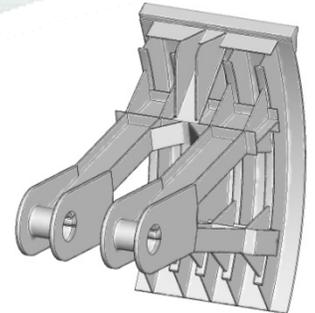


Lock Culvert Valves, Simple Design?

U.S. Army Corps of Engineers
Technology Exchange Meeting
October 28 – 30, 2014

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

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US Army Corps of Engineers
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Current Situation

Design Life

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

Engineering Design

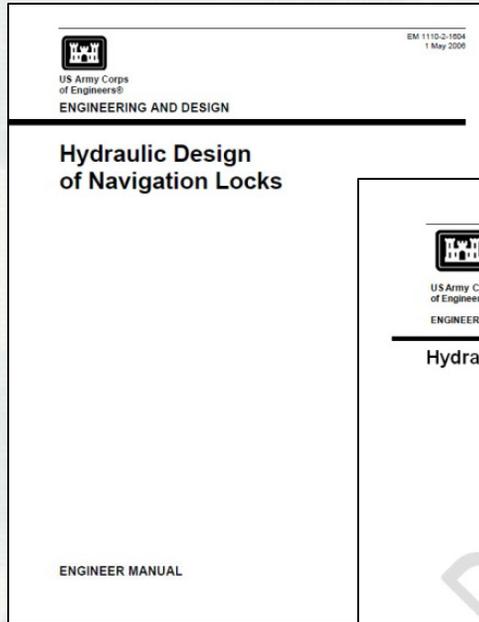
- Maintenance, rehab, or replacement of lock valves often requires engineering design.
- EM 111-2-1610 “Hydraulic Design of Lock Culvert Valves” has not been updated since 1975.

O & M Experience

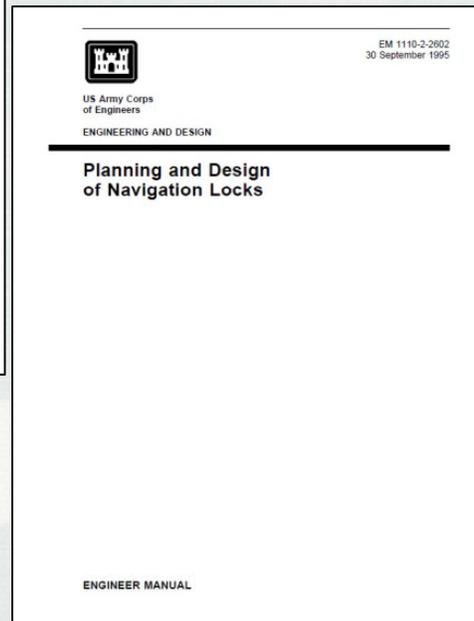
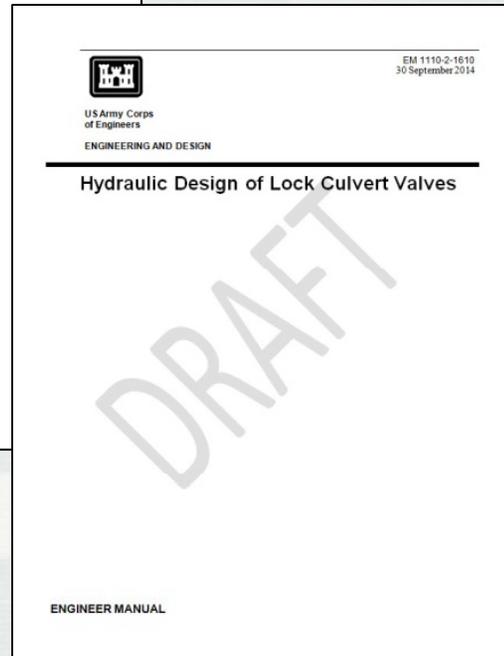
- Some replacement valves have not performed well
 - ▶ Larger hoist loads – both downpull and uplift.
 - ▶ Vibration issues.
- Field measurements suggest that current design guidance under-predicts hoist loads.



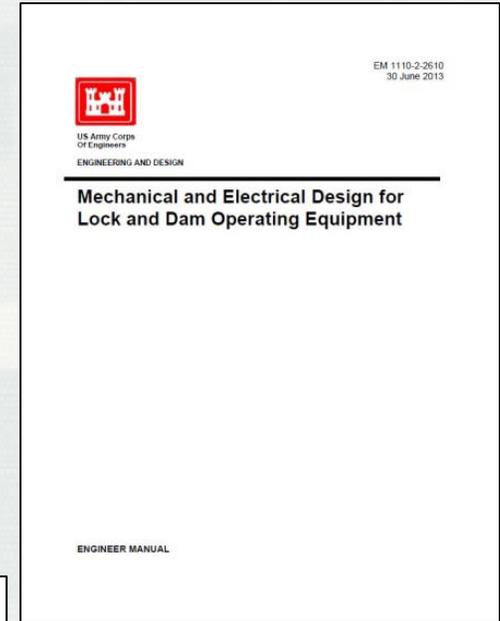
USACE HQ Engineering Manuals



**Hydraulic
Design**



Planning



**Mechanical &
Electrical
Design**



BUILDING STRONG®

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”



Navigation Research Program Publications

ERDC/CHL CHETN-067
June 2013



Hydrodynamic forces on reverse tainter valves; hydraulic model investigation

US Army Corps of Engineers, 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 Nelson 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 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.

PHYSICAL MODELING FACILITY: Completion of a physical model study of the culvert valves of the Eisenhower and Shell Locks, St. Lawrence Seaway (Stockstill et al. 2012), 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-066
September 2013



Field experience with lock culvert valves

US Army Corps of Engineers, 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 become 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

EM 1110-2-1618
30 September 2015



Hydraulic Design of Lock Culvert Valves

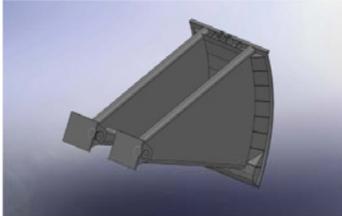
US Army Corps of Engineers
ENGINEERING AND DESIGN

ERDC/CHL TR-13-4



Lock Culvert Valves; Hydraulic Design Considerations

Navigation Systems Research Program
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-027
October 2011



Computational flow model of a reverse tainter valve

US Army Corps of Engineers, 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 Nelson 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" construction prevents large volumes of air from being drawn into the culvert at the valve well, thereby preventing dangerous surges in the lock chamber.

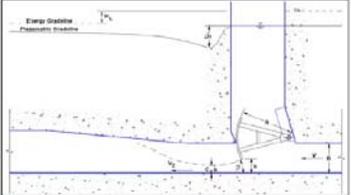


Figure 1. Geometric and hydraulic parameters describing a reverse tainter valve.

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_u and V_d 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



