PIANC Workshop
13-14th September 2011

# Mooring Forces and Vessel Behaviour in Locks: Experiences in USA

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PIANC
Setting the course

## Tows Setting Up for Lock Operation

Check Posts

Line Hooks

Floating Mooring Bitts

## U.S. Army Corps of Engineers

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)

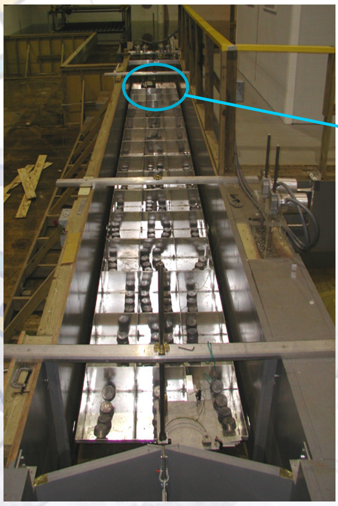
have shown that there is good agreement between hawser force measurements in physical models and corresponding prototype locks

## 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

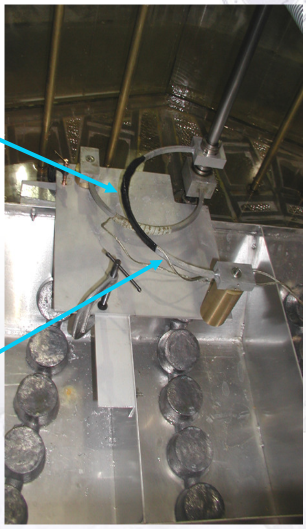


## Physical Model Setup

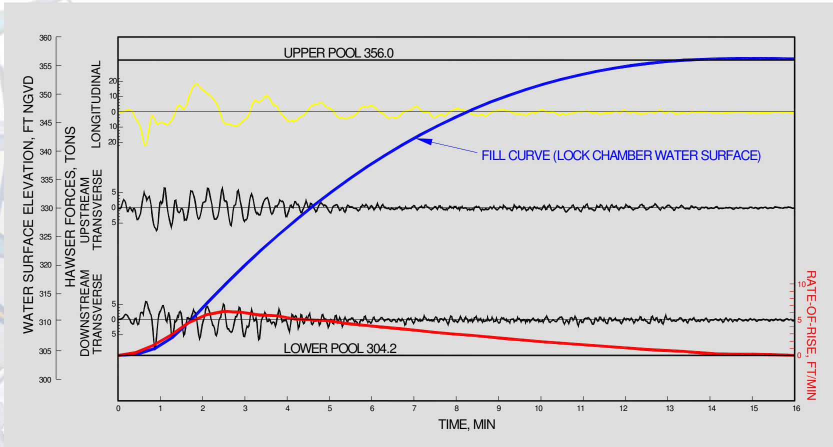


Strain Gage

Longitudinal Hawser Ring



# Physical Model Filling Test Data

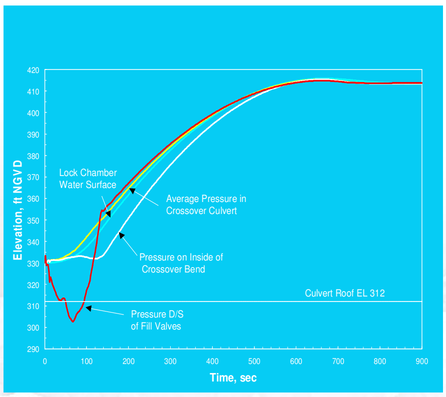





# Numerical Model Solution

**Hydrodynamic solutions using 1-D model such as LOCKSIM:**

- Water-surface elevations
- Pressures
- Velocities



## 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

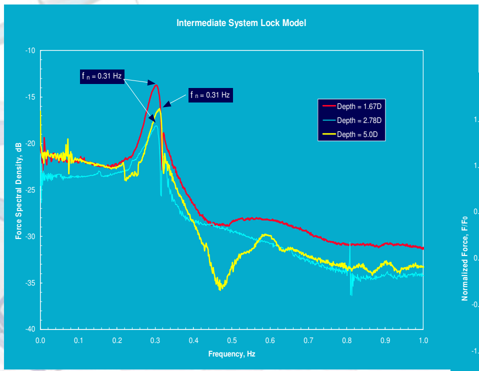
$F$ = hydrostatic force, drag, and shear

Need to quantify coefficients:

$C_a$ = *added mass* $C_h$ = *damping*

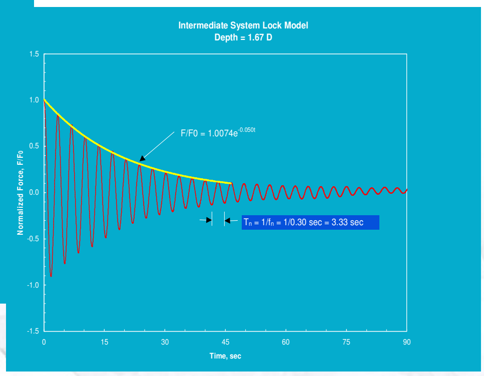
$k$ = *hawser property*

# Laboratory Experiments: Still Water




System Frequency

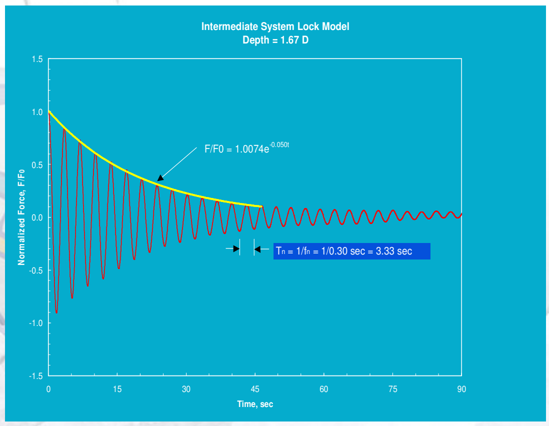
System Damping






# Determining System Coefficients

- Added Mass Coefficient



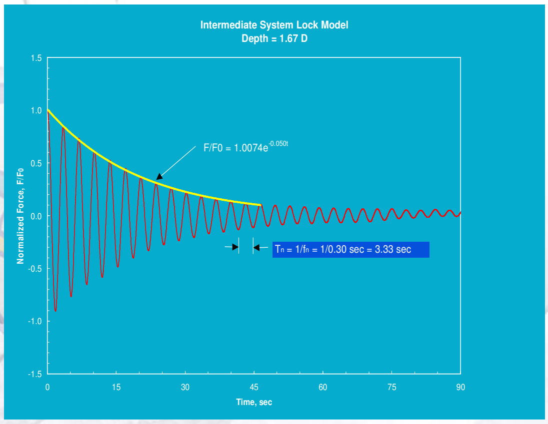

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m_{eff}}}$$

$$m_{eff} = \frac{k}{4\pi^2 f_n^{\,2}}$$

$$m_{eff} = m_v(1 + C_a)$$

# Determining System Coefficients

- **Hydrodynamic Damping Coefficient**




$$F/F_0 = \alpha e^{-\beta t}$$

$$\beta = \frac{C_h}{2m_v}$$



# Determining System Coefficients: Lock Chamber Sizes

**33.5-m x 360-m (110’ x 1200’) Locks**

- **McAlpine Lock model ⇒ 387 m**
- **Intermediate System Lock model ⇒ 408 m**
- **JT Myers Lock model ⇒ 402 m**

**25.6-m x 240-m (84’ x 790’) Lock**

- **Monongahela No. 4 Lock model**

# System Coefficients

$C_a$ = ***added mass*** = 0.50 for all chambers tested

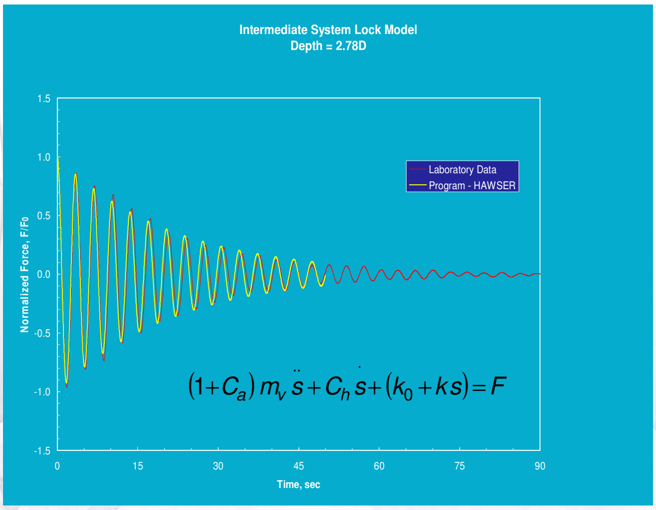
$C_h$ = ***damping*** *(dimensions of M/T)*

$$\text{Nondimensional damping} = C_h^* = \frac{C_h}{\rho b^2 d}\sqrt{\frac{b}{g}}$$

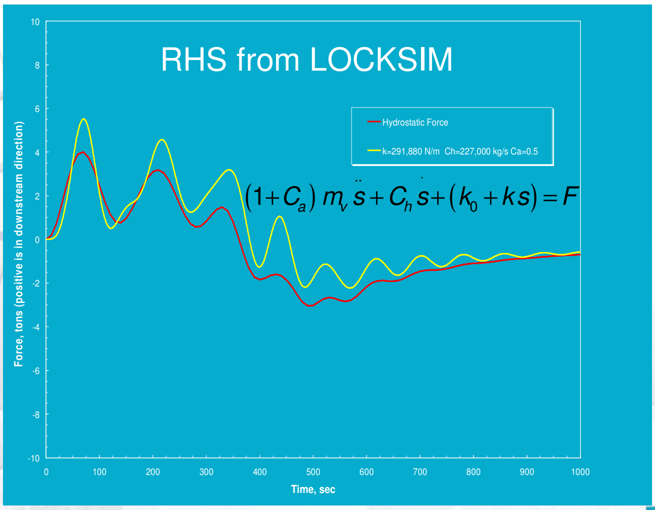
$C_h^*$: 0.146 for 33.5-m x 360-m locks
0.156 for 25.6-m x 240-m lock



# Validation



# Slope Method vs. Equation Of Motion






# 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