Sloshing and swirling in partially loaded membrane tanks

Makoto Arai, Yokohama National University
Hideyuki Ando, MTI
Akio Usami, ClassNK

株式会社 MTI Monohakobi Technology Institute　YNU 横浜国立大学 YOKOHAMA National University　ClassNK

April 3, 2017

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:

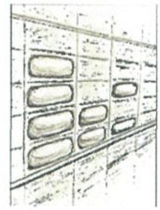
- Rapid growth of demand for LNG and increase of LNGCs worldwide
- Emergence of new voyage routes such as for transporting US shale gas through newly expanded Panama Canal, LNG transport from Russia to Asia using Arctic Ocean, etc.
- Large ships
- Operations in partially loaded condition such as those 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 CassNK to ensure safe navigation of LNG carriers in the actual seaways.

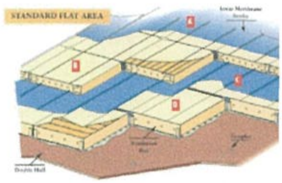
Sloshing and swirling in partially loaded membrane tanks

Sloshing in membrane tanks

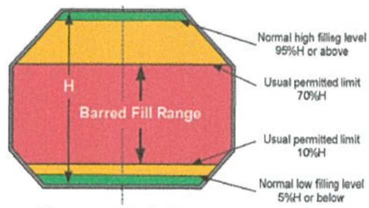
Membrane type LNGC and cargo tank
(MHI Tech. Rev., 2007)



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



Insulation boxes (GTT)

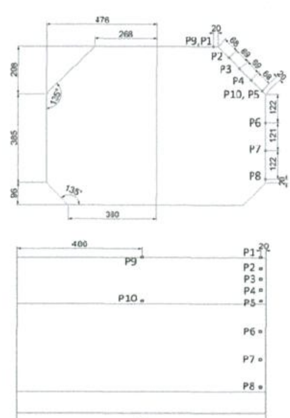


Fill range limitation

Sloshing and swirling in partially loaded membrane tanks

Model tests at MTI Yokohama Lab

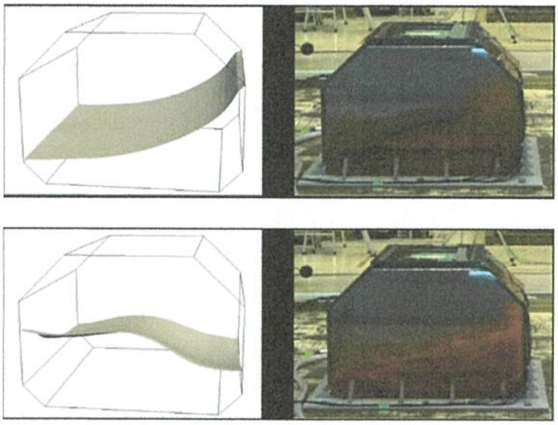
Model tanks on moving table



- ・Pressure: 10 points
- ・Hydrodynamic forces to the tank:
  2 directions
- ・Scale: 1/40
- ・Length x Breadth x Depth:
  971mm x 952mm x 689mm

Sloshing and swirling in partially loaded membrane tanks

Comparison of liquid motion in the tank
(30% , amp.=2cm, 90deg., f=0.71Hz)



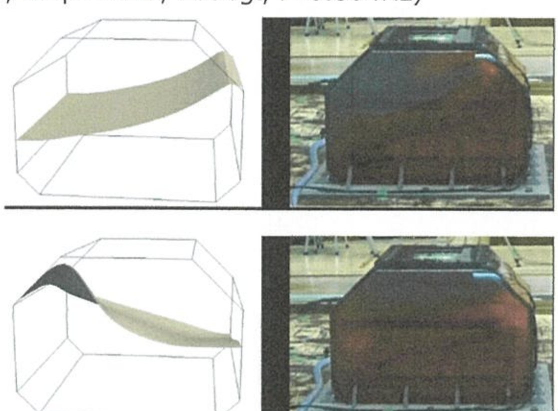
Sloshing

Swirling

Numerical simulation   Experiment

Sloshing and swirling in partially loaded membrane tanks

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



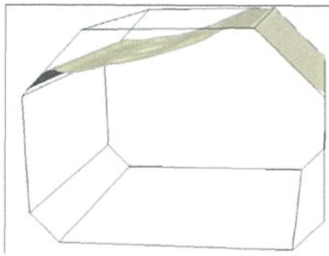
Sloshing

Swirling

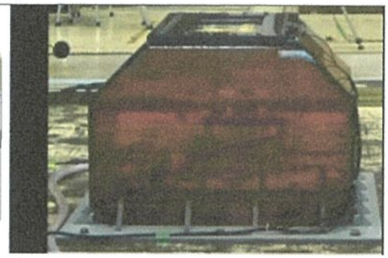
Numerical simulation   Experiment

Sloshing and swirling in partially loaded membrane tanks

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



Numerical simulation

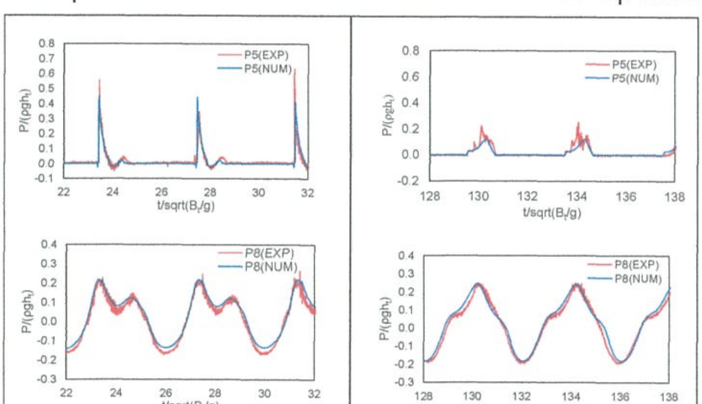


Experiment

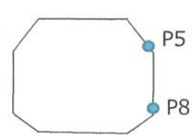
Only sloshing occurs

Sloshing and swirling in partially loaded membrane tanks

Comparison between measured and computed pressures



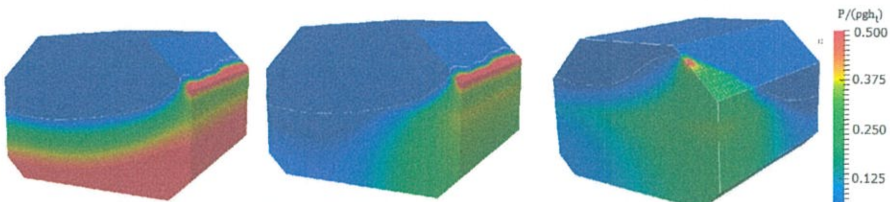
Sloshing phase   Swirling phase



(50% , amp.=2cm, 90deg., f=0.804Hz)

Sloshing and swirling in partially loaded membrane tanks

Snapshots of pressure distribution in the tank
(50%filling, excitation at resonant frequency)



Total pressure in sloshing phase

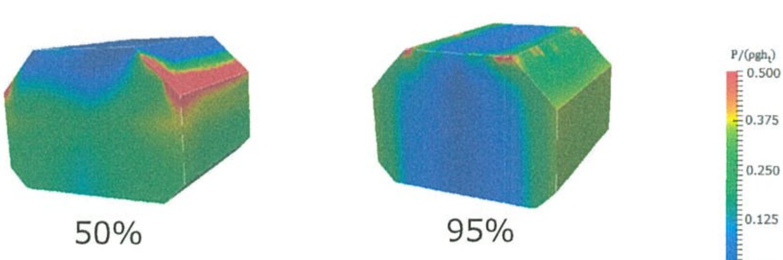
Dynamic pressure in sloshing phase

Dynamic pressure in swirling phase

(Dynamic pressure) = (Total pressure) – (Static pressure)

Sloshing and swirling in partially loaded membrane tanks

Maximum dynamic pressure in the whole simulation

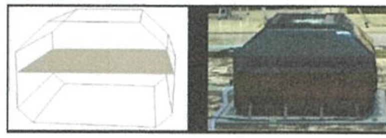


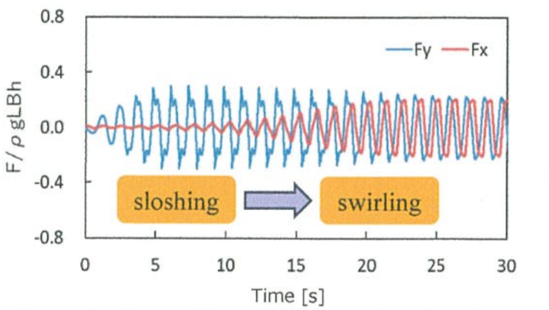
- In case of middle fill levels (30% to 70%), the lower part of the top chamfers suffer the highest pressure, and when swirling occurs its effect is observed on the edges of the top chamfers.
- In case of high fill levels, high pressure occurs at the intersections between top chamfers and tank ceiling.

