Rule development for sloshing and structure assessment of the liquid tanks

MULTIPHASE 2017 · PARIS

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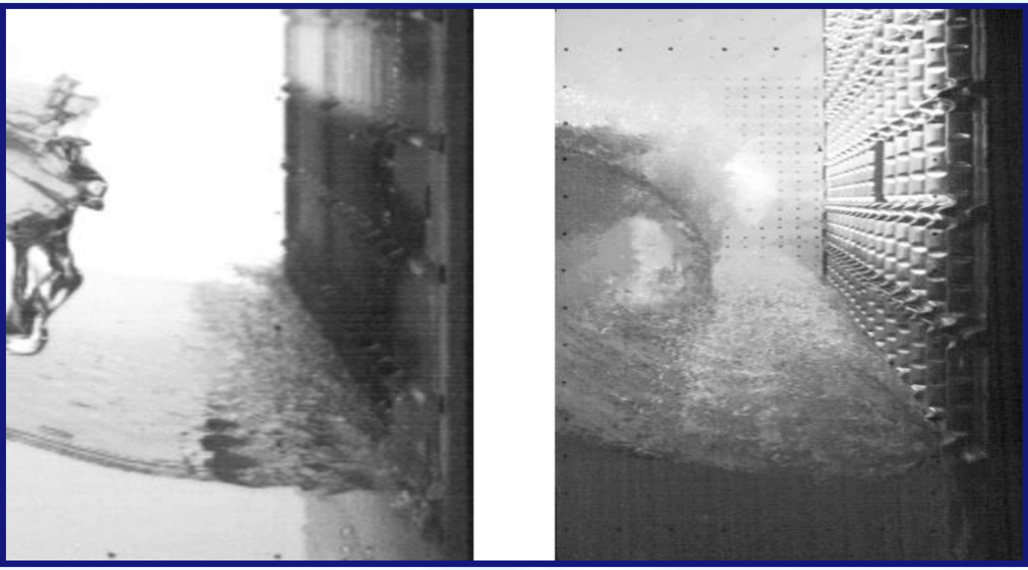
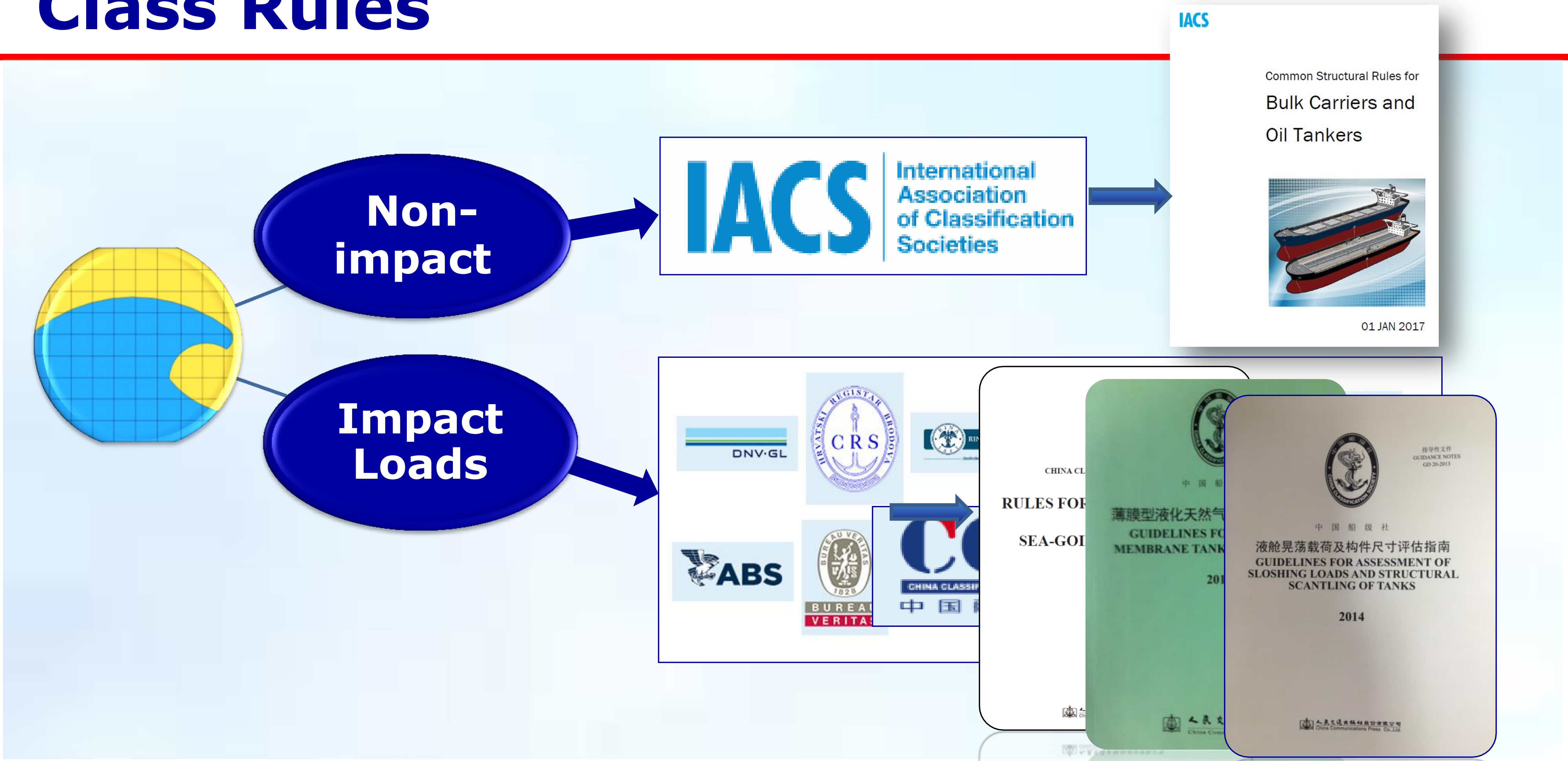
1. Rule Design Principle



Primary Goal

What is the main concern of the Class?

Class Rules



Non-impact
Impact Loads
IACS
International Association of Classification Societies
IACS
Common Structural Rules for
Bulk Carriers and
Oil Tankers
01 JAN 2017
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液舱晃荡载荷及构件尺寸评估指南
GUIDELINES FOR ASSESSMENT OF SLOSHING LOADS AND STRUCTURAL SCANTLING OF TANKS
2014

Sloshing Definition in Class Rules

Non-impact

Moderate sloshing **standing wave** type liquid motion cause dynamic pressure loads with magnitude **similar to hydrostatic pressure**.

