS)

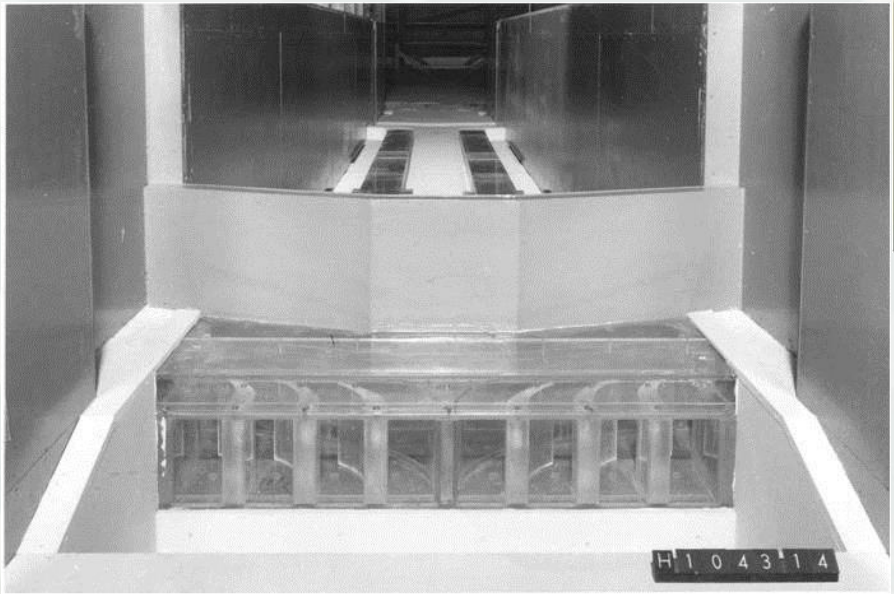


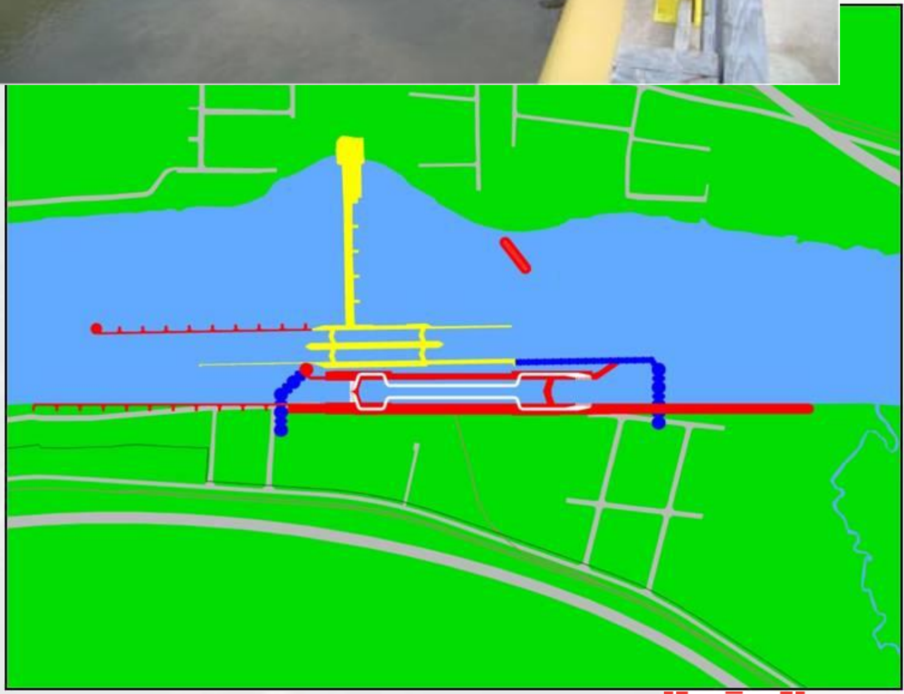
Intake Manifolds McAlpine Lock

Layout Fit
Existing Conditions



Intake Manifolds Marmet Lock





Through-the-Sill Design Reduced Cofferdam Size

Lock Coefficients - Previous Model Studies

Filling: Side Port = 0.73, ILCS = 0.64

Project	Filling and Emptying System	Initial Head, m	Lock Coefficient		Reference
			Filling	Emptying	
Cannelton Model Type 45 Port Arrangement	Sidewall Port	6.1	0.74	0.57	Ables and Boyd (1966a)
		7.9	0.74	0.60	
		9.1	0.73	0.61	
		12.2	0.74	0.60	
Cannelton Model Type 100 Port Arrangement	Sidewall Port	6.1	0.71	0.56	Ables and Boyd (1966a)
		9.1	0.73	0.56	
		12.2	0.74	0.56	
Arkansas River Model	Sidewall Port	3.0-15.2	0.73	0.67	Ables and Boyd (1966b)
Marmet Model Type 5 Chamber Design	ILCS	4.3	0.63		Hite (1999)
		7.3	0.63		
		10.4	0.63		
McAlpine Model Type 1 Chamber Design	ILCS	11.3	0.63	0.56	Hite (2000)
McAlpine Model Type 11 Chamber Design	ILCS	11.3	0.65	0.57	Hite (2000)