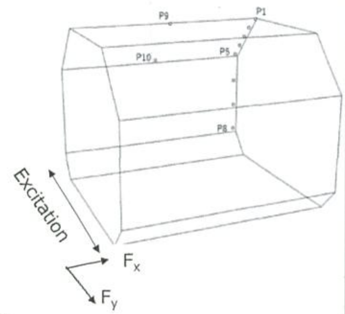
Sloshing and swirling in partially loaded membrane tanks

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.





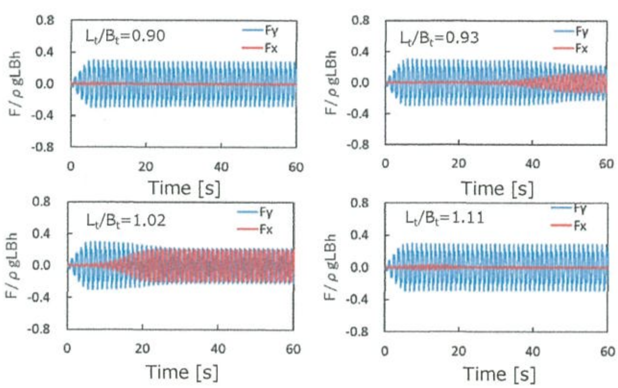


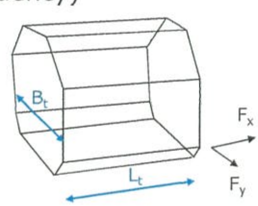
Example of force histories generated by liquid motion

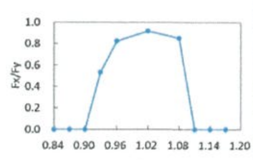
Sloshing and swirling in partially loaded membrane tanks

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





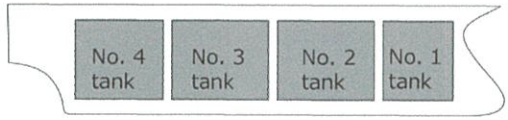


Swirling occurs when fill level= 30%～60% and L_t/B_t=0.9～1.1

Sloshing and swirling in partially loaded membrane tanks

Actual ship's tank dimensions

Condition of swirling occurrence: L_t/B_t=0.9～1.1



Ship A

L_t/B_t	No. 4 tank	No. 3 tank	No. 2 tank	No. 1 tank
L_t [m]	38.38	43.58	43.89	
B_t [m]	37.81	37.81	37.81	Wedge shape
L_t/B_t	1.01	1.15	1.16	

Ship B

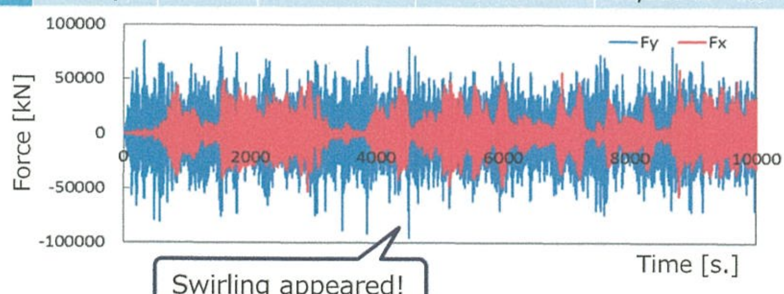
L_t/B_t	No. 4 tank	No. 3 tank	No. 2 tank	No. 1 tank
L_t [m]	40.00	44.75	44.75	31.45
B_t [m]	37.81	37.81	37.81	33.75
L_t/B_t	1.06	1.18	1.18	0.93

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.