Impact Loads

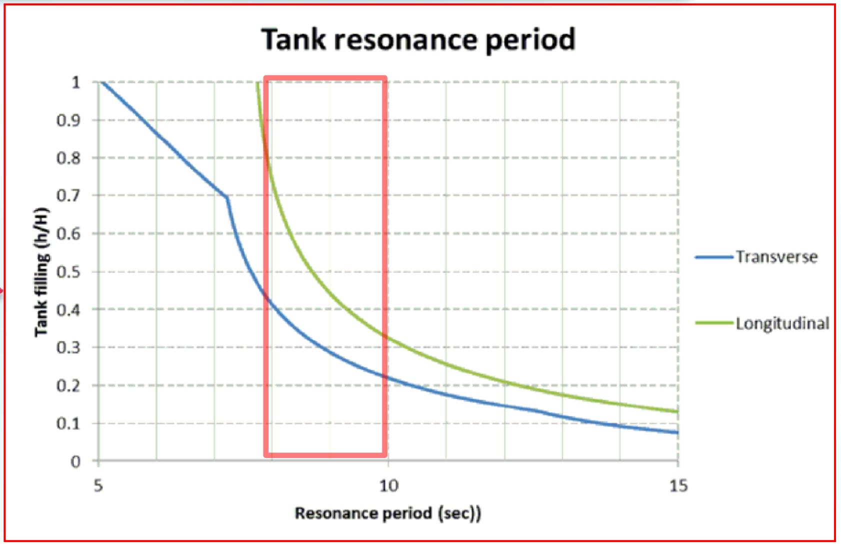
Violent sloshing may cause **breaking waves** and high velocities of the fluid surface, have **a high pressure** with short duration.

- Effective sloshing width **0.56B**
- Effective sloshing length **0.13L**

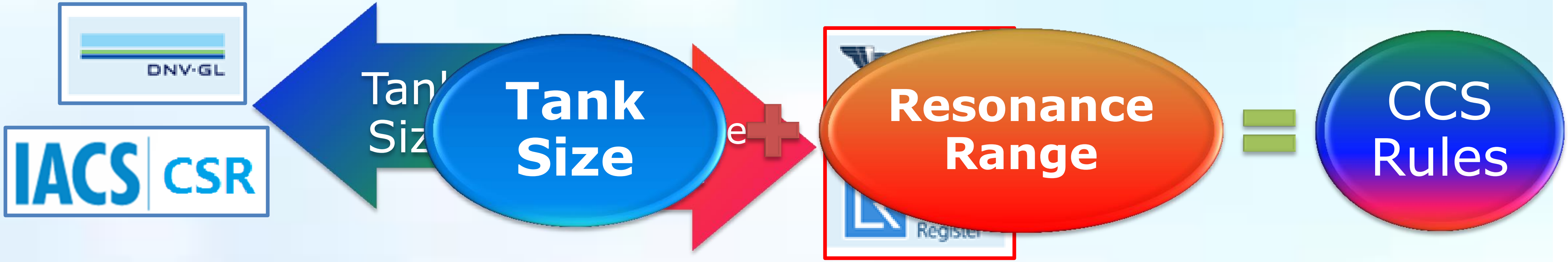
NO — **Small tank**

YES — **Large tank**

Tank Size — **Resonance Range**



Sloshing Definition in CCS Rules



Level 1:

- a quasi-static process;
- small tank without resonance.

Level 2:

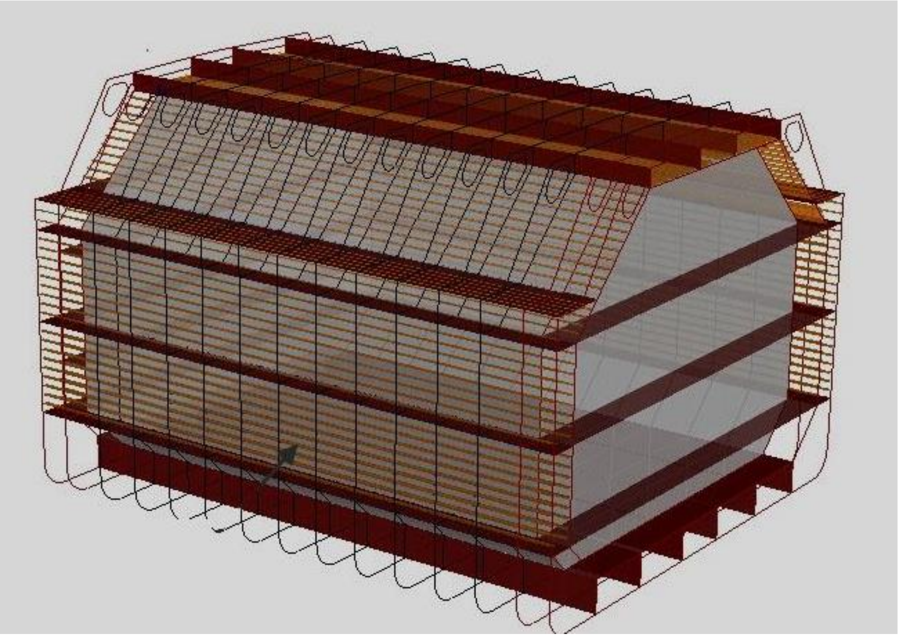
- a dynamic process;
- small tank within resonance;
- large tank without resonance.

Level 3:

- the nonlinear impact motion;
- large tank within resonance.

Obviously, the membrane tanks are the kind of large size tanks which can easily fall into the sloshing resonance range. The prismatic shape of the membrane tanks has been designed to reduce the risk of severe sloshing induced impact loads. The flow chan

