Mooring Forces and Vessel Behaviour in Locks: Experiences in USA
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Tows Setting Up for Lock Operation

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USACE Lock Performance Criteria:
• Hawser force in physical model must not exceed 4.5 t (metric tons) for barge tows
• Water-surface slope that produces a 4.5 t hydrostatic force on a 3-wide by 5-long barge train moored in a nominal 360-m by 33.5-m lock is 0.0002.

Prototype Experience

Field experiments at
• Barkley Lock, Cumberland River (split-lateral system) and
• Jackson Lock, Tombigbee River (side-port system)
have shown that there is good agreement between hawser force measurements in physical models and corresponding prototype locks
Physical & Numerical Models are used to Evaluate Lock Systems

- **Physical Models (1:25-scale)**
  - Pressures are measured with pressure cells
  - Hawser forces are measured with strain gages
  - Time variance of the chamber water surface is measured with pressure cells

- **Numerical Model (LOCKSIM)**
  - Pressures and velocities throughout the system are calculated
  - Hawser forces are computed during post-processing
Physical Model Filling Test Data

Water surface elevations, ft NGVD:
- Lower Pool: 304.2
- Upper Pool: 356.0

Hawsers forces, tons:
- 0
- 10
- 20

Direction:
- Downstream
- Upstream

Hydrodynamic solutions using 1-D model such as LOCKSIM:
- Water-surface elevations
- Pressures
- Velocities

Numerical Model Solution
Numerical Model with Tow

Equations are modified to account for the effect of drafted tow moored within the chamber:
Barge affects the flow by ...
- Reducing the flow area
- Increasing the wetted perimeter

Hydrodynamics and vessel response can be computed separately if we assume the vessel is flexible

Mooring System Model

\[(1+C_a) m_v \ddot{s} + C_h \dot{s} + (k_0 + k s) = F\]

\(s = \) displacement
\(F = \) hydrostatic force, drag, and shear

Need to quantify coefficients:
\(C_a = \) added mass \(C_h = \) damping \(k = \) hawser property
Laboratory Experiments: Still Water

System Frequency

System Damping

Determining System Coefficients

- Added Mass Coefficient

\[
\begin{align*}
    f_n &= \frac{1}{2\pi} \sqrt{\frac{k}{m_{\text{eff}}}} \\
    m_{\text{eff}} &= \frac{k}{4\pi^2 f_n^2} \\
    m_{\text{eff}} &= m(1+C_a)
\end{align*}
\]
Determining System Coefficients

- Hydrodynamic Damping Coefficient

\[ \frac{F}{F_0} = \alpha e^{-\beta t} \]
\[ \beta = \frac{C_h}{2m_c} \]

Lock Chamber Sizes

- 33.5-m x 360-m (110' x 1200') Locks
  - McAlpine Lock model \( \Rightarrow 387 \) m
  - Intermediate System Lock model \( \Rightarrow 408 \) m
  - JT Myers Lock model \( \Rightarrow 402 \) m

- 25.6-m x 240-m (84' x 790') Lock
  - Monongahela No. 4 Lock model
System Coefficients

\( C_a = \text{added mass} = 0.50 \) for all chambers tested
\( C_h = \text{damping (dimensions of } M/T) \)

Nondimensional damping:

\[
C_h^* = \frac{C_h}{\rho b^2 d \sqrt{g}}
\]

\( C_h^* :\)
- 0.146 for 33.5-m x 360-m locks
- 0.156 for 25.6-m x 240-m lock

Validation

\[
(1 + C_a) m \ddot{s} + C_h s + (k_0 + ks) = F
\]
Conclusions

- Added mass is 0.50 for barge tows in lock chambers
- Damping coefficient varies with lock chamber size
  - 0.146 for 33.5-m x 360-m locks
  - 0.156 for 25.6-m x 240-m lock
- Hydrostatic calculation is not necessarily conservative in computing maximum hawser forces
Questions?

Marmet Lock, Kanawha River

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