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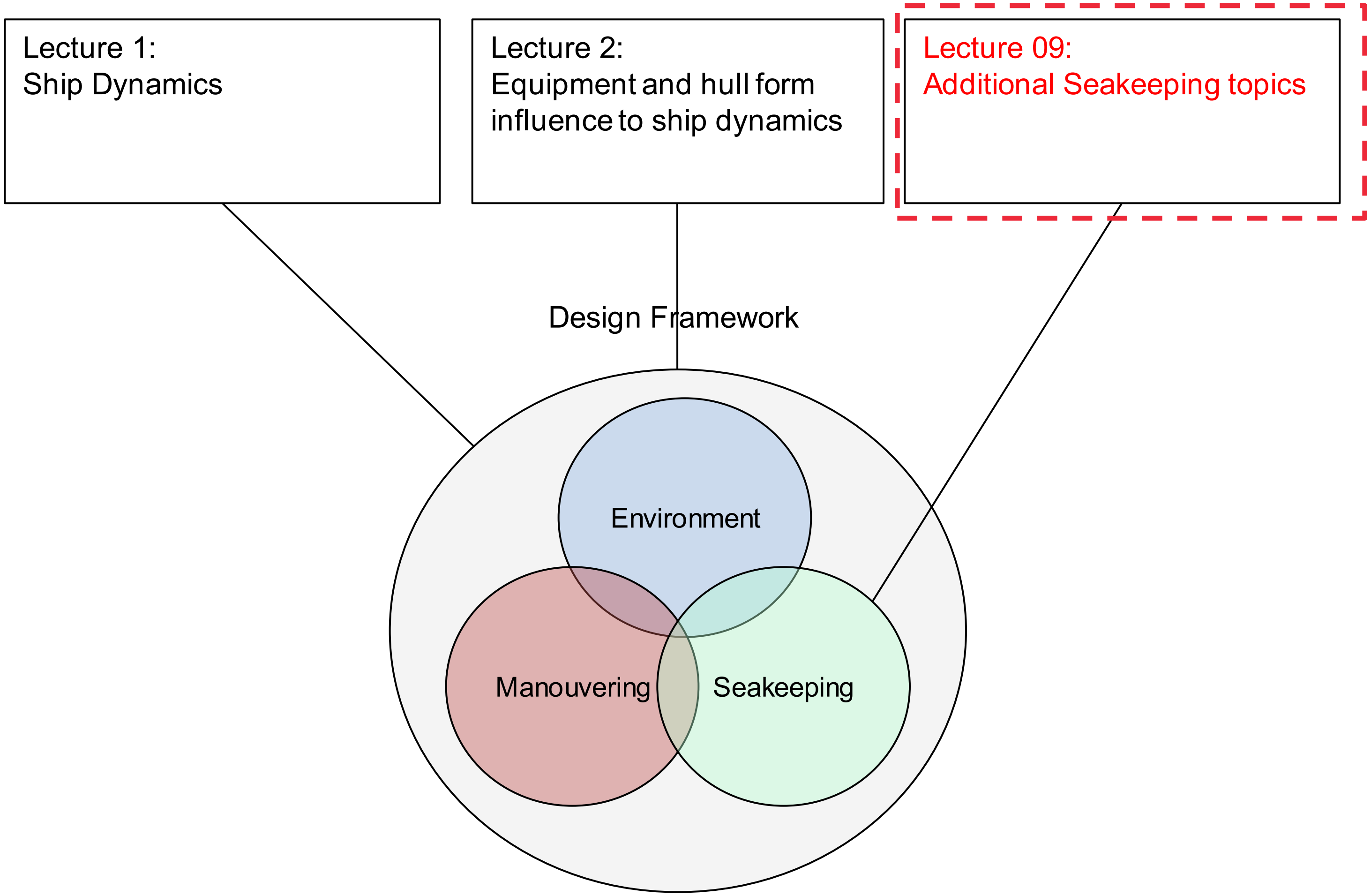
MEC-E2004 Ship Dynamics (L)

Lecture 9

Additional Seakeeping Topics

Where is this lecture on the course?