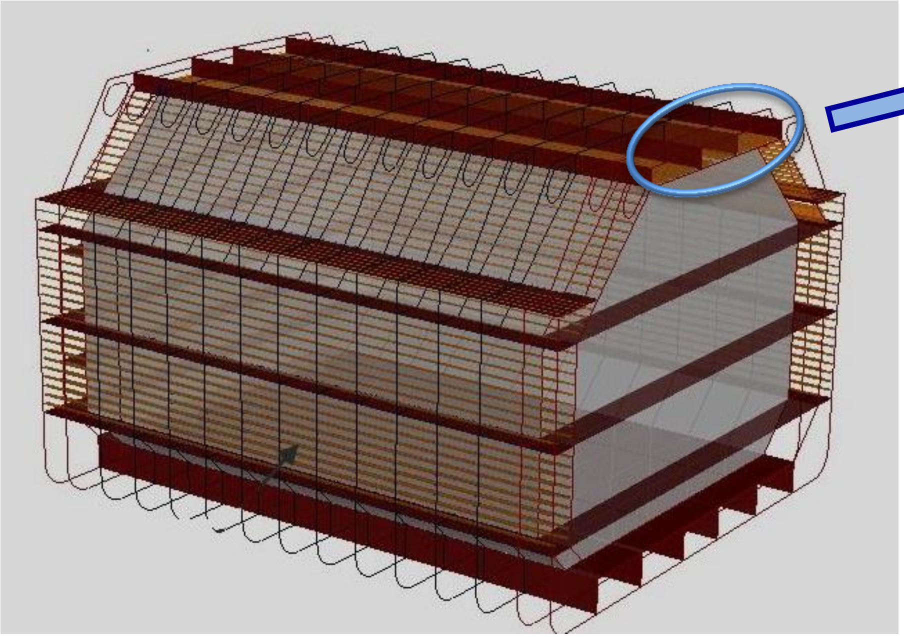
Impact and Filling Level

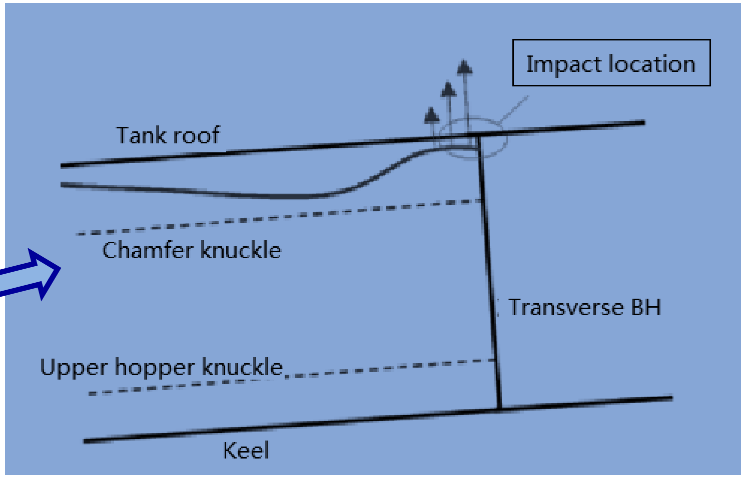


- **Large size tanks** which can easily fall into the sloshing resonance range.
- **Prismatic shape** reduces the risk of severe sloshing induced impact loads.
- Sloshing is characterized **by two** excitation direction and **different** fluid flow phenomena on **different** filling height.

Impact and Filling Level

High-filling (>90%H)



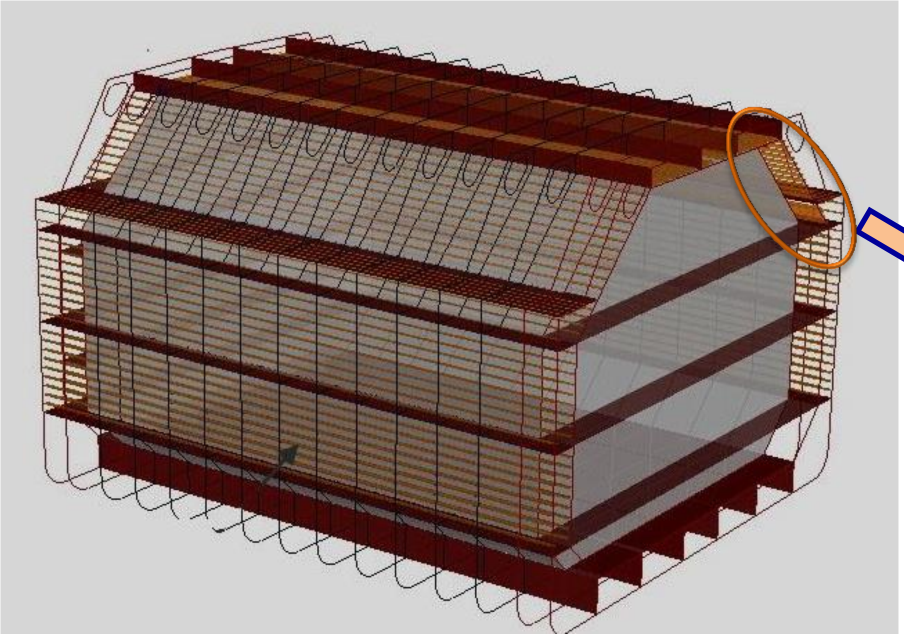


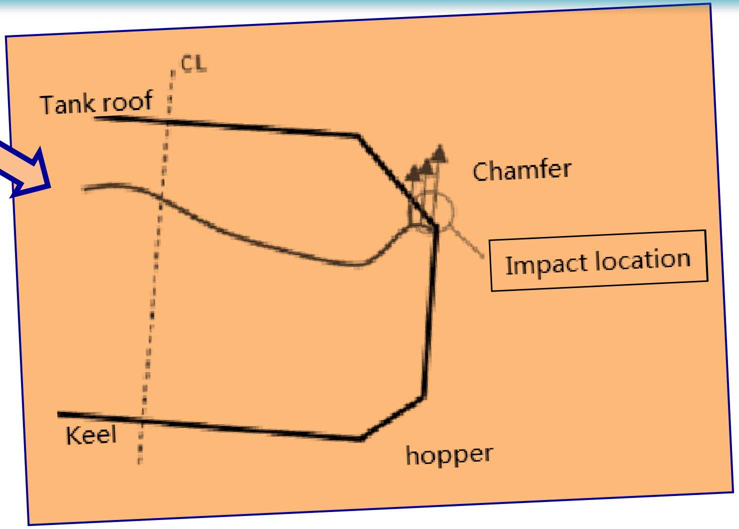
Pressure can be of significant magnitude, but the effect is much localized in the corner of the tanks.