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

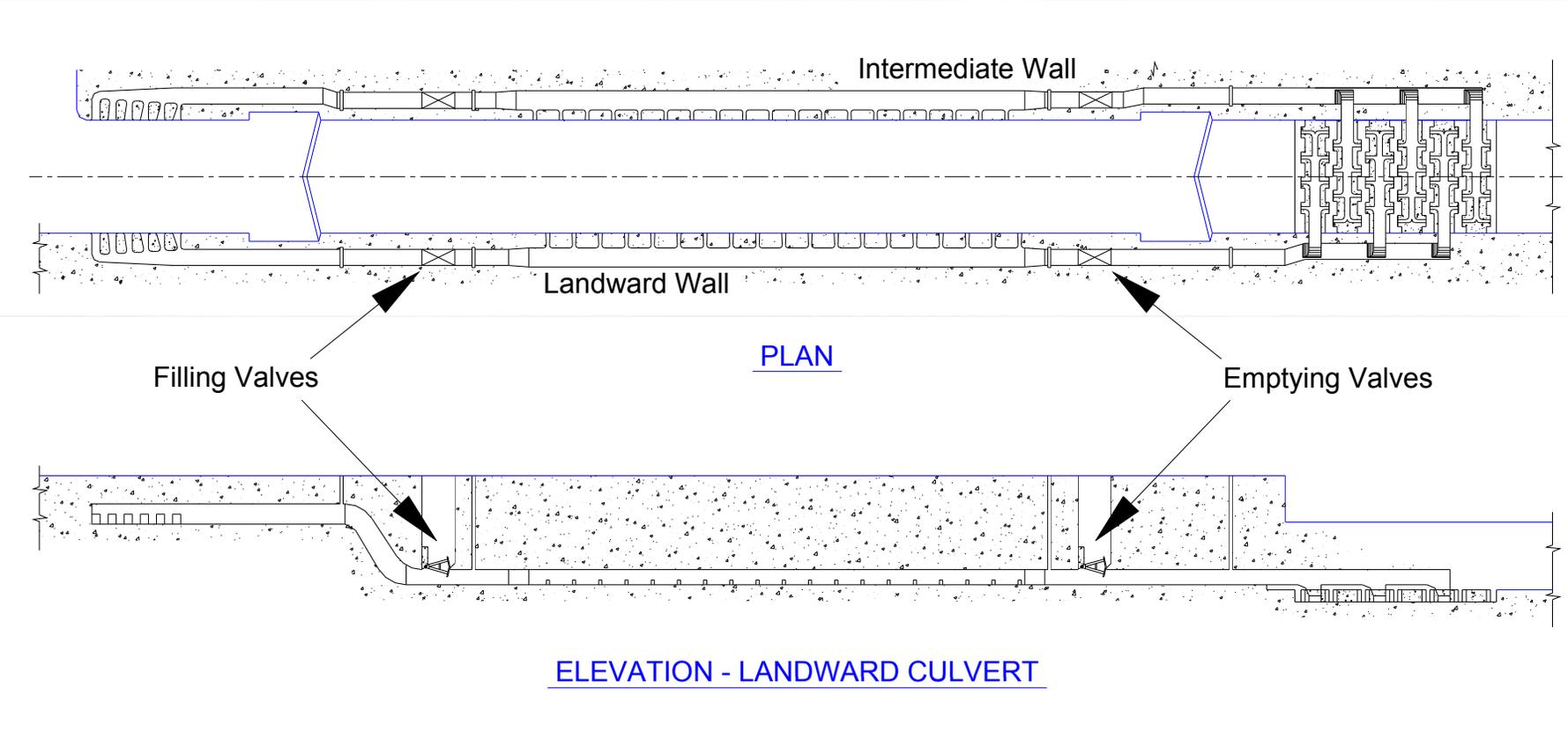
DSP = Double-Skin Plate

VF = Vertical Frame

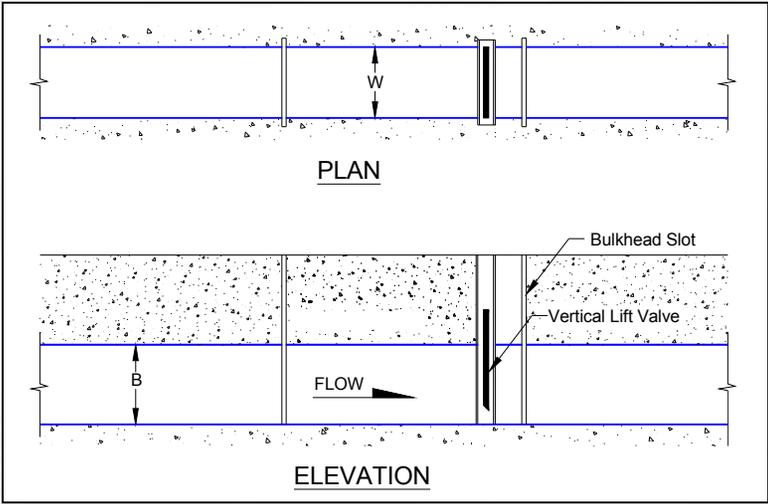
HF = Horizontal Frame



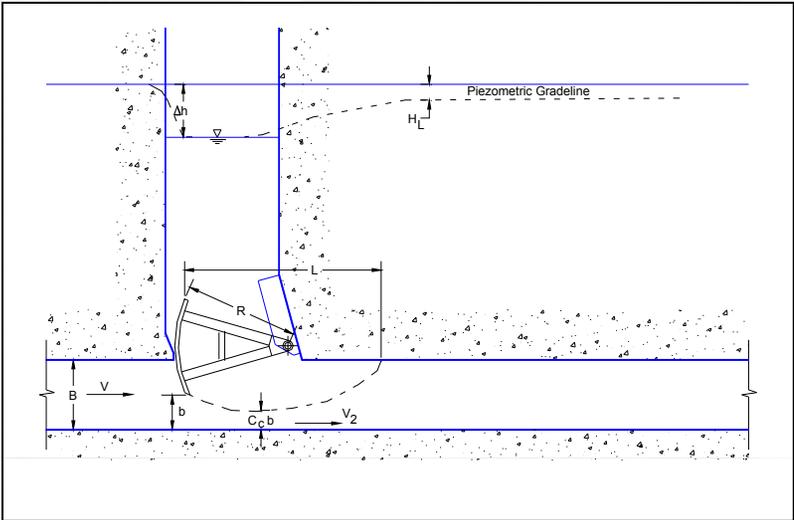
Sidewall-port System



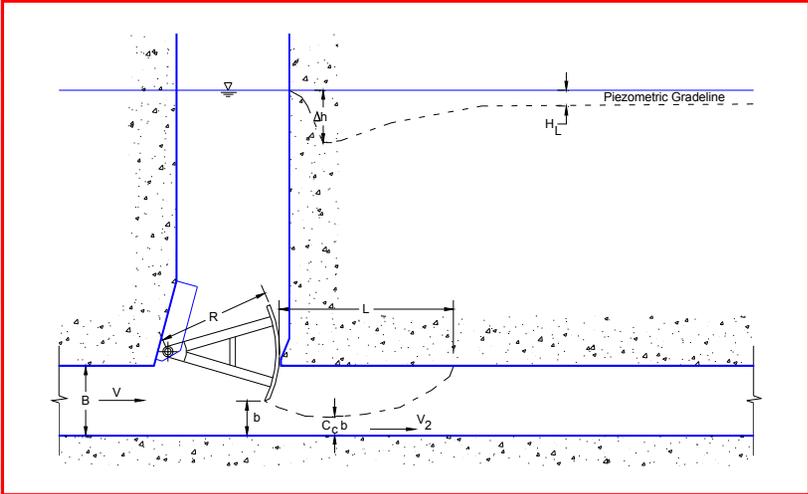
3 Valve Configurations



Vertical-Lift Valve



Conventional Tainter Valve



Reverse Tainter Valve



Reverse Tainter Valve



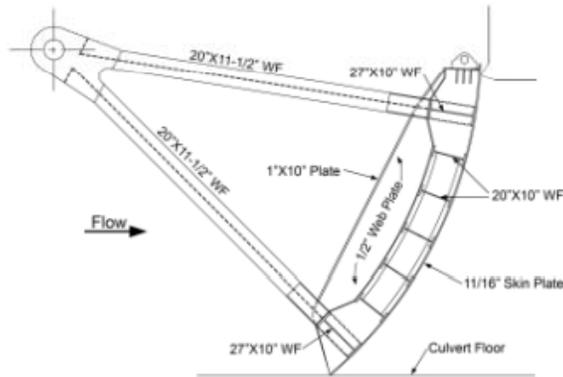
MODEL



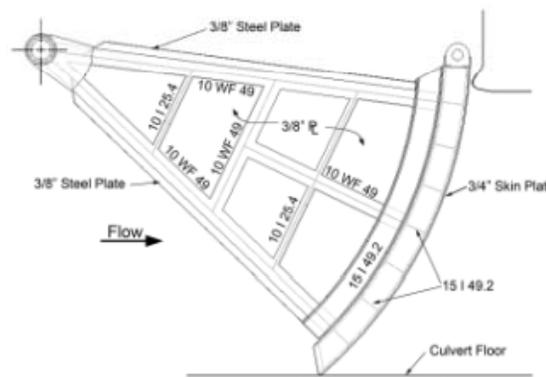
MODEL



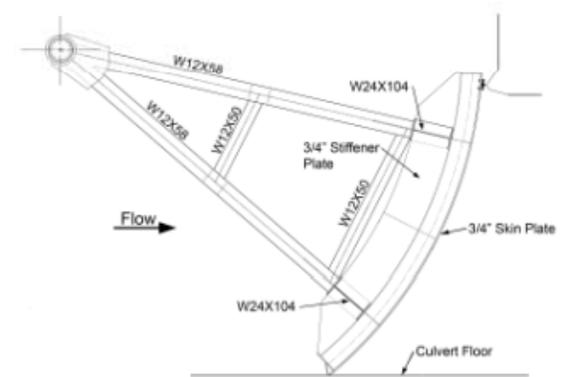
MODEL