Contents

- **Aim :** Understand key issues related to local loads (e.g. slamming, green water on deck, sloshing etc.) and how different criteria (e.g. motion sickness, voluntary speed loss) are set and assessed for asset safety, people safety and operational performance. A brief overview of seakeeping model tests is also provided. Examples of criteria looked at are motion sickness and voluntary speed loss.



- **Literature:**

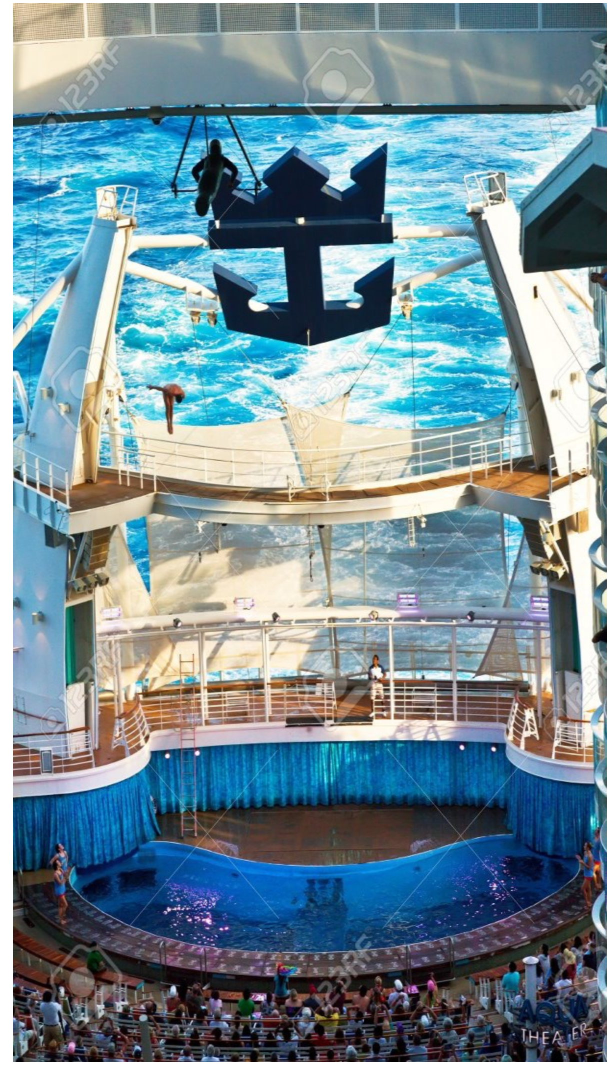
1. Lloyd, A.R.J.M., “Seakeeping – Ship Behavior in Rough Weather”, Chapters 21-23
2. Razola, M., “New Perspectives on Analysis and Design of High- Speed Craft with Respect to Slamming”, Doctoral Thesis, KTH, 2016
3. RED Bishop and WG Price, Hydroelasticity of Ships, Cambridge University press ISBN 9780080439211
4. Yong Bai, Chapter 2 - Wave Loads for Ship Design and Classification, In Marine Structural Design, Elsevier Science, Oxford, 2003, Pages 19-37, ISBN 9780080439211
5. Lewis E.V., Principles of Naval Architecture Vol.3 ‘Motions in waves and controllability’

Motivation

- Excessive ship motions, accelerations and loads may lead to significant asset risks, can make onboard operations unsafe or difficult and may be harmful for people's health.

- Good example is the habitability of passenger ships. In the cruise sector excessive motions can be harmful for people and bad for business.

- When designing a ship the mission has large impact on the criteria we can use for acceptable responses. For example, war ship operability standards can be fairly different to passenger ship or luxury yacht standards. In any case we have to identify the responses early on in the design stage and limit operations.