Impact and Filling Level

High-filling (60~90%H)

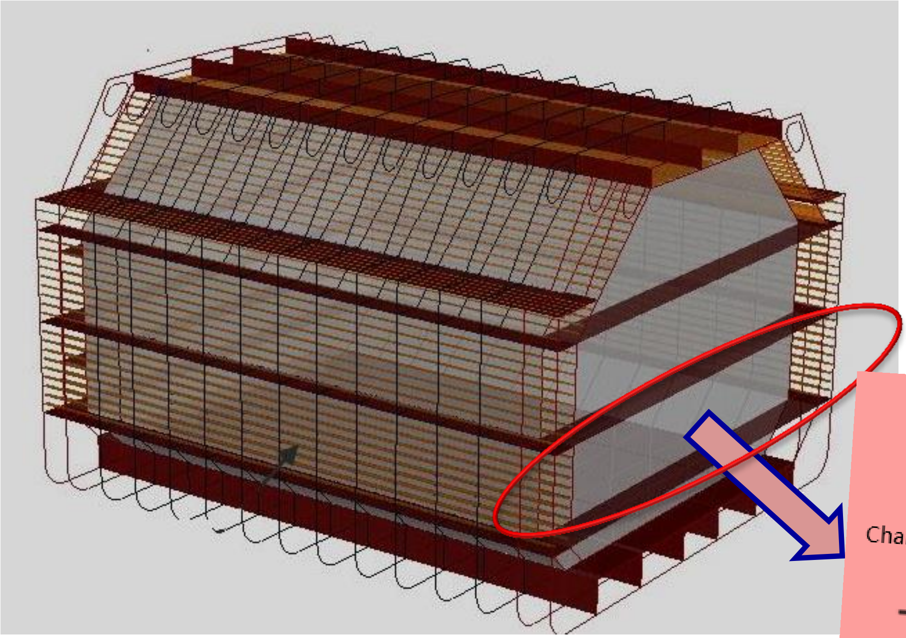
the largest impacts occur in the corners and knuckles of the chamfer caused by run-ups against the longitudinal or transverse bulkheads or by a 'flat' fluid surface impact.



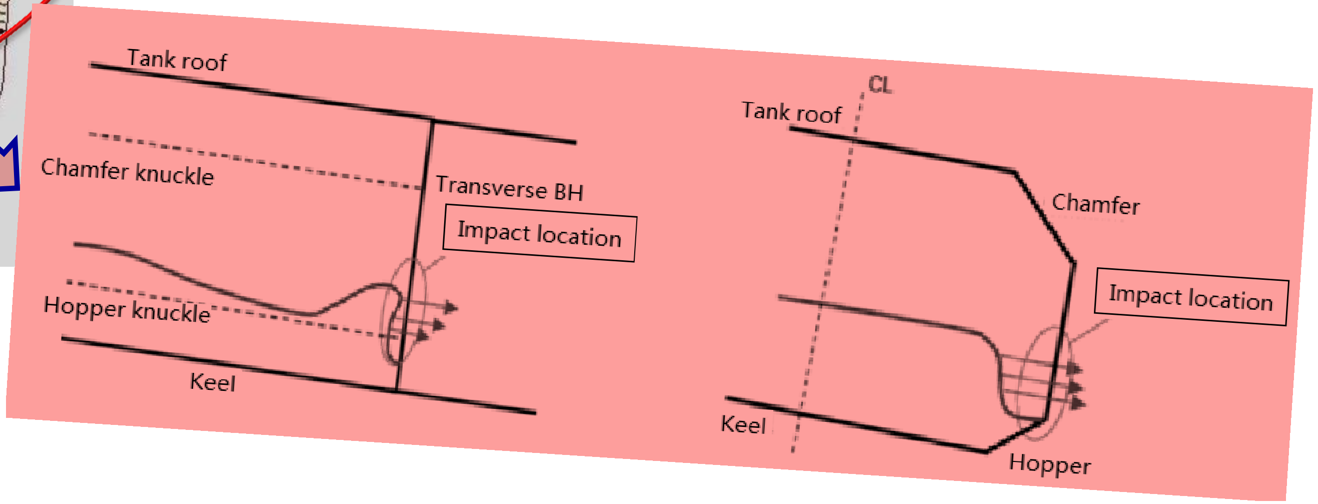


Impact and Filling Level

Low-filling (10~40%H)

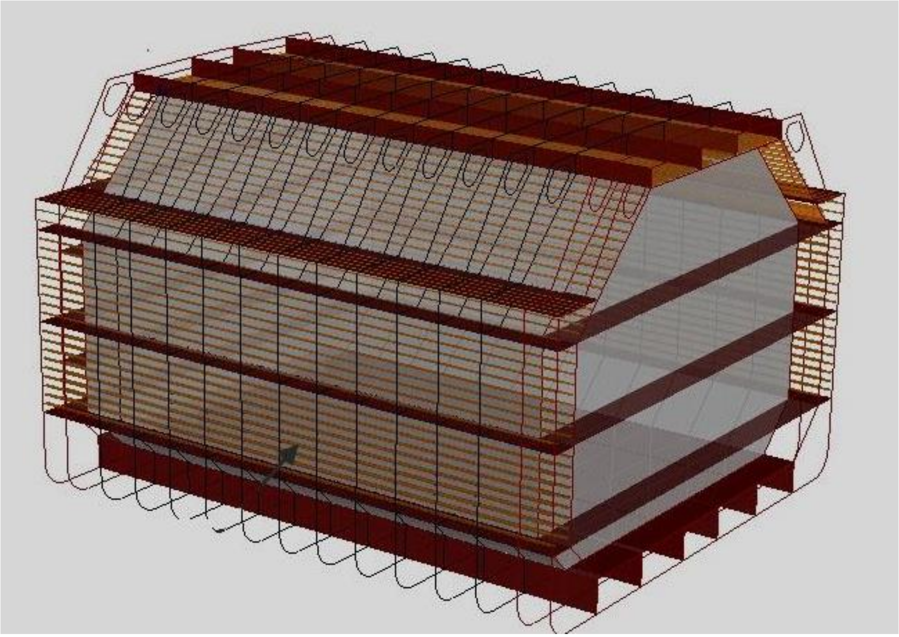


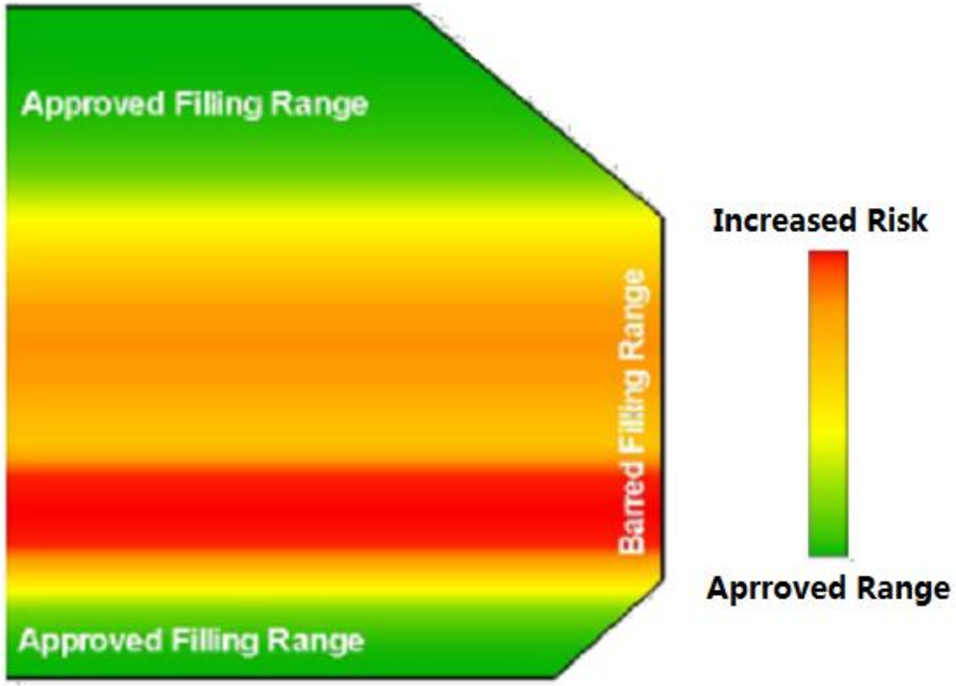
the largest impacts occur at the longitudinal and transverse bulkheads due to breaking waves with very high impact pressures, more severe than the phenomena encountered at higher filling levels.



