Sloshing and swirling in partially loaded membrane tanks

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Sloshing and swirling in partially loaded membrane tanks

Introduction
Remarkably good safety records in LNG transportation for about 50 years of LNG carriers’ history.
Possible factors affecting the safety records of LNG fleets:
• Rapid growth of demand for LNG and increase of LNGCs worldwide
• Emergence of new voyage routes such as for transporting US shale gas through newly expanded Panama Canal, LNG transport from Russia to Asia using Arctic Ocean, etc.
• Large ships
• Operations in partially loaded condition such as those of FLNGs and their shuttle tankers, LNG as fuel for all type of ships, etc.

Collaborative research on sloshing in partially loaded membrane tanks are carried out between Yokohama National University, MTI and ClassNK to ensure safe navigation of LNG carriers in the actual seaways.
Sloshing and swirling in partially loaded membrane tanks

Sloshing in membrane tanks

Membrane type LNGC and cargo tank (MTI Tech. Rev., 2007)

Example of damage due to sloshing (Lloyd's register)

Insulation boxes (GTT)

Fill range limitation

- Normal high filling level
- Usual permitted level
- Usual permitted level
- Normal low filling level

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Model tests at MTI Yokohama Lab

Model tanks on moving table

- Pressure: 10 points
- Hydrodynamic forces to the tank:
  - 2 directions
- Scale: 1/40
- Length x Breadth x Depth:
  - 971mm x 952mm x 689mm
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Comparison of liquid motion in the tank
(30%, amp.=2cm, 90deg., f=0.71Hz)

Sloping
Swirling
Numerical simulation Experiment

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Comparison of liquid motion in the tank
(50%, amp.=2cm, 90deg., f=0.804Hz)

Sloping
Swirling
Numerical simulation Experiment
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Comparison of liquid motion in the tank
(90%, amp.=2cm, 90deg., f=0.95Hz)

Numerical simulation  Experiment

Only sloshing occurs

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Comparison between measured and computed pressures

(50%, amp.=2cm, 90deg., f=0.804Hz)
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Snapshots of pressure distribution in the tank
(50% filling, excitation at resonant frequency)

(Dynamic pressure) = (Total pressure) - (Static pressure)

Maximum dynamic pressure in the whole simulation

- In case of middle fill levels (30% to 70%), the lower part of the top chamfers suffer the highest pressure, and when swirling occurs its effect is observed on the edges of the top chamfers.
- In case of high fill levels, high pressure occurs at the intersections between top chamfers and tank ceiling.
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Condition for swirling generation
In some test cases, 2-dimensional sloshing motion occurs in the beginning of the test but it transfers to swirling motion later.

Example of force histories generated by liquid motion

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Computed force histories for different $L_t/B_t$ ratio
(Fill level: 50%, excitation: tank liquid natural frequency)

$L_t$: tank length, $B_t$: tank breadth

Swirling occurs when fill level $= 30\% \sim 60\%$ and $L_t/B_t = 0.9 \sim 1.1$
**Sloshing and swirling in partially loaded membrane tanks**

**Actual ship's tank dimensions**

Condition of swirling occurrence: $L_t/B_t = 0.9 \sim 1.1$

**Ship A**

<table>
<thead>
<tr>
<th>$L_t/B_t$</th>
<th>No. 4 tank</th>
<th>No. 3 tank</th>
<th>No. 2 tank</th>
<th>No. 1 tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_t$ [m]</td>
<td>38.38</td>
<td>43.58</td>
<td>43.89</td>
<td></td>
</tr>
<tr>
<td>$B_t$ [m]</td>
<td>37.81</td>
<td>37.81</td>
<td>37.81</td>
<td>Wedge shape</td>
</tr>
<tr>
<td>$L_t/B_t$</td>
<td>1.01</td>
<td>1.15</td>
<td>1.16</td>
<td></td>
</tr>
</tbody>
</table>

**Ship B**

<table>
<thead>
<tr>
<th>$L_t/B_t$</th>
<th>No. 4 tank</th>
<th>No. 3 tank</th>
<th>No. 2 tank</th>
<th>No. 1 tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_t$ [m]</td>
<td>40.00</td>
<td>44.75</td>
<td>44.75</td>
<td>31.45</td>
</tr>
<tr>
<td>$B_t$ [m]</td>
<td>37.81</td>
<td>37.81</td>
<td>37.81</td>
<td>33.75</td>
</tr>
<tr>
<td>$L_t/B_t$</td>
<td>1.06</td>
<td>1.18</td>
<td>1.18</td>
<td>0.93</td>
</tr>
</tbody>
</table>

**Sloshing and swirling in partially loaded membrane tanks**

Does swirling occur in actual irregular seaways?

Model tank was excited on a moving table with irregular sway motions.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Type of excitation</th>
<th>Liquid level</th>
<th>Significant wave height</th>
<th>Average wave period</th>
<th>Duration of test in actual scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>Sway</td>
<td>50%</td>
<td>5.93 m</td>
<td>9.58 sec.</td>
<td>10,000 s. = 2.8 hrs</td>
</tr>
</tbody>
</table>

Swirling appeared!
Sloshing and swirling in partially loaded membrane tanks

Membrane tank sloshing tests at model basin

LNG carrier model (L=4.0m)

Acrylic tank

Actual Sea Model Basin, National Maritime research Institute

Measured items: Ship motions, Liquid motion in tanks, Tank forces (Fx, Fy), Pressures, ...

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Ex.1: Encounter wave period ≈ Natural period of ship's roll motion

Beam sea (90°), 
Hw = 5.5 m, 
50% loading

MTI
**Sloshing and swirling in partially loaded membrane tanks**

**Ex.2:** Encounter wave period $\approx$ Natural period of liquid motion

![Graph showing tank forces over time with labeled sections A, B, C, D]

- A: Sloshing → B: Swirling (Counter clockwise) → C: Transition → D: Swirling (Clockwise)

Beam sea (90°),

$H_s = 5.5 \text{ m}$,

50% loading

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**Summary**

1. The general fluid motion and dynamic pressures obtained by our numerical sloshing simulation agree well with experimental data, which confirms the suitability of the numerical tool to represent the phenomena.

2. For middle to low filling levels, swirling occurs if the tank length to breadth ratio is near 1.0. On the other hand, swirling does not appear in high filling conditions, i.e., 70% or more filling levels. We also confirmed that swirling in membrane tanks can occur in the actual irregular seaways.

3. In partially loaded conditions, very complicated liquid motion in the tank is generated when the encounter wave period is near the natural period of the tank liquid motion. For other encounter periods, the liquid motion in the tank is almost two dimensional and the wave inside the tank is generated almost parallel to the tank walls.

Part of this research was carried out as ClassNK's Joint R&D with industries and Academic Partners Project. Final research results of the project will be presented this autumn.
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Thank you very much for your kind attention!