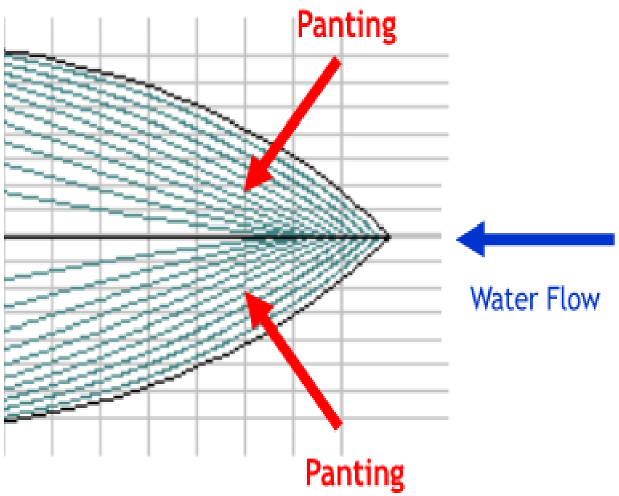
Assignment 5

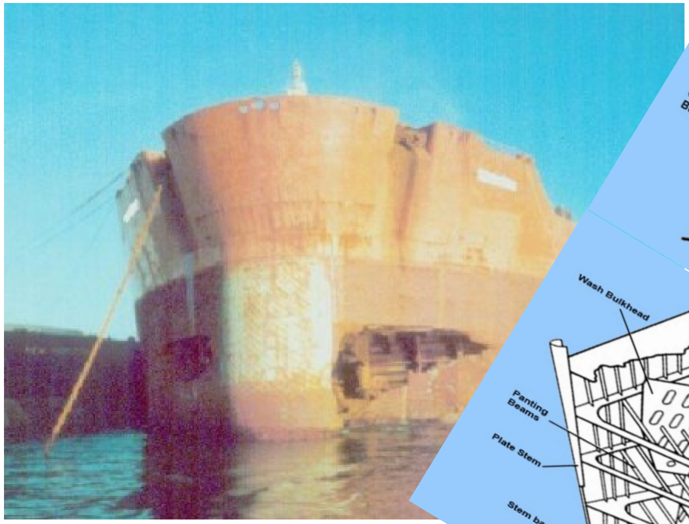
- Grades 1-3:
  - ✓ Select book-chapters related with (1) seakeeping design criteria (2) added resistance (3) maneuvering and reflect to your ship
  - ✓ Assess seakeeping criteria with some software and assess the performance of the initial design with respect to those
  - ✓ Discuss the simplifications made in added resistance/maneuvering modelling and analysis of your ship
  - ✓ Select the maneuvering tests to be simulated and justify the selections
- Grades 4-5:
  - ✓ Based on scientific literature, discuss the accuracy of the obtained results
  - ✓ Compute the part of added resistance in selected wave conditions in relation to still water resistance & discuss results
  - ✓ Discuss what issues you can still improve for you ship in the follow-up courses
- Report and discuss the work.

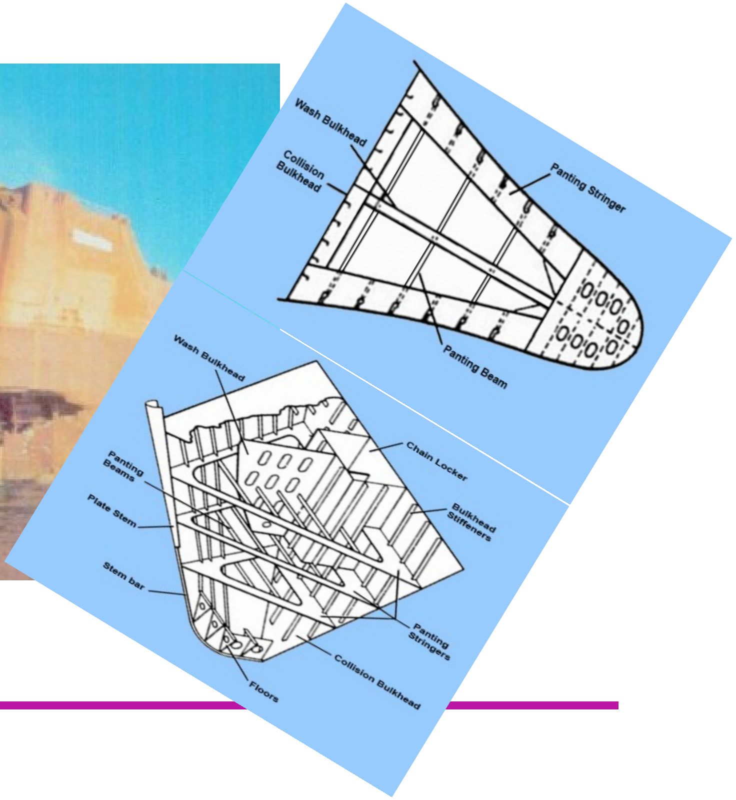
Local Loads

- Local wave / fluid induced loads act usually over small area of the vessel. These loads are usually absorbed by the local structure.

