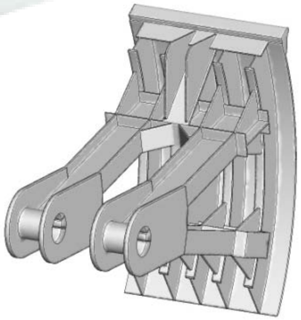
Repair and Replacement Guidance for Lock Culvert Valves
or
The Lock Valves are Worn Out, Now What?



U.S. Army Corps of Engineers
Navigation Structures Research Program

U.S. Army Engineer Research & Development Center
Coastal and Hydraulics Laboratory
Navigation Branch

Richard Stockstill

Current Situation

Design Life

- Many structures have reached or exceeded their design life.
- Valves are being repaired or replaced.

Engineering Design

- Maintenance, rehab, or replacement of lock valves often requires engineering design.
- EM 111-2-1610 “Hydraulic Design of Lock Culvert Valves” has not been updated since 1975.

O & M Experience

- Some replacement valves have not performed well
  - Larger hoist loads – both downpull and uplift.
  - Vibration issues.
- Field measurements suggest that current design guidance under-predicts hoist loads.

Webinar Outline

- References: Sources of Information
- Lock Filling & Emptying Systems
- Types of Lock Valves
  - Vertical Lift
  - Conventional Tainter
  - Reverse Tainter
- Hydraulics of Lock Valves
  - Flow Conditions during Operation
  - Cavitation Potential
- Hoist Loads
- Repair & Replacement Project Examples
  - Watts Bar Lock – Tennessee River
  - Snell & Eisenhower Locks – St. Lawrence Seaway
  - Bankhead Lock – Black Warrior River
  - John Day Lock – Columbia River
- Valve Stabilizers
- Summary

USACE HQ Engineering Manuals

EM 1110-2-1604
1 May 2006

US Army Corps
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ENGINEERING AND DESIGN

**Hydraulic Design
of Navigation Locks**

ENGINEER MANUAL

EM 1110-2-1610
30 September 2014

US Army Corps
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ENGINEERING AND DESIGN

Hydraulic Design of Lock Culvert Valves

DRAFT

ENGINEER MANUAL

Hydraulic Design

EM 1110-2-2602
30 September 1995

US Army Corps
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ENGINEERING AND DESIGN

**Planning and Design
of Navigation Locks**

ENGINEER MANUAL

Planning

EM 1110-2-2610
30 June 2013

US Army Corps
Of Engineers

ENGINEERING AND DESIGN

**Mechanical and Electrical Design for
Lock and Dam Operating Equipment**

ENGINEER MANUAL

Mechanical & Electrical Design

Corps' Design Guidance

Hydraulic Design

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

Mechanical Design

- **EM 1110-2-2610 "Engineering and Design – Lock and Dam Gate Operating and Control System"**

General Discussion

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

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Navigation Structures Research Program Publications

ERDC/CHL CHETN-X-x
June 2013

US Army Corps of Engineers®

Hydrodynamic forces on reverse tainter valves; hydraulic model investigation

by Richard L. Stockstill, E. Allen Hammack, David S. Smith, Jane M. Vaughan, and Keith Green

BACKGROUND: The maintenance, rehabilitation, or replacement of lock culvert valves is an issue that many U.S. Army Corps of Engineers (USACE) offices are dealing with partly because many of the navigation locks maintained by the USACE have reached or are beyond their design life. Reverse tainter valves are the most common valve type found on navigation locks constructed by the USACE (Pickett and Neilson 1988 and Headquarters, USACE 1975). Virtually all locks constructed in the United States since 1940 have had reverse tainter valves (Davis 1989).

This technical note presents laboratory data of loads on vertical-frame and double-skin-plate valve designs. The objective is to point out differences in resultant forces for these two reverse tainter valve designs. A physical model was instrumented with a load cell to measure hoist loads. Trunnion loads were subsequently calculated from the measured hoist loads, valve weight, and geometry. Comparison is made between the hoist and trunnion forces acting on a vertical-frame and a double-skin-plate valve.

The geometric and hydraulic parameters describing a reverse tainter valve are shown in Figure 1. Lock culvert flow is controlled by rotating the valve about the trunnion axis. The valve position is commonly listed as the ratio b/B, where b is the distance from the valve lip to the culvert floor and B is the culvert height upstream and downstream of the valve.

PHYSICAL MODELING FACILITY: Completion of a physical model study of the culvert valves of the Eisenhower and Snell Locks, St. Lawrence Seaway (Stockstill et al. 2013), provided the opportunity to study the differences in vertical-frame and double-skin-plate valve designs. The lock valves were modeled at a scale of 1:15 in a test facility (Figure 2) that reproduced the valve, valve well, bulkhead slots, and approximately five culvert heights upstream and twelve culvert heights downstream of the valve. The upper pool was represented with a pressure tank. Culvert pressure was regulated with a slide gate located near the end of the culvert. The valve well, bulkhead slots, and culvert were constructed of transparent plastic to permit observation of flow. Water was supplied to the model through a circulating system in which discharge was measured using a standard orifice meter in the supply line upstream of the model.

Physical Model

ERDC/CHL CHETN-IX-x
September 2013

US Army Corps of Engineers®

Field experience with lock culvert valves

by E. Allen Hammack, Richard L. Stockstill, and Thomas E. Hood

INTRODUCTION: Many of the nation's navigation structures have reached their design life thereby making maintenance, rehabilitation, or replacement of their lock culvert valves a critical concern. Valves are regularly inspected and evaluated for repair and replacement, however these tasks becomes more costly as the structure ages.

The reverse tainter valves are the most common valve type found on major locks constructed by the U.S. Army Corps of Engineers (USACE). There are three structurally different types of reverse tainter valves: horizontally framed, vertically framed, and double-skin plated (Headquarters, USACE 2006). The horizontal-frame valve are restricted for use on lifts less than 30 ft because the vertically-framed and double-skin-plate valves are less susceptible to critical hydraulic loads and load variations during the opening cycle.

The objective of this technical note was to identify lock culvert valve issues that challenge the USACE's as it continues to provide reliable transport at navigation projects. A survey of navigation projects, with particular interest in lock culvert valves, was made to identify common issues and to share information gained from the vast knowledge base of the operations and maintenance personnel. Particular attention was given to the valves on locks with lifts in excess of 30 ft which are classified as high-lift and very-high-lift locks (Headquarters, USACE 2006). In order to accomplish this objective, __ navigation projects were visited and discussions were held with operations and maintenance personnel. The personnel interviewed varied from area office engineers to maintenance contractors.

A summary of previously published lock valve prototype tests is also included to provide sufficient information from which conclusions and recommendations regarding engineering designs and operations procedures that have performed well and those that have not.

Projects were visited to observe operations and discuss maintenance history with lock personnel. Do operations differ from engineering design suggestions (e.g. bulkhead seals have been removed, valve speed has been changed)? If so, why have operation procedures migrated from the original design. Perhaps engineering design objectives should be extended to include the realities that operations and maintenance offices face.

Prototype Experience

ERDC/CHL TR-11-4

Coastal and Hydraulics Laboratory

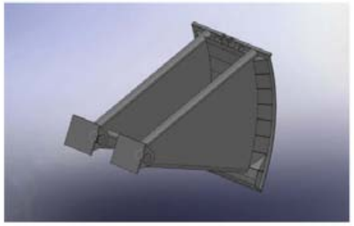
US Army Corps of Engineers®
Engineer Research and Development Center

Navigation Systems Research Program

Lock Culvert Valves; Hydraulic Design Considerations

Richard L. Stockstill, E. Allen Hammack, and John E. Hite, Jr.

June 2011



Approved for public release; distribution is unlimited.

Design Considerations

ERDC/CHL CHETN-IX-27
October 2011

US Army Corps of Engineers®

Computational flow model of a reverse tainter valve

by E. Allen Hammack and Richard L. Stockstill

BACKGROUND: Reverse tainter valves are the most common valve type found on navigation locks constructed by the U.S. Army Corps of Engineers (Pickett and Neilson 1988 and Headquarters, U.S. Army Corps of Engineers 1975). Virtually all locks constructed in the United States since 1940 have had reverse tainter valves (Davis 1989). Reverse tainter valves differ from radial gates found on spillways in that the trunnions are upstream of the skin plate and the convex surface of the skin plate faces downstream and seals against the downstream end of the valve well. A typical reverse tainter valve layout is shown in Figure 1. This "reverse" orientation prevents large volumes of air from being drawn into the culvert at the valve well, thereby preventing dangerous surges in the lock chamber.

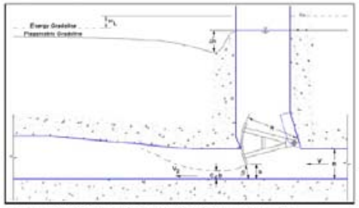


Figure 1. Geometric and hydraulic parameters describing a reverse tainter valve.

The geometric and hydraulic parameters describing a reverse tainter valve are shown in Figure 1. Lock culvert flow is controlled by rotating the valve about the trunnion axis. The valve position is listed commonly as the ratio b/B, where b is the distance from the valve lip to the culvert floor and B is the culvert height upstream and downstream of the valve. The average velocity in the culvert upstream of the valve is denoted as V, and V_2 is the velocity of the valve jet at its most contracted section. The minimum height of the jet is related to the valve opening by the contraction coefficient, C_c.

Computational Model

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Navigation Projects Visited or Tested

Lock Project	River/Waterway	Chamber Size, Width and Length, ft	Culvert Width and Height at Valve, ft	Valve Radius, ft	Reverse Tainter Valve Design	Lift, ft
Eisenhower	St. Lawrence Seaway	80 x 860	12 x 14	21.0	DSP	43
Snell	St. Lawrence Seaway	80 x 860	12 x 14	21.0	3 DSP, 1 VF	49
Bankhead	Black Warrior	110 x 600	14 x 14	20.0	VF	69
Holt	Black Warrior	110 x 600	12.5 x 12.5	17.0	VF	64
Melton Hill	Clinch	75 x 400	8 x 10	16.0	VF	54
Cheatham	Cumberland	110 x 800	12.5 x 12.5	18.0	DSP	26
Barkley	Cumberland	110 x 875	16 x 16	24.0	DSP	57
Fort Loudoun	Tennessee	60 x 360	6 x 7	10.7	DSP	70
Watts Bar	Tennessee	60 x 360	6 x 8	10.75	VF	70
Chickamauga	Tennessee	60 x 360	8 x 8	10.58	VF	50
Wheeler	Tennessee	110 x 600	12 x 14	20.5	DSP	48
Wilson	Tennessee	110 x 600	15 x 15	22.0	DSP	94
Kentucky	Tennessee	110 x 600	12 x 12	16.0	DSP	56
Demopolis	Tombigbee	110 x 600	12.5 x 12.5	18.25	PDSP	40
Whitten	Tennessee-Tombigbee	110 x 670	14 x 14	20.0	VF	84
Heflin	Tennessee-Tombigbee	110 x 600	13.5 x 13.5	19.0	VF	36
Bonneville	Columbia	86 x 675	12 x 14	19.5	VF	69.5
The Dalles	Columbia	86 x 675	12 x 14	19.5	DSP	90
John Day	Columbia	86 x 675	12 x 14	19.5	DSP	110
McNary	Columbia	86 x 675	11 x 12	17.0	DSP	92

[1] Tool (1980)
[2] Neilson (1975)
[3] McGee (1989)
[4] Waller (1997)
[5] Neilson and Pickett (1986)
[6] US Army Engineer Waterways Experiment Station (1960)

Physical Model Studies

Lock Project	River/Waterway	Model Scale	Prototype Culvert Width x Height, ft	Model Culvert Width x Height, ft	Reverse Tainter Valve Design	Lift, ft
Snell	St. Lawrence Seaway	1:15	12 x 14	0.83 x 0.83	DSP & VF	49
Holt	Black Warrior	1:15	12.5 x 12.5	0.83 x 0.83	VF & DSP	64
Watts Bar	Tennessee	1:10	6 x 8	0.60 x 0.80	VF & DSP	60
Walter Boulden	Coosa	1:15	12 x 12	0.80 x 0.80	VF	130
Lock 19	Mississippi	1:12	14.5 x 14.5	1.21 x 1.21	HF	38
McNary	Columbia	1:20	11 x 12	0.55 x 0.60	DSP	92
John Day	Columbia	1:25	12 x 14	0.48 x 0.56	DSP	113

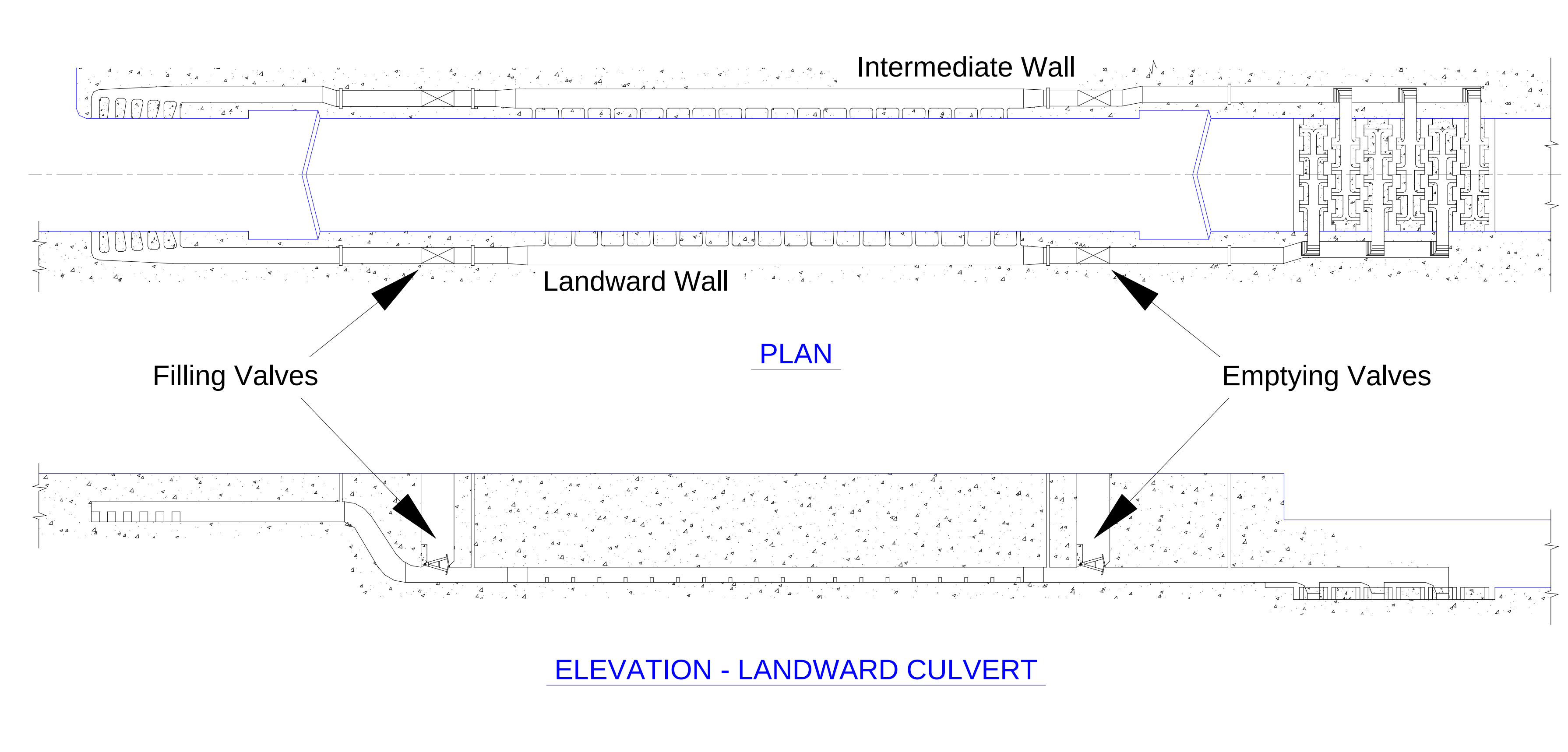
DSP = Double-Skin Plate
VF = Vertical Frame
HF = Horizontal Frame

Lock Filling & Emptying Systems

Classification by Lift

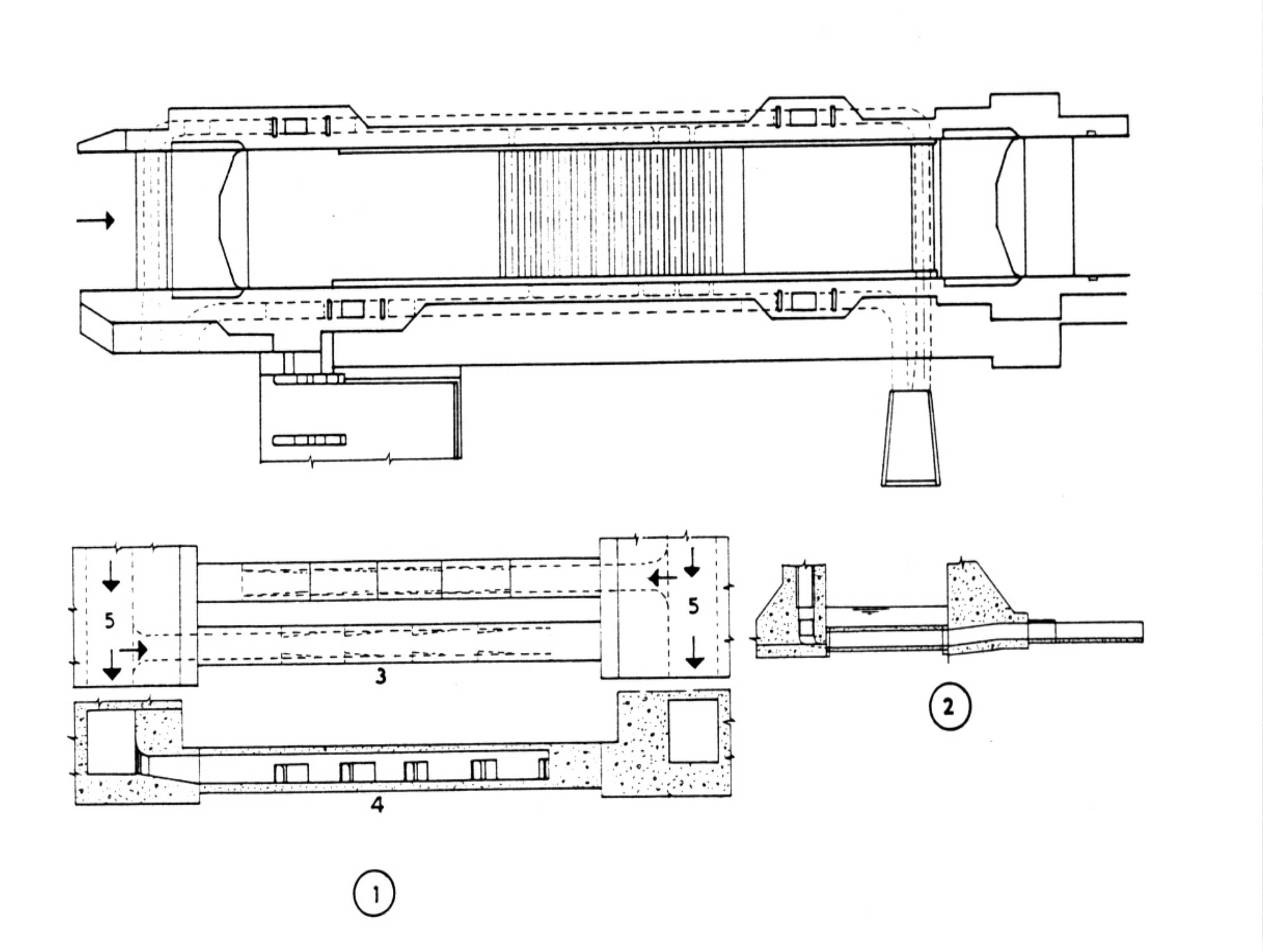
Range of Maximum Design Lift	Project Classification	% of CoE Locks	Suitable Design Types
0 to 10 ft	Very Low Lift	25	End F&E (primarily sector gate)
10 to 30 (or 40)	Low Lift	60	Side-port system or Lateral w/ 1 Culvert
30 (or 40) to 100	High Lift	15	Longitudinal Manifold System
100 to ? (not yet determined)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

Sidewall-port System



Sidewall-port System

Interlaced Lateral System



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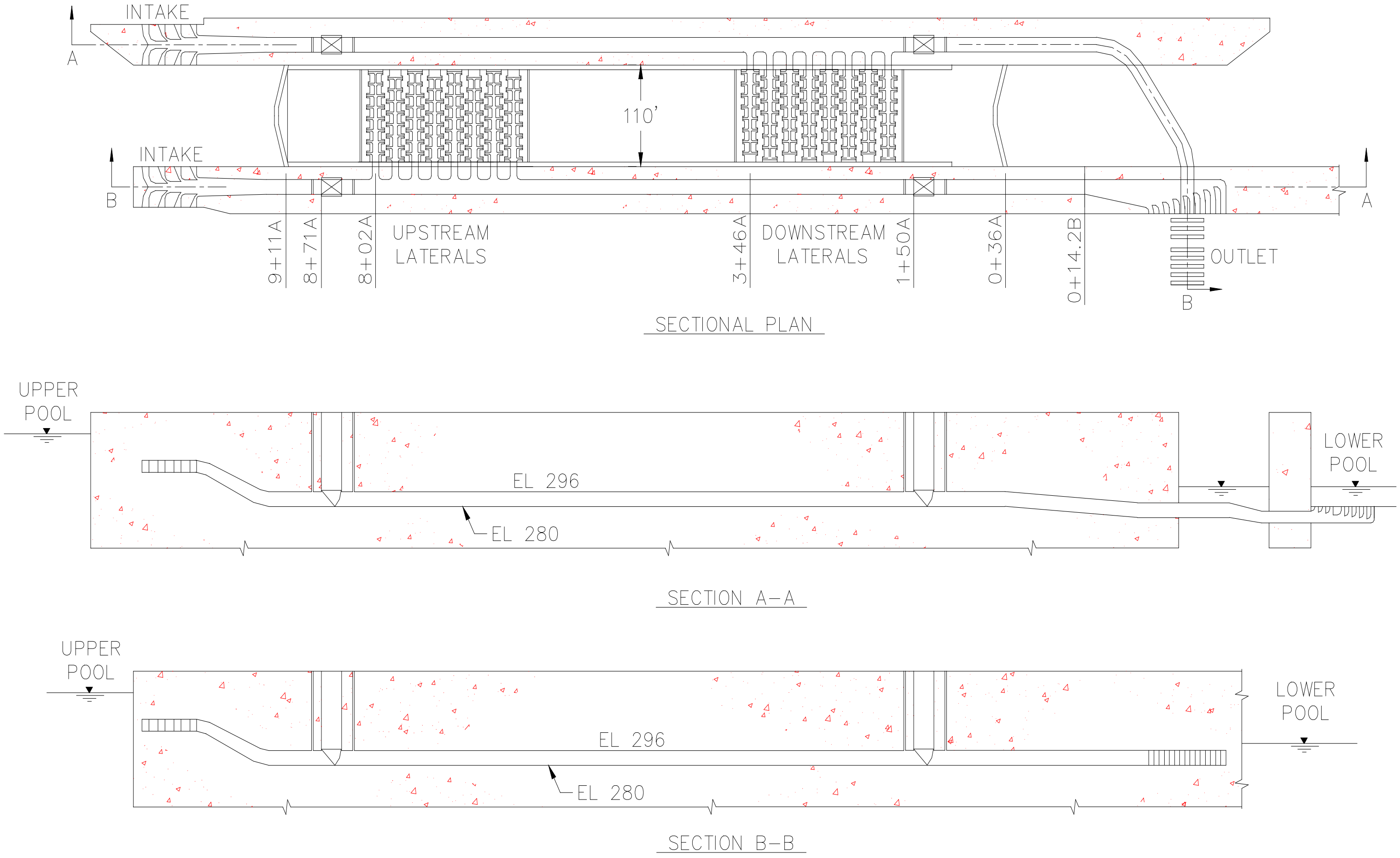
Split Lateral System



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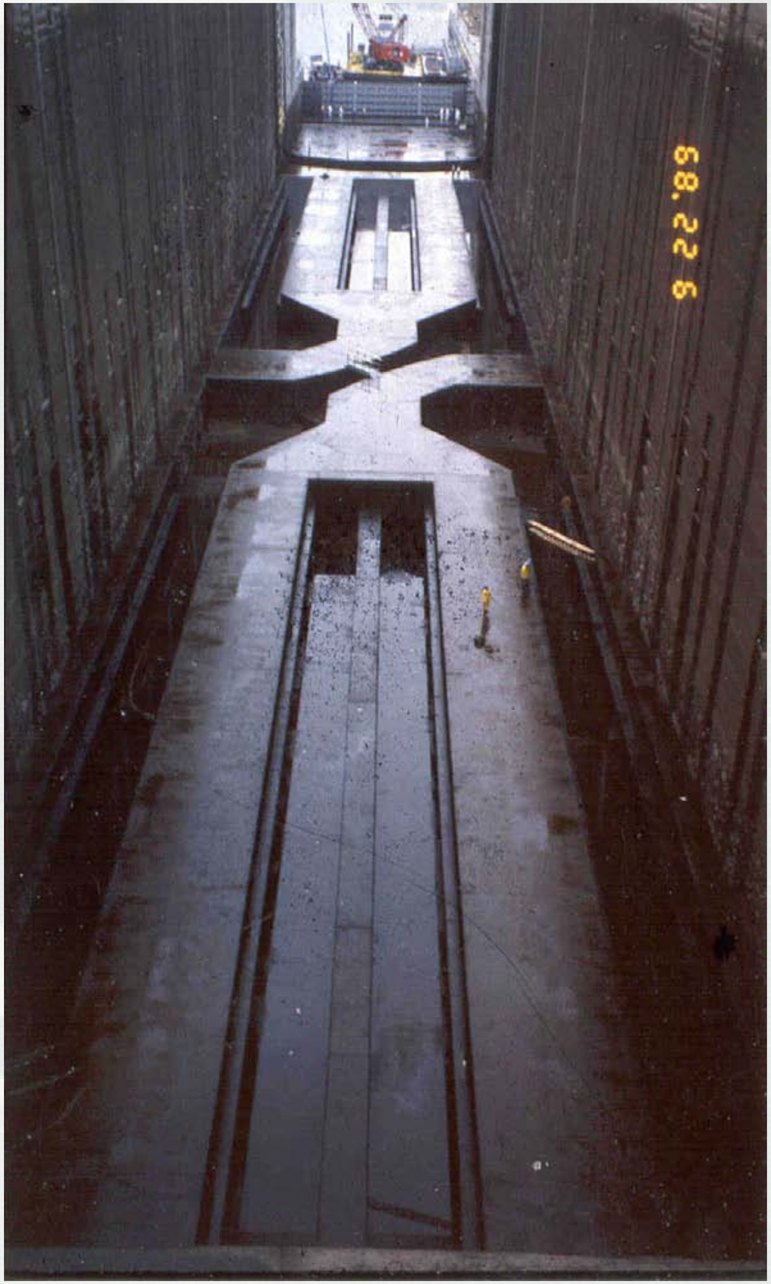
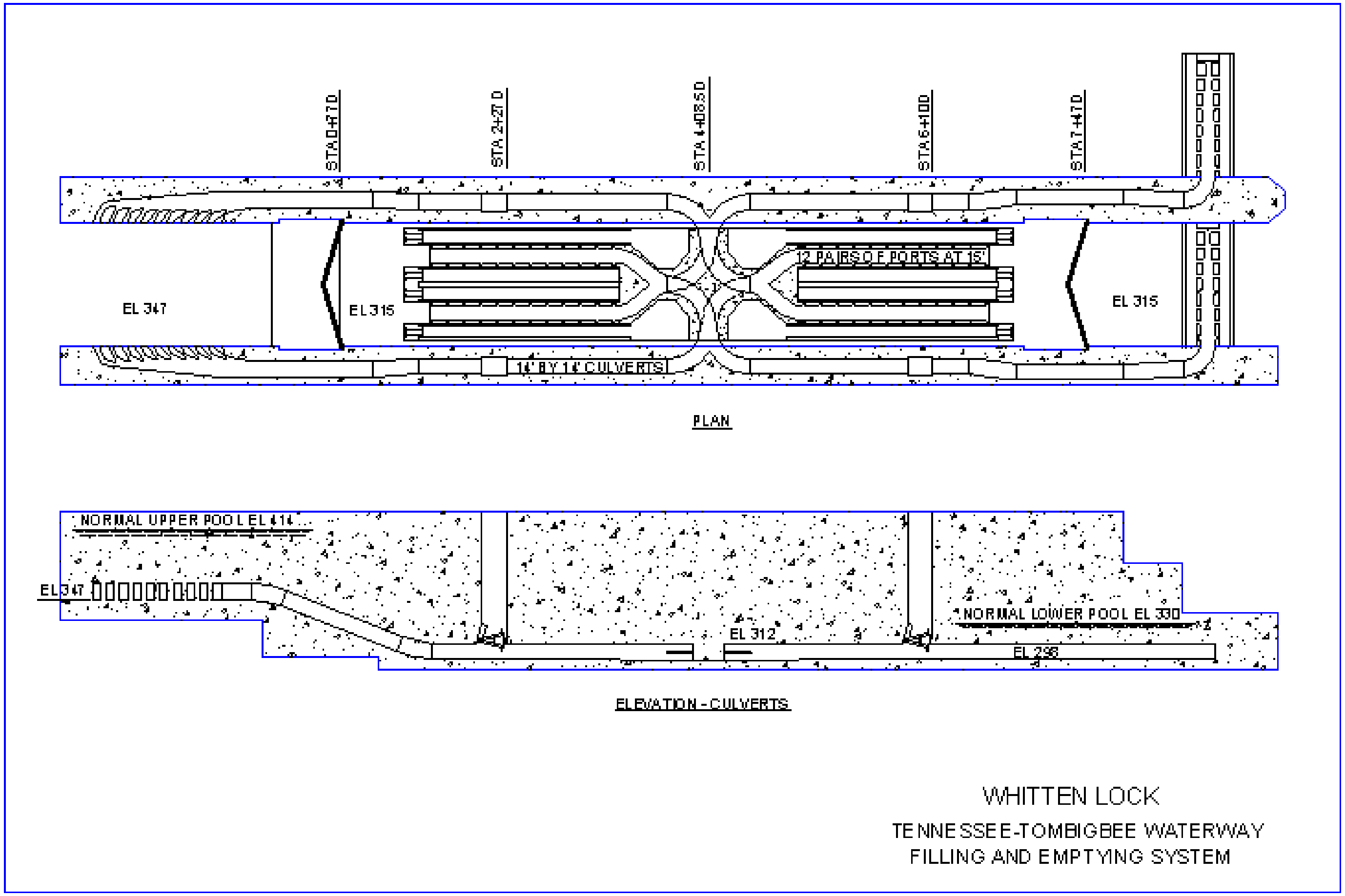
Single H System

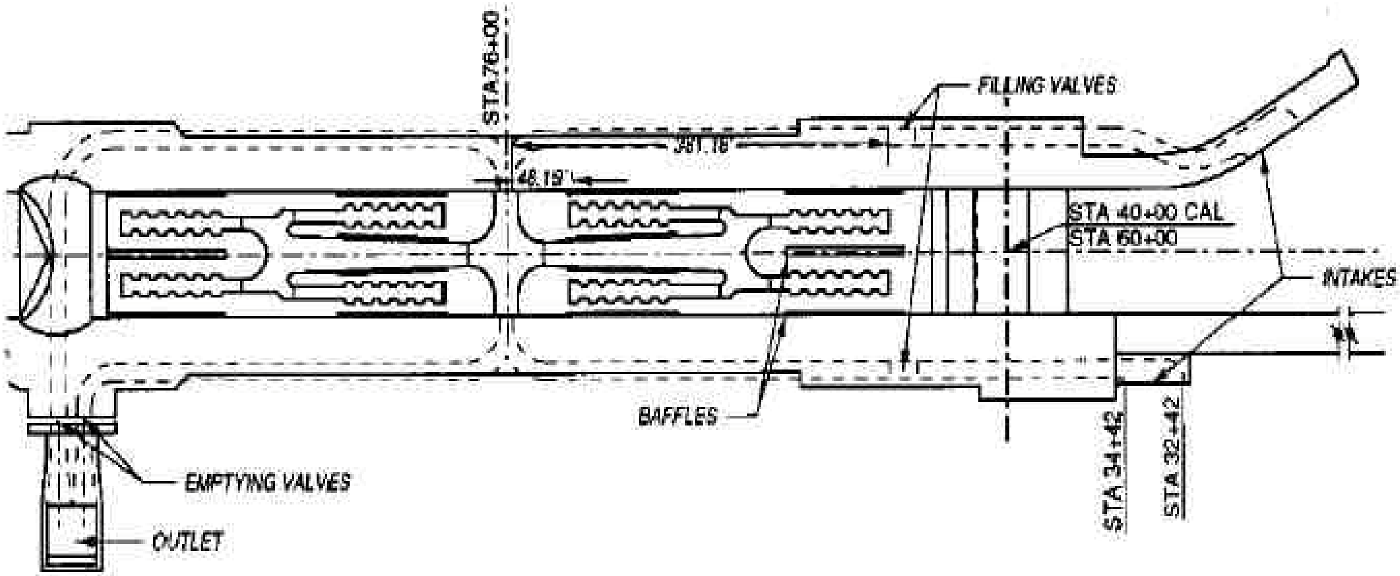


Single H System



Bottom Longitudinal Filling & Emptying System with Reverse Tainter Valves

Double H System



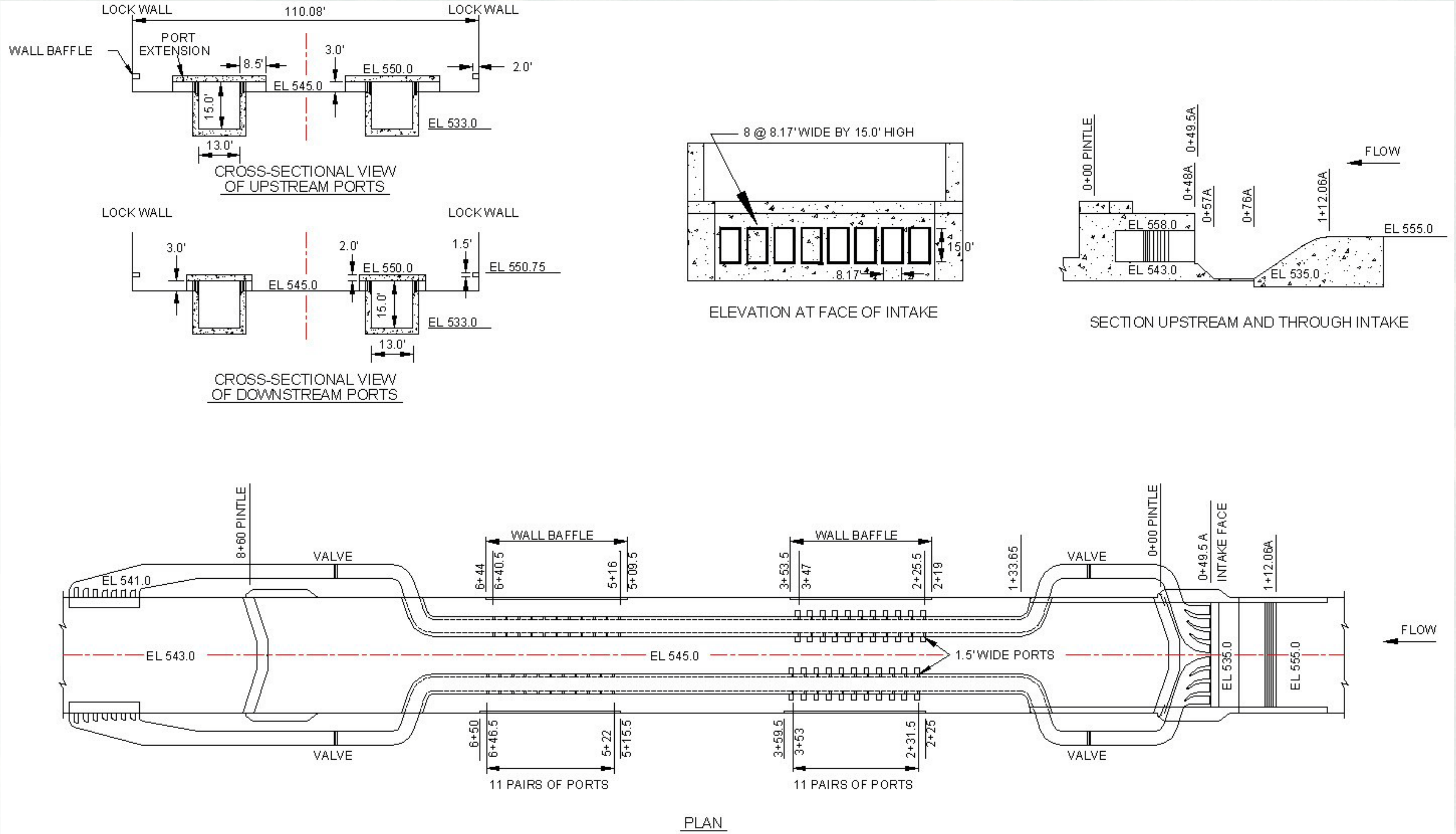
LOWER GRANITE
HORIZONTAL FLOW DIVIDERS
8-MANIFOLD (HB8) LOCK

In-chamber Longitudinal Culvert System (ILCS)

Marmet

McAlpine

In-chamber Longitudinal Culvert System (ILCS)



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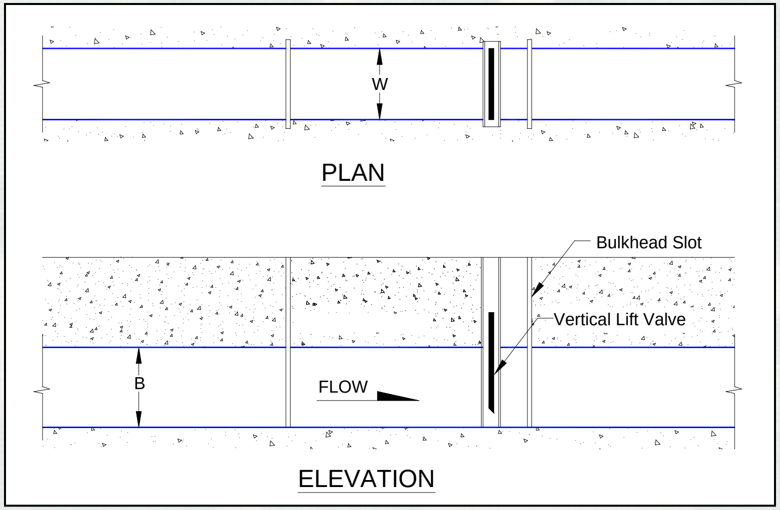
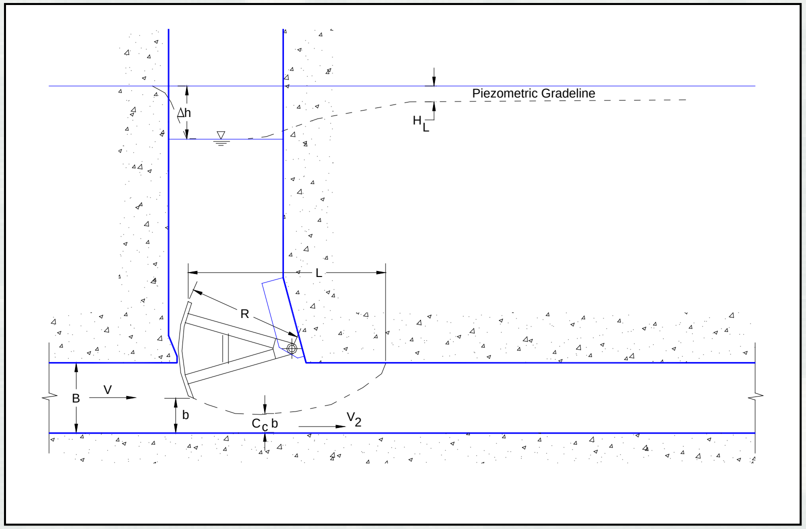
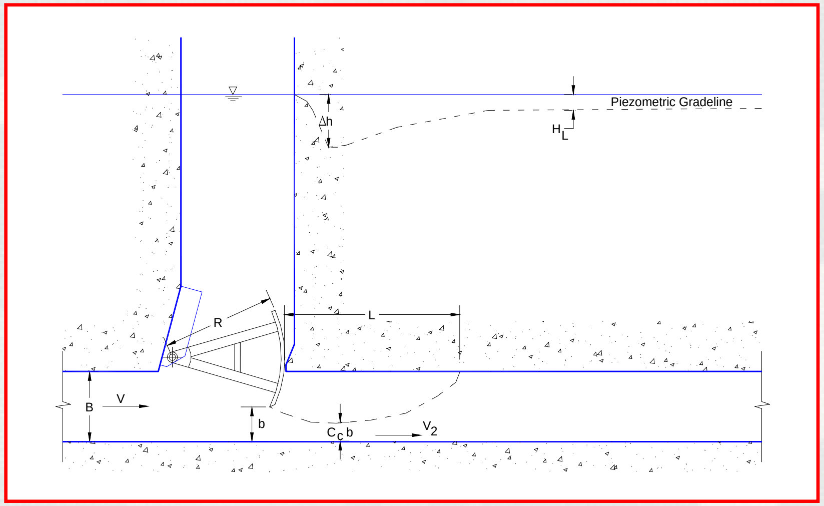
3 Valve Configurations



Vertical-Lift Valve



Conventional Tainter Valve



Reverse Tainter Valve

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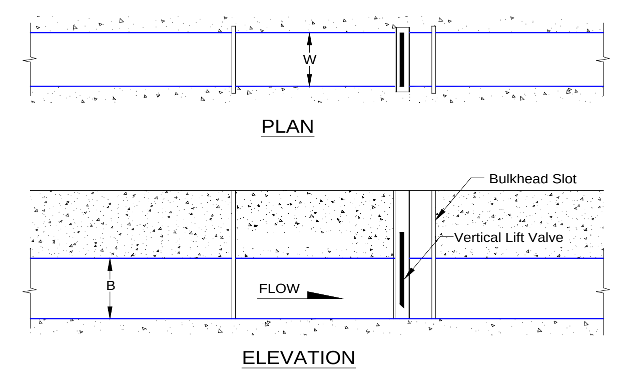
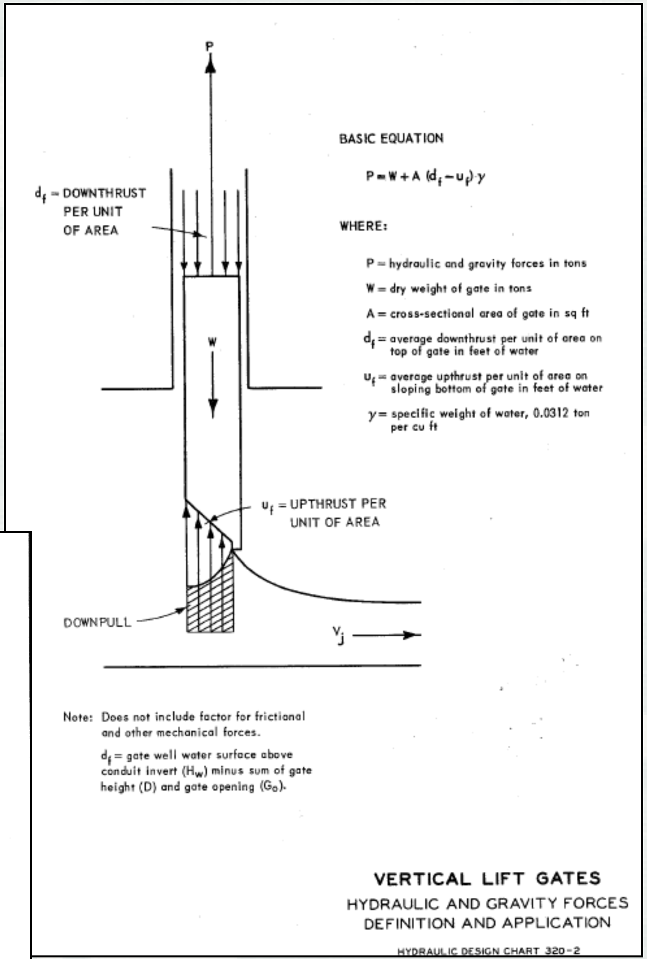
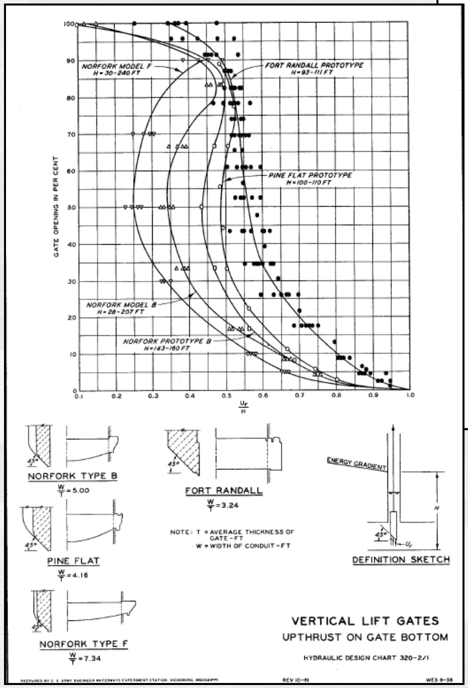
Vertical Lift Valves

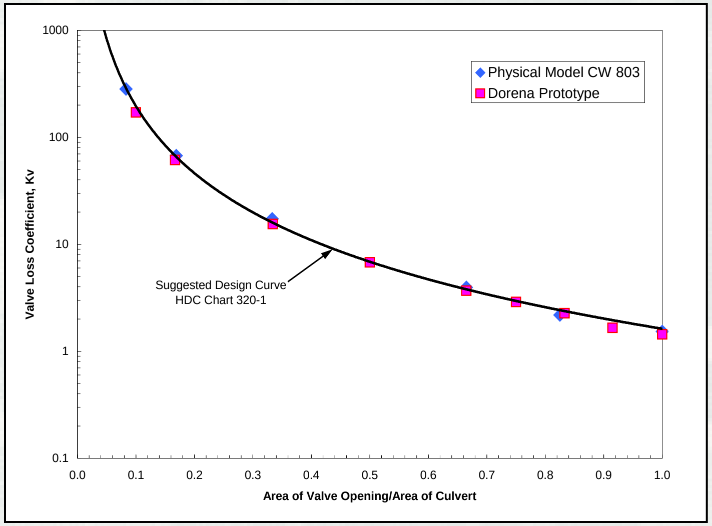


Vertical-Lift Lock Culvert Valve





Hoist Loads



Loss Coefficient

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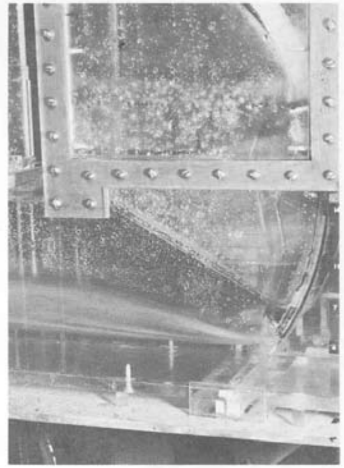
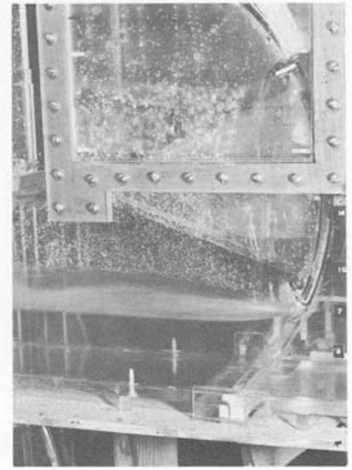
Conventional Tainter Valve

Flow Conditions During Valve Opening

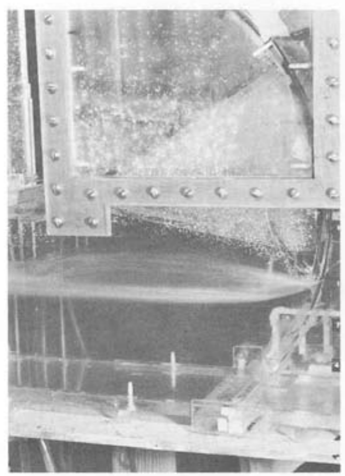
Free Surface Flow Downstream of Valve



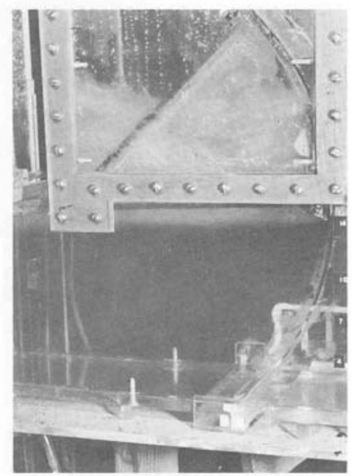
Valve open 4 ft; lock water surface at elev 539.0



Valve open 7 ft; lock water surface at elev 537.7



Valve open 10 ft; lock water surface at elev 535.7



Valve open 14 ft; lock water surface at elev 533.8

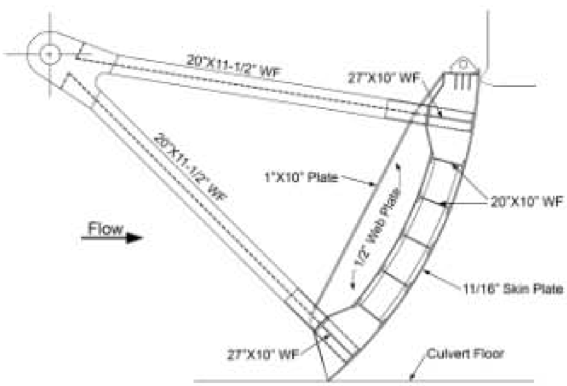
Flow is Right to Left

Reverse Tainter Valve

MODEL

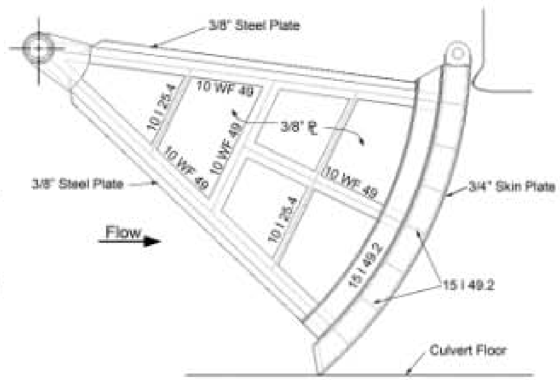
MODEL

MODEL



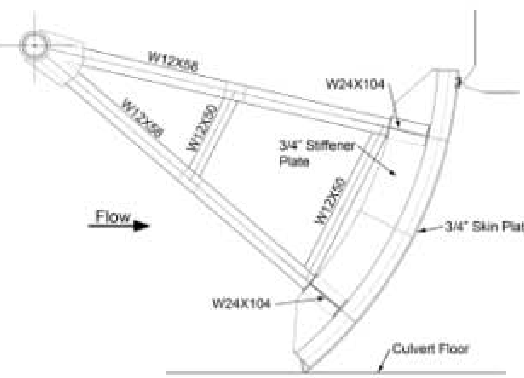
SECTION ALONG CENTER LINE

FIG. a HORIZONTALLY FRAMED



SECTION ALONG CENTER LINE

FIG. b DOUBLE SKIN PLATE



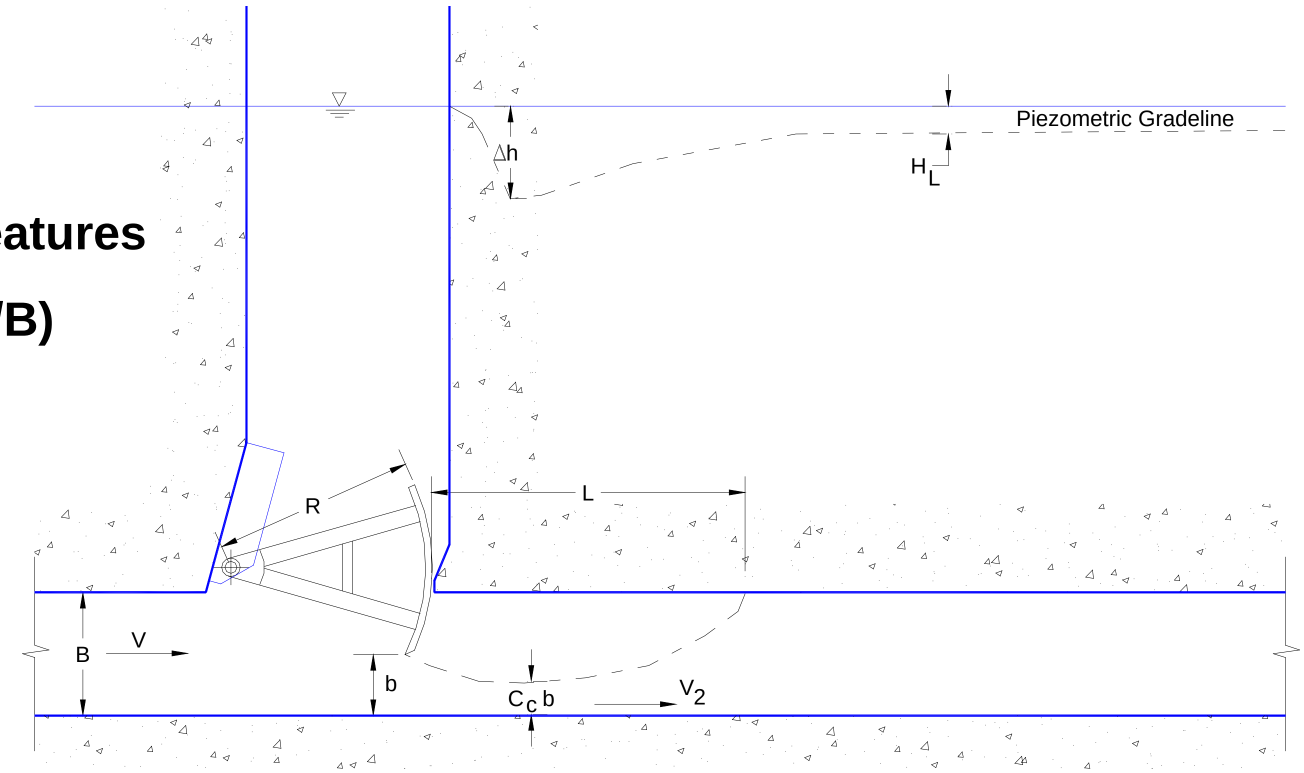
SECTION ALONG CENTER LINE

FIG. c VERTICALLY FRAMED

Hydraulics of Lock Culvert Valves

Important geometric features

- **Valve opening (b/B)**
- **Valve radius**
- **Rib members**
- **Valve lip**



Reverse Tainter Valve Schematic

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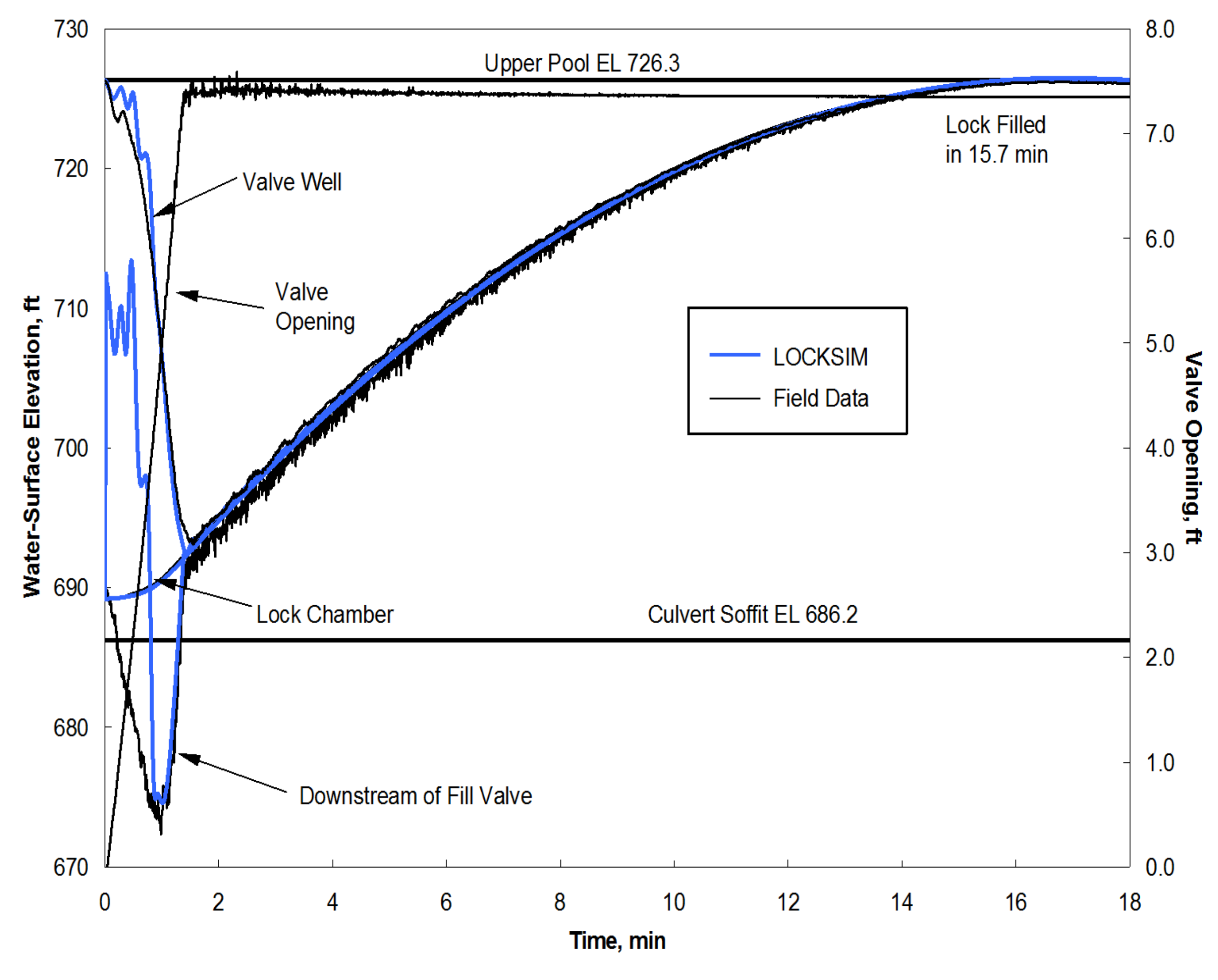
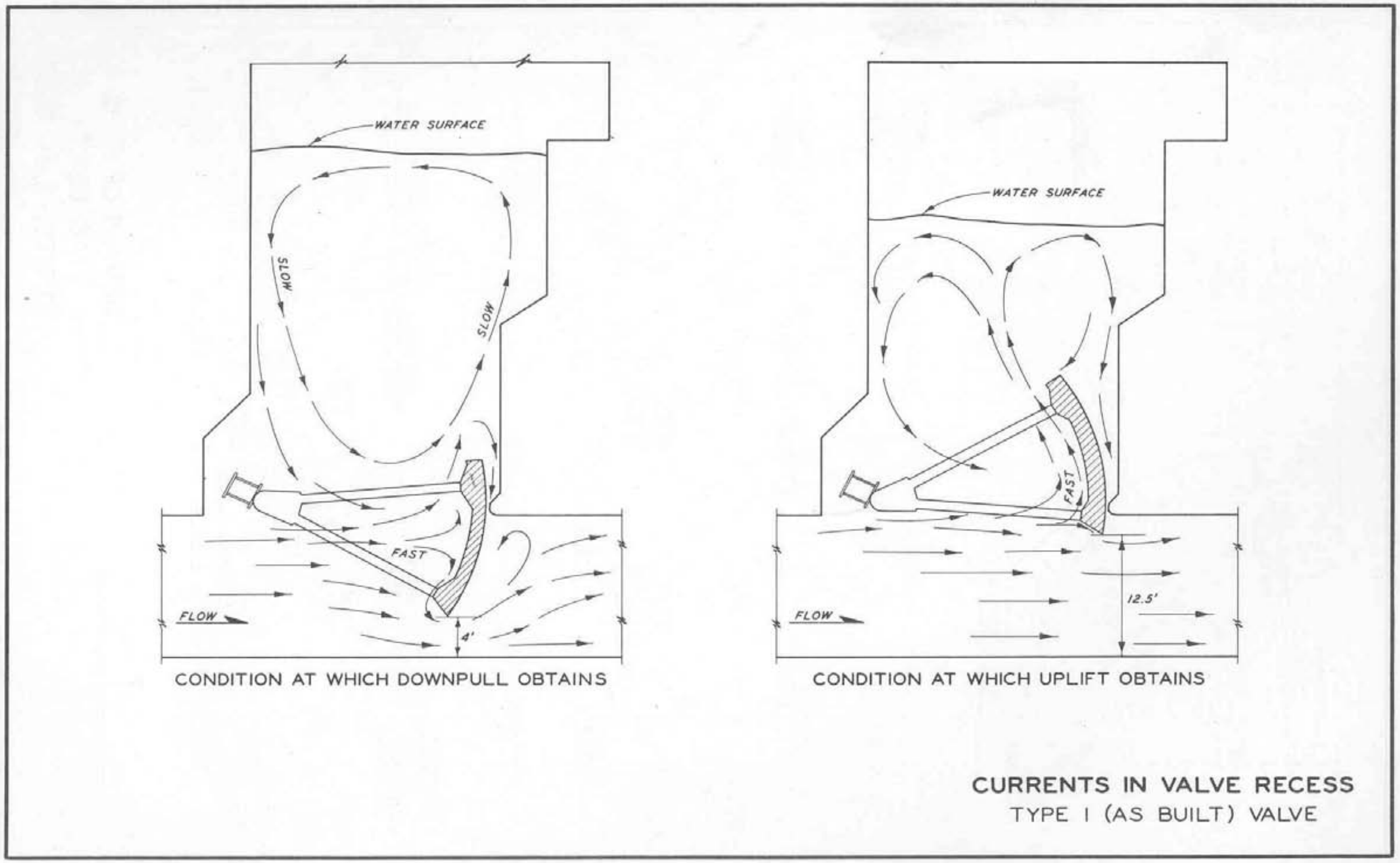
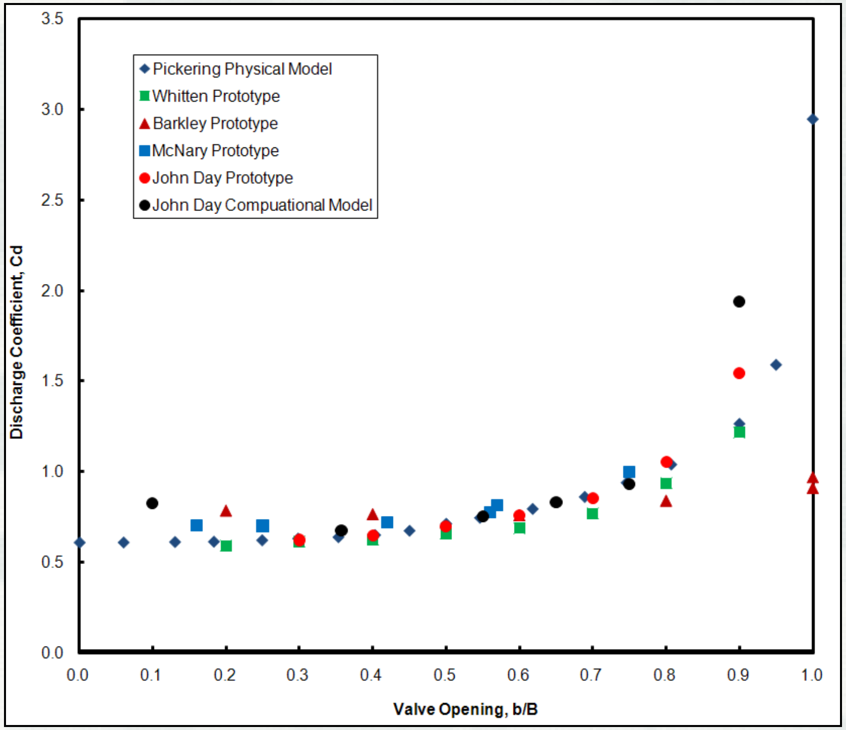
Flow Conditions at Valve During Filling Operation



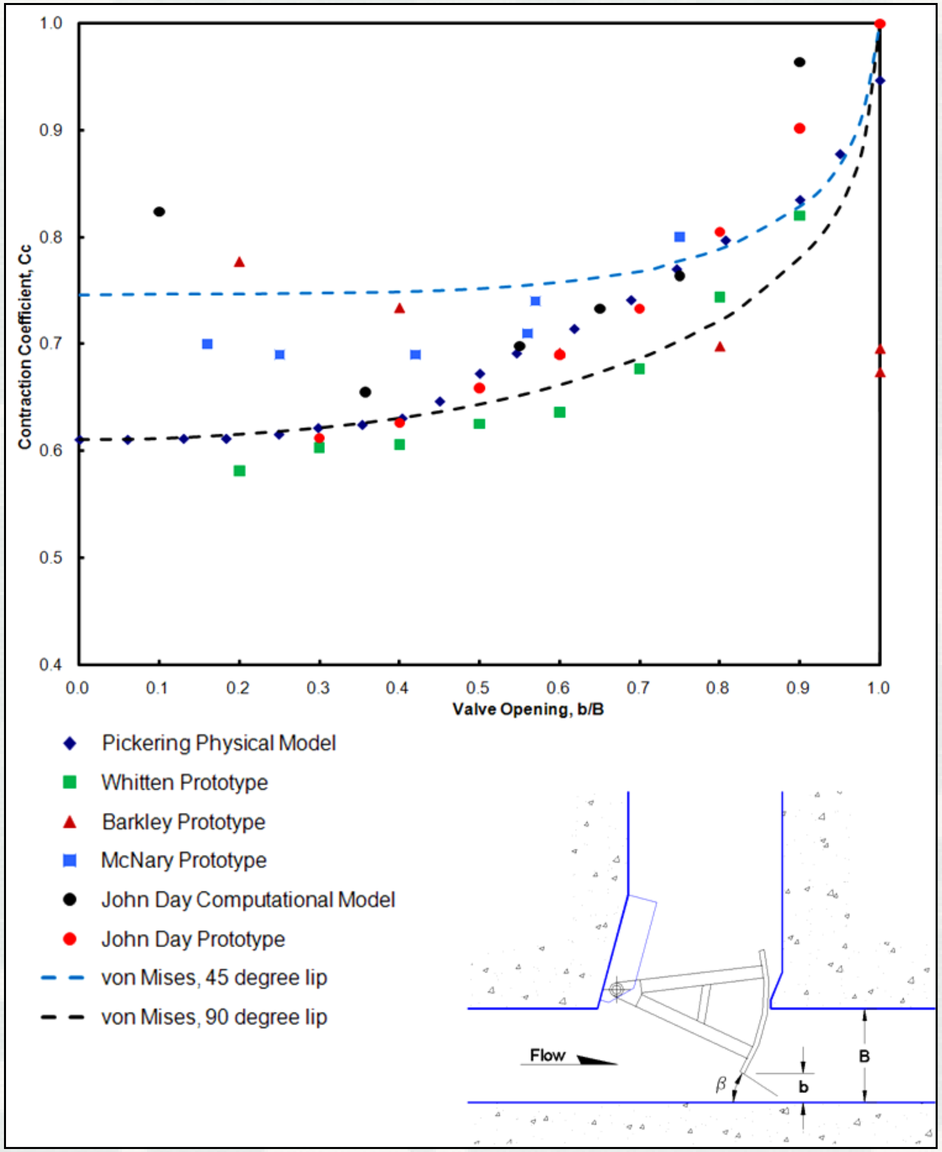
Flow Patterns at Reverse Tainter Valves



Hydraulic Coefficients Reverse Tainter Valves

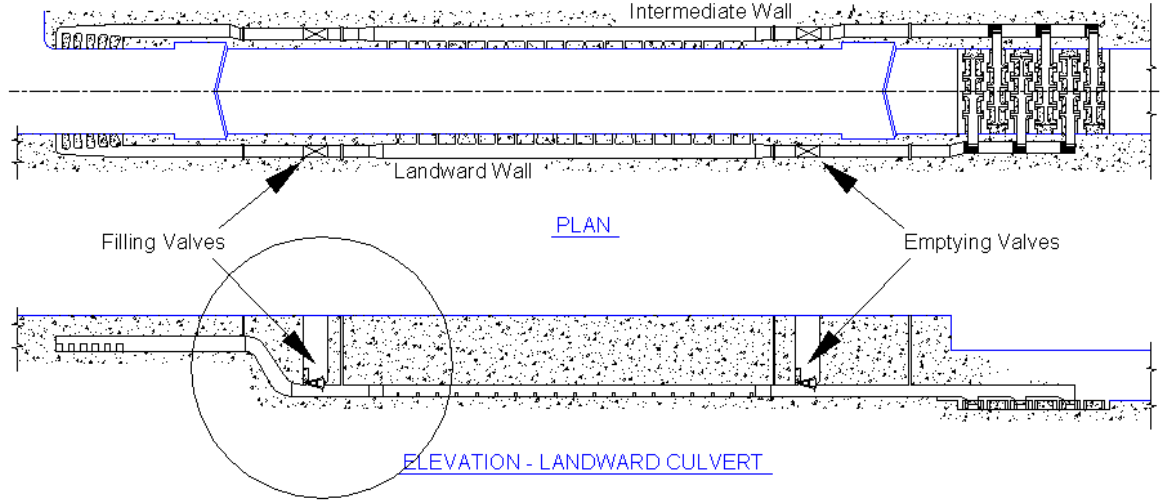


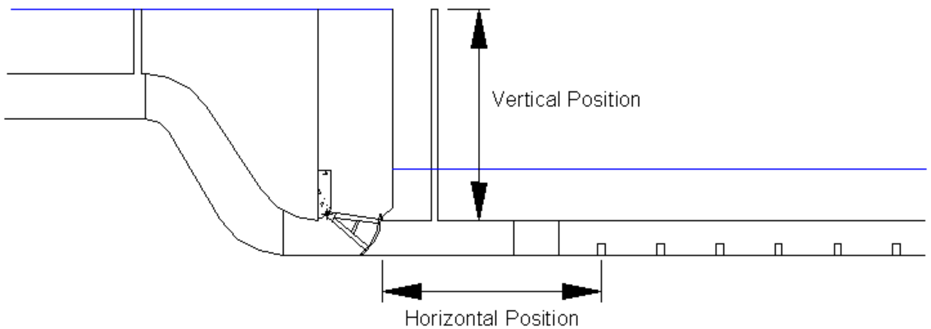
Discharge Coefficient



Contraction Coefficient

Valve Position





Cavitation Index

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

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

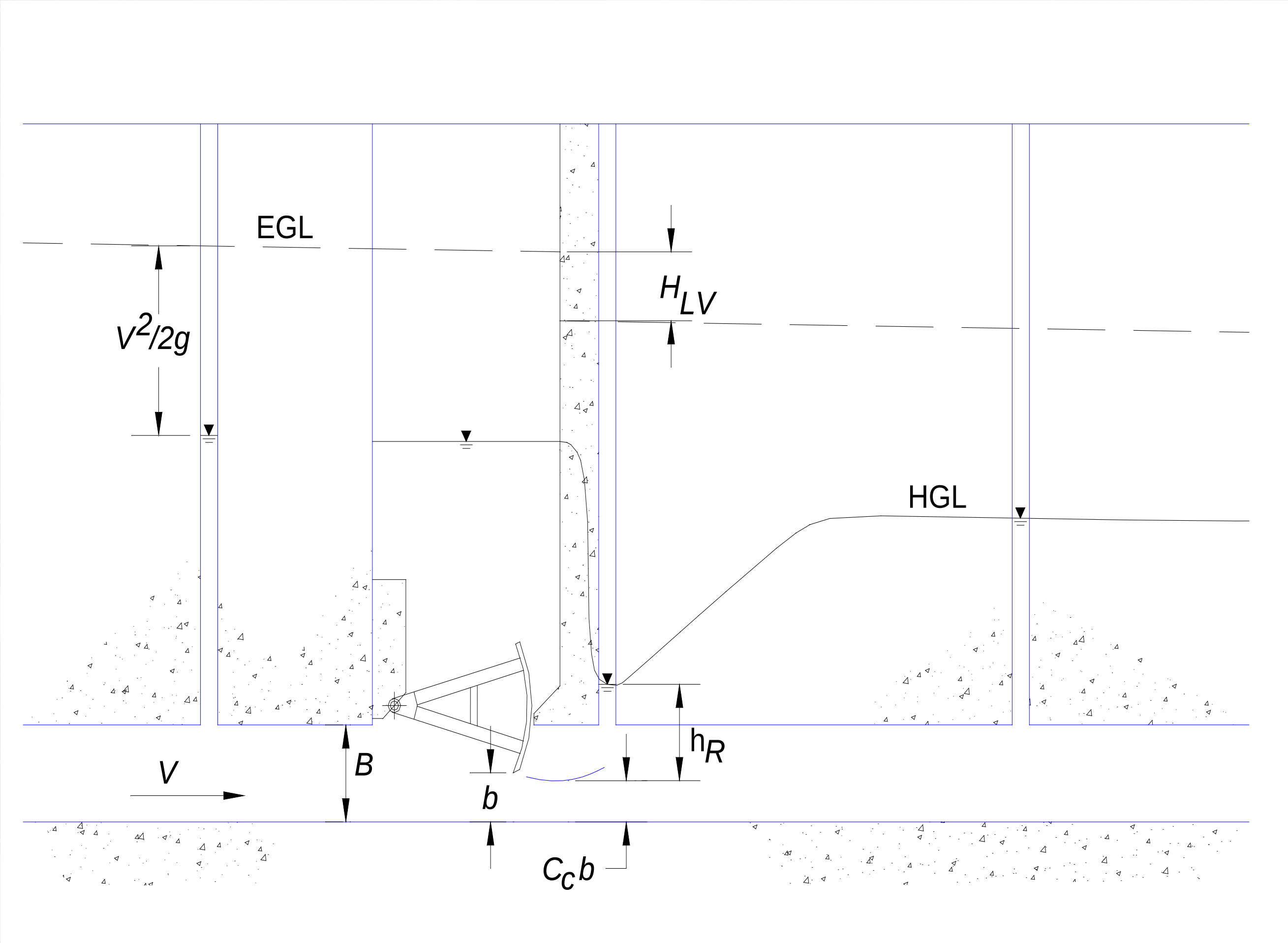
<u>Vertical</u> – Cavitation Potential (Cavitation Index > 0.6)

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

PRESSURES DOWNSTREAM OF VALVES

Cavitation Index

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



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 should operate with fast valve openings, so that the concentrated flow period is small.

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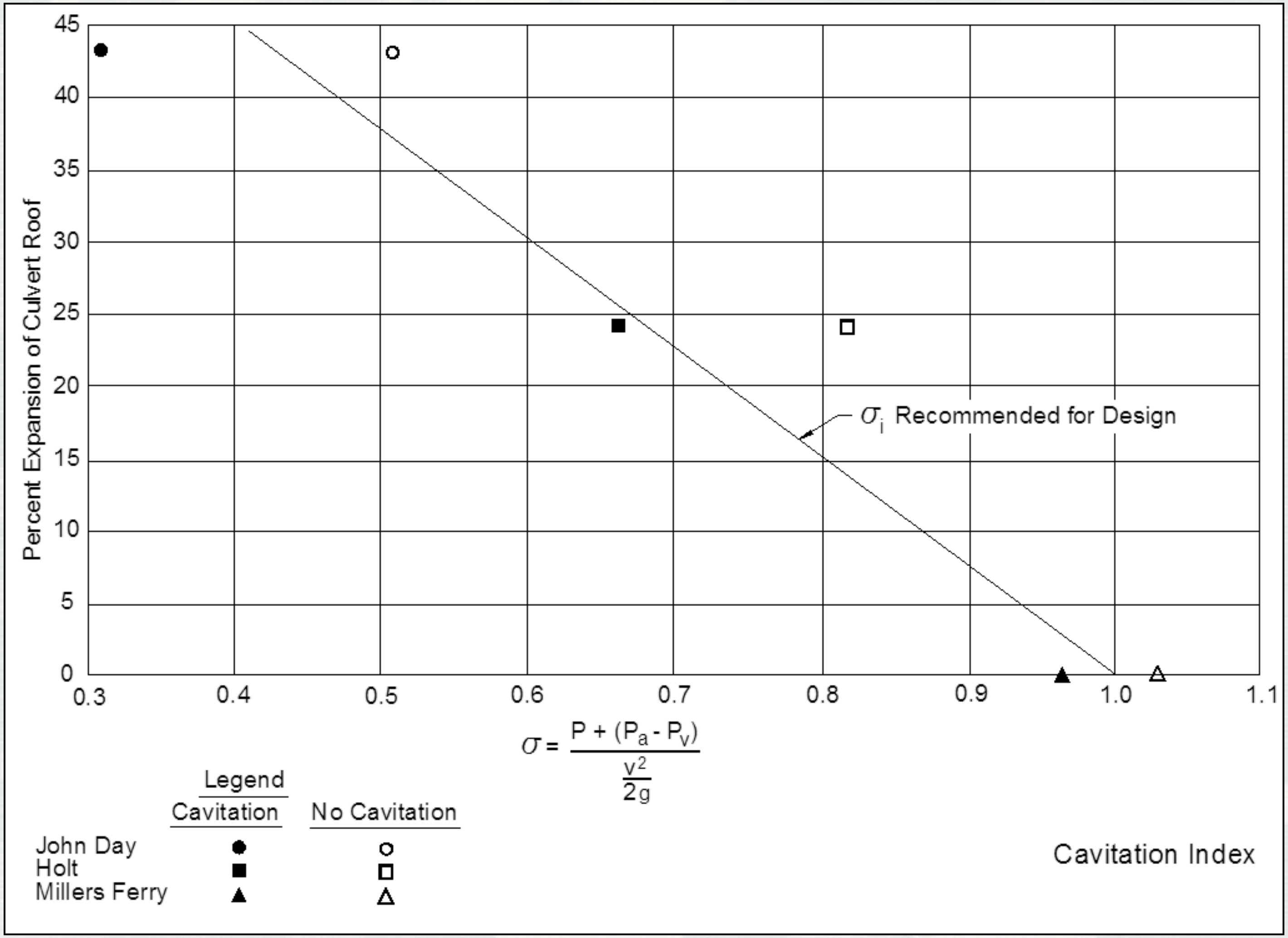
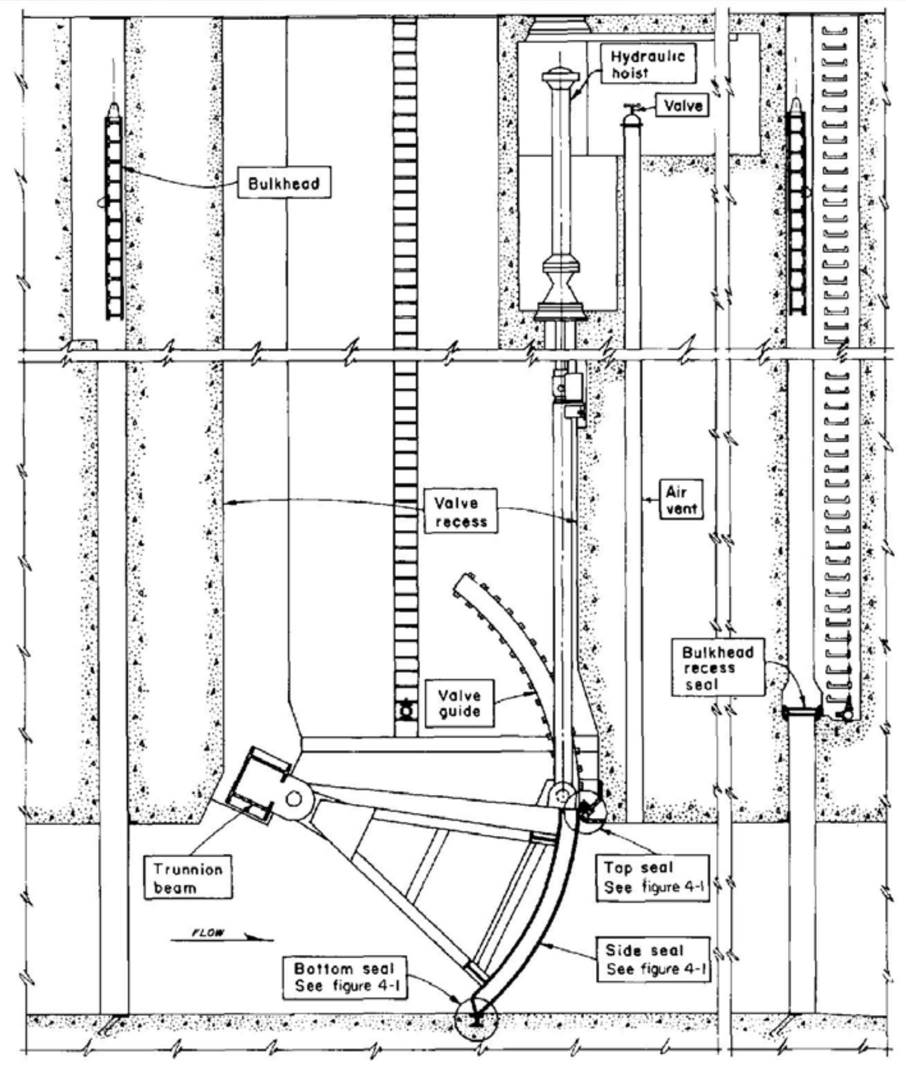


Cavitation Index Design Criteria

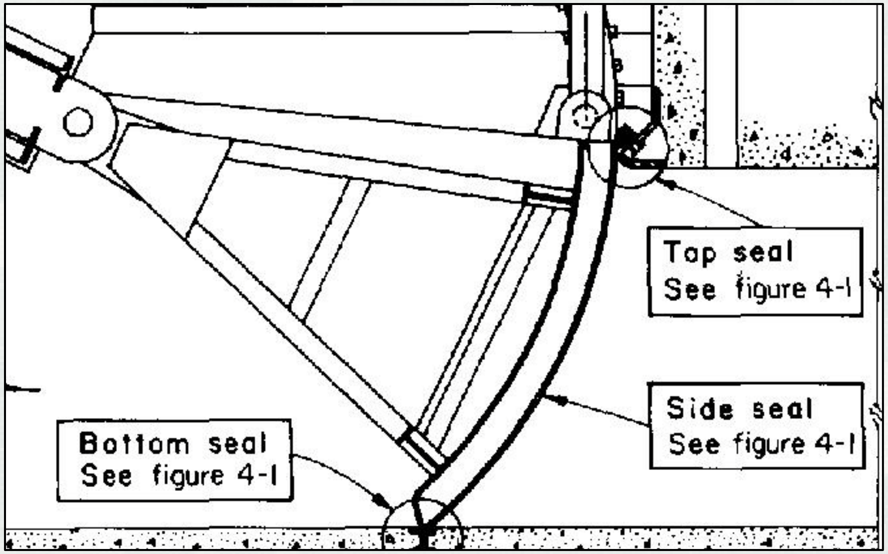
Cavitation

Repairing cavitation damage on Bankhead Lock valve skin plate

Cavitation damage on downstream face of skin plate at Bankhead Lock valve



Typical Reverse Tainter Valve Installation



Top Seal

Operations & Maintenance Experience

- Chickamauga, Watts Bar, and Fort Loudon Locks: replaced valves – new valve has large uplift forces and cannot be closed under flow = safety issue during emergencies
- John Day and the Dalles Locks: valves – cracks in wrapper plate have been repaired numerous times – rigid framed design considered for replacement.
- Holt Lock: valve - maintenance problems since the lock opened - personnel describe the culvert valves as not being stiff enough.
  - Holt Lock valve is the Corps' recommended design (Davis 1989) - Existing hydraulic design guidance does not reflect actual operational experiences and needs.
- Bankhead Lock: operations personnel have commented that the Bankhead Lock valves perform well - valve design is much heavier than the Holt valve.
- The reason for performance differences in the Bankhead and Holt valves is unknown. Perhaps because Bankhead valve is larger and heavier than the Holt.

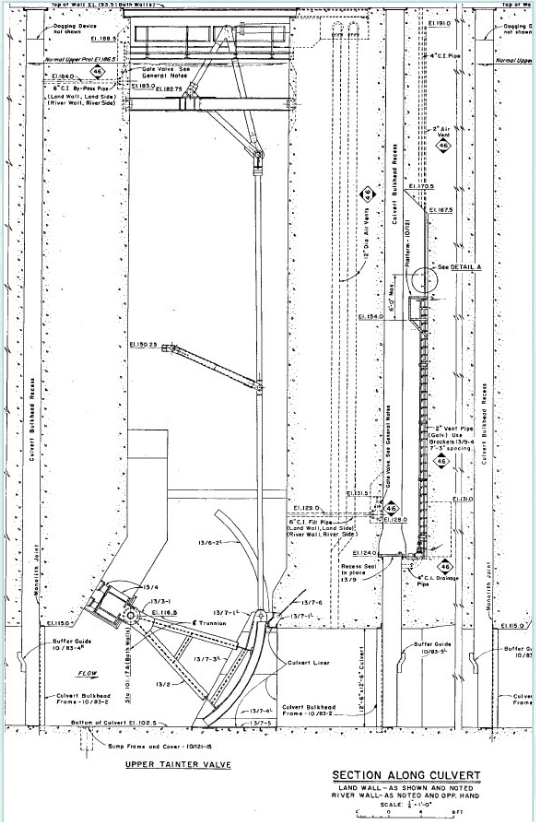
Recommended Design – Vertically Framed

Holt Lock Model Study, Murphy and Ables (1965)

Davis (1989) recommends Holt Lock design for all new construction

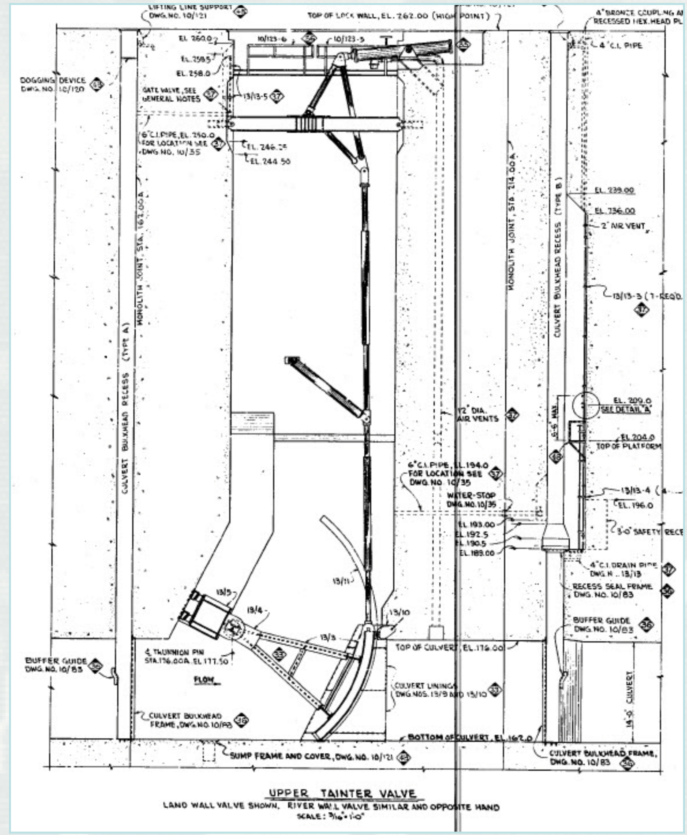
Operations: Holt & Bankhead Locks

Operations Personnel: - Poor Performance at Holt
- Good Performance at Bankhead



Holt Lock

12.5' x 12.5' Culvert



Bankhead Lock

14' x 14' Culvert

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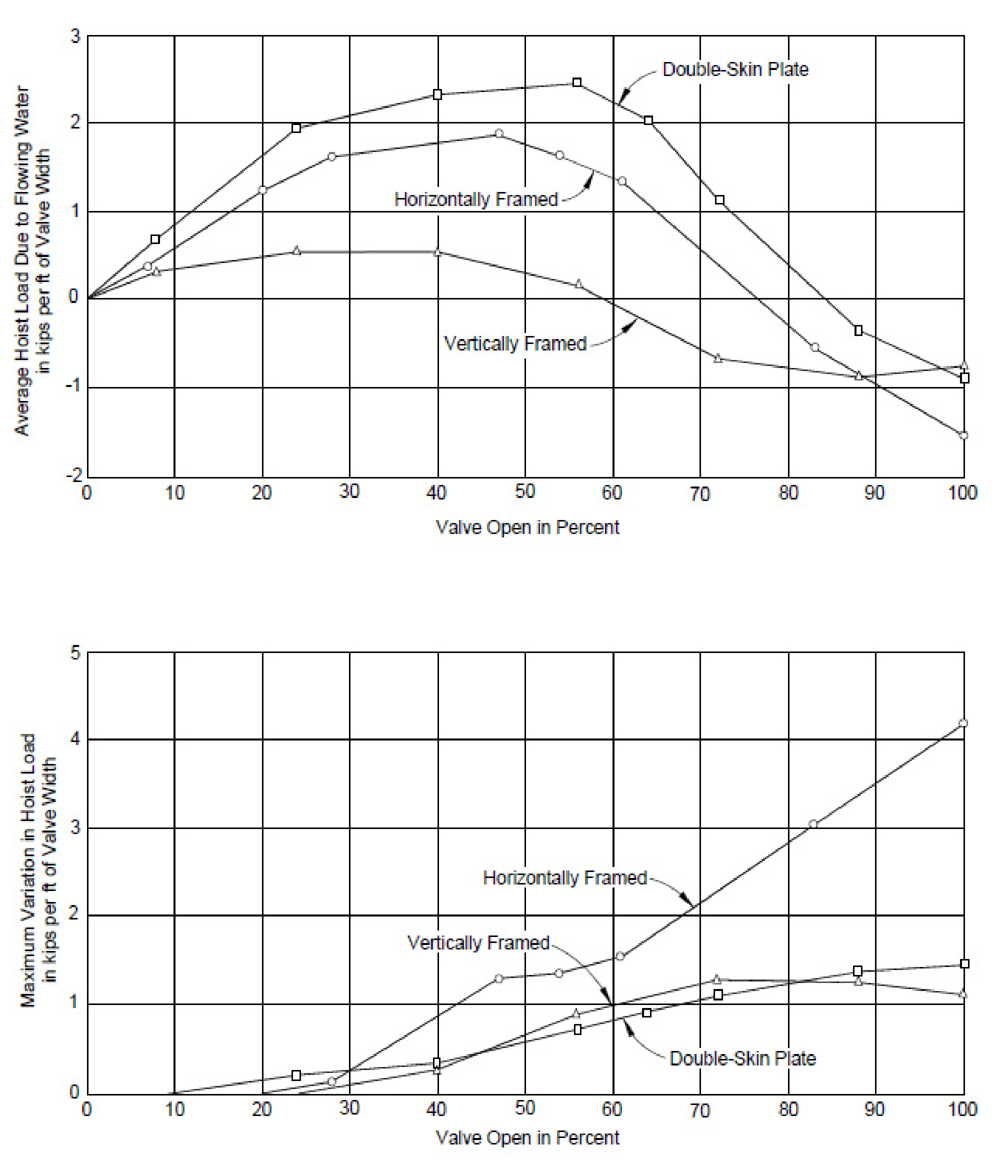
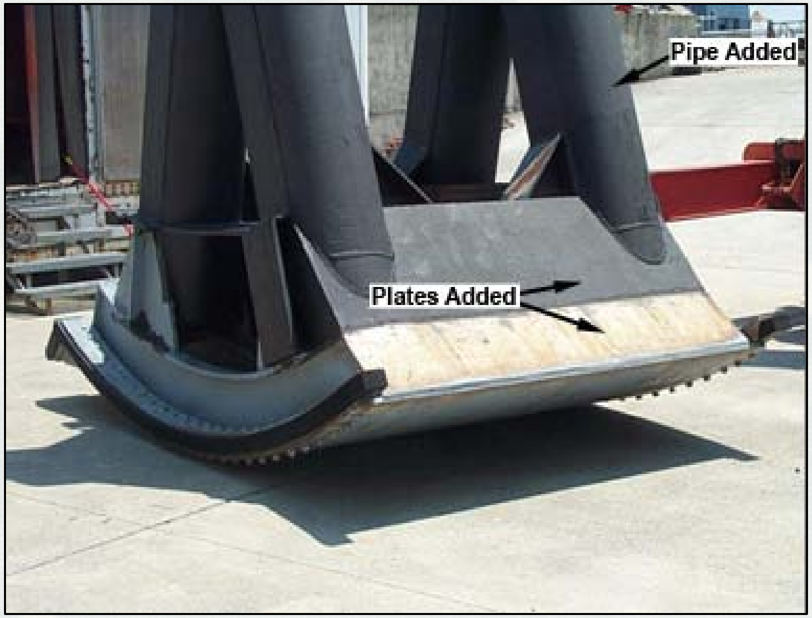
Typical Hoist Loads: Reverse Tainter Valve



Horizontally Framed
- **Large Downpull**
- **Large Vibration**

Field Modifications



Chickamauga Lock Modified Valve

Snell Lock New Valve

Kentucky Lock New Valve

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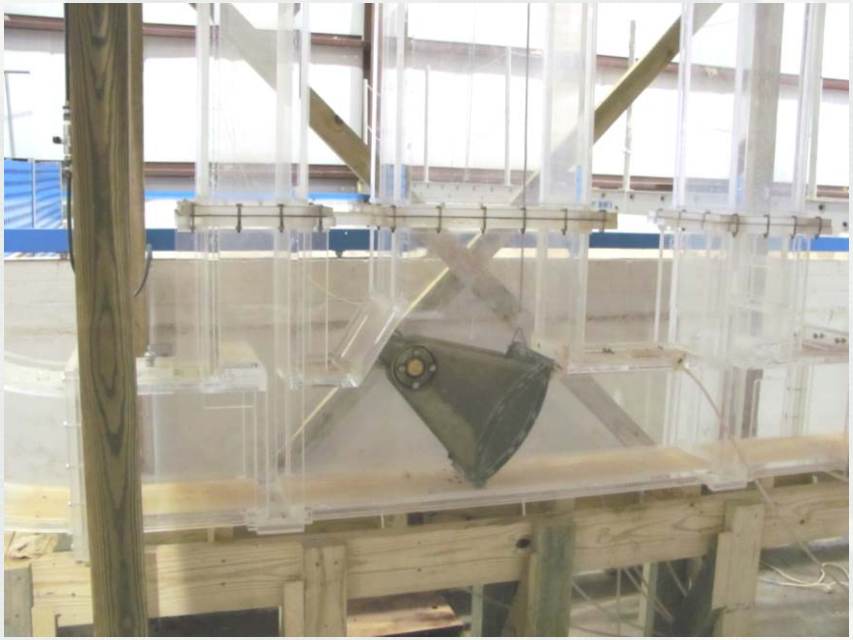
Watts Bar Lock
Tennessee River

Original and Replacement Valves

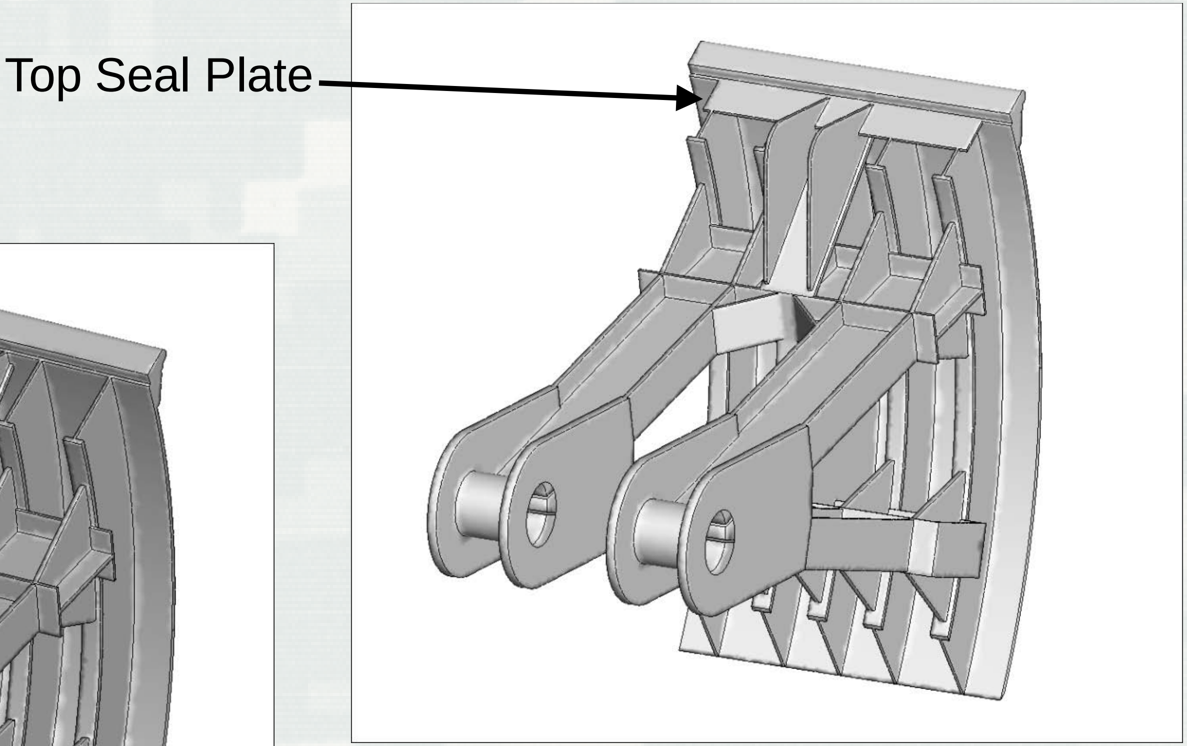
Watts Bar Lock Valve
1:10-scale Physical Model



Double-skin Plate

Vertical Frame

Watts Bar Lock
Replacement Valve – Modifications



With Plate

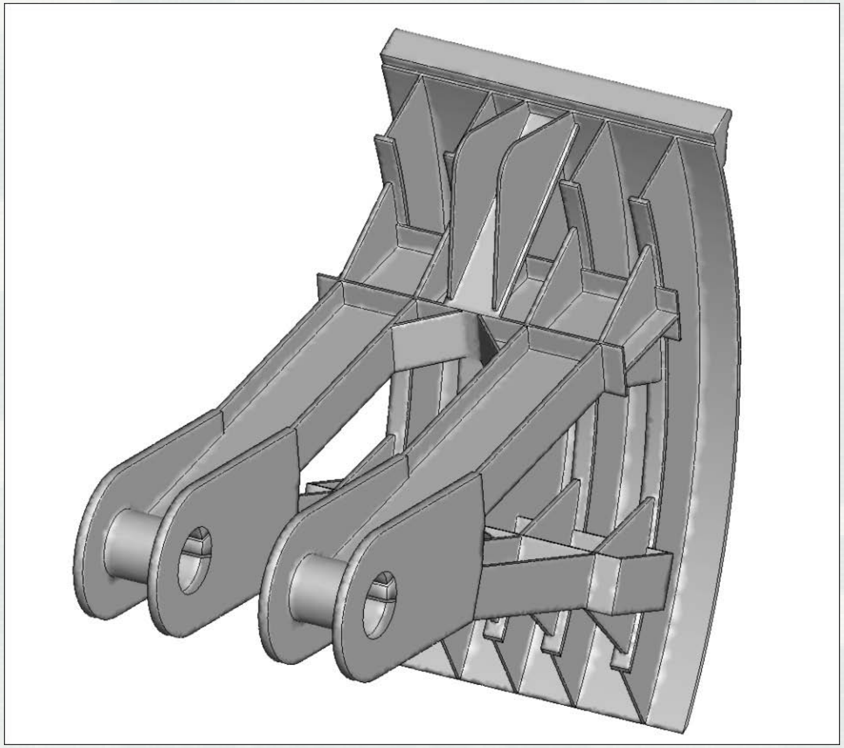
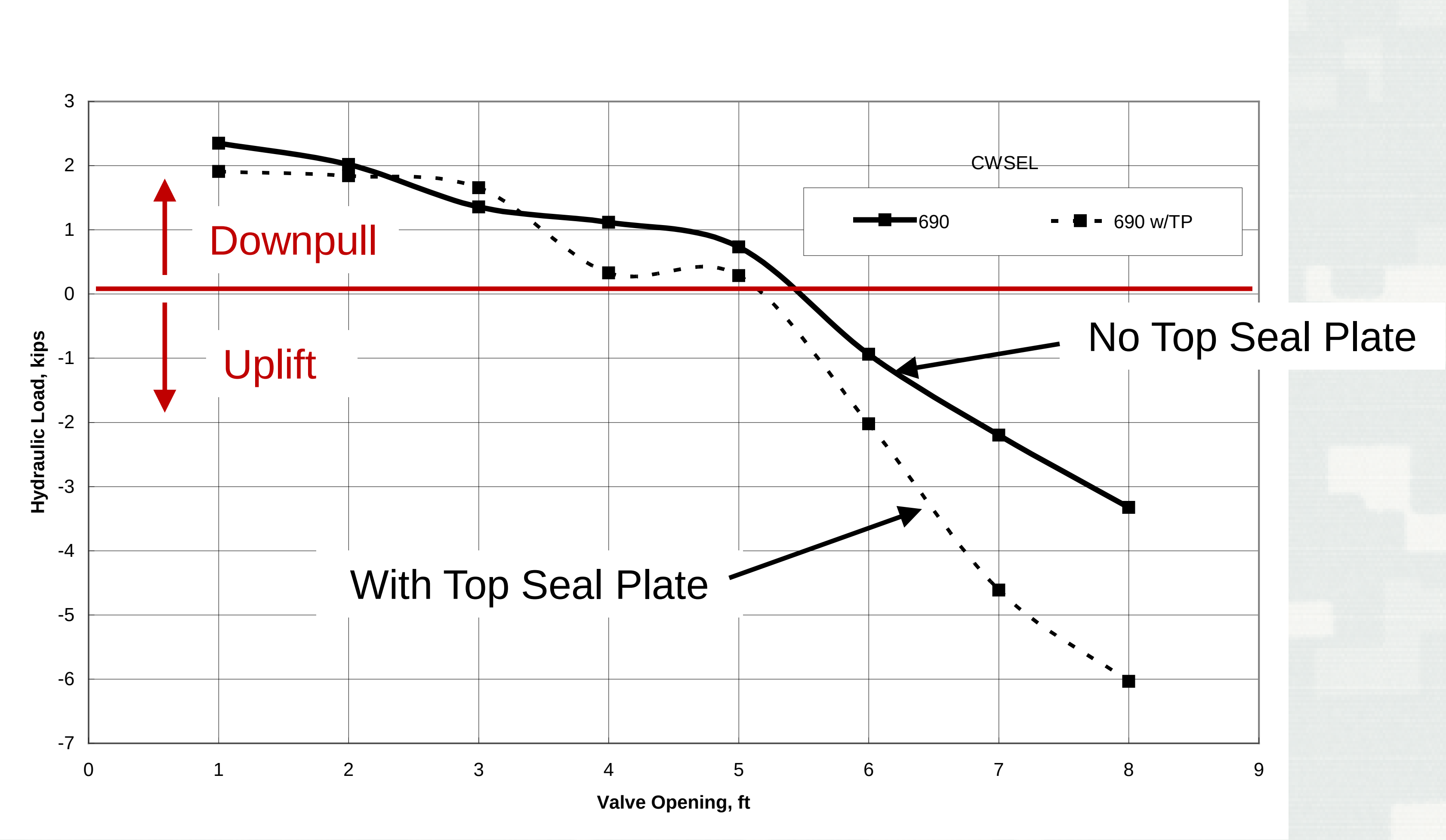


Plate Removed

Comparison of Hydraulic Loads



Snell & Eisenhower Locks
St. Lawrence Seaway

Original Valve

New Valve

Valve replacement often requires engineering design:

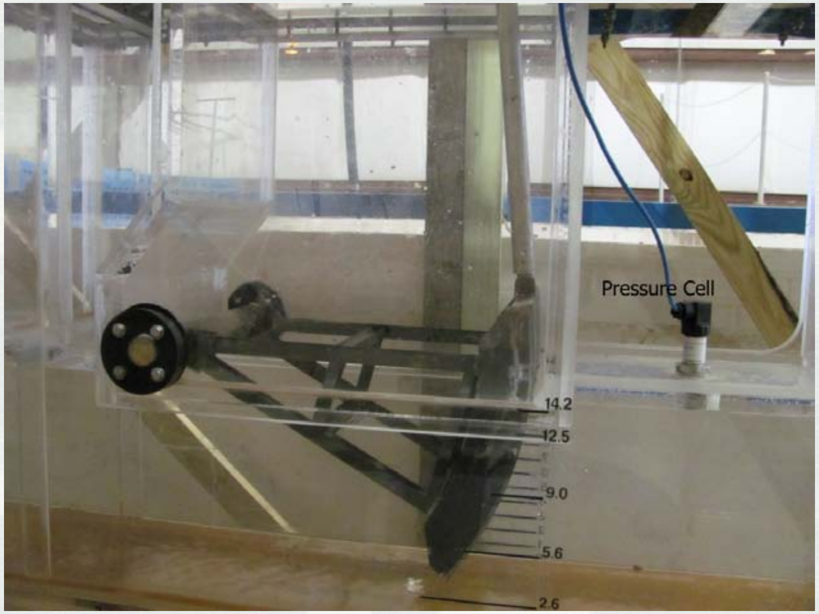
- **Double skin plated valve replaced with vertically framed design.**
- **New valves are requiring more power to operate.**

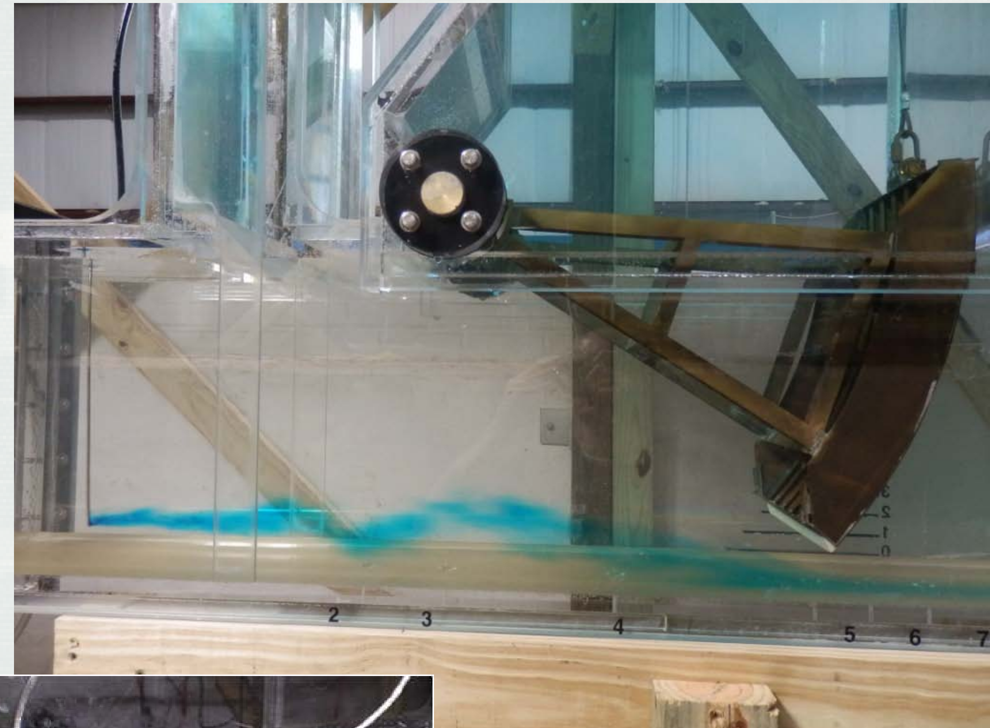
Snell Lock Valve
1:15-Scale Physical Model

Dry Bed View Looking Downstream

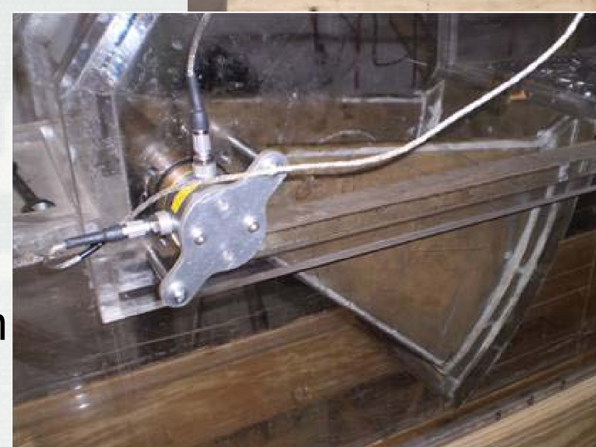
Dry Bed View Looking Upstream

Snell Lock Valve
1:15-Scale Physical Model



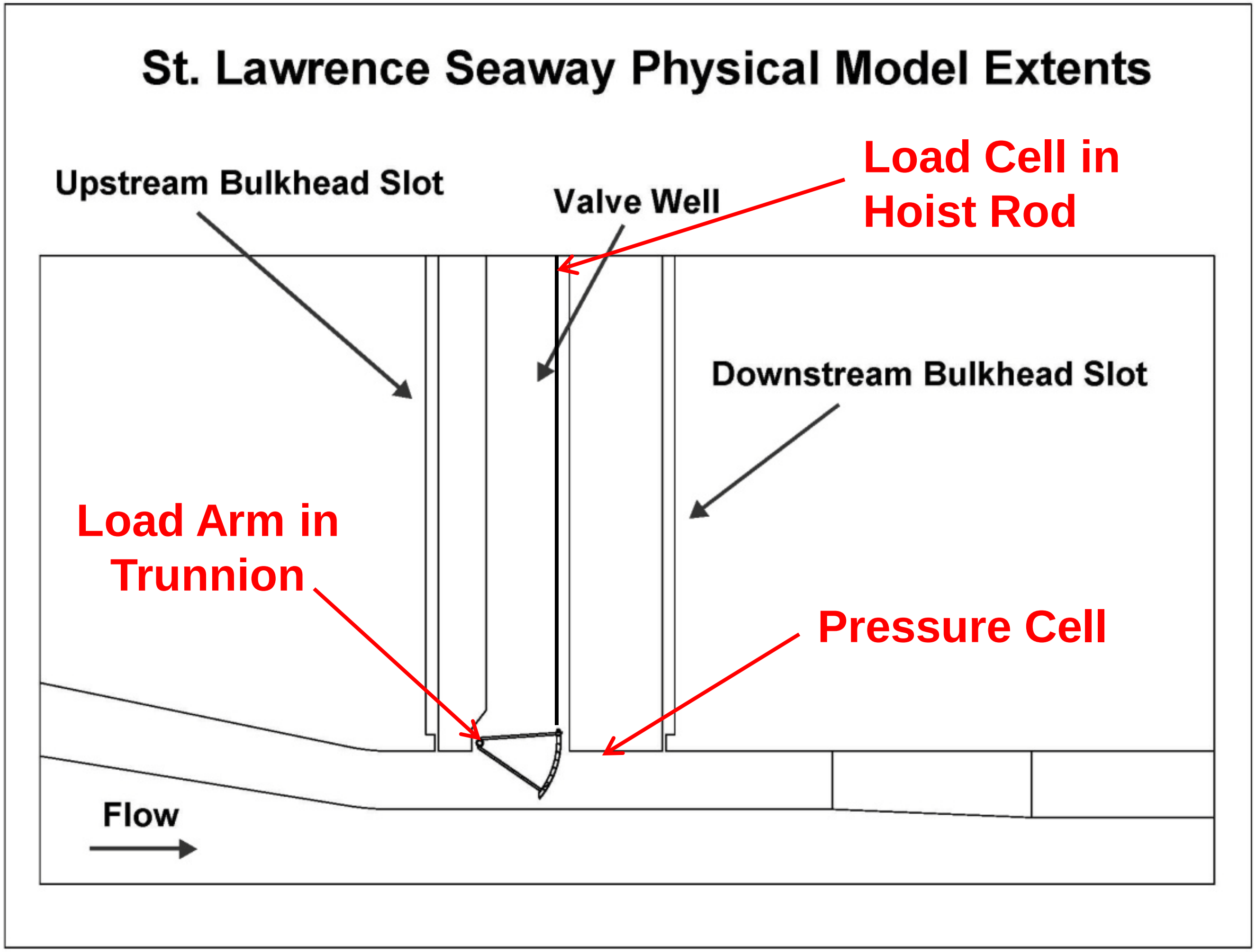


Close-up Views of Valve



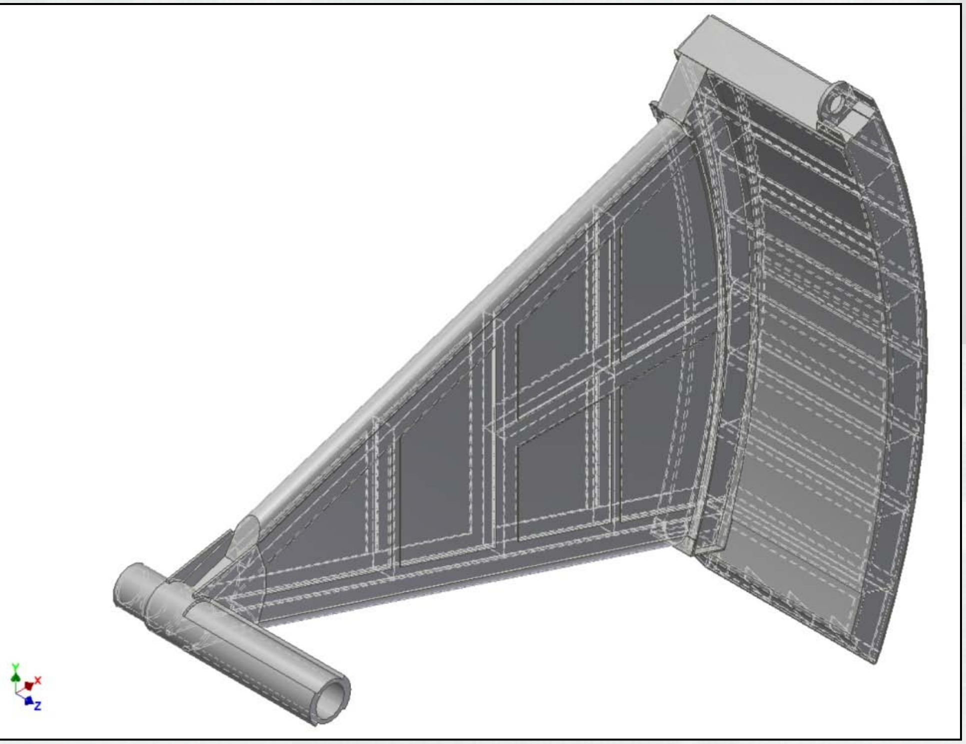
Trunnion Load Arm

Physical Model – Instrumentation



Double-Skin Valve

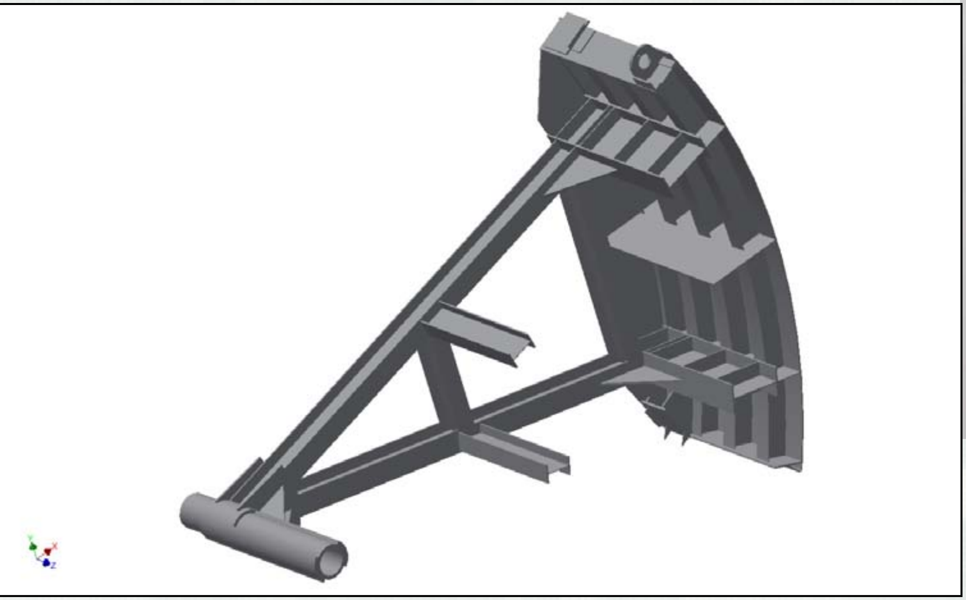
Double-skin-plate
Reverse Tainter Valve

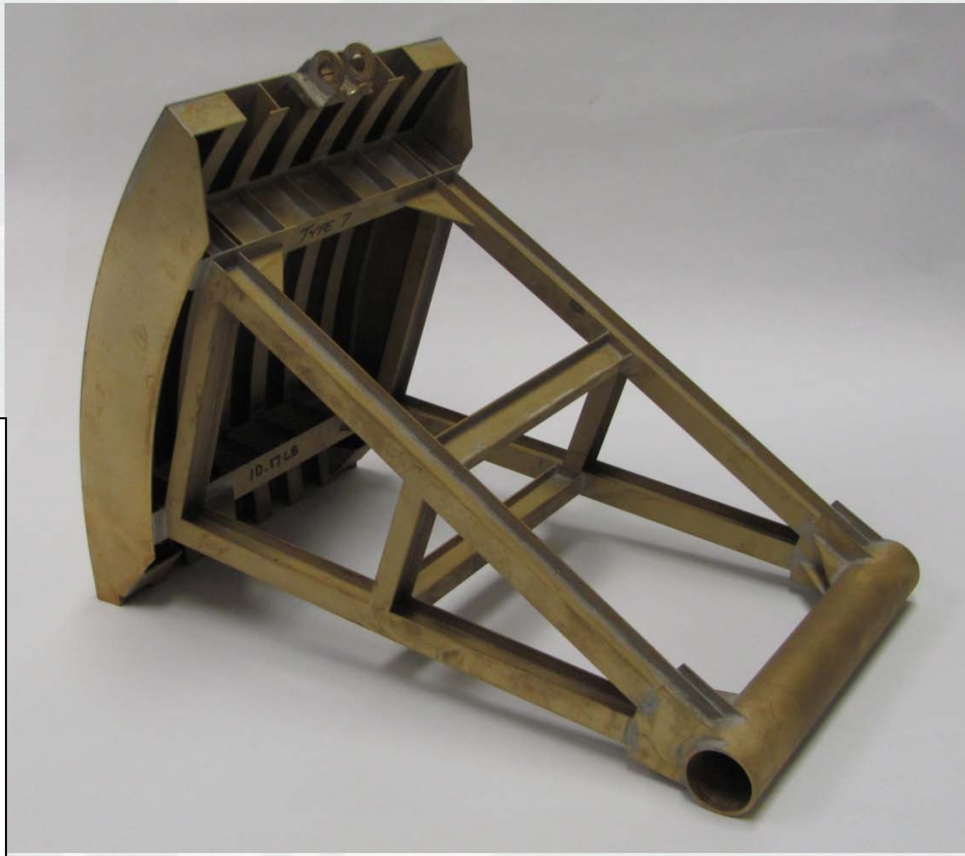


Half-section View of Double-skin Plate Valve, the Hidden Lines Show the Internal Framing Members

Vertical Frame Valve

Half-section View
of the Vertical-frame Valve





Vertical-frame Reverse Tainter Valve

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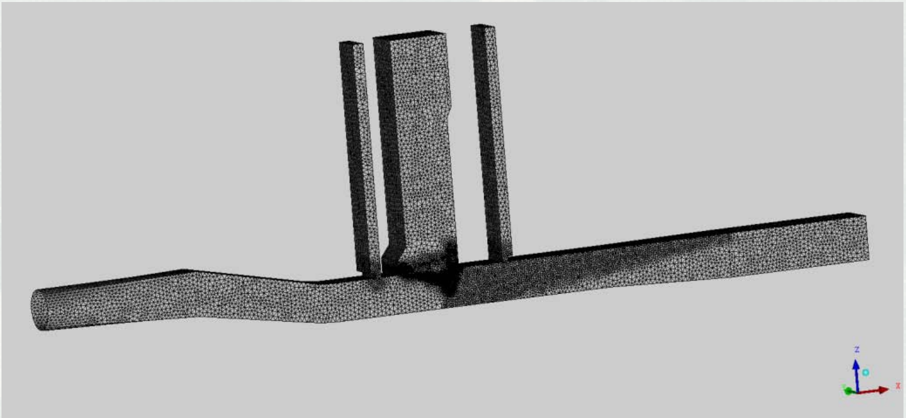
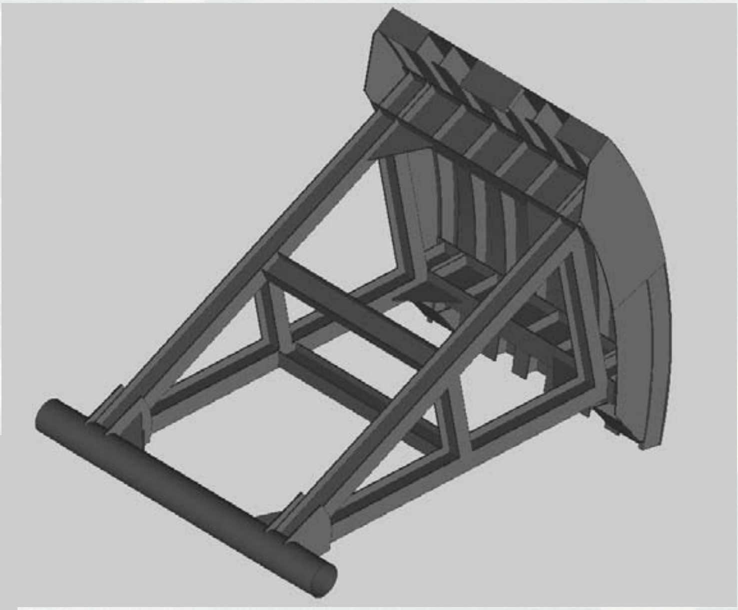
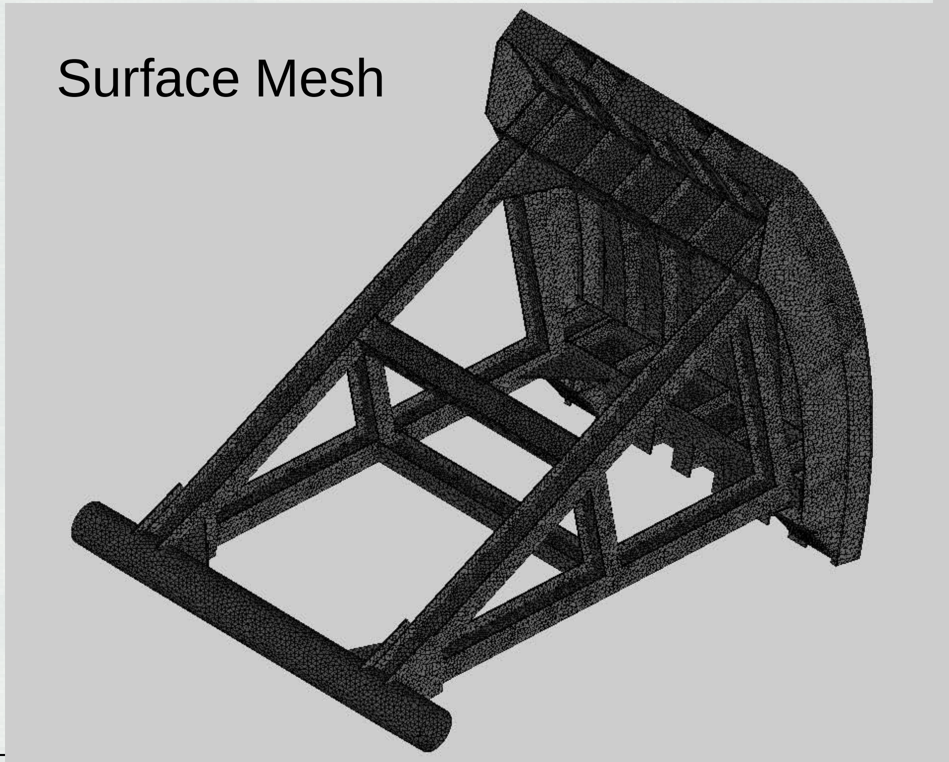
Vertical Frame Valve – Computational Flow Model



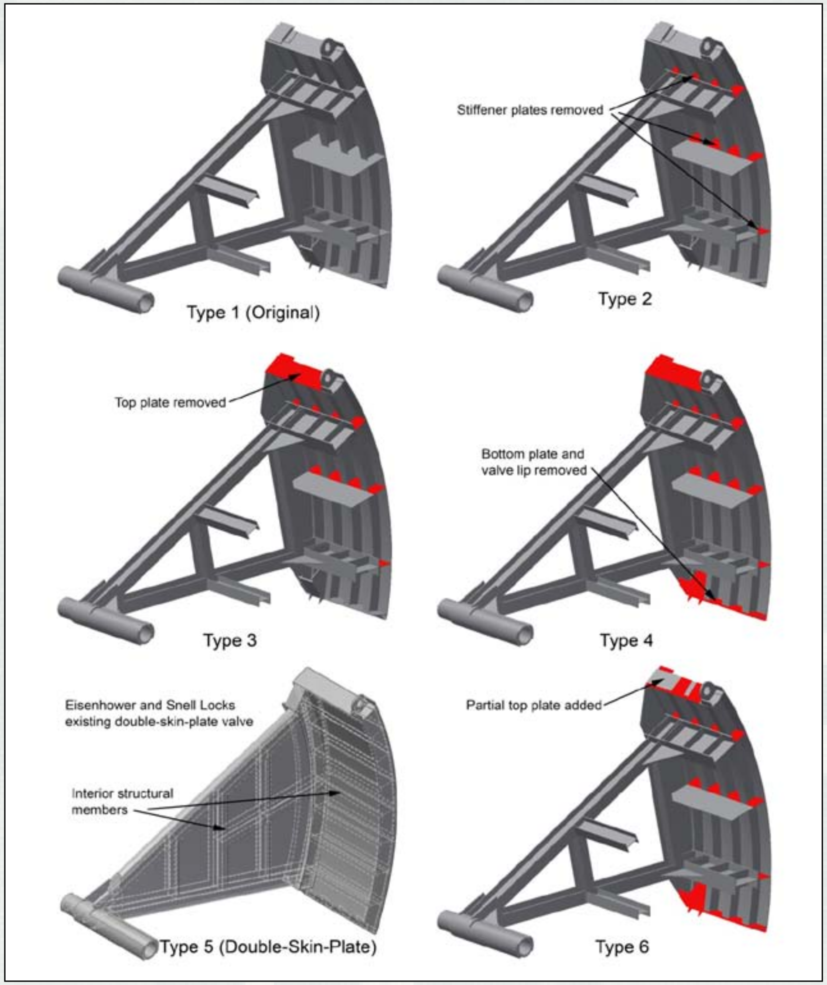


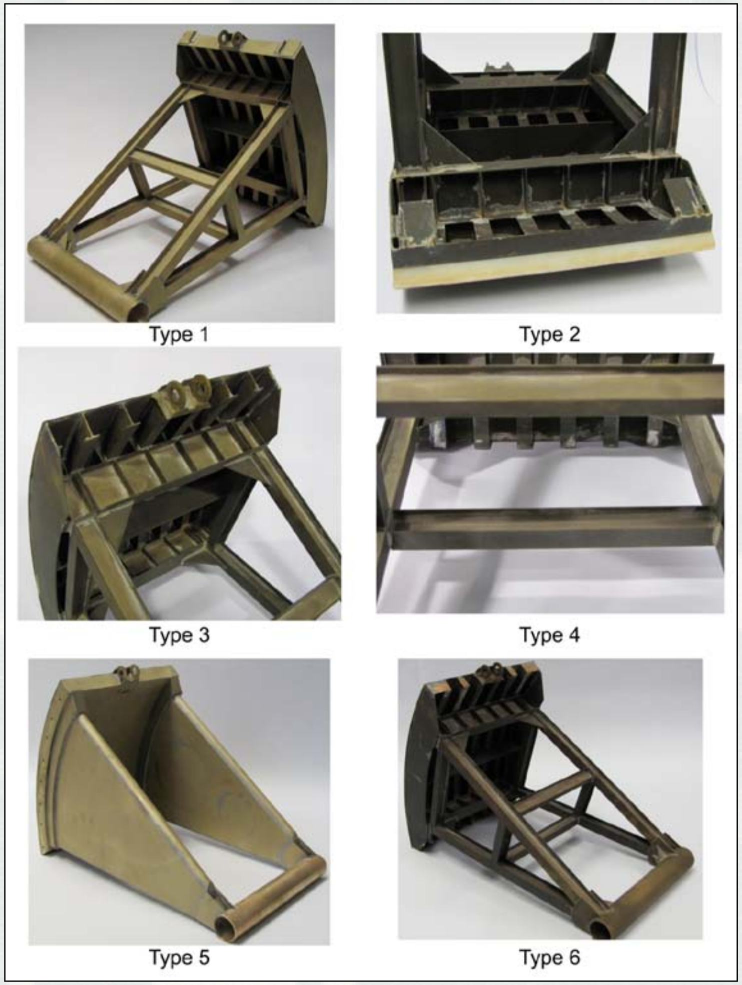
CAD Model



Double-Skin & Vertical Frame Valves

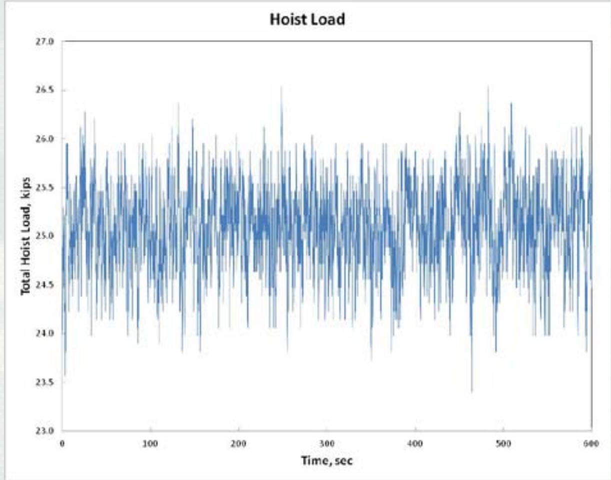
Flow Passages Must Be Open



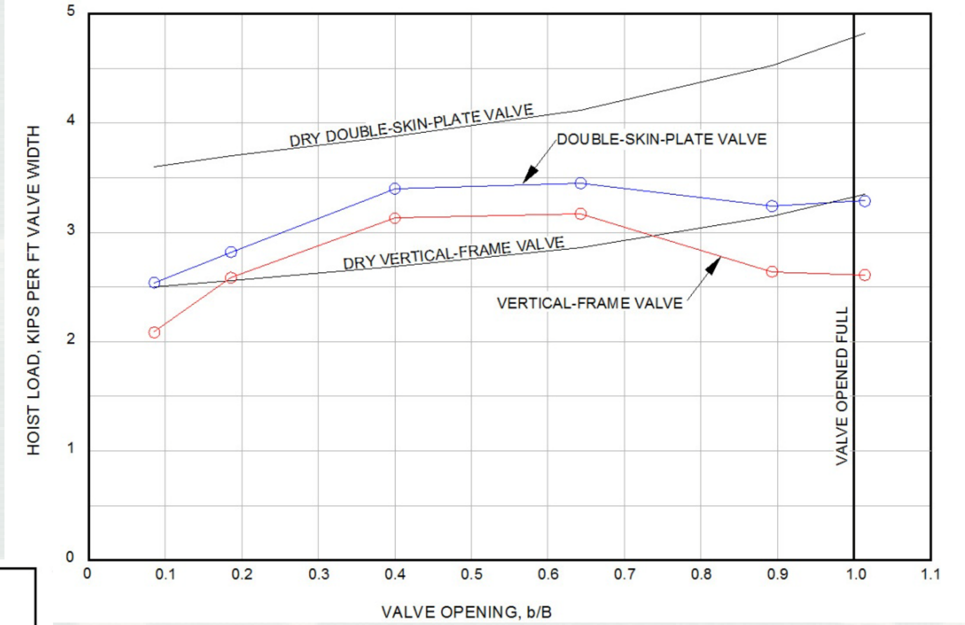


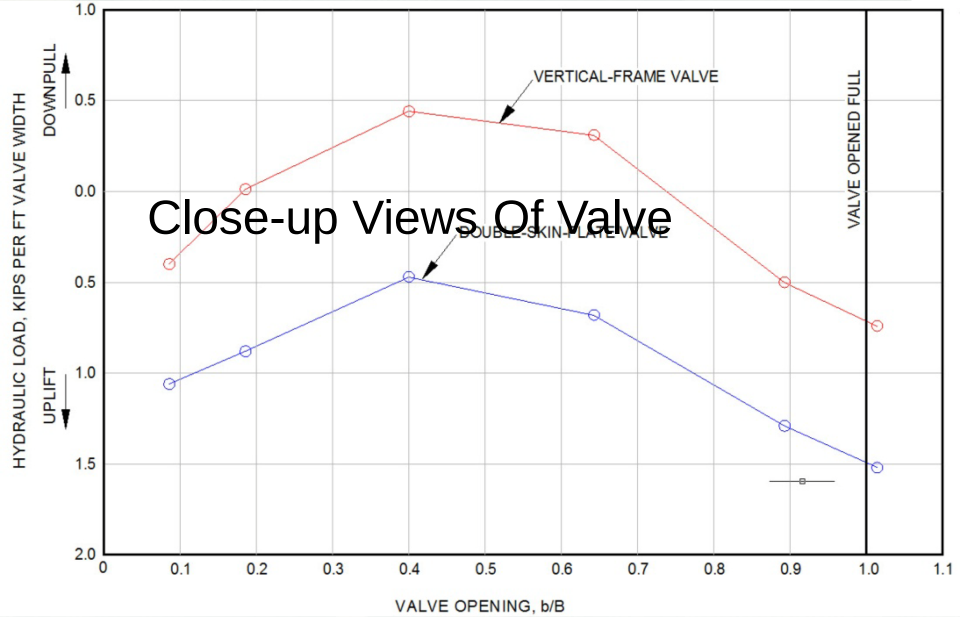
BUILDING STRONG®

Snell Lock Valve – Hoist Loads



Hydraulic loads for vertical-frame and double-skin-plate valves



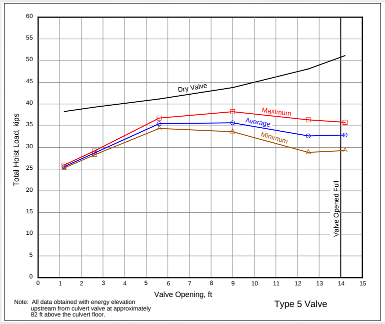


Close-up Views Of Valve

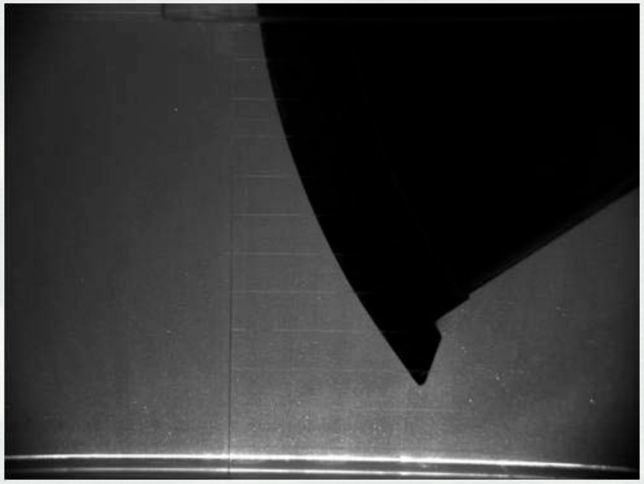
Hoist loads for vertical-frame and double-skin-plate valves

Snell Lock Physical Model Data

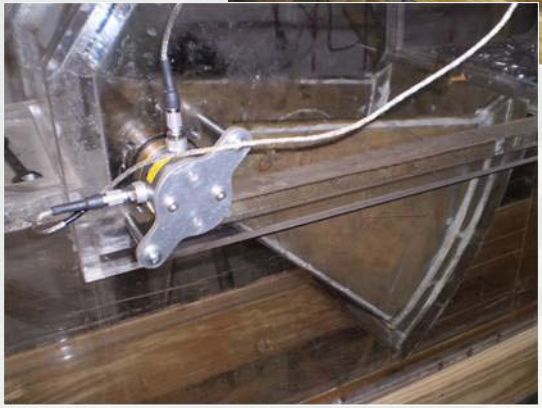
- 1:15-scale model used to determine:
  - Hoist loads: load cell in valve stem
  - Anchorage forces: load cells in trunnion
  - Head losses: pressure cell and piezometers
  - Velocity distribution: PIV



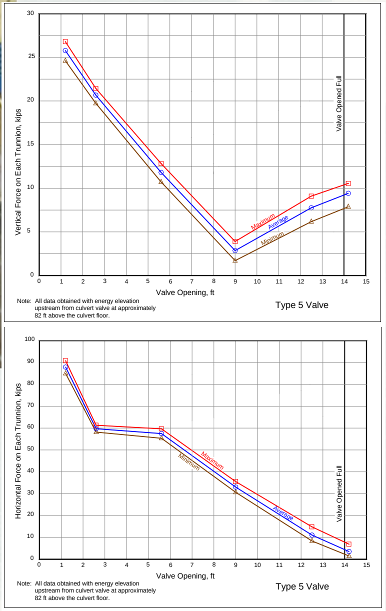
Hoist Loads



PIV Image

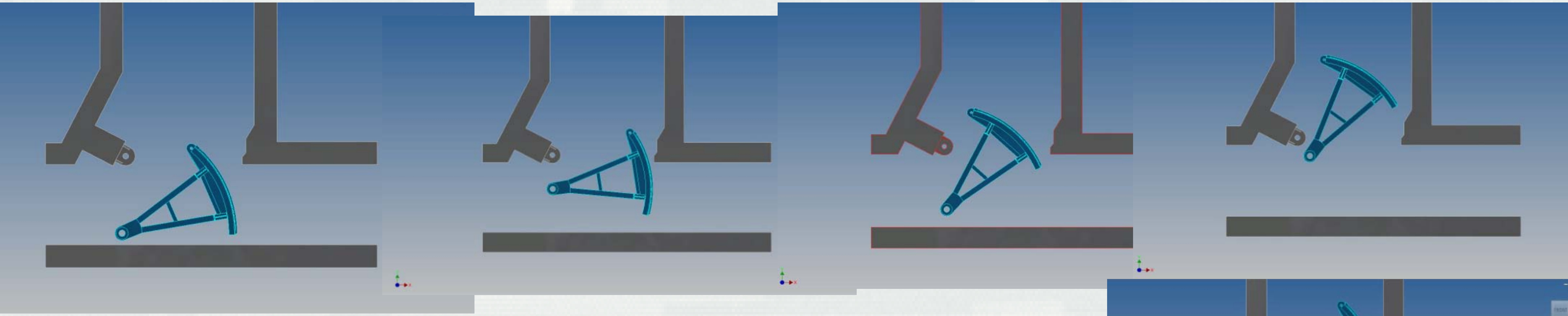


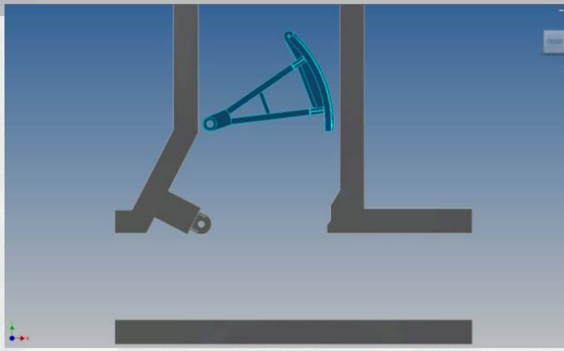
Trunnion Load Cell

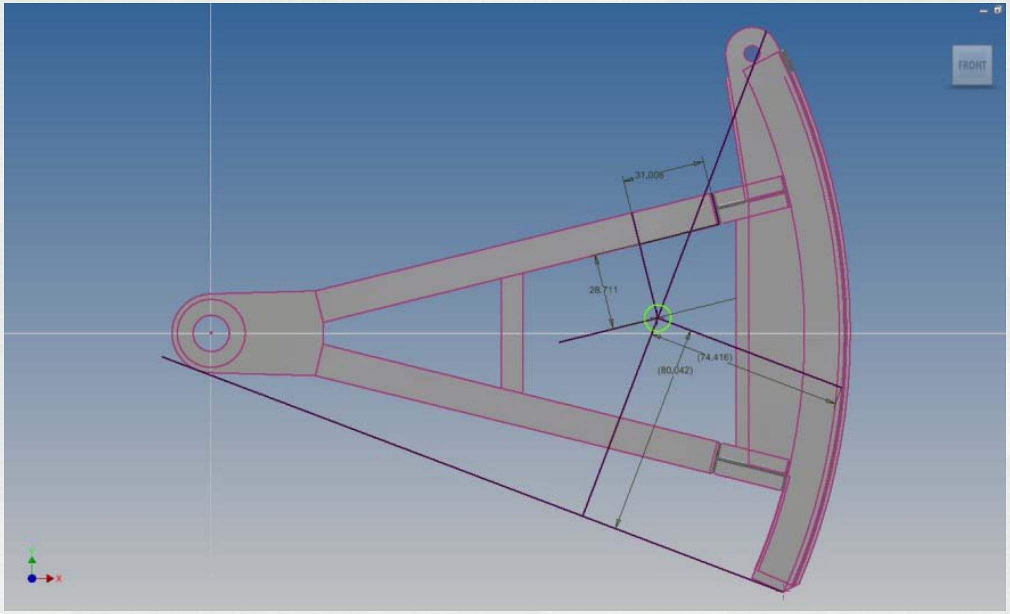


Trunnion Loads

Bankhead Lock Valve Extraction – CAD Model







Center of Gravity

The Dalles & John Day Locks

The same valve design is used for Lower Monumental, Ice Harbor, Little Goose, and Lower Granite Locks.

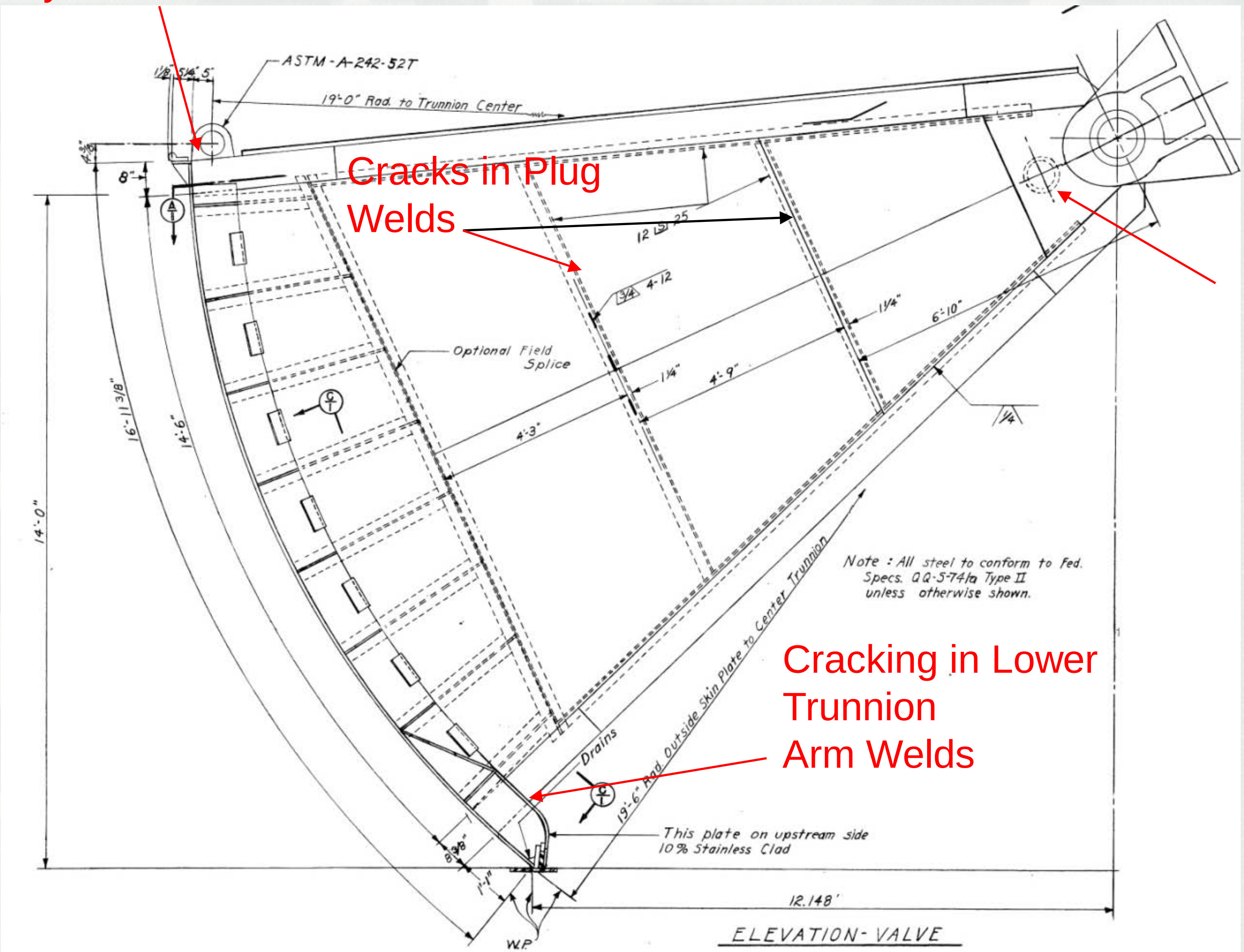
Thanks to
Tom North, NWP

The Dalles NAVLOCK TV#1
Built 1954

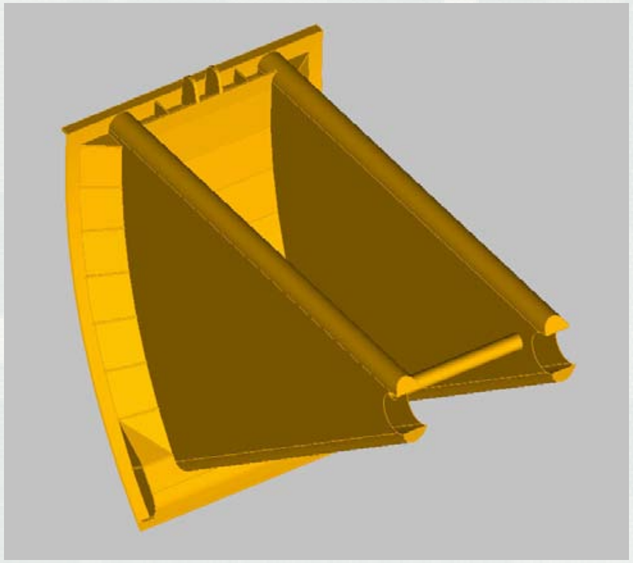
John Day NAVLOCK TV#3
Built 1960

John Day NAVLOCK TV#2

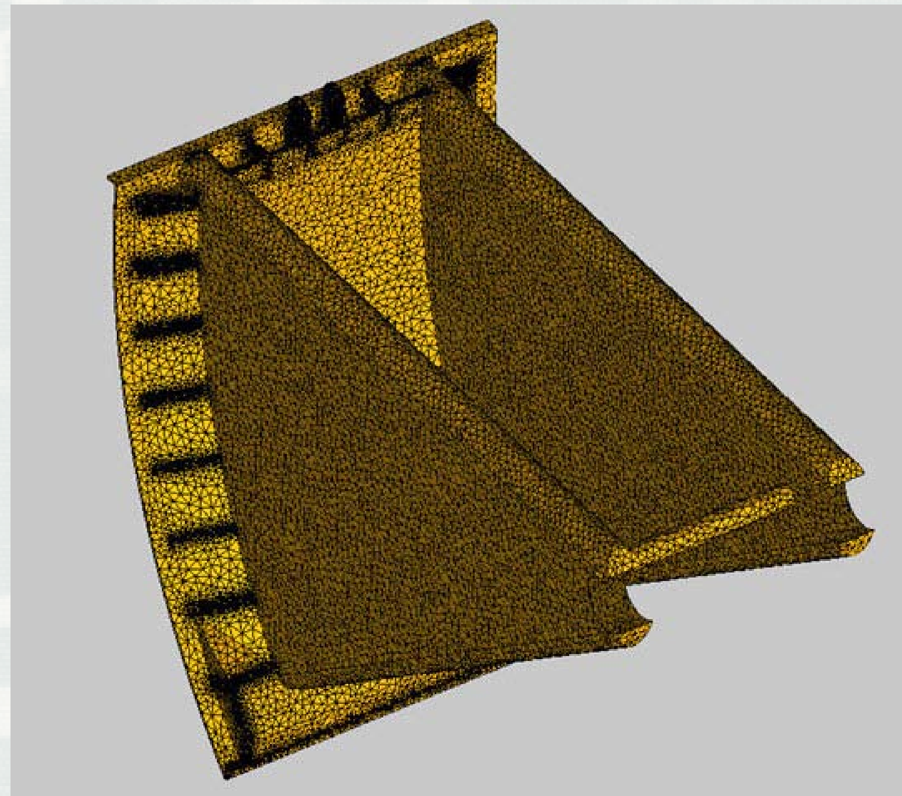
John Day Lock – Problems



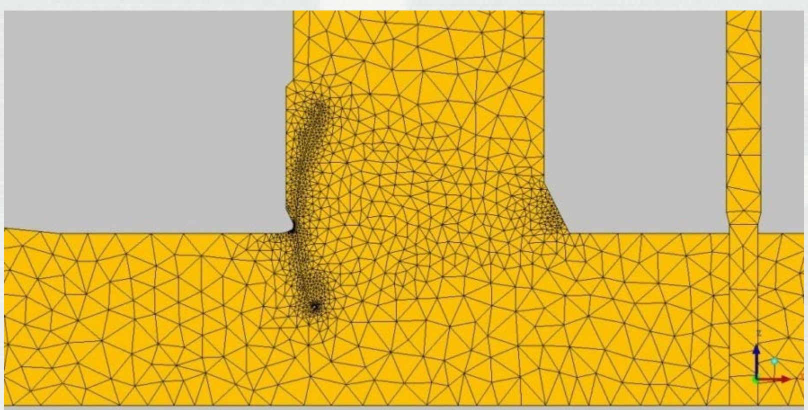
John Day Lock – Computational Flow Model



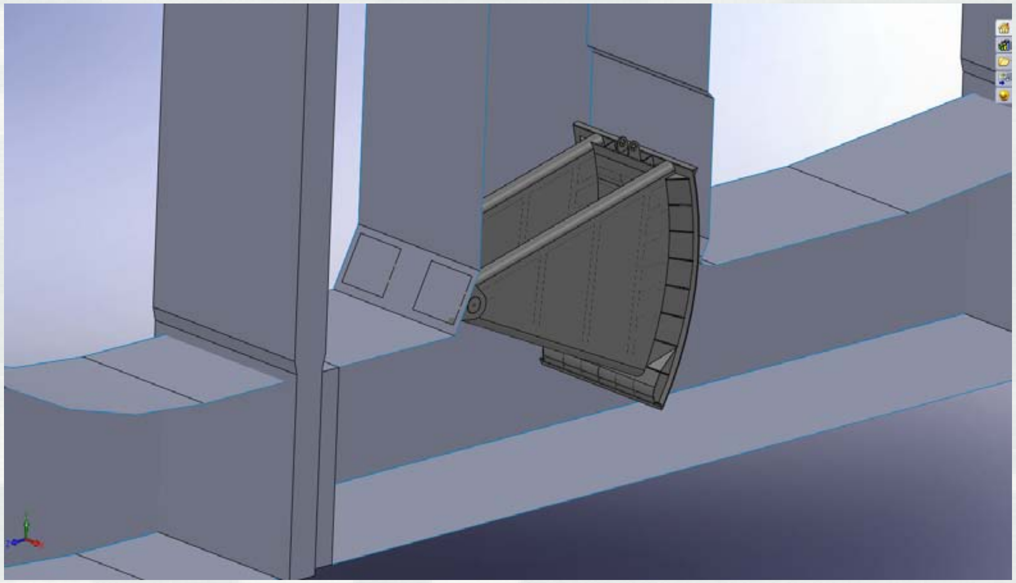
CAD Model



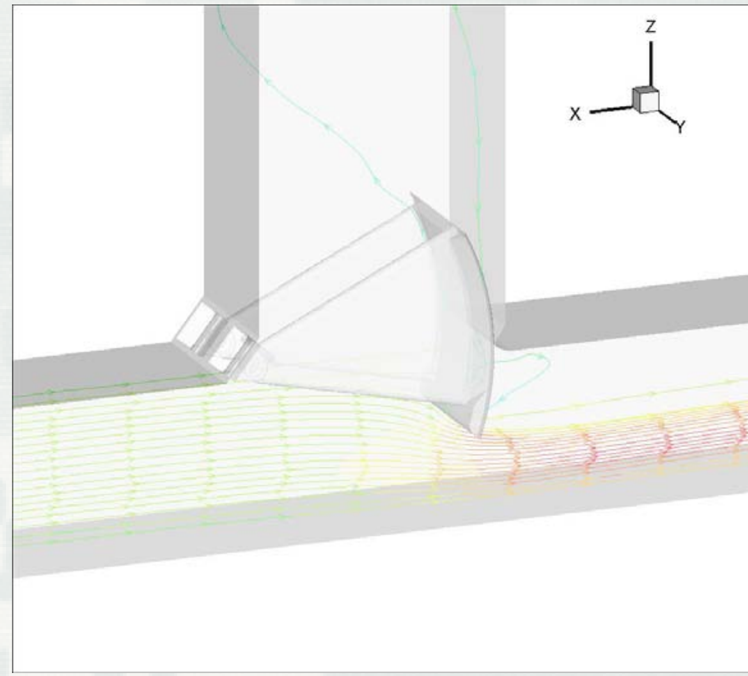
Surface Mesh



John Day Lock Valve – Computational Flow Model

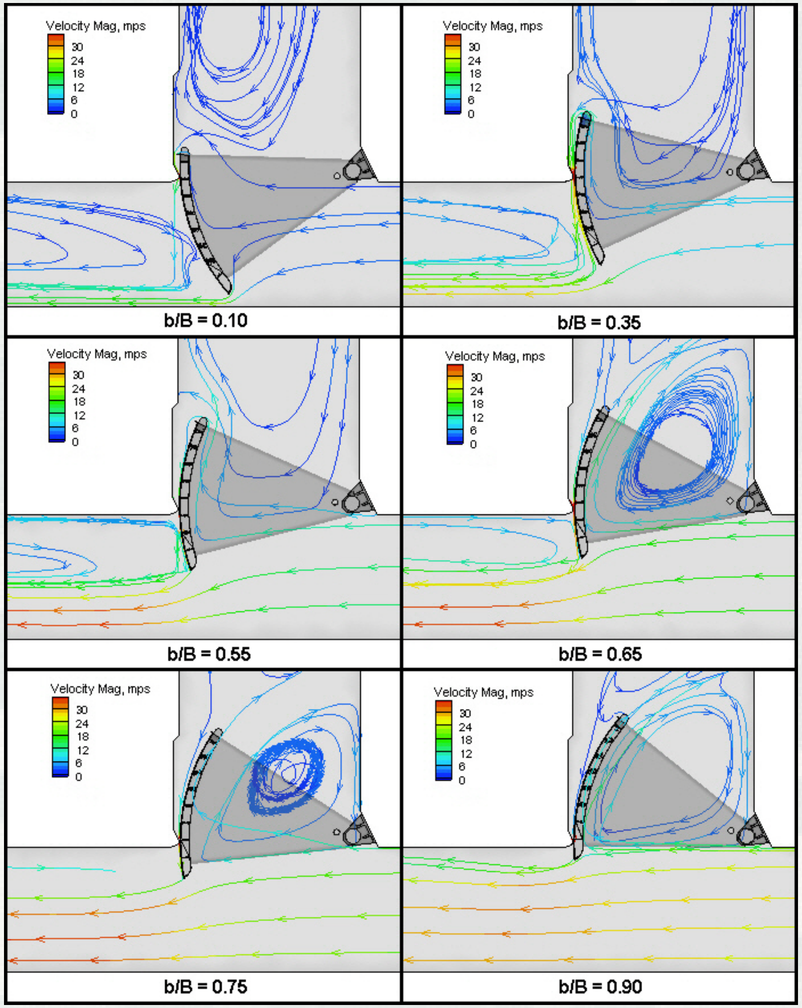


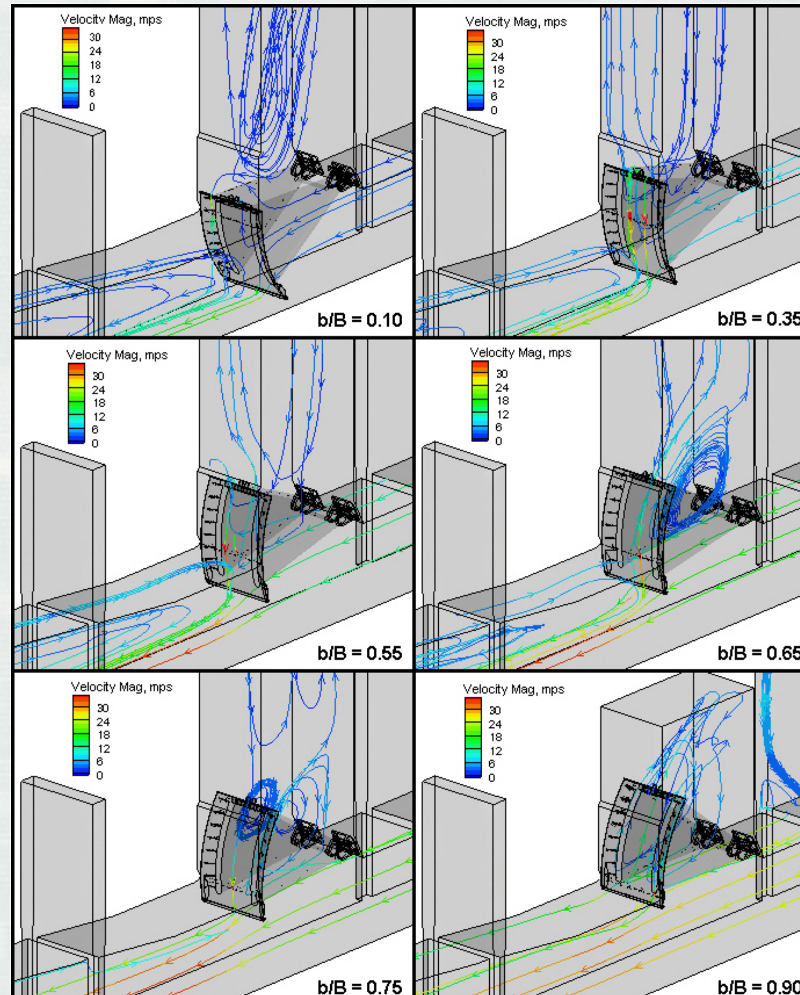
CAD Model



Flow Model Results

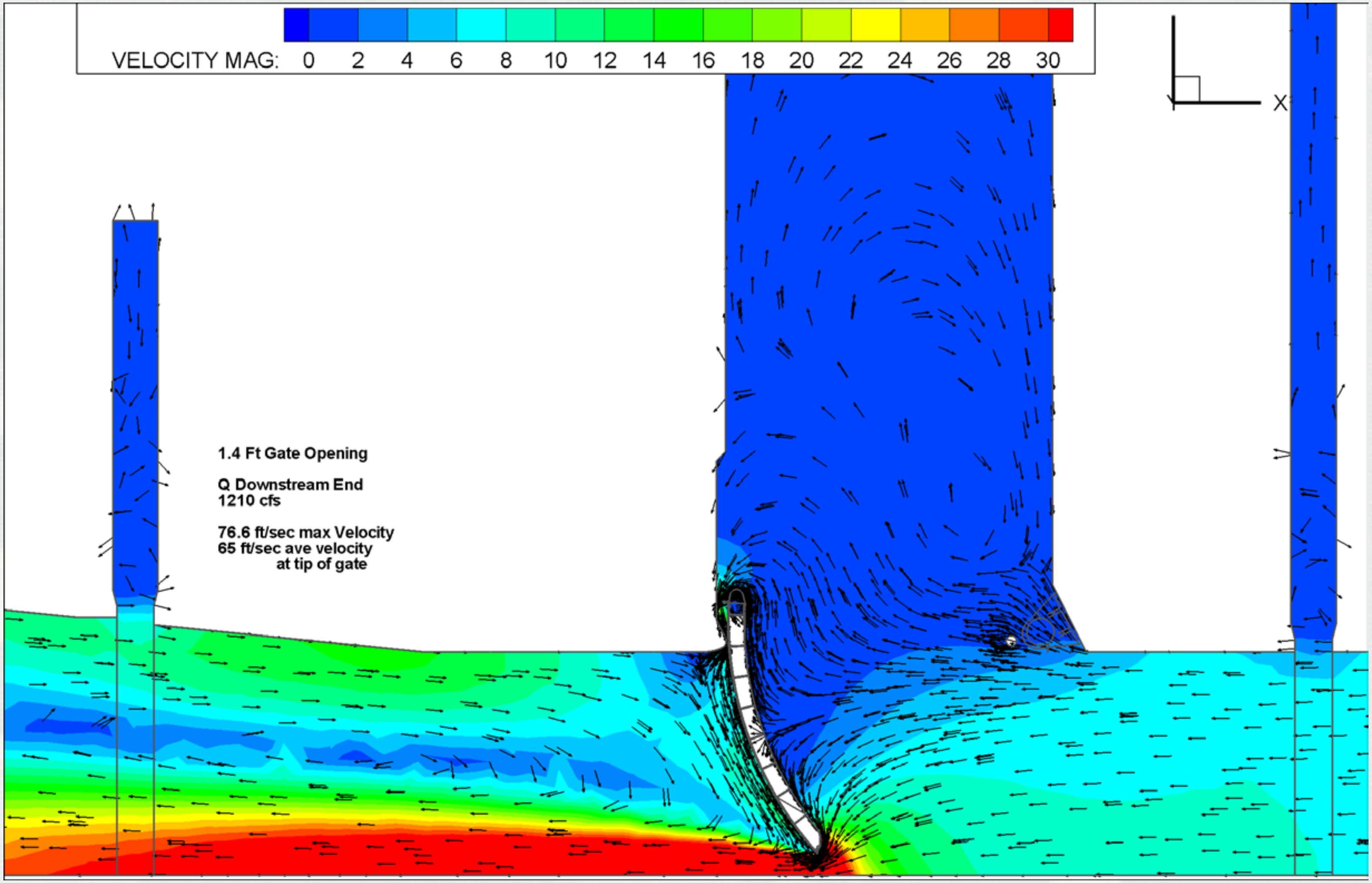
John Day Lock – Velocities and Flow Patterns



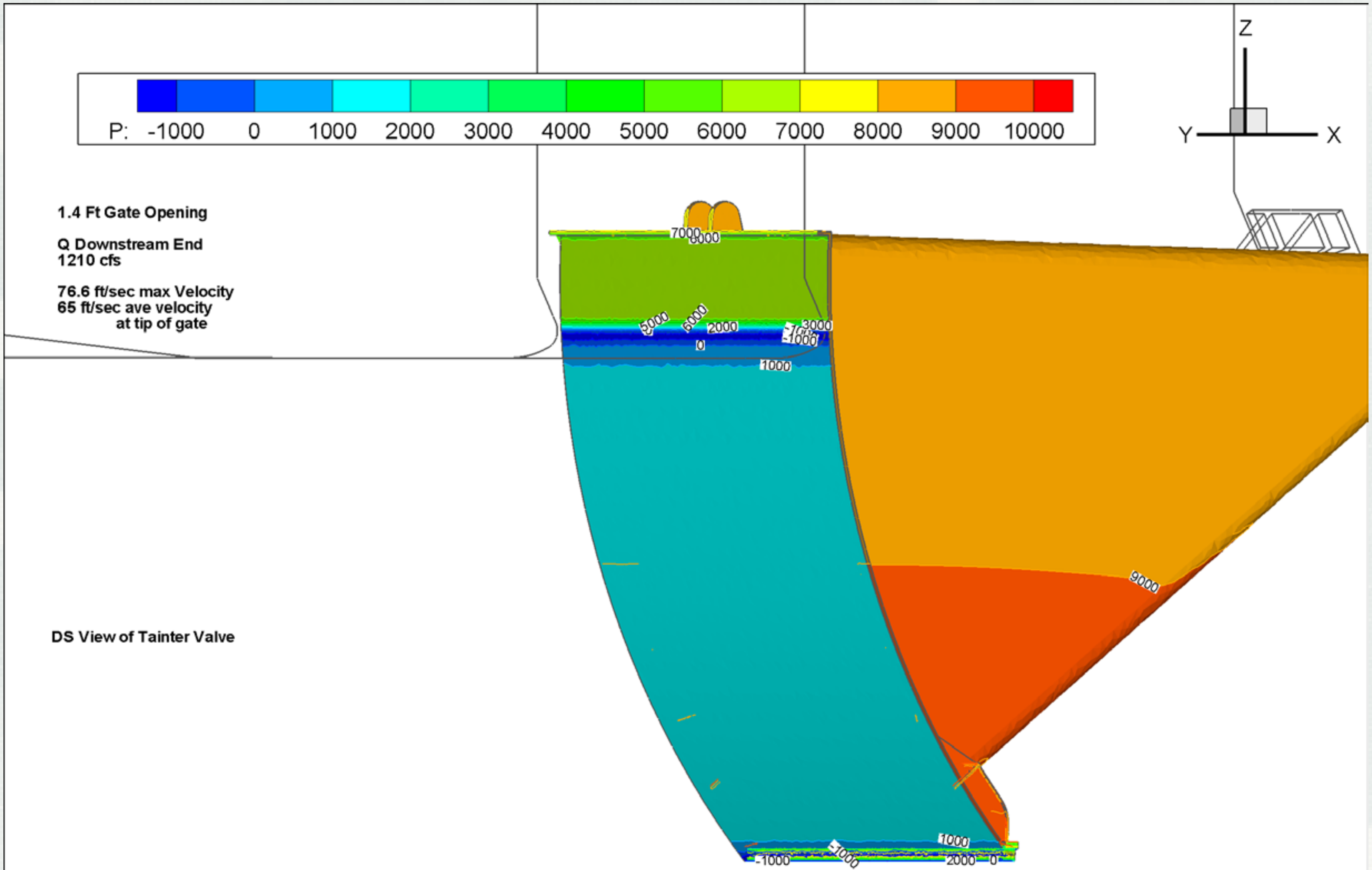


Flow is Directed Upward Against the Skin Plate

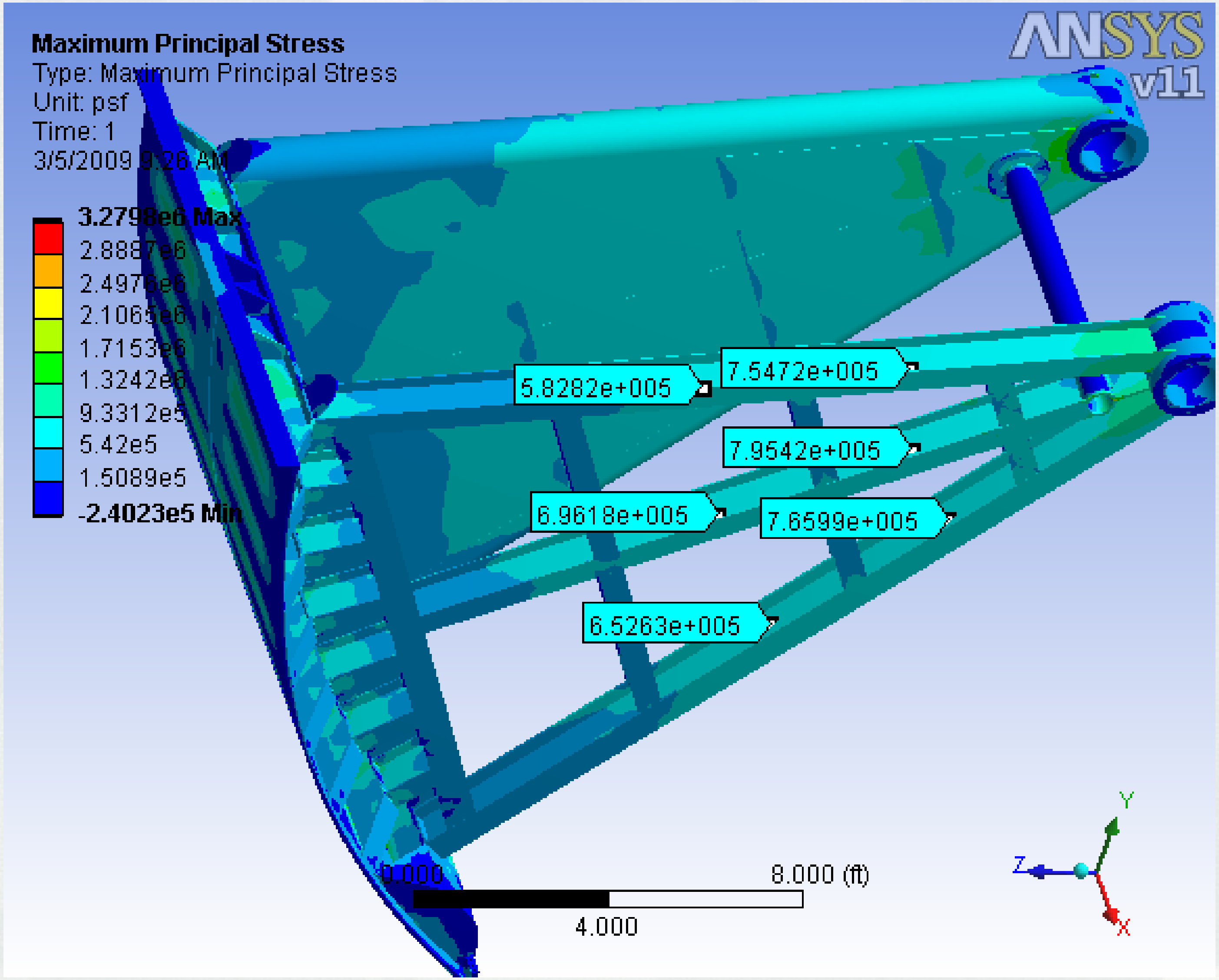
John Day Lock Valve
Computational Flow Model Results



John Day Lock Valve Computational Flow Model Pressure Distribution



CFD Results Coupled with FEA Model

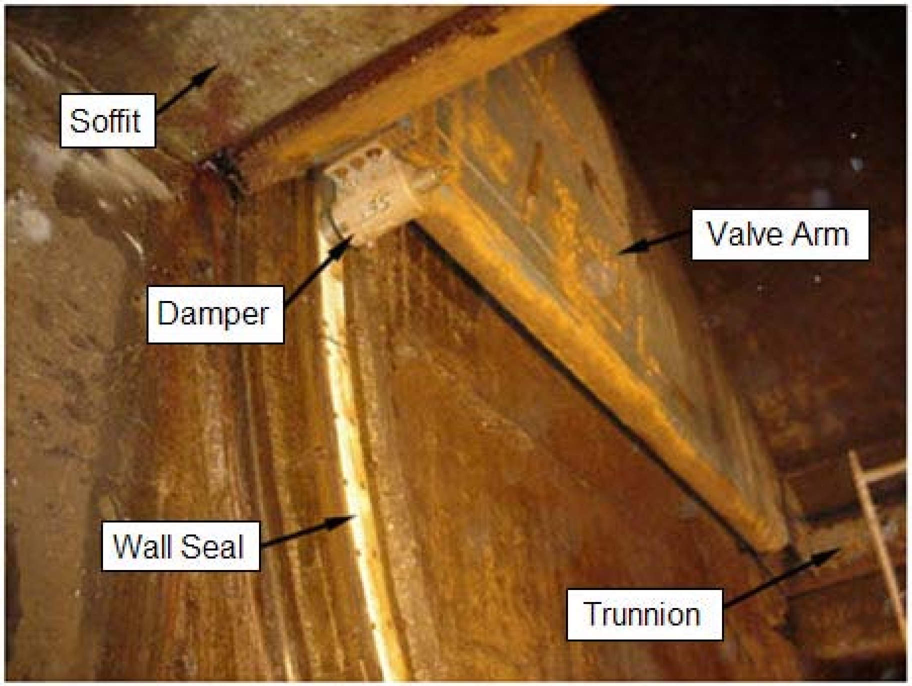


John Day Lock Valve – Fabrication

John Day Lock Valve – Replacement

Installation & Inspection

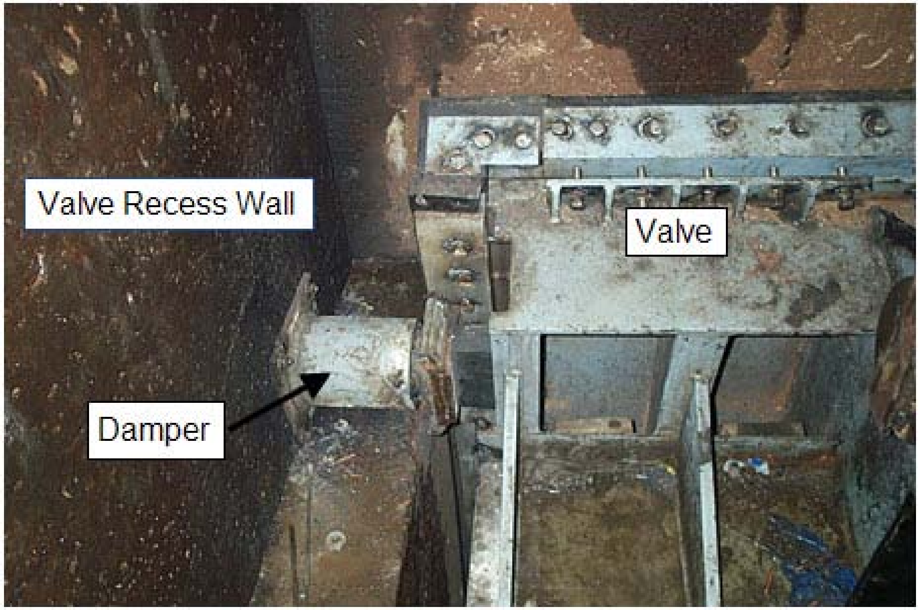
Valve Stabilization – Dampers



Mounted on Valve Arm

Snell Lock,

St. Lawrence Seaway

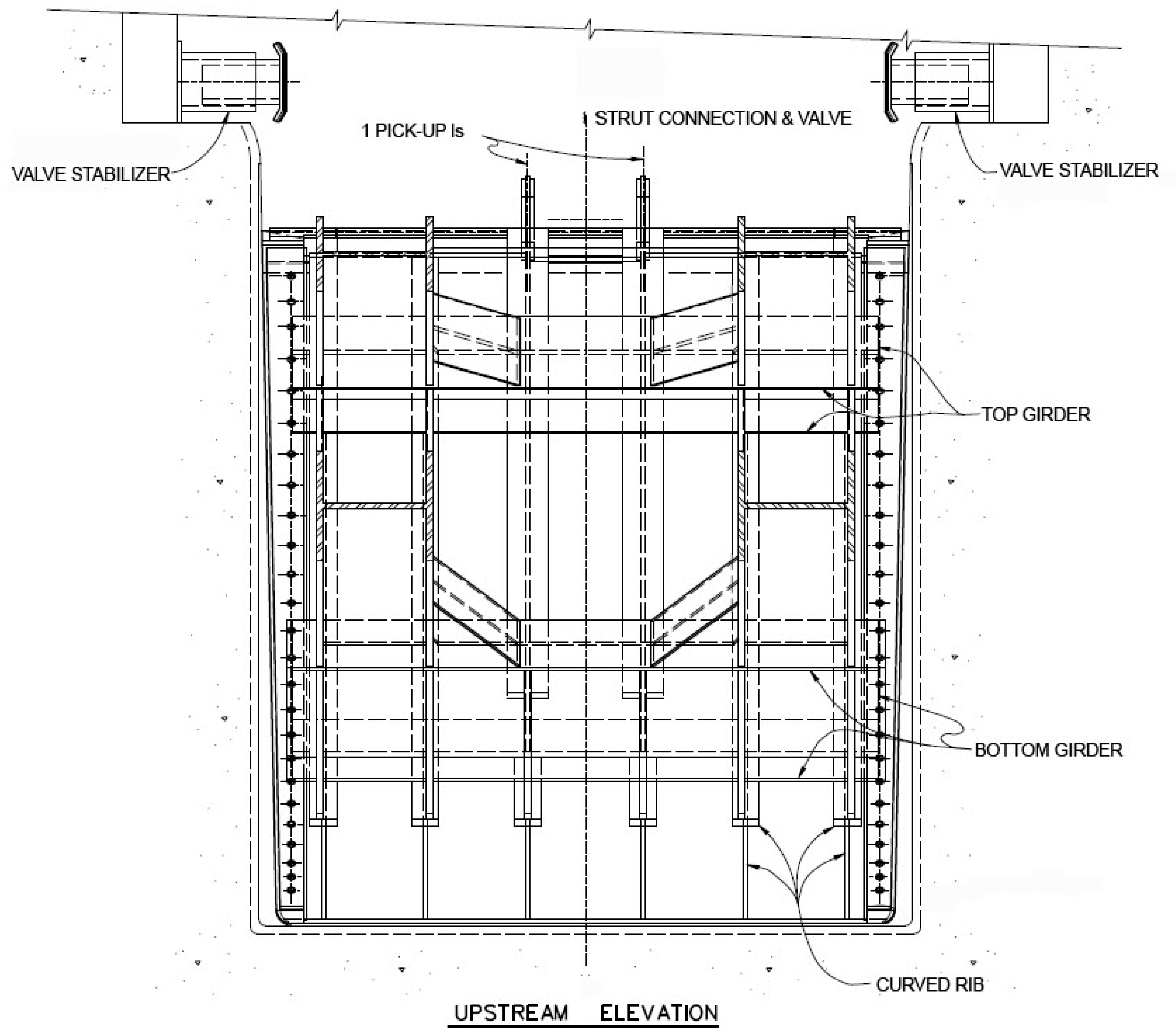


Mounted on Valve Well Wall

Chickamauga Lock,

Tennessee River

Valve Stabilization – Dampers



Chickamauga Lock,

Tennessee River

Summary

- Reverse tainter valves are used almost exclusively in lock culverts
- Valve Position
  - Horizontal: manifold is not very sensitive to location
  - Vertical: High enough to draw air or deep enough to avoid cavitation ($\sigma > 0.6$)
- Many projects are rehabilitating or replacing lock valves
- Vertical frame tainter valve is the recommended design
- Rib geometry is important regarding uplift loads
- Design guidance is being updated – EM 1110-2-1610


QUESTIONS?