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

US Army Corps of Engineers
BUILDING STRONG®
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

Hydraulic Design

Mechanical & Electrical Design

Planning
Corps’ Design Guidance

Hydraulic Design
- 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 Structures Research Program

Publications

Prototype Experience

Physical Model

Design Considerations

Prototype Experience

Physical Model

Design Considerations

Computational Model
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<tr>
<th>Lock Project</th>
<th>River/Waterway</th>
<th>Chamber Size, Width and Length, ft</th>
<th>Culvert Width and Height at Valve, ft</th>
<th>Valve Radius, ft</th>
<th>Reverse Tainter Valve Design</th>
<th>Lift, ft</th>
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# Physical Model Studies

<table>
<thead>
<tr>
<th>Lock Project</th>
<th>River/Waterway</th>
<th>Model Scale</th>
<th>Prototype Culvert Width x Height, ft</th>
<th>Model Culvert Width x Height, ft</th>
<th>Reverse Tainter Valve Design</th>
<th>Lift, ft</th>
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<td>Snell</td>
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DSP = Double-Skin Plate  
VF = Vertical Frame  
HF = Horizontal Frame
## Lock Filling & Emptying Systems

### Classification by Lift

<table>
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<tr>
<th>Range of Maximum Design Lift</th>
<th>Project Classification</th>
<th>% of CoE Locks</th>
<th>Suitable Design Types</th>
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<tbody>
<tr>
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<td>25</td>
<td>End F&amp;E (primarily sector gate)</td>
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<tr>
<td>10 to 30 (or 40)</td>
<td>Low Lift</td>
<td>60</td>
<td>Side-port system or Lateral w/ 1 Culvert</td>
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<tr>
<td>30 (or 40) to 100</td>
<td>High Lift</td>
<td>15</td>
<td>Longitudinal Manifold System</td>
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<tr>
<td>100 to ? (not yet determined)</td>
<td>Very High Lift</td>
<td>1</td>
<td>John Day is the exception w/ design lift of 107 ft</td>
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</table>
Sidewall-port System
Sidewall-port System
Interlaced Lateral System
Split Lateral System
Single H System
Single H System

Bottom Longitudinal Filling & Emptying System with Reverse Tainter Valves
Double H System
In-chamber Longitudinal Culvert System (ILCS)

McAlpine

Marmet
In-chamber Longitudinal Culvert System (ILCS)
3 Valve Configurations

- **Vertical-Lift Valve**
- **Conventional Tainter Valve**
- **Reverse Tainter Valve**
Vertical Lift Valves

**Vertical-Lift Lock Culvert Valve**

**Loss Coefficient**

Suggested Design Curve

HDC Chart 320-1

**Hoist Loads**

**BASIC EQUATION**

\[ P = W + A \left( d_0 - u_0 \right) y \]

**WHERE:**

- \( P \) = hydraulic and gravity forces in tons
- \( W \) = dry weight of gate in tons
- \( A \) = gross-sectional area of gate in sq ft
- \( d_0 \) = average downstream per unit of area on top of gate in feet of water
- \( u_0 \) = average vertical per unit of area on sloping bottom of gate in feet of water
- \( y \) = specific weight of water, 62.4 lb per cu ft

**Hoist Loads**

**Vertical Lift Gates**

Hydraulic and Gravity Forces

**Definition and Application**

**Physical Model CW 803**

**Dorena Prototype**

**Note:**

- Does not include factor for frictional and other mechanical forces.
- \( d_0 \) = gate well water surface above conduit invert (ft); \( u_0 \) = sum of gate height (ft) and gate opening (ft)

**Suggested Design Curve**

HDC Chart 320-1

**Area of Valve Opening/Area of Culvert**

0.1

1

10

100

1000

**Vertical Lift Valve**

**Bulkhead Slot**

**PLAN**

**ELEVATION**
Conventional Tainter Valve

Flow Conditions During Valve Opening

Flow is Right to Left

Free Surface Flow Downstream of Valve
Reverse Tainter Valve

MODEL

SECTION ALONG CENTER LINE
FIG. a HORIZONTALLY FRAMED

MODEL

SECTION ALONG CENTER LINE
FIG. b DOUBLE SKIN PLATE

MODEL

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 Conditions at Valve During Filling Operation
Flow Patterns at Reverse Tainter Valves

CONDITION AT WHICH DOWNPULL OBTAINS

CONDITION AT WHICH UPLIFT OBTAINS

CURRENTS IN VALVE RECESS
TYPE I (AS BUILT) VALVE
Hydraulic Coefficients
Reverse Tainter Valves

Discharge Coefficient

Contraction Coefficient
**Valve Position**

**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

Cavitation Index

\[
\sigma = \frac{P + (P_a - P_y)}{\sqrt{2g}}
\]
PRESSURES DOWNSTREAM OF VALVES

Cavitation Index

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

\[ V = \frac{Q}{A} \quad A \downarrow \text{ at a contraction, so } V \uparrow \text{ and } P \downarrow \]

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.
Cavitation Index Design Criteria

\[ \sigma = \frac{P + (P_a - P_v)^2}{\frac{v^2}{2g}} \]

Legend:
- Cavitation
- No Cavitation

John Day
Holt
Millers Ferry

\( \sigma \) Recommended for Design
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
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
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
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

Plate Removed

Top Seal Plate

With Plate
Comparison of Hydraulic Loads

- Downpull
- Uplift

With Top Seal Plate
No Top Seal Plate

Valve Opening, ft
Hydraulic Load, kips

- 690
- 690 w/TP
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

St. Lawrence Seaway Physical Model Extents

- Load Arm in Trunnion
- Valve Well
- Load Cell in Hoist Rod
- Pressure Cell
- Upstream Bulkhead Slot
- Downstream Bulkhead Slot

Flow
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
Vertical Frame Valve – Computational Flow Model

Surface Mesh

CAD Model
Double-Skin & Vertical Frame Valves

Flow Passages Must Be Open

Type 1 (Original)
- Stiffener plates removed
- Top plate removed

Type 2
- Bottom plate and valve tip removed

Type 3
- Eisenhower and Snell Locks existing double-skin plate valve

Type 4
- Partial top plate added

Type 5 (Double-Skin-Plate)

Type 6
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

PIV Image

Hoist Loads

Trunnion Loads

Note: All data obtained with energy elevation upstream from culvert valve at approximately 82 ft above the culvert floor.
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#2
Built 1960

John Day NAVLOCK TV#3
Built 1960
John Day Lock – Problems

- Cracking in Lifting Eye Welds
- Cracks in Plug Welds
- Cracking in Lower Trunnion Arm Welds
- Cracking in Trunnion Plate & Spreader Pipe Welds
John Day Lock – Computational Flow Model

CAD Model

Surface Mesh
John Day Lock Valve – Computational Flow Model

CAD Model

Flow Model Results
Flow is Directed Upward Against the Skin Plate
John Day Lock Valve
Computational Flow Model Results

1.4 Ft Gate Opening
Q Downstream End
1210 cfs
78.8 ft/sec max Velocity
65 ft/sec avg velocity at tip of gate
John Day Lock Valve
Computational Flow Model
Pressure Distribution

1.4 ft Gate Opening
Q Downstream End
1210 cfs
78.6 ft/sec max Velocity
85 ft/sec ave velocity at tip of gate

DS View of Tainter Valve
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?