- **Panting** is an in/out motion of the plating in way of the bow of the ship caused by unequal water pressure as the bow passes through successive waves. It is greater on fine bow ships. Fore peak tanks are designed to resist it.



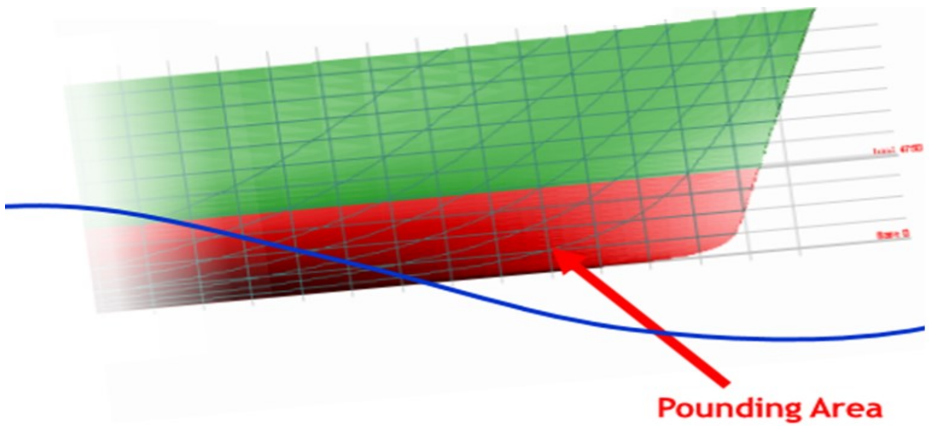


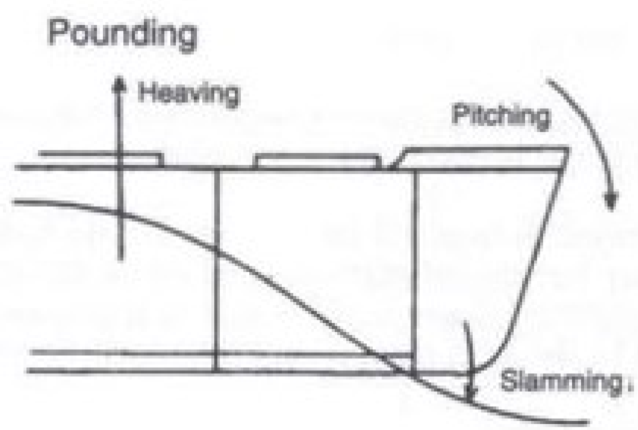


Local Loads – *Pounding leading to bow slamming*

- As a ship moves through the water fluid actions (i.e. hydrodynamic forces) push in and out in a cyclic fashion in way of the waterline / bow area of the vessel. As the ship moves trough the water especially in large head seas the bow tends to lift clear of the water. As it drops back to the sea the vessel slams at the forefoot. **The phenomenon in known as pounding or bow slamming.**

- The phenomenon is linked up with heavy pitching assisted by heaving as the whole ship is lifted in a seaway. Based on in service experience it is believed that that greatest effect is experienced in the lightship condition. To compensate for this the bottom over 30% fwd of the ship strengthened for ships exceeding 65m in length when min draft is less than 0.045L(OA) in any operating condition.