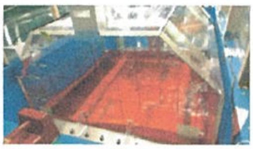
Test No.	Type of excitation	Liquid level	Significant wave height	Average wave period	Duration of test in actual scale
54	Sway	50 %	5.93 m	9.58 sec.	10,000 s.≈ 2.8 hrs



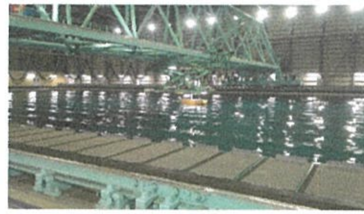
Sloshing and swirling in partially loaded membrane tanks

Membrane tank sloshing tests at model basin

LNG carrier model (L=4.0m)



Acrylic tank



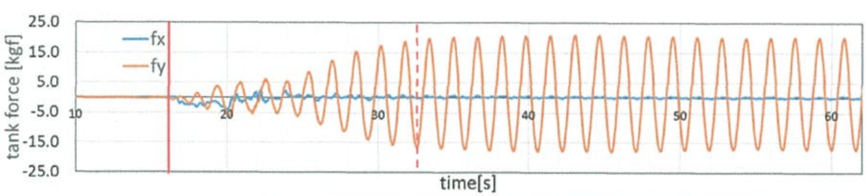
Actual Sea Model Basin,
National Maritime research Institute

Measured items: Ship motions, Liquid motion in tanks, Tank forces (F_x, F_y), Pressures, …

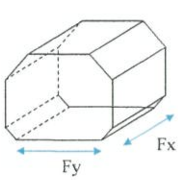
株式会社 MTI Monohakobi Technology Institute　YNU 横浜国立大学 YOKOHAMA National University　ClassNK

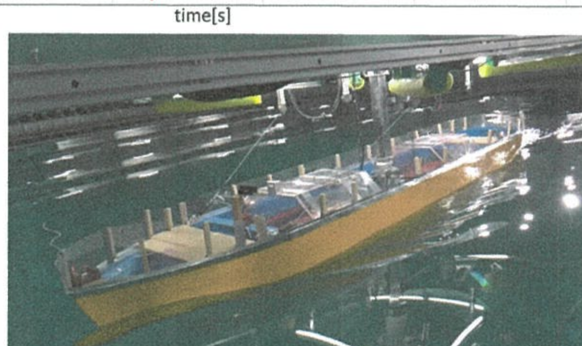
Sloshing and swirling in partially loaded membrane tanks

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



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

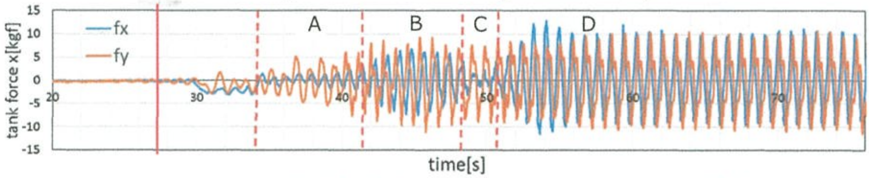




株式会社 MTI Monohakobi Technology Institute　YOKOHAMA National University

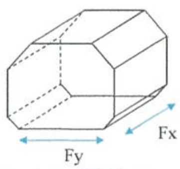
Sloshing and swirling in partially loaded membrane tanks

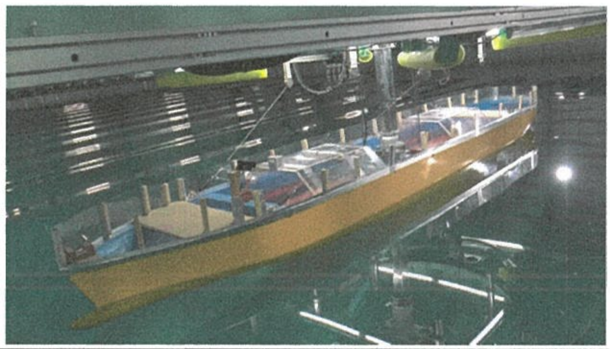
Ex.2: Encounter wave period ≈ Natural period of liquid motion



A:Sloshing→B:Swirling(Unticlockwise)→C:Transition→D:Swirling(Clockwise)

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





株式会社 MTI Monohakobi Technology Institute

Sloshing and swirling in partially loaded membrane tanks

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.

株式会社 MTI Monohakobi Technology Institute　YNU 横浜国立大学 YOKOHAMA National University　ClassNK

Sloshing and swirling in partially loaded membrane tanks

Thank you very much for your kind attention!