Comparison of Sloshing-Induced Impact Pressures between 2D and 3D Tanks

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Technical Issues in This Study

1. Sensitivity Study on the Time Window

• How many cycles is enough to get reliable result for regular motion test?

2. Comparison of sloshing pressures in 2D and 3D Tanks

• Model tests from 2D and 3D tanks can give the same results?
• What are main differences between 2D and 3D tank tests?
Sloshing Experimental Facility in SNU

- **Motion Platform**
  - 3 Motion platforms (1.5, 5, 10 ton)

- **Pressure Sensor & DAQ**
  - Total 500 pressure sensors
  - Total 480 channel DAQ system
  - 436TB Storage capacity

- **High Speed Camera & PIV**
  - 2 high speed camera
  - 3D PIV system
  - Pressure-image synchronization system
Measurement System

Schematic Diagram of Measurement System

- Video recorder
- Model tank
- Pressure sensors
- Coupler
- Monitoring system
- Data acquisition system
- Motion controller
- Motion platform
- Data storage server

Components:
- DAQ board
- Coupler
- Data storage system
- Motion platform and controller
- Pressure sensor
- High speed camera
Test 1

: Sensitivity Study of Time Window
Sensitivity Study of Time Window

2D Model Tank (1/40)

Test Condition – Harmonic Excitation

<table>
<thead>
<tr>
<th>Filling Depth</th>
<th>Excitation Amplitude</th>
<th>Excitation Frequency ((\omega/\omega_0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95(H)</td>
<td>0.015(L), 0.042(L), 0.10(L)</td>
<td>0.7 – 1.3</td>
</tr>
<tr>
<td>0.70(H)</td>
<td>0.015(L) 0.042(L) , 0.10(L)</td>
<td>0.7 – 1.3</td>
</tr>
<tr>
<td>0.50(H)</td>
<td>0.015(L), 0.042(L), 0.10(L)</td>
<td>0.7 – 1.3</td>
</tr>
<tr>
<td>0.25(H)</td>
<td>0.10(L)</td>
<td>0.7 – 1.3</td>
</tr>
<tr>
<td>0.15(H)</td>
<td>0.10(L)</td>
<td>0.7 – 1.3</td>
</tr>
</tbody>
</table>

Time Window

\(\omega\) : excitation frequency, \(\omega_0\) : Frequency of the fundamental mode of sloshing
Filling Depth $= 0.95H$ – Statistical Result

Average of 10 largest peak pressures

Amplitude $= 0.015L$

Amplitude $= 0.042L$
Filling Depth = 0.70H – Statistical Result

Average of 10 largest peak pressures

Amplitude = 0.015L

Amplitude = 0.042L
Asymmetric Flow - 0.70H

Amplitude = 0.015L

\[
\frac{\omega}{\omega_0} = 0.95
\]

\[
\frac{\omega}{\omega_0} = 1.00
\]

\[
\frac{\omega}{\omega_0} = 1.035
\]

\[
\frac{\omega}{\omega_0} = 1.05
\]
Filling = 0.25H, 0.15H – Statistical Result

Average of 10 largest peak pressures

Filling = 0.25H, Amplitude = 0.10L

Filling = 0.15H, Amplitude = 0.10L
Exceedance Probability Distribution

**Filling=0.70H, Ampl.=0.015L**

\[
\frac{\omega}{\omega_0} = 1.03
\]

200-period time window is not enough to obtain convergent results.

**Filling=0.15H, Ampl.=0.010L**

\[
\frac{\omega}{\omega_0} = 1.20
\]
Test 2

: Sloshing Pressures in 2D and 3D Tanks
Sloshing Pressures in 2D and 3D Tanks

**2D Tank Model**
- 1/50 scale
- Total 112 measuring points
- Transverse section model

**3D Tank Model**
- 1/50 scale
- Total 187 measuring points
- Measuring points are not axis-symmetric

2D tank model

3D tank model
Test Condition

**Test Condition – Harmonic Sway**

<table>
<thead>
<tr>
<th>Filling Depth</th>
<th>Excitation Amplitude</th>
<th>Excitation Frequency ((\omega/\omega_0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95(H)</td>
<td>0.05(B), 0.10(B)</td>
<td>0.5 – 1.5</td>
</tr>
<tr>
<td>0.70(H)</td>
<td>0.05(B), 0.10(B)</td>
<td>0.5 – 1.5</td>
</tr>
<tr>
<td>0.30(H)</td>
<td>0.05(B), 0.10(B)</td>
<td>0.5 – 1.5</td>
</tr>
<tr>
<td>0.15(H)</td>
<td>0.05(B), 0.10(B)</td>
<td>0.5 – 1.5</td>
</tr>
</tbody>
</table>

Time window = 500 cycles
Post Processing

Time History of Pressure Signal

Peak Sampling

Statistical Analysis

\[ p_1 > p_2 > \ldots > p_{N-1} > p_N \]

\[ p_{10} = \frac{1}{10} \sum_{i=1}^{10} p_i \]

\[ p_{1/10} = \frac{1}{N/10} \sum_{i=1}^{N/10} p_i \]
Average of 10 largest peak pressures

Filling Depth = 0.95H – Statistical Result

Amplitude = 0.05B

Amplitude = 0.10B

Large discrepancies between 2D and 3D in high-frequency conditions
Filling Depth = 0.95H – Test Movie

2D tank

Ampl.=0.05B
\(\omega/\omega_0 = 0.70\)

3D tank

Ampl.=0.05B
\(\omega/\omega_0 = 1.00\)
Filling Depth = 0.70H – Statistical Result

Average of 10 largest peak pressures

Amplitude = 0.05B

- Show a consistency in critical excitation frequency
- Show a discrepancy in the magnitude of pressure peak

Amplitude = 0.10B
Filling Depth = 0.70H – Test Movie

2D tank

Ampl. = 0.05B
\( \omega / \omega_0 = 1.00 \)

3D tank

Ampl. = 0.10B
\( \omega / \omega_0 = 0.95 \)
Filling = 0.30H, 0.15H – Statistical Result

**Average of 10 largest peak pressures**

- Filling = 0.30H, Amplitude = 0.05B
- Filling = 0.15H, Amplitude = 0.10B

- Show a consistency in critical excitation frequency
- Pressures from 3D tank tests are slightly larger 2D tank tests
Hot Spots for Sloshing Pressure (1)

Filling depth = 0.70H, Amplitude = 0.05B

<table>
<thead>
<tr>
<th>$\omega/\omega_0$</th>
<th>0.75</th>
<th>0.8</th>
<th>0.85</th>
<th>0.9</th>
<th>0.95</th>
<th>1</th>
<th>1.05</th>
<th>1.1</th>
<th>1.15</th>
<th>1.2</th>
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<tbody>
<tr>
<td>2D Tank Location</td>
<td>CH</td>
<td>73</td>
<td>73</td>
<td>73</td>
<td>74</td>
<td>73</td>
<td>73</td>
<td>27</td>
<td>84</td>
<td>29</td>
<td>83</td>
<td>27</td>
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<tr>
<td>3D Tank Location</td>
<td>CH</td>
<td>95</td>
<td>108</td>
<td>113</td>
<td>21</td>
<td>7</td>
<td>27</td>
<td>1</td>
<td>21</td>
<td>21</td>
<td>7</td>
<td>25</td>
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</table>

: Critical frequency
Hot Spots for Sloshing Pressure (2)

**Filling depth** = 0.15H, **Amplitude** = 0.05B

<table>
<thead>
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<th>$\omega/\omega_0$</th>
<th>0.90</th>
<th>0.95</th>
<th>1.00</th>
<th>1.05</th>
<th>1.10</th>
<th>1.15</th>
<th>1.20</th>
<th>1.25</th>
<th>1.30</th>
<th>1.35</th>
<th>1.40</th>
<th>1.45</th>
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<tbody>
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<tr>
<td>Location</td>
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<td>L.C.</td>
<td>L.C.</td>
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<td>CH</td>
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<td>105</td>
<td>24</td>
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<td>110</td>
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<tr>
<td><strong>3D Tank</strong></td>
<td></td>
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<td></td>
<td></td>
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<td>140</td>
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$\omega/\omega_0$ : Critical frequency
Conclusion

Study on Time Window
- 200-period time window for the regular sloshing experiment may be not enough to obtain convergent results.
- Although the experiment cost increases for longer time window, a longer time window is better even in regular tests. We recommend at least 500 cycles for convergent measurement.

Comparison of Sloshing Pressure in 2D and 3D Tank
- In most filling conditions, 2D and 3D tanks results show a consistency in critical excitation frequency.
- Sloshing pressures from 2D tank are relatively smaller than those from 3D tank.
- Even though filling depth and motion amplitude are the same, hotspots for large impact occurrence are dependent on excitation frequency.
Thank you!

Q&A