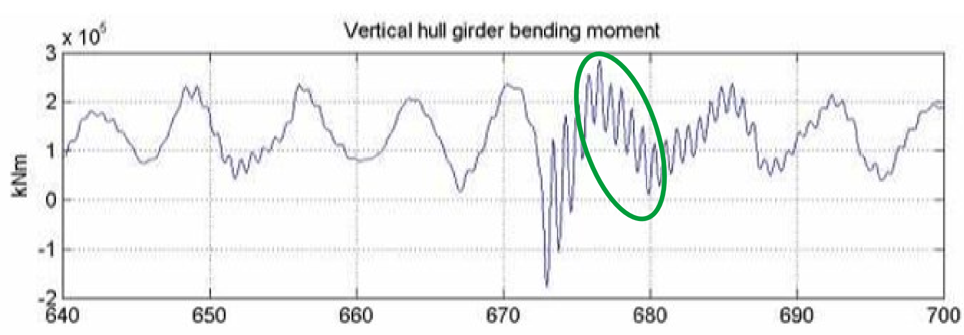


Local Loads – *Slamming leading to Whipping*

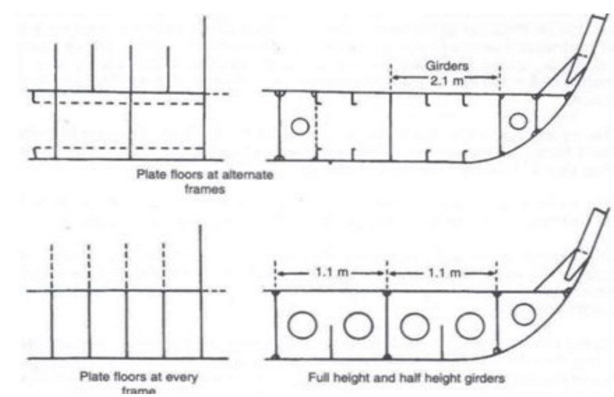
- Whipping is usually defined as a transient hydroelastic ship structural response due to impulsive loading such as slamming, green water, underwater explosion, etc. **Slamming induced whipping** is observed both in experiments and in full scale measurements for any kind of ships as far as they encounter heavy seas in which the slamming type of loading is likely to occur.

- The figure below represents the time evolution of the VBM, following severe slamming event, at the midship of a small (Lpp = 124m) general cargo/container vessel.

- The whipping contribution to the overall vertical bending moment is important but it also lasts for a relatively long time due to the low structural damping. One slam event increases multiple extremes in the bending moment which makes the whipping phenomena to be relevant both for extreme and fatigue loading of the ship structure.