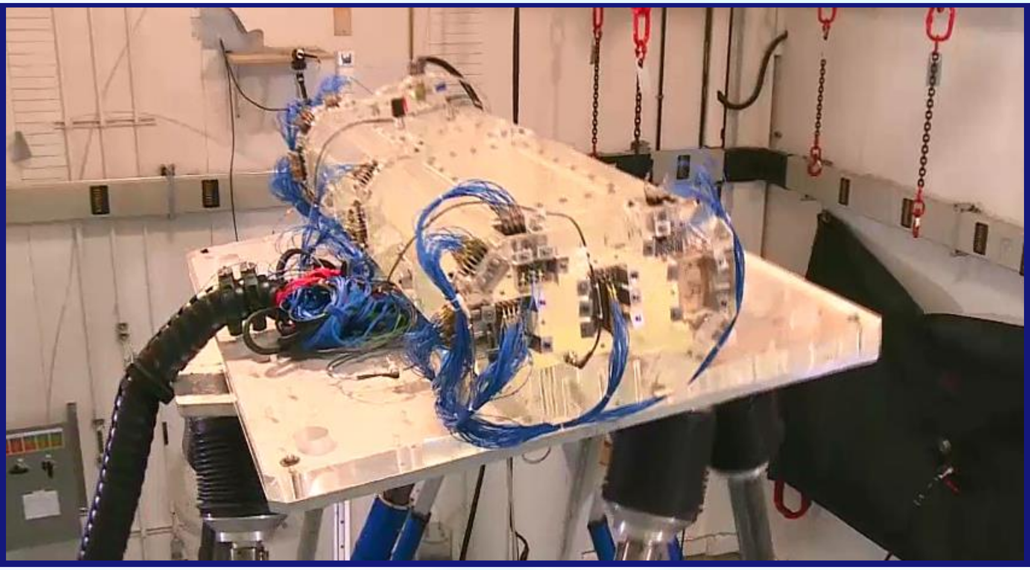
Impact and Filling Level

Barred Filling Range



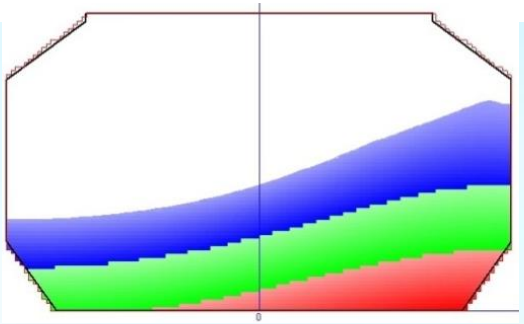


2. Model Scale Tests

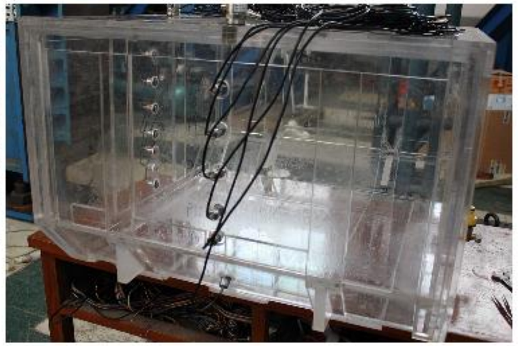


Numerical Analysis

- ***Very important in preliminary design***
- ***Regarded as supplement of model test***

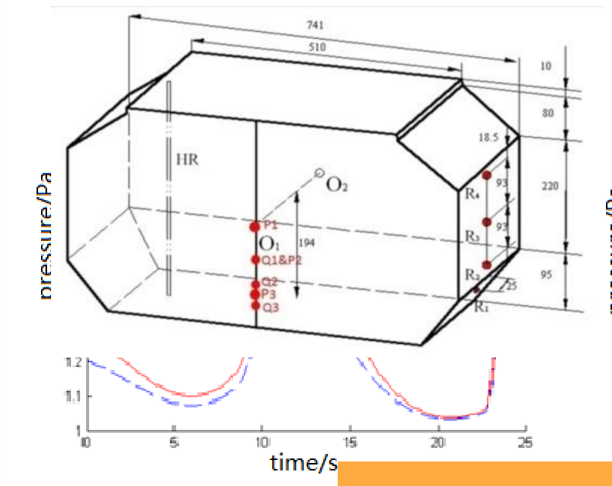


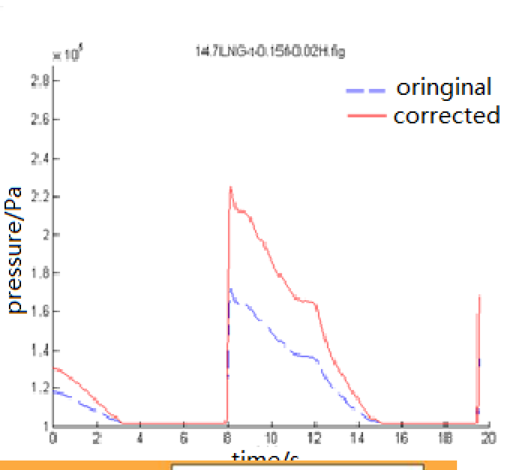
- **Approved universal CFD software**
- **Sloshing2D:**
  - ✓ The VOF method is applied;
- **Advantage of Sloshing2D:**
  - ✓ Consistent with the experiment;
  - ✓ More real surface movement;
  - ✓ Faster, better astringency.