SECTION ALONG CENTER LINE
FIG. a HORIZONTALLY FRAMED



SECTION ALONG CENTER LINE
FIG. b DOUBLE SKIN PLATE



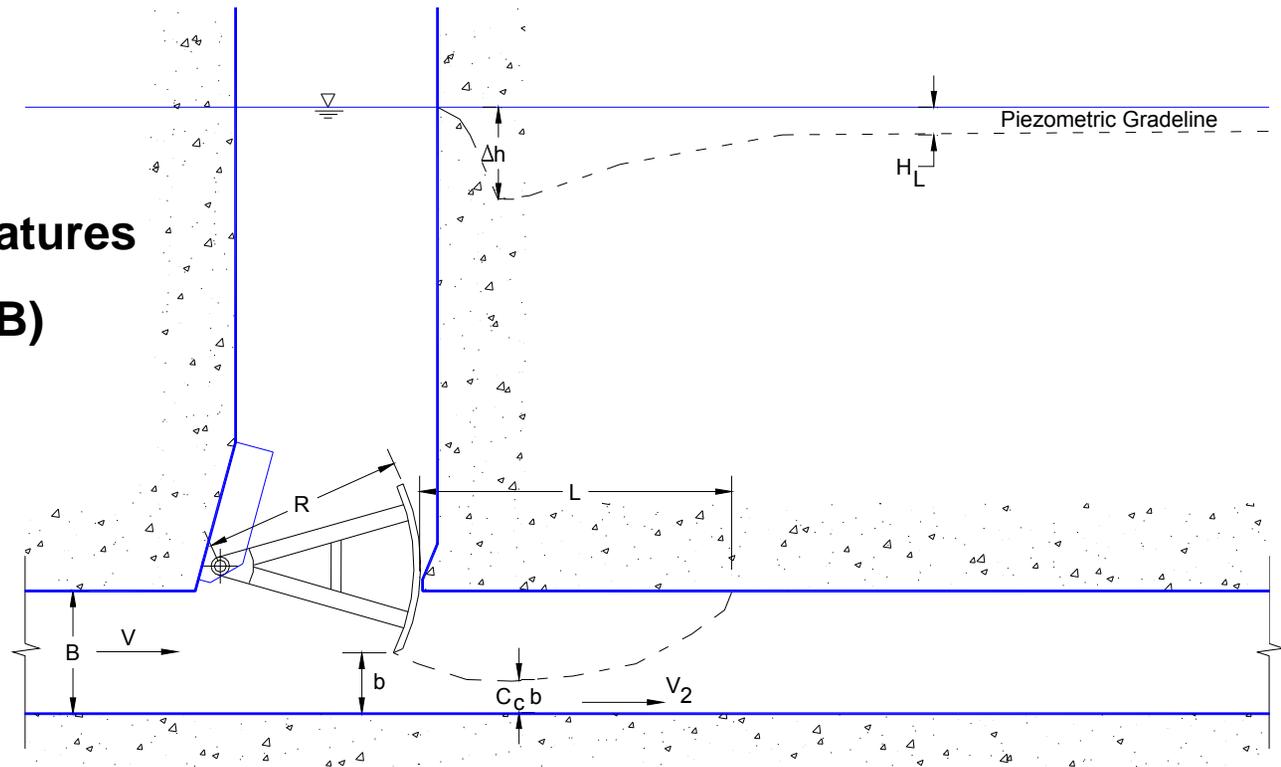
SECTION ALONG CENTER LINE
FIG. c VERTICALLY FRAMED



Hydraulics of Lock Culvert Valves

Important geometric features

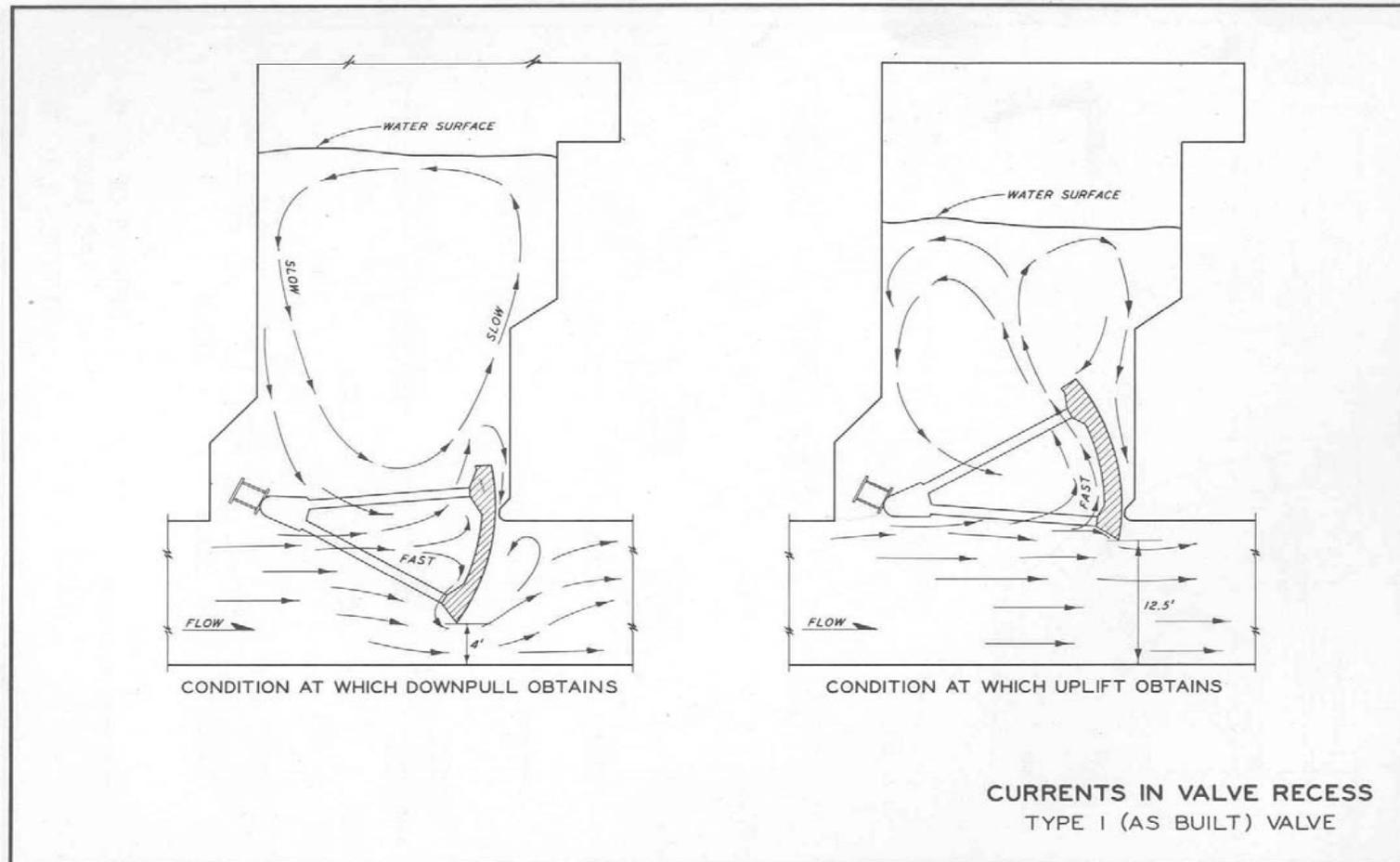
- Valve opening (b/B)
- Valve radius
- Rib members
- Valve lip



Reverse Tainter Valve Schematic



Flow Patterns at Reverse Tainter Valves

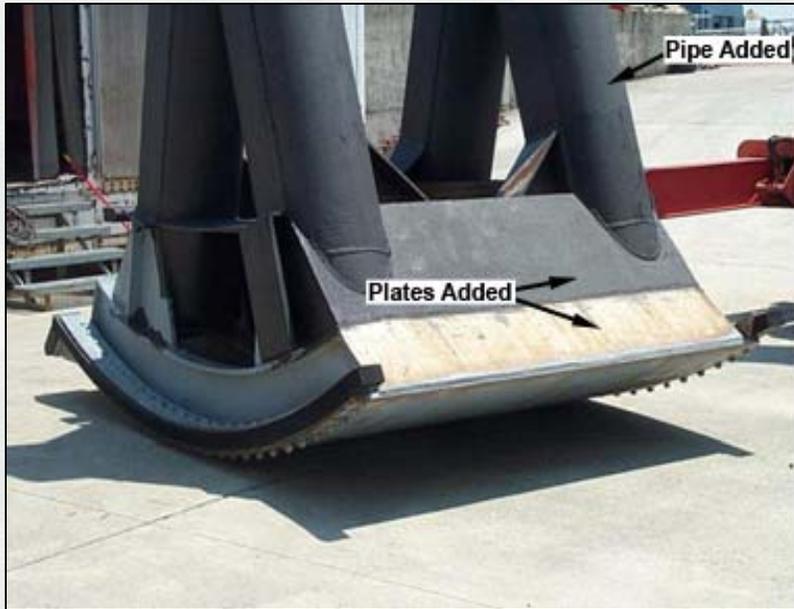


Operations & Maintenance Experience

- **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.