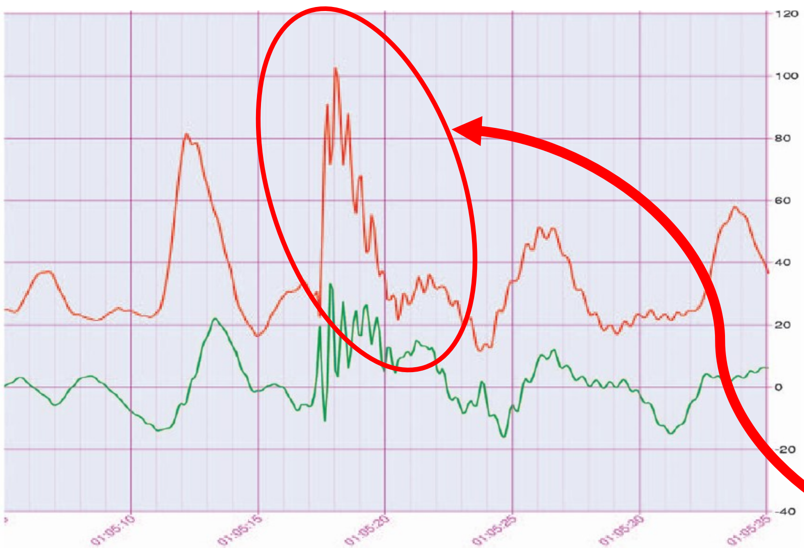


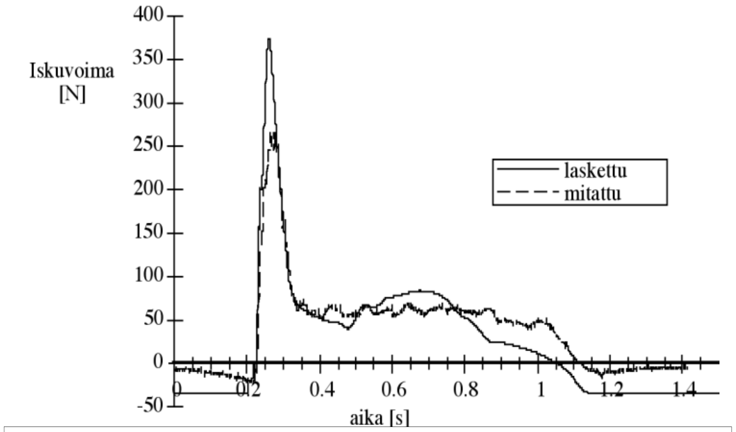
Typical whipping event

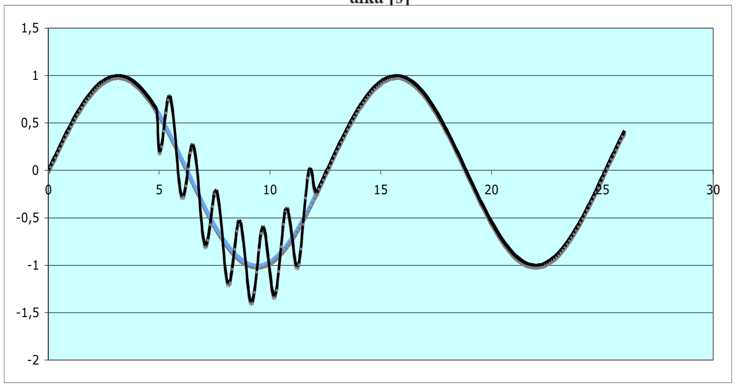


Whipping – Wave VBM + Impact response

- Whipping is caused by impact type loading due to harsh weather conditions
- The key issue is the ***relative motion*** **and** ***speed*** between the ship and waves
- The impact load causes transient vibrations on the ship, which is called whipping (compare to springing)







Time evolution of the stresses following severe slamming event

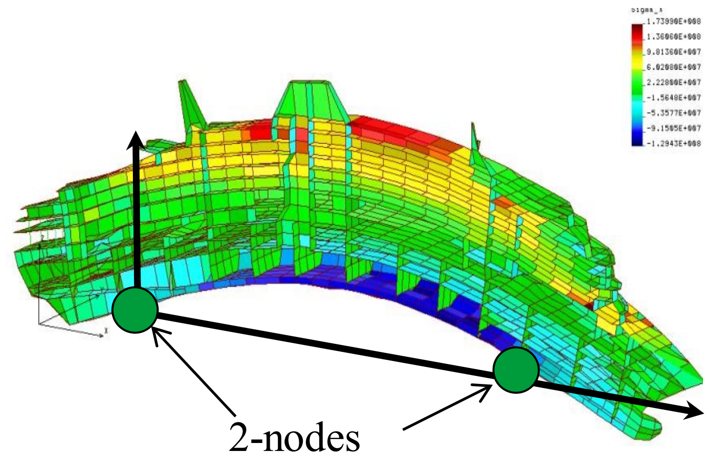
Can we sperate springing from whipping?

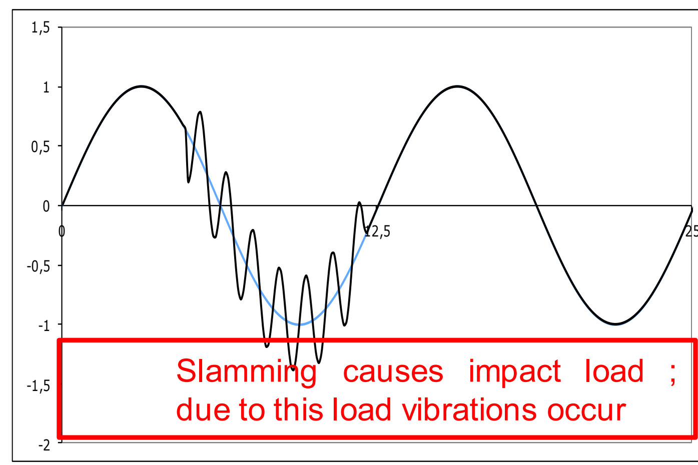
- If wave encounter frequency = frequency of hull girder we experience **springing.** The phenomenon is more evident in ships with low natural frequency (i.e. low stiffness /mass ratio).

- Springing may also contribute to the extreme response for some ships, but springing vibrations are generally more important for fatigue, up to 50%.