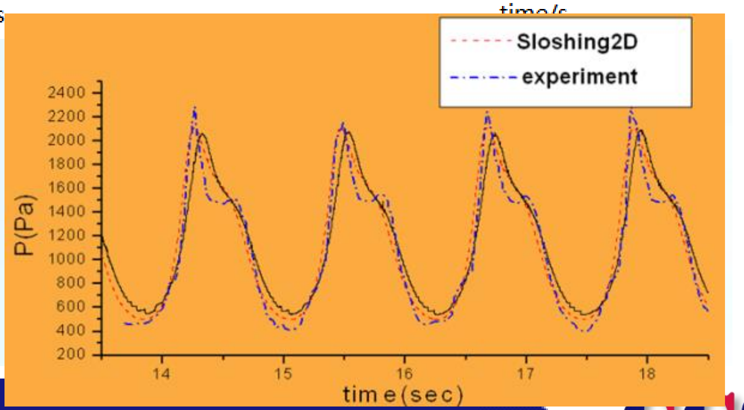


Validations of the Code

- ***Set up basic parameters***
  - including the excitation, tank size, liquid density, pressure, filling rate and measure point height
- ***Scale ratio determination***
  - based on the size of target tank and the model
- ***Pressure measurement***
  - the density, measure points and the static pressure
- ***Pressure correction；***
  - to correct the peak value of pressure curve with the correction factor.
- ***Popularized application.***

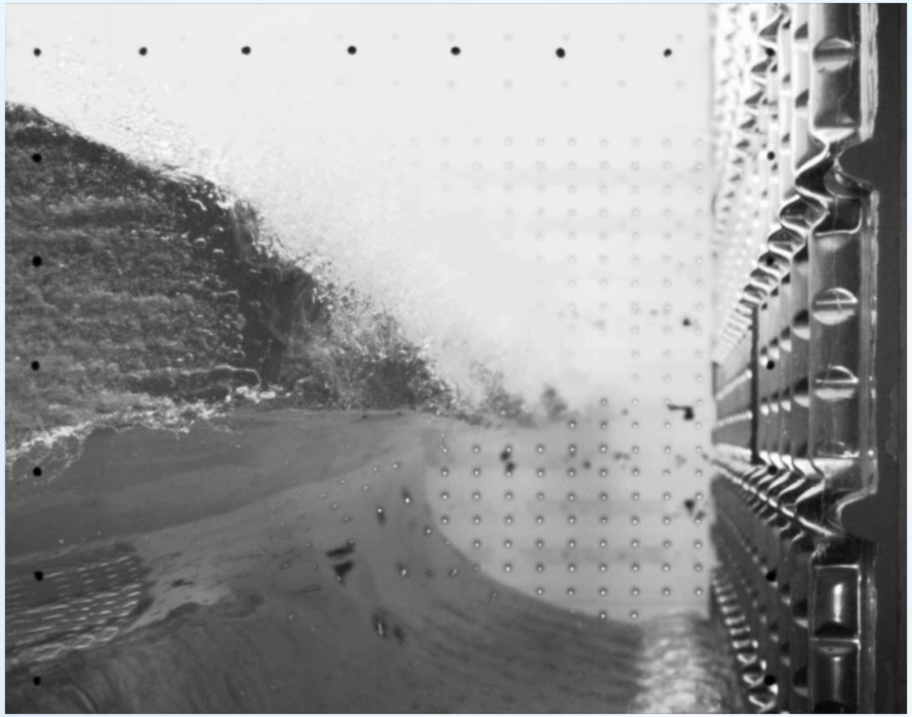






Sloshing Phenomena Review

Reliable conclusions are confirmed



- Transfer of liquid momentum to gas momentum (DR)
- Development of free surface instabilities
- Compression of escaping gas (GC)
- Compression of entrapped gas (GC)
- Phase transition (PT)
- Change of liquid momentum
- Compression of liquid (LC)
- Fluid structure interaction (FSI)
- Propagation of time-space distributed loads through composite structure

- Global flow is **not** deteriorated over time by local perturbations.
- Sloshing model tests provide **conservative** results.

Comparative Approach

Approach: *Consistent treatment of the reference and the target cases to reduce bias and obtain the accurate scaling factor.*

the reference vessel: *proven service, system of GTT, and similar wave climate, as well as 90% and 98.5% filling height.*

the target vessel: *Same test rig, same measurement equipment and data acquisitions and processing methods and system, as well as the similar response and strength analysis methods.*

New designs

Novel vessel designs will typically be:

- Vessels **without** filling restrictions.
- Ships on a **special** trading route or in a **restricted** sea area.
- Offshore terminals or units (**FLNG, RV, FSRU, FPSO** etc.)

The approach of the reference vessel may not suitable to the novel vessel designs.

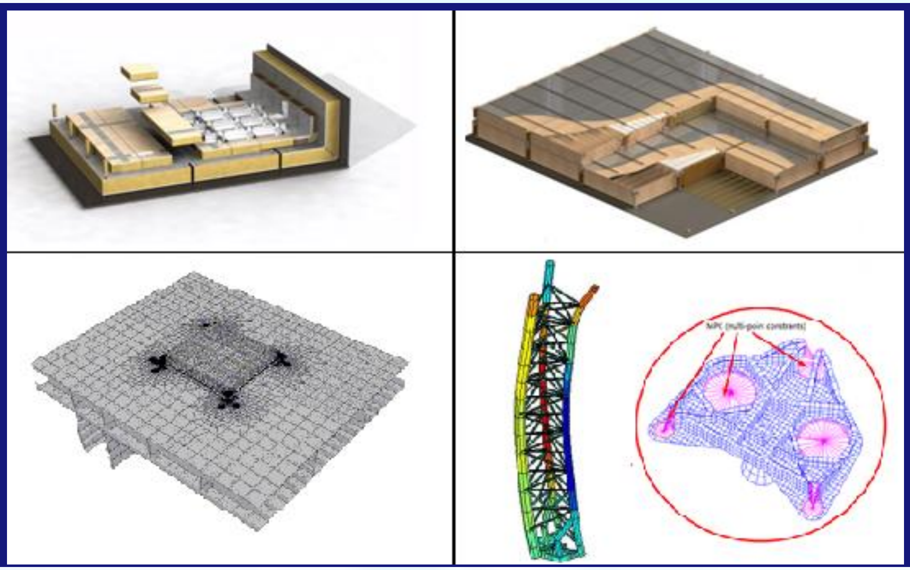
SLING Programme

What can make the balance for the Class?

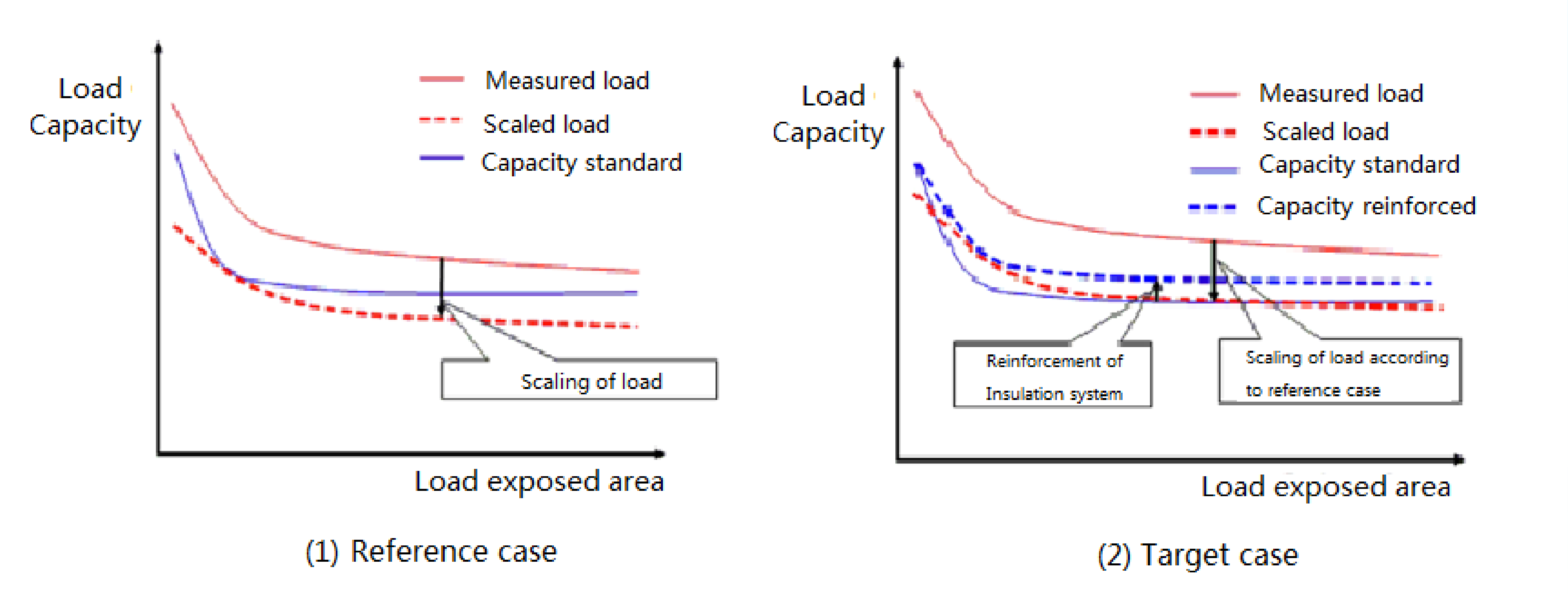
A shift to **a first-principle-based approach** which can disentangle all the physical problems and explore the unknown frontiers in the impacts.

Safety | **Optimization**

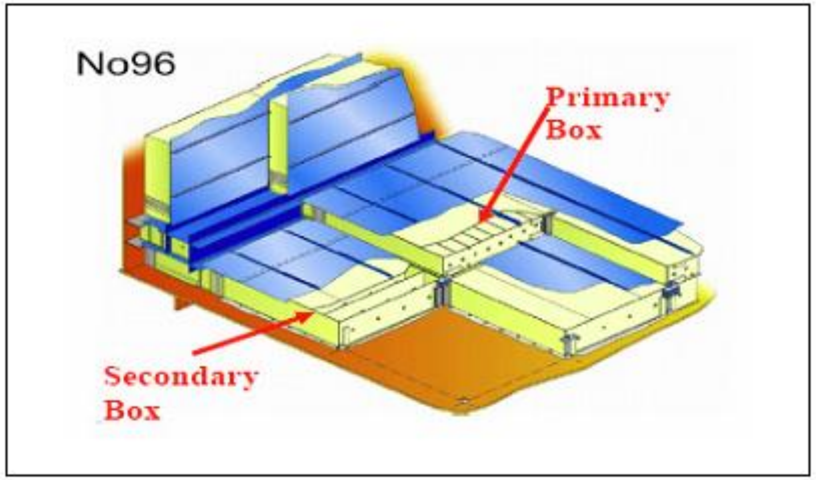
3. Strength Assessment

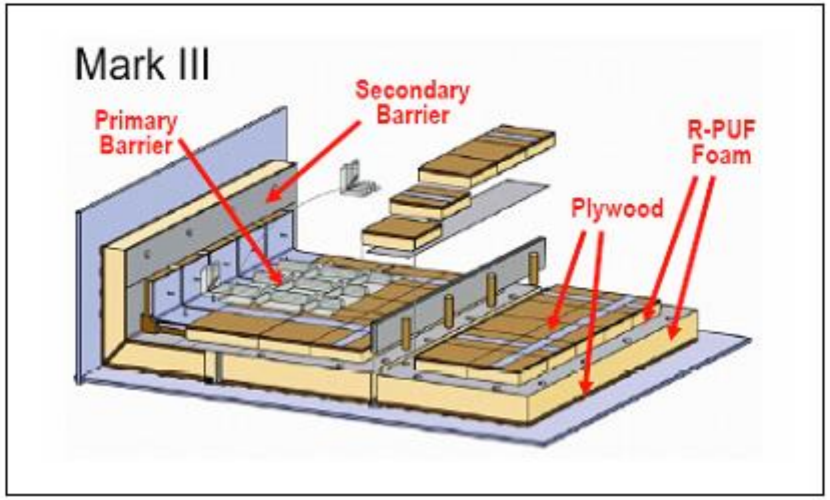


Comparative Assessment Methodology



STRENGTH ASSESSMENT of CCS





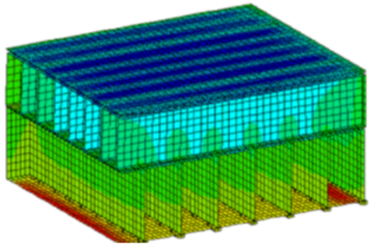
The dynamic loads:

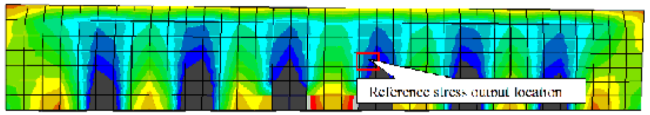
- The most important effects—the dynamic response effects should be considered.
- A simplified approach including the use of a dynamic load factor along with quasi-static response analyses is used.

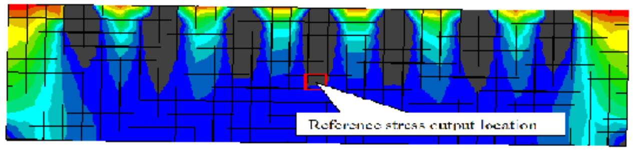
STRENGTH ASSESSMENT of CCS

The requirements in the Class rules:

- Through the FEM analysis and the output obtained, the ultimate capacity models are able to predict the limit states associated with damages to the CCS.
- Acceptance criteria for the ultimate strength assessment of the CCS is given.







STRENGTH ASSESSMENT of hull structure

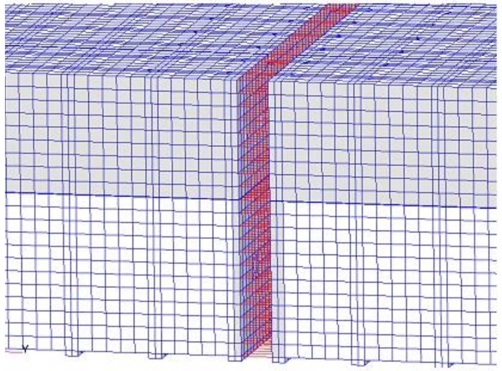
Classes pay attention to hull structures: Structural collapse of the inner hull structure is likely to cause loss of containment of the tank. Further, adequate support of the cargo containment system is of high importance to avoid excessive interaction loads and deformations that can lead to damages from extreme impact loads and during long time exposure.

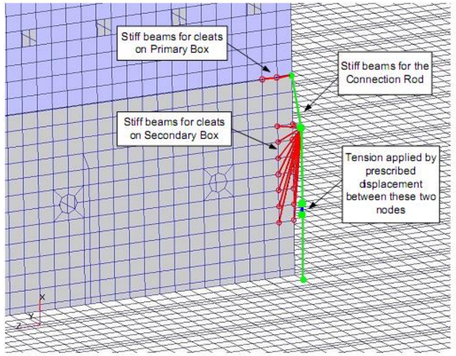
Performance of the hull structure: The plates and stiffeners have significantly larger proportions than the structural components of Membrane, and are less sensitive to the highest localized sloshing impact loads. Plate and stiffener dimensions will be determined by the integrated loads over a larger area of the structure.

Buffer Effect of CCS

Method: stress and deformation is defined respectively as the response variables, defining the buffer effect as displacement and stress buffer coefficients to conduct a comprehensive inspection of the insulation boxes. The coefficients are obtained through the ratio calculation of the maximum displacement or stress response by using FEM model with and without containment system respectively.

Result: the buffering coefficient is roughly at 40%-50% in general load case, and 50%-60%during a shot pulse loading which means that if the insulation layer is not considered directly, the stress result of the HULL structure multiplied by 0.4~0.5 is equivalent to the result with an insulated box.





STRENGTH ASSESSMENT of Pump Tower

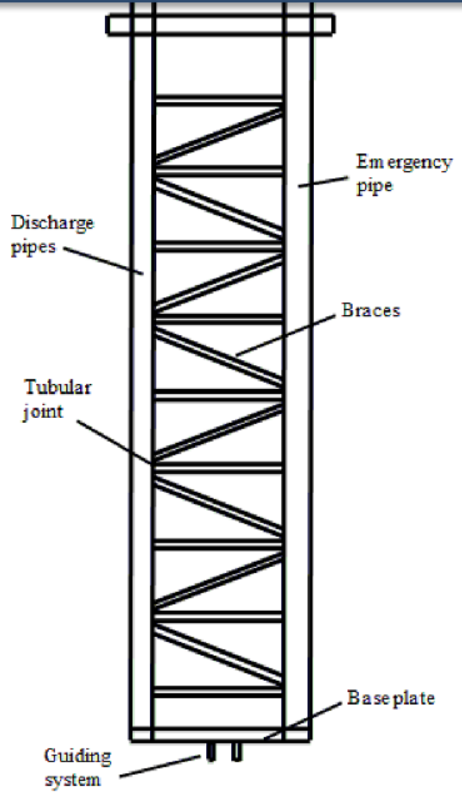
The pump tower structure shall be designed to withstand both extreme loads (**ULS**) and repetitive loading(**FLS**).

Several load effects need to be considered:

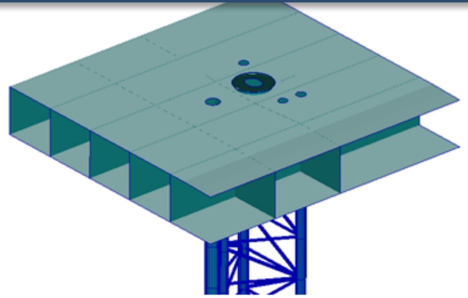
- Sloshing load, gravity loads and inertia loads in time domain.
- Thermal loads due to the low temperature of the cargo.
- Hull girder loads (for liquid dome area and for base support).
- Internal tank pressure and external sea pressure (for base support).

STRENGTH ASSESSMENT of Pump Tower

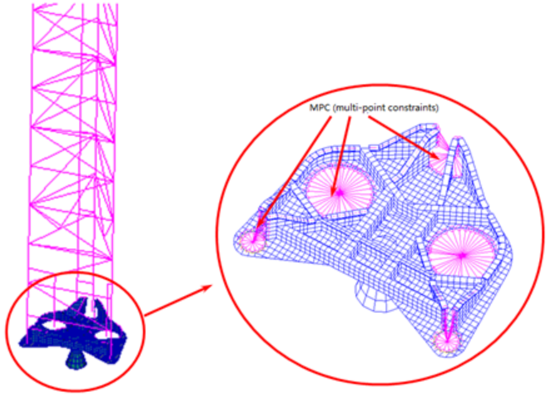
FEM analysis of the pump tower structure **based on API rule** should be carried out to determine the response for the main structure, the base support, and the liquid dome.



(1) Pump tower structure



(2) Pump tower top structure FE model including the liquid dome



(3) Pump tower foundation structure FE model

4. Conclusion

Conclusion

The requirements on sloshing of the Class rules are described:

- Based on the example of prismatic LNG tank with GTT containment system
- Sloshing loads and the methodology for assessment of the containment system, hull structure and the pump tower.

The application and the benefit of Class rules:

- Good control effect for those tanks which are smaller or without suffering severe impact.
- Practical but conservative engineering approach is proposed by considering the factor for scaling of model test loads to full scale of the reference vessel.

The perspective: SLING can establish a first-principle-based approach which can disentangle all the physical problems and bonus the structure design and release the impact restrain in the Class rules.

Reference

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