Field Modifications



Chickamauga Lock Modified Valve



Snell Lock New Valve



Kentucky Lock New Valve



Snell & Eisenhower Locks St. Lawrence Seaway



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

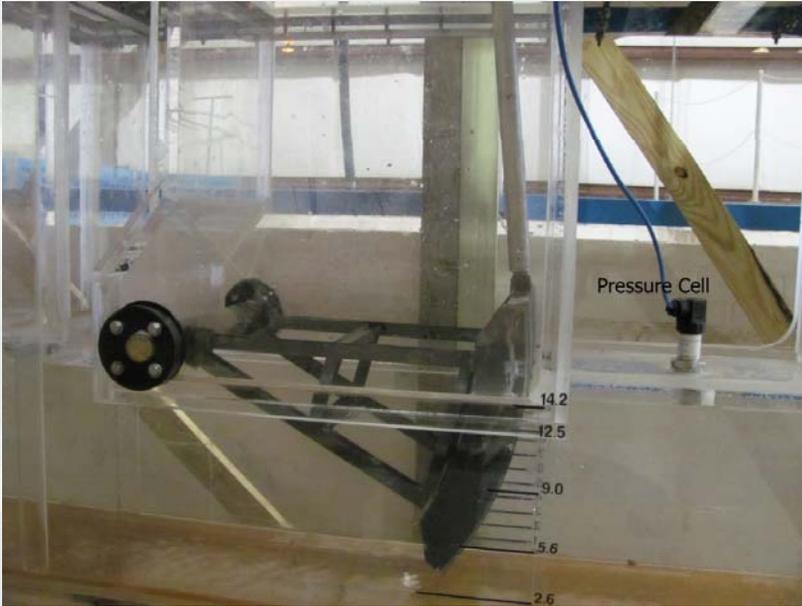


Dry Bed View Looking
Upstream

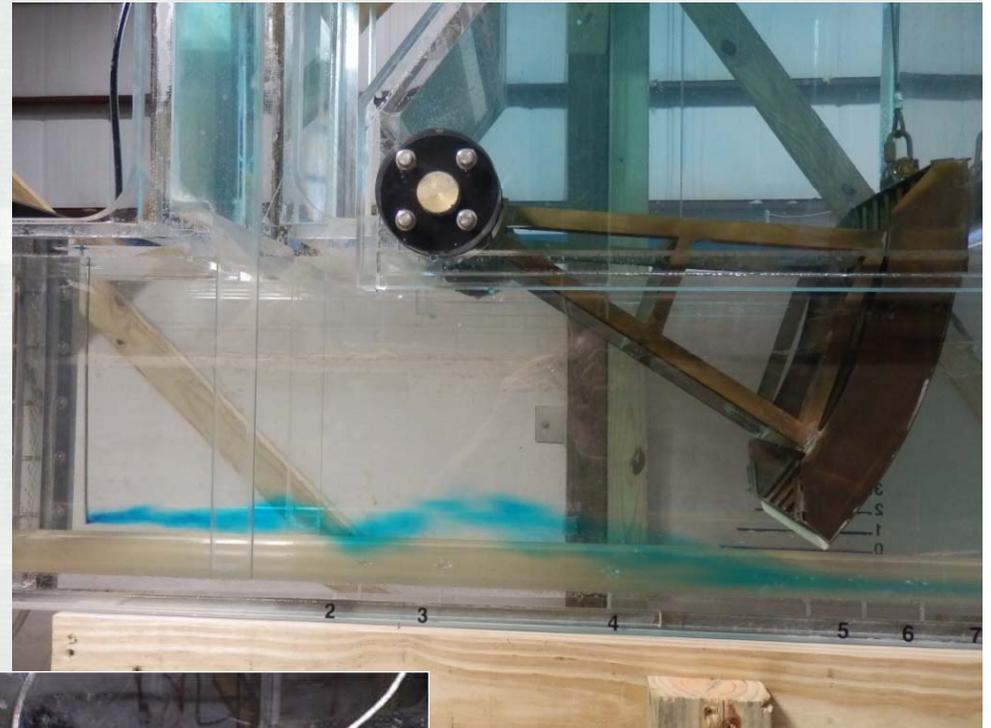


Snell Lock Valve

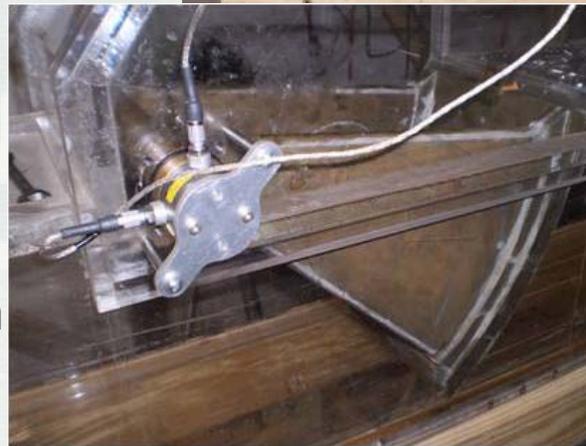
1:15-Scale Physical Model



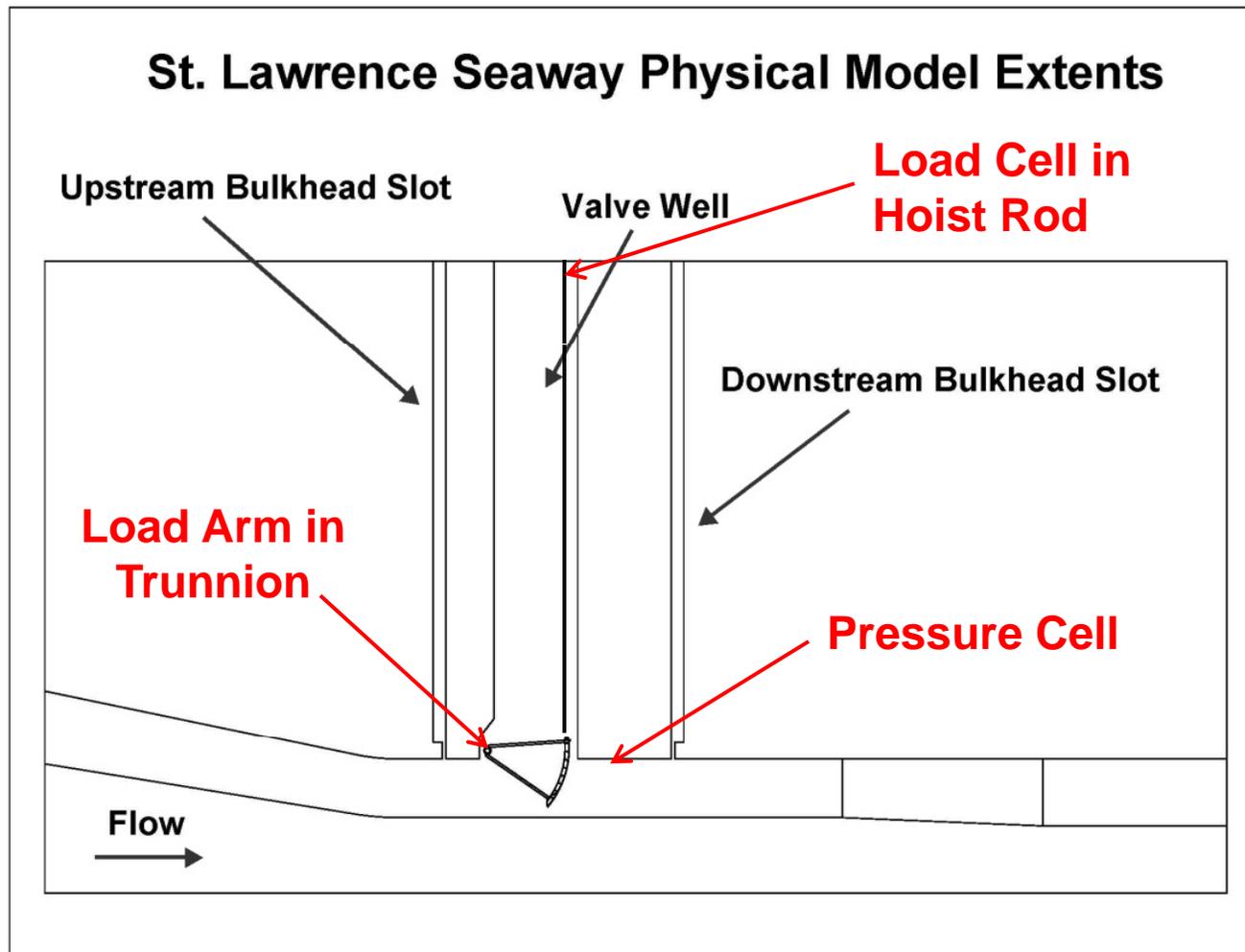
Close-up Views of Valve



Trunnion Load Arm

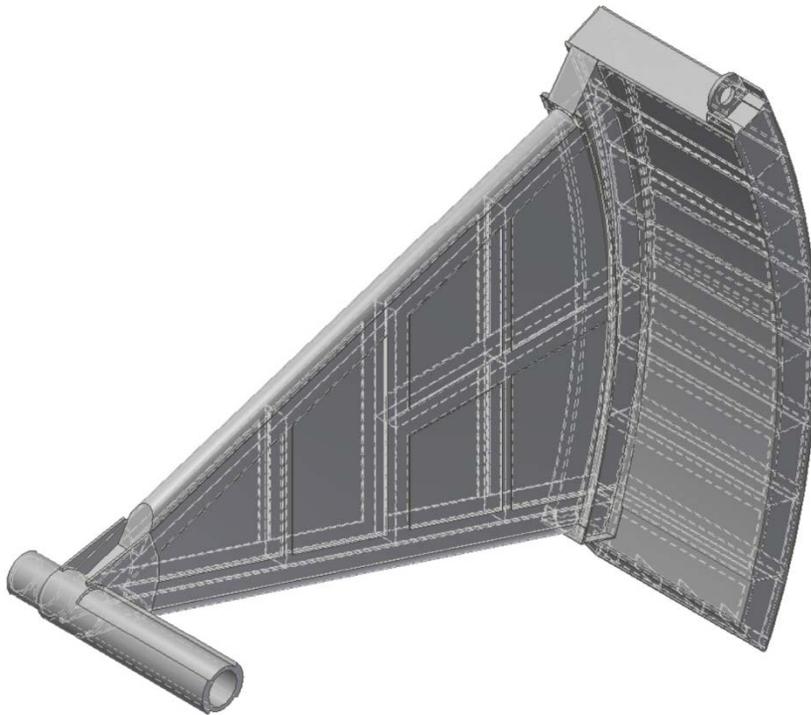


Physical Model – Instrumentation



Double-Skin Valve

Double-skin-plate
Reverse Tainter Valve

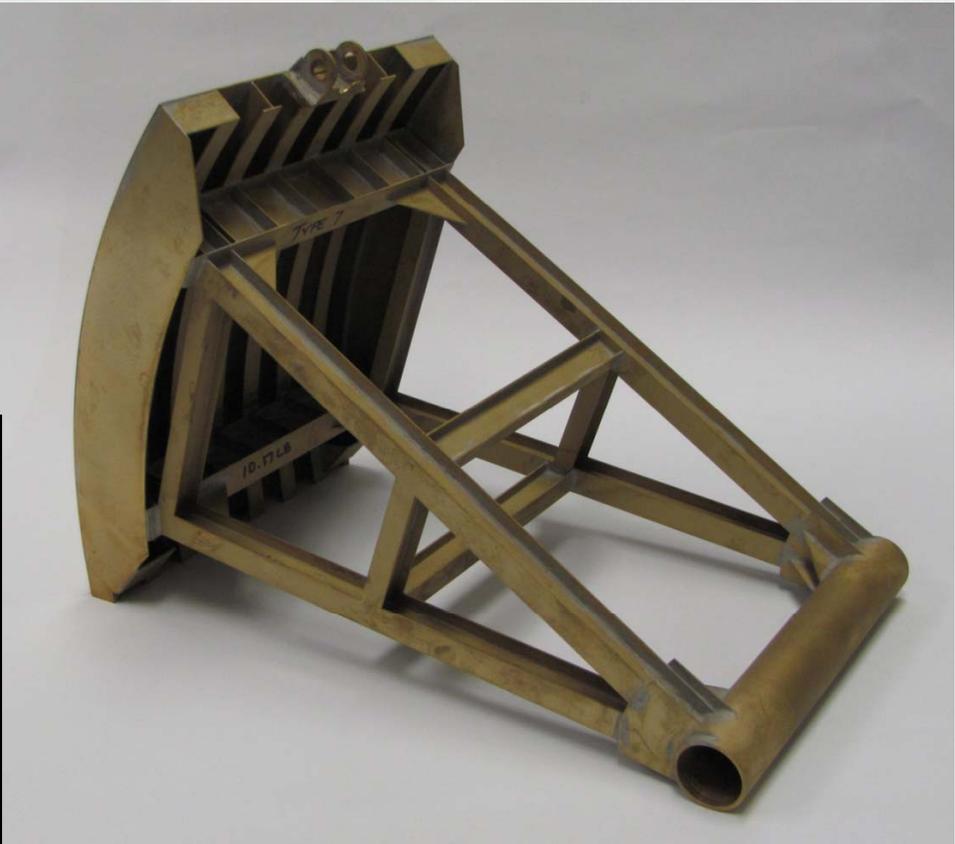
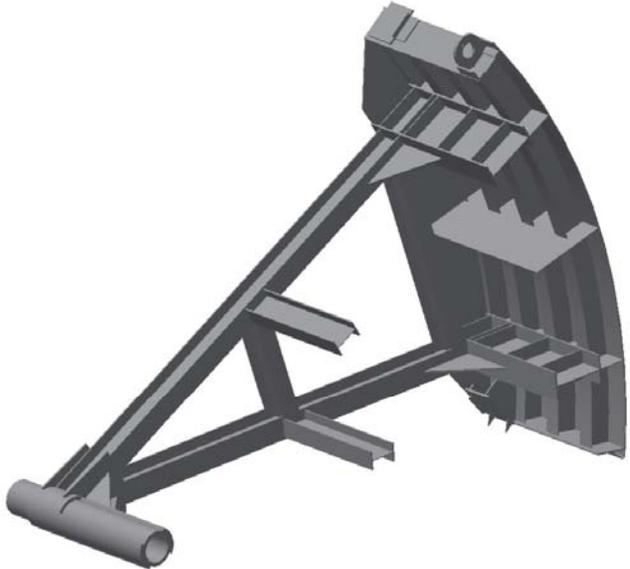


Half-section View of Double-skin
Plate Valve, the Hidden Lines
Show the Internal Framing
Members



Vertical Frame Valve

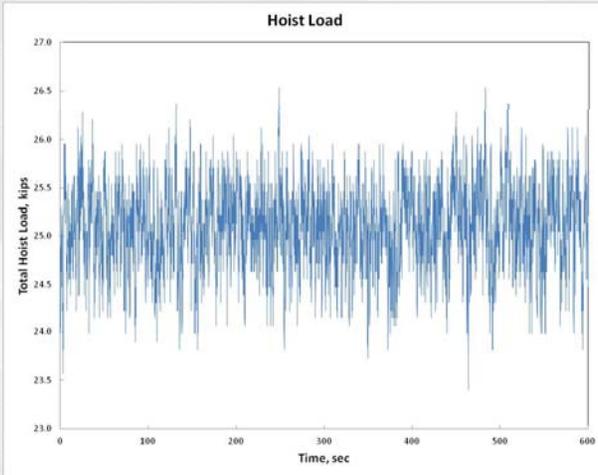
Half-section View
of the Vertical-frame Valve



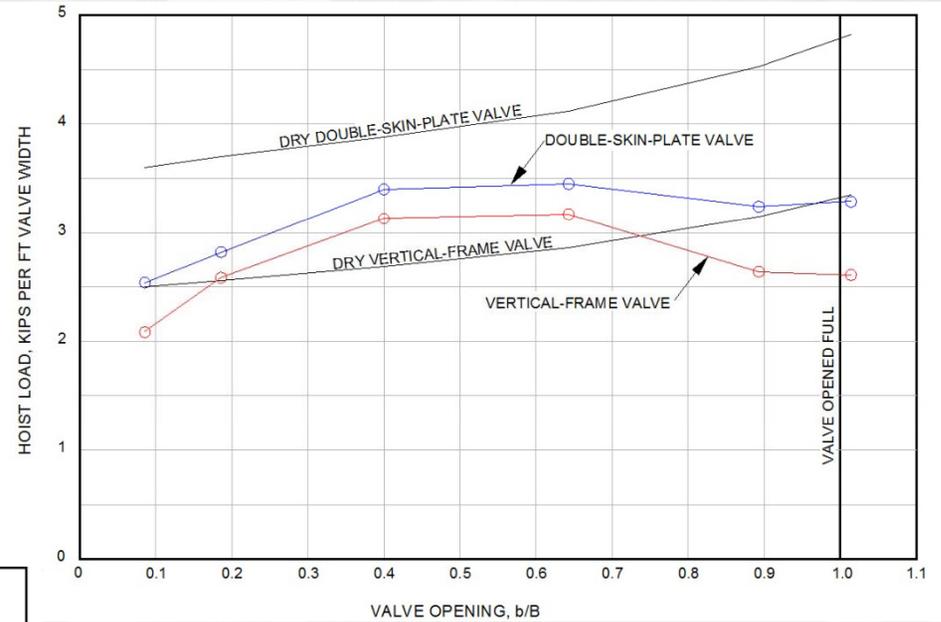
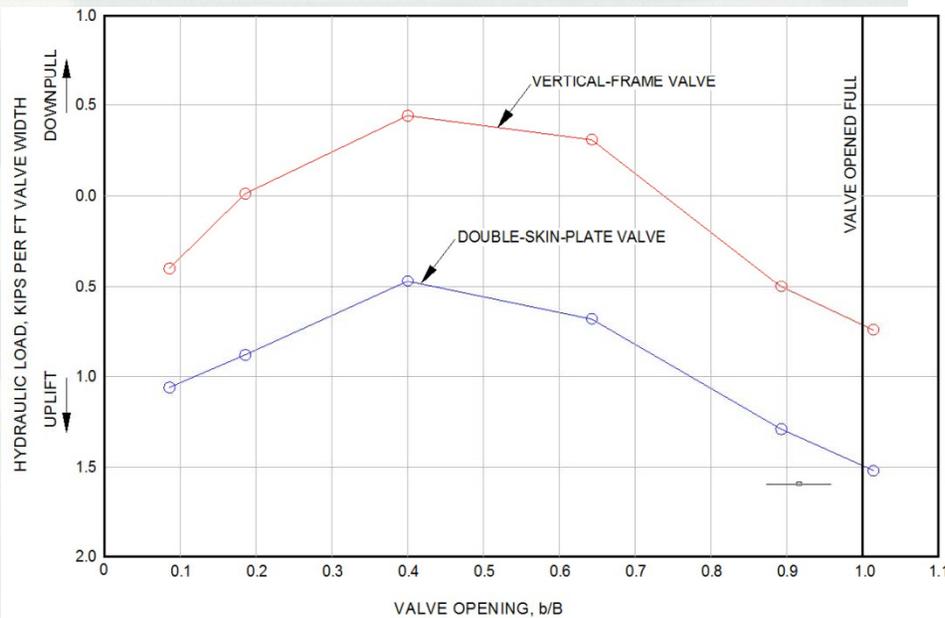
Vertical-frame Reverse Tainter Valve