- When a transient load causes hull girder vibrations the phenomenon is **whipping.**

- In some wave conditions a ship may experience slamming loads for almost every wave encounter and then **these two phenomena occur at the same time**. If the damping is low, this gives rise to continuous hull girder vibrations. **This illustrates that there is not always a clear distinction between whipping and springing.**





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Whipping FFSI – a basic TD model

- Whipping is a hydroelastic phenomenon. It is idealised by 2D beam dynamics coupled with 2D (strip theory) or 3D potential flow (FD or TD) hydrodynamics. Full 3D models studying the combined influence of symmetric and antisymmetric distortions on ship dynamics do not exist. All hydroelastic theories are symmetric.

- The numerical model we use is based on coupling between 3D diffraction / radiation Hydrodynamic principles and Timoshenko beam dynamics. The modal approach presented in SD8 is followed and the equation used in the time domain is :

$$([\,\mathbf{m}\,]+[\,\mathbf{A}^{\infty}\,])\{\ddot{\xi}(t)\}+[\,\mathbf{b}\,]\{\dot{\xi}(t)\}+([\,\mathbf{k}\,]+[\,\mathbf{C}\,])\{\xi(t)\}+\int_0^t [\,\mathbf{K}(t-\tau)\,]\{\dot{\xi}(\tau)\}d\tau=\{F(t)\}+\{Q(t)\}$$

Modal mass matrix

Infinite frequency added mass matrix

Damping matrix

Structural stiffness matrix

Hydrostatic restoring matrix

Vector of modal amplitudes

Matrix of hydro memory functions

Non impulsive wave loading

Vector of impulsive loads

Matrix size $(6+N_f)\times(6+N_f)$ 6 motions + N *symmetric* distortions

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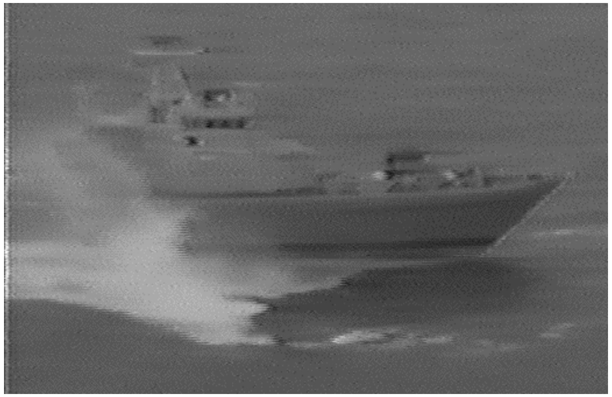
1. RED Bishop and WG Price, Hydroelasticity of Ships, Cambridge University press ISBN 9780080439211

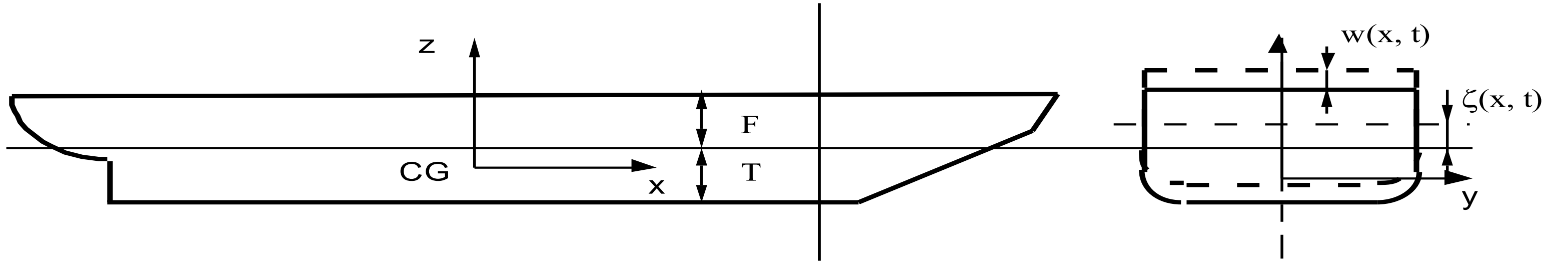
Slamming FSI (rigid body)



- Slamming is the result of large relative motion between ship and waves. It relates with displacement and speed. It may cause local damages on bottom structures and vibrations called whipping
- The relative motion is defined as difