Mooring forces and vessel behaviour in locks -- experience in China

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1 INTRODUCTION

Technical codes for the design of locks used by inland vessels in China:

- Code for Master Design of Shiplocks
- Code for Design of Hydraulic Structure of shiplocks
- Design Code for Filling and Emptying System of Shiplocks
- Code for Design of Lock Gates and Valves of shiplocks
- Code for Design of Headstock Gears of shiplocks
- Code for Electrical Design of shiplocks

SAFE MOORING

The vessel tonnage means the deadweight of the motor barge. For a push train it means the deadweight of one barge of the train. Allowable mooring force on a push train shall be determined by the minimum barge tonnage in the train. When the fixed bollard or hook is used the mooring force shall be multiplied by cos\(\beta\), where \(\beta\) refers to the maximum angle of the hawser and water level.

SAFE MOORING

For locks with only fixed mooring equipment, the maximum water surface lifting speed in lock chamber during filling and emptying shall not exceed 5-6 cm/s. When floating bollards are used, there is no similar limitation.

Table 1: Acceptable mooring forces of vessels

<table>
<thead>
<tr>
<th>Vessel Tonnage (t)</th>
<th>1000</th>
<th>2000</th>
<th>3000</th>
<th>4000</th>
<th>5000</th>
<th>6000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal longitudinal components of allowable mooring forces (kN)</td>
<td>46</td>
<td>40</td>
<td>32</td>
<td>25</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>Horizontal transverse components of allowable mooring forces (kN)</td>
<td>23</td>
<td>20</td>
<td>16</td>
<td>13</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>
SAFE MOORING

To simplify the problem the vessel forces are used to compare the acceptable mooring forces of vessels and to evaluate the design of filling and emptying system of the lock. The vessel forces are usually got by analytical method for loop culvert system and physical model for more complicated system.

For the short culvert system the vessel forces could be calculated by the following formula. In the process of filling:

\[ P_1 = P_B = \frac{k_1DwW}{t_{tv}} \left( \sqrt{2gH} - \omega \right) \]

In the process of emptying:

\[ P_1 = P_2 + P_i \]

Where:
- \( P_1 \): Hydrodynamic force on vessel (kN);
- \( P_B \): Wave force in the initial stage of filling (kN);
- \( P_i \): Force produced by water-surface gradient during the emptying process (kN);
- \( P_v \): Force produced by longitudinal velocity in lock chamber;
- \( k_1 \): Coefficient concerning valve configuration (could be 0.725 for a plate valve);
- \( D \): Wave force coefficient;
- \( w \): Sectional area of lock chamber at the initial water level (m²);
- \( \omega \): Sectional area of culvert with valve (m²);
- \( t_{tv} \): Valve opening time (s);
- \( g \): Acceleration of gravity (m/s²).

SAFE MOORING

HYDRAULIC CRITERION FOR APPROACH CHANNELS

The water depth in approach channel should be decided as follows:

\[ \frac{H_c}{T} \geq 1.50 \]

Where:
- \( H_c \): the water depth in approach channel at the lowest navigation level (m);
- \( T \): full loaded draft of design vessel (m).

REDUCING THE FORCE ON VESSEL

The forces acting on the vessel are determined by the water level differences around the vessel, the flow velocity and friction on the vessel. The forces acting on the vessel depend mainly on the design of the hydraulic system of the lock. Fine design could evidently reduce the forces.
Reduction of Force on Vessels

In the longitudinal filling system, the transverse force on vessels is limited. A new type of short culvert system is used in Shihutang lock in China. The forces acting on vessels during filling and emptying are mainly longitudinal and some results got from laboratory model test are shown in Table 2.

<table>
<thead>
<tr>
<th>Lift(m)</th>
<th>F/El/min(min)</th>
<th>Max. longitudinal force</th>
<th>Max. Transverse force</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.14</td>
<td>11.2 (F)</td>
<td>30.8</td>
<td>15.2</td>
</tr>
<tr>
<td></td>
<td>8.4 (E)</td>
<td>31.4</td>
<td>6.6</td>
</tr>
<tr>
<td>10.54</td>
<td>10.76 (F)</td>
<td>31.4</td>
<td>8.7</td>
</tr>
<tr>
<td></td>
<td>7.56(E)</td>
<td>24.4</td>
<td>3.6</td>
</tr>
<tr>
<td>9.77</td>
<td>9.62 (F)</td>
<td>20.4</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>6.72 (E)</td>
<td>23.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Note: Acceptable longitudinal force is 32 kN and transverse force is 16 kN.

For example, there are 24 ports on one side wall. All have the same height of 0.85m. They were divided into three groups which has the width of 0.8, 0.74 and 0.68m separately. In the test the width of the third group of ports was reduced from 0.68m to 0.52m. The maximum longitudinal force acting on vessel was reduced from 16.2 kN to 8 kN.

But in the wall culvert side port system, the longitudinal force could be reduced by a fined design to the port size. Along the flow direction the port size could be divided into three groups. The height of all ports can be the same and the width can be narrower along the water flow direction during filling and emptying. This makes the water into the chamber more uniform in the longitudinal direction and reduces the slope of the water surface during filling. So the longitudinal mooring force becomes smaller.
REDUCTING THE FORCE ON VESSEL

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