Snell Lock Valve – Hoist Loads



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

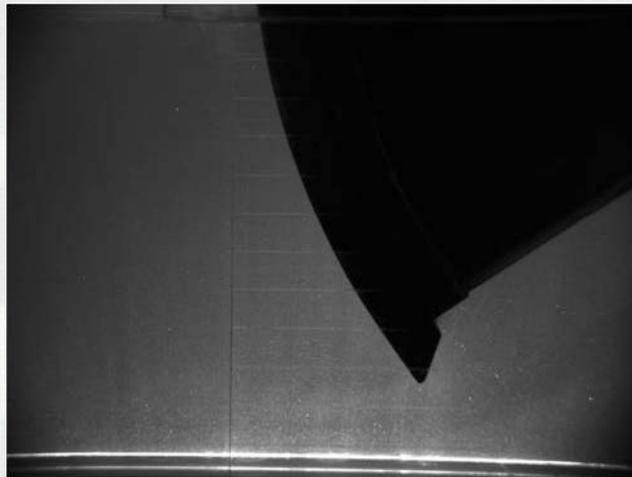


Hoist loads for vertical-frame and double-skin-plate valves

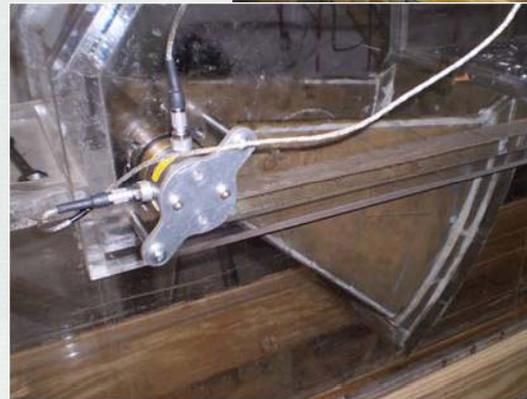


Snell Lock Physical Model Data

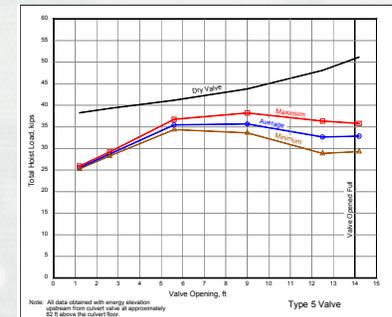
- 1:15-scale model used to determine:
 - ▶ Hoist loads: load cell in valve stem
 - ▶ Anchorage forces: load cells in trunnion
 - ▶ Head losses: pressure cell and piezometers
 - ▶ Velocity distribution: PIV



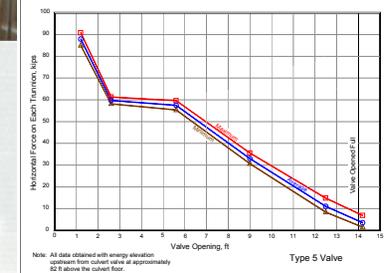
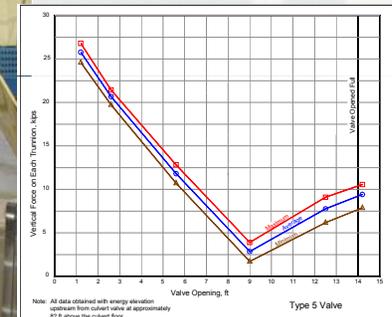
PIV Image