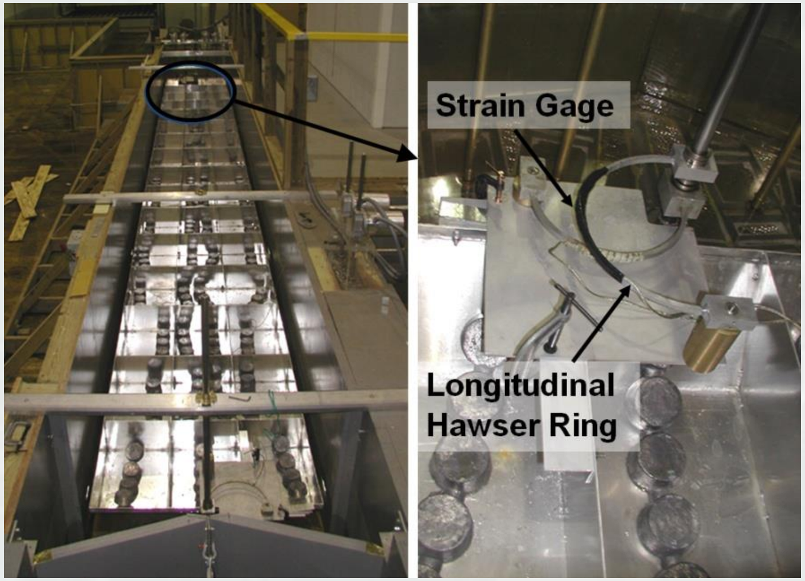
ILCS Manifolds

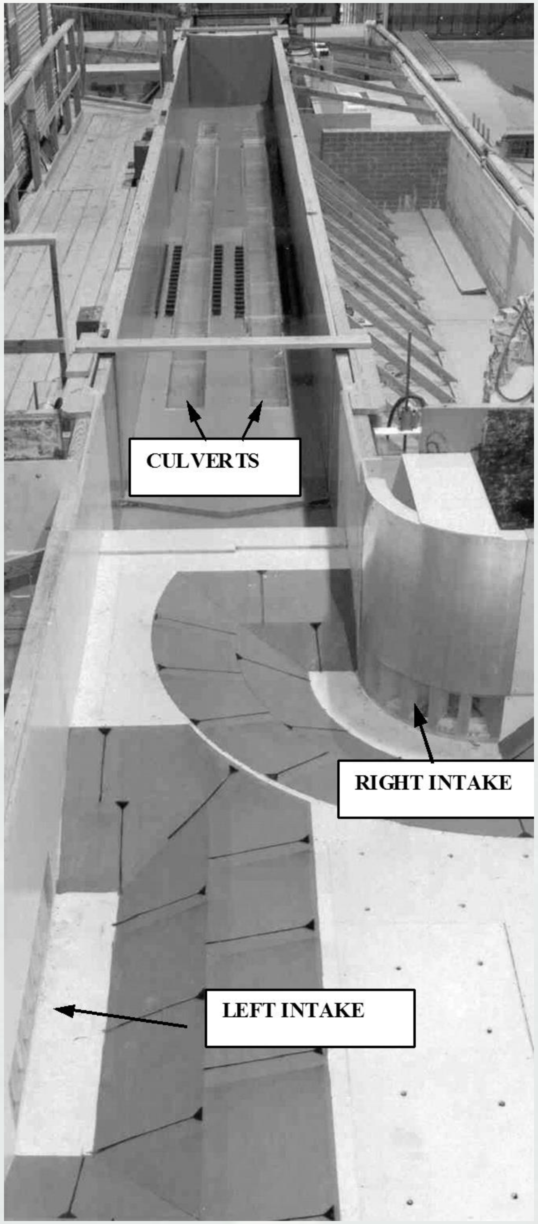
- Allow for alternative lock wall construction, such as RCC or in-the-wet construction
- Port extensions and wall baffles provide uniform distribution of flow and dissipate energy

ILCS Research

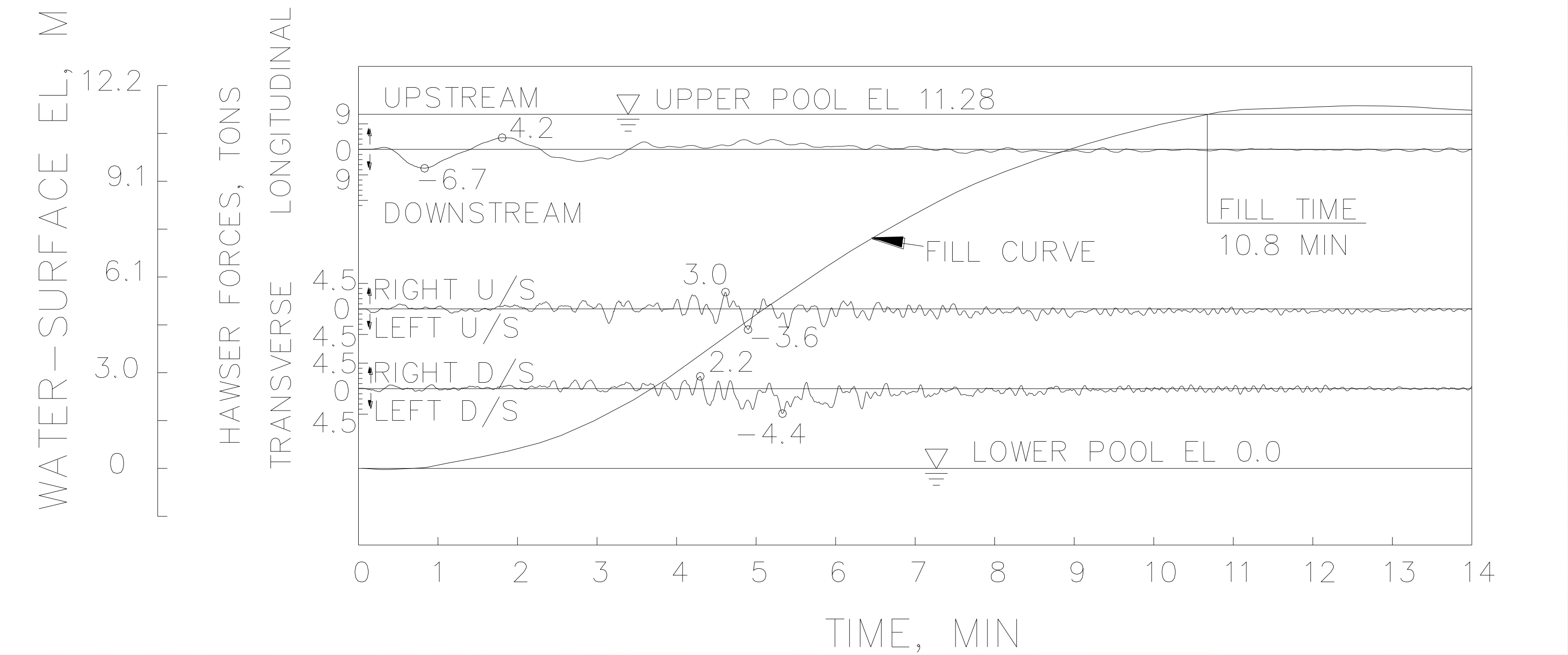
1:25-Scale Hydraulic Model

- **Hawser Forces**
- **Filling & Emptying Times**



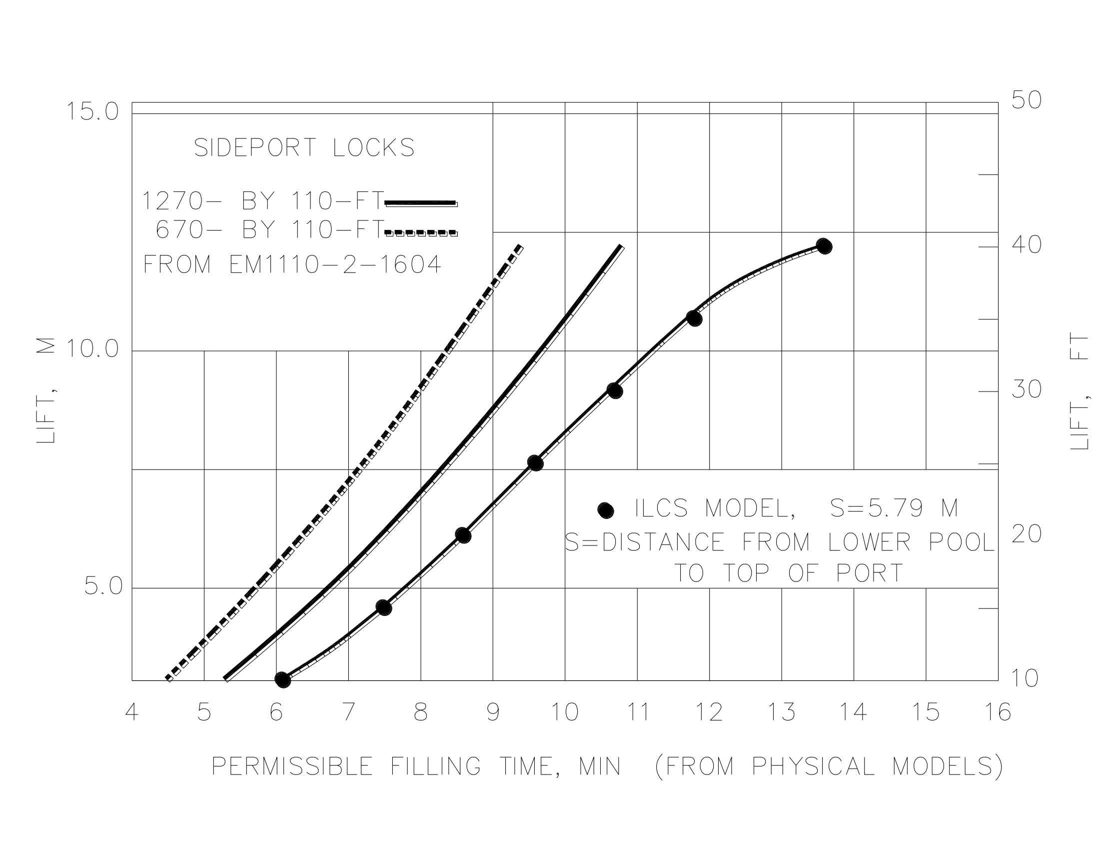


ILCS – Filling Characteristics



11.28-m lift, 5.79-m submergence, 5-min normal valve

Permissible Filling Times



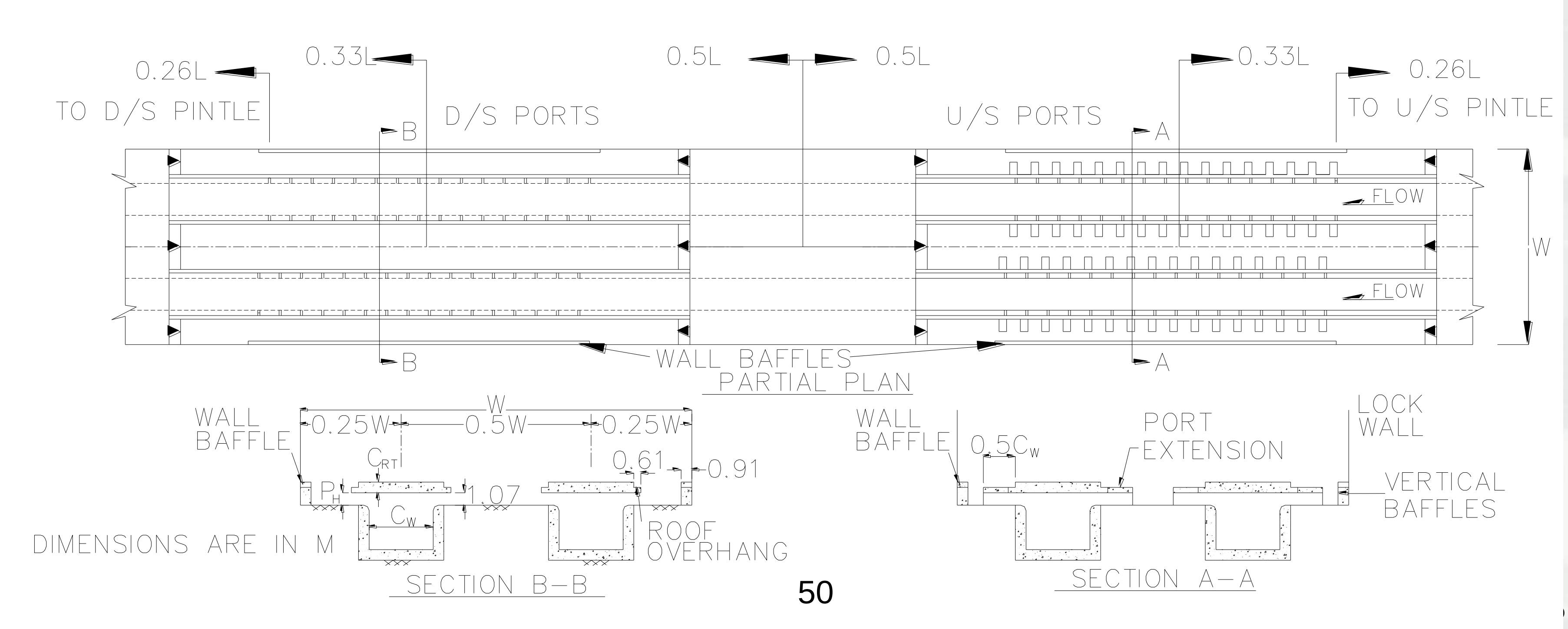
Sidewall Port System Allows Faster Filling than ILCS

ILCS Design Guidance

<u>Ports:</u>

- **Spacing – chamber width dependent (~ 12m)**
- **Number – port-to-culvert ratio about 0.96**
- **2 Groups – at 1/3 points of chamber length**
- **Extensions – needed on upstream group**

<u>Wall Baffles:</u> diffuse port jets near lock floor and inhibit upwelling along walls



Questions?