Trunnion Load Cell



Hoist Loads



Trunnion Loads



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

John Day NAVLOCK TV#3
Built 1960



The Dalles NAVLOCK TV#1
Built 1954



John Day NAVLOCK TV#2



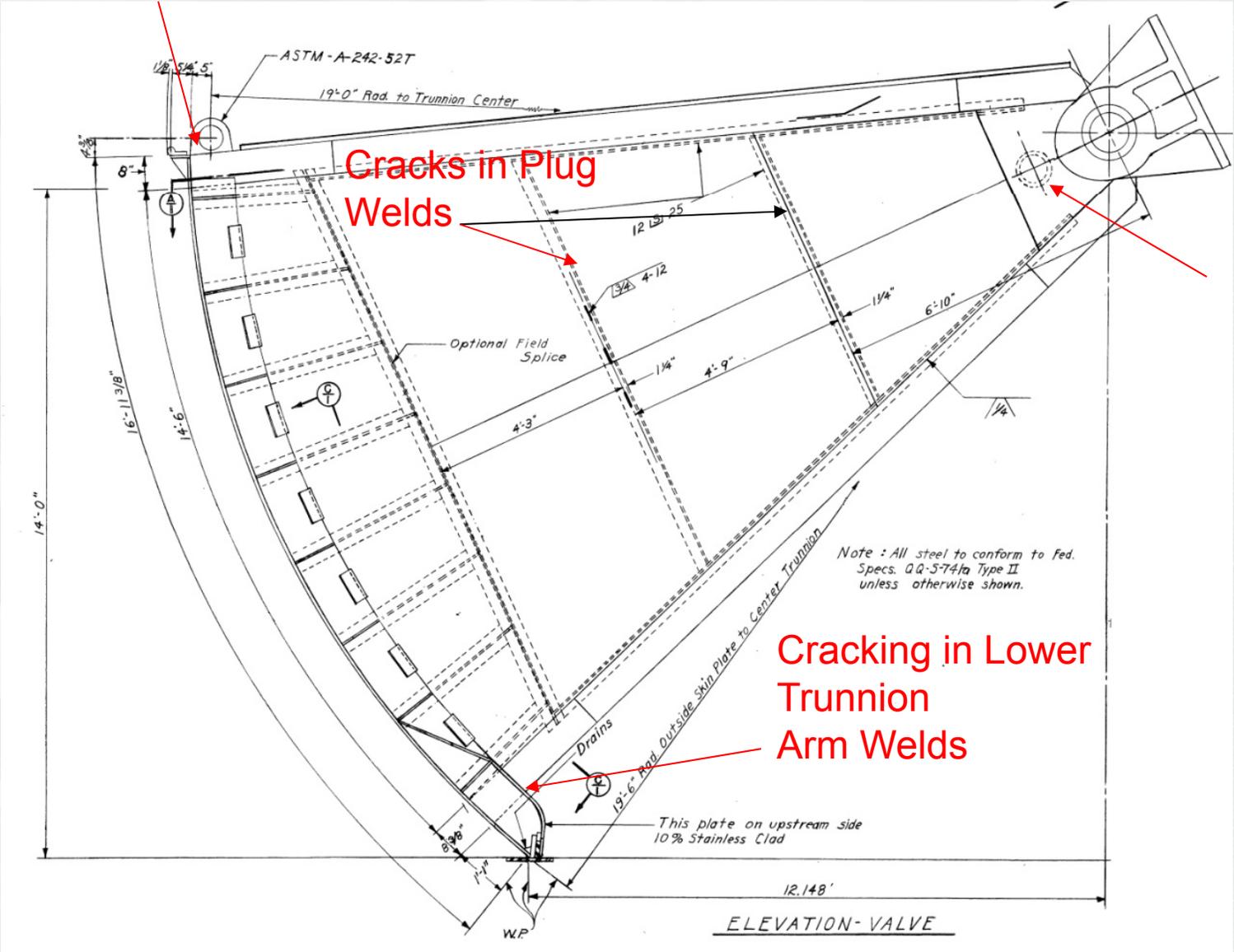
John Day Lock – Problems

Cracking in Lifting Eye Welds

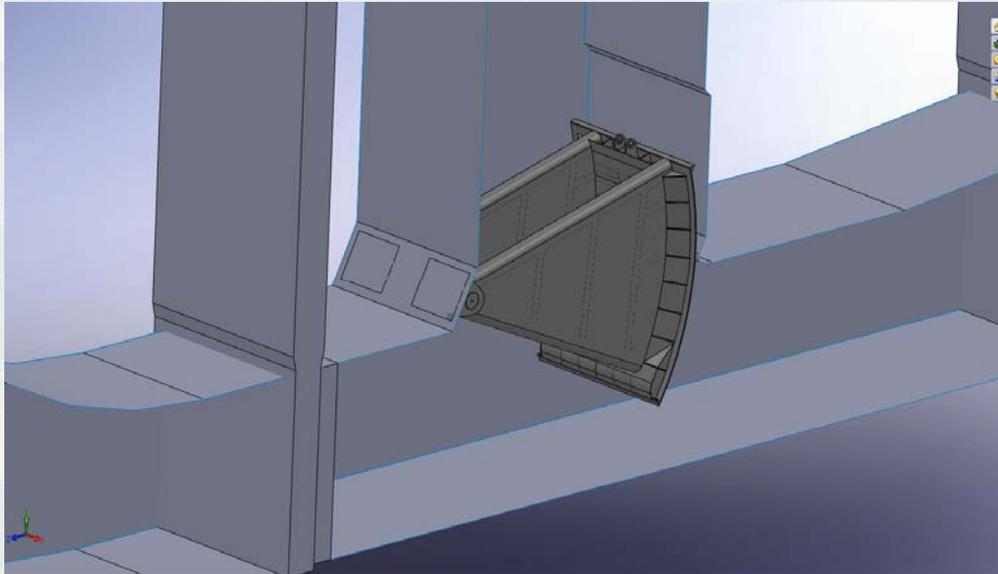
Cracks in Plug Welds

Cracking in Trunnion Plate & Spreader Pipe Welds

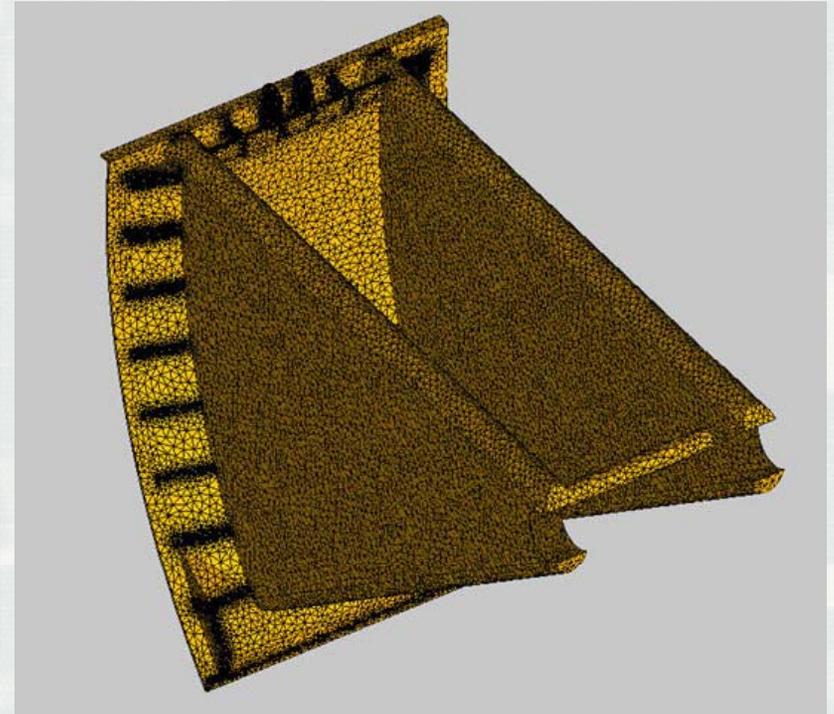
Cracking in Lower Trunnion Arm Welds



John Day Lock Valve – Computational Flow Model



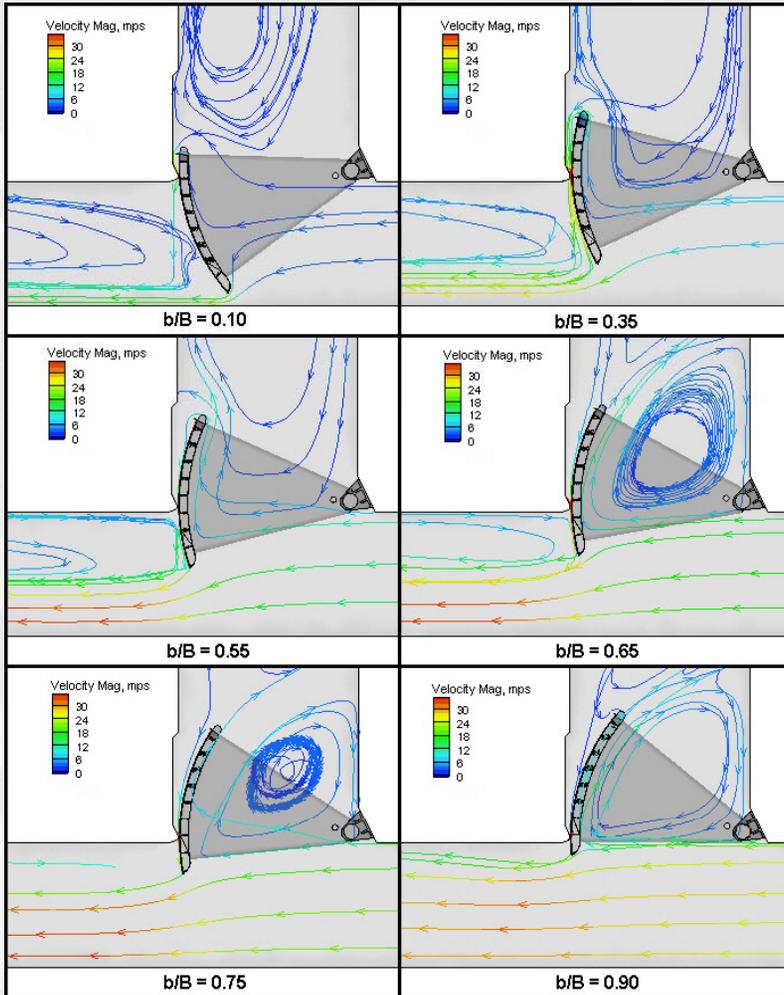
CAD Model



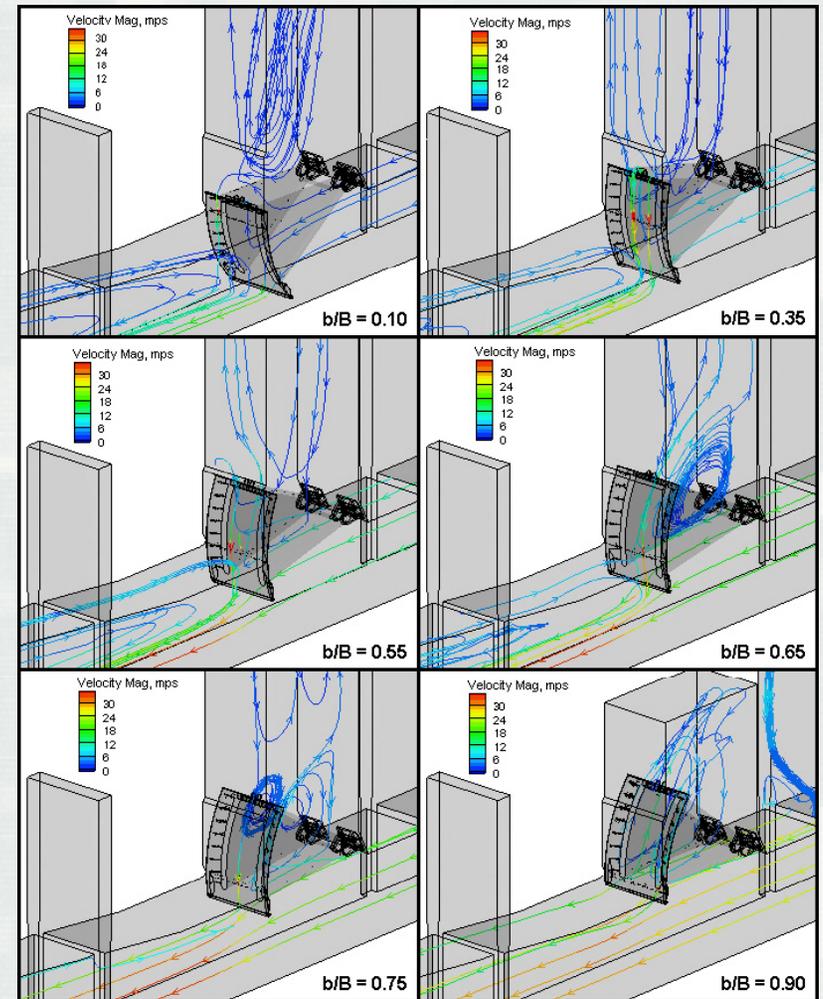
Surface Mesh



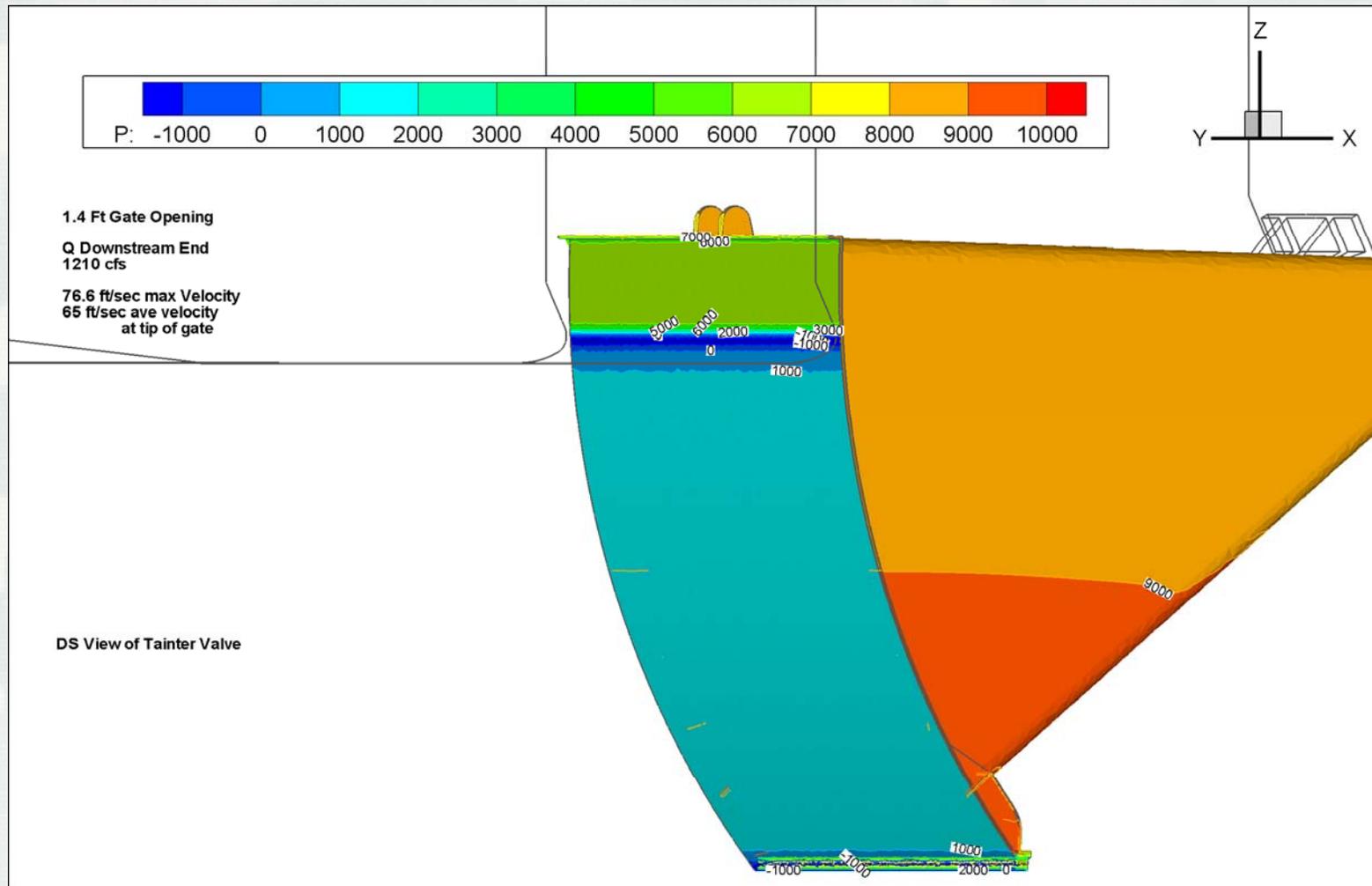
John Day Lock – Velocities and Flow Patterns



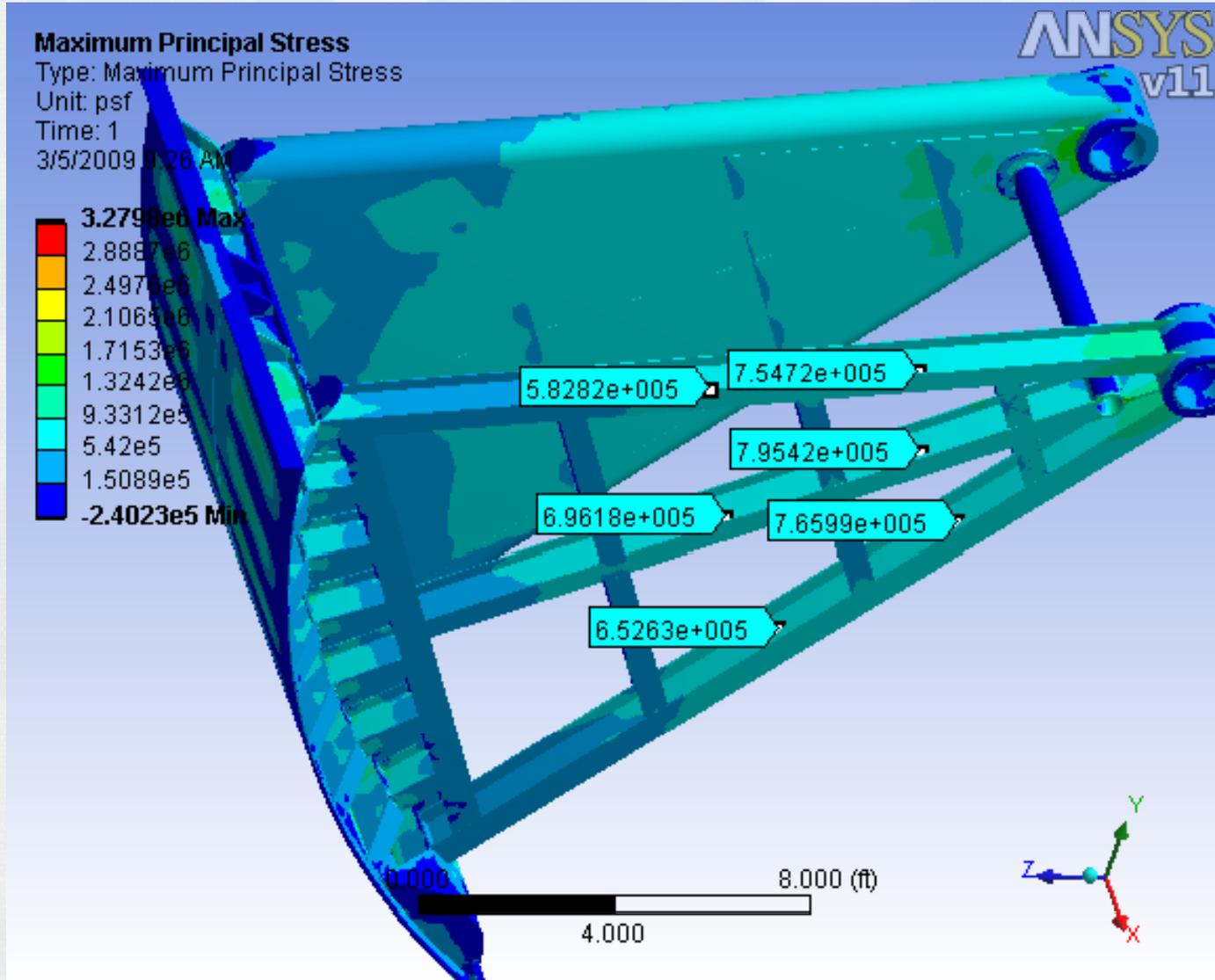
**Flow is Directed Upward
Against the Skin Plate**



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



Cavitation

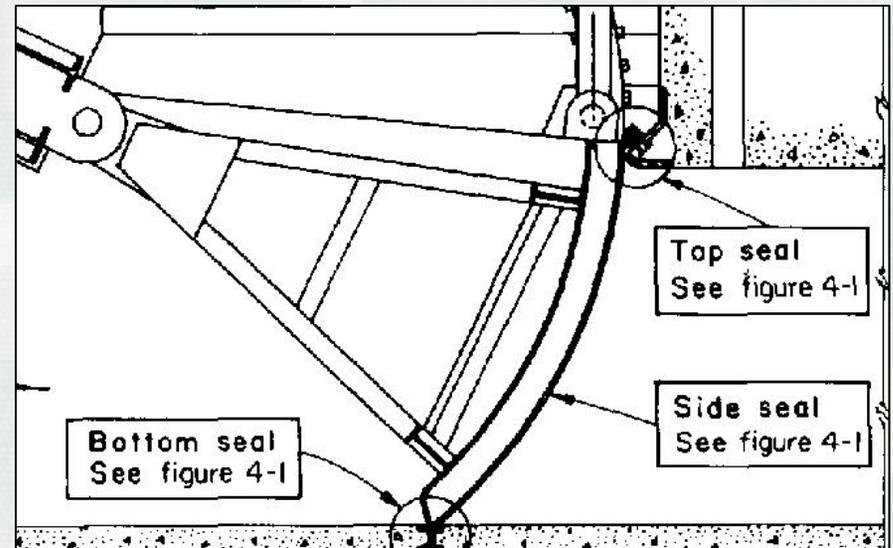
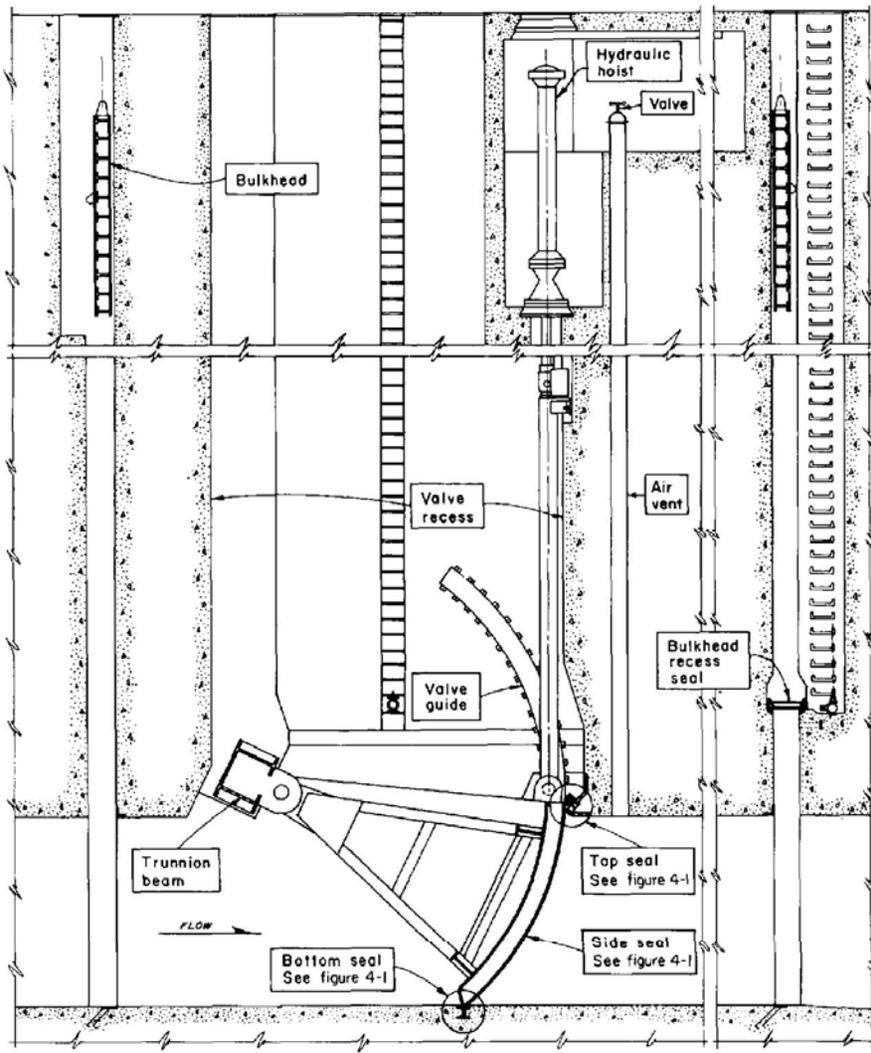


Repairing cavitation damage on Bankhead Lock valve skin plate



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





Top Seal

Typical Reverse Tainter Valve Installation



Summary

- Reverse tainter valves are used almost exclusively in lock culverts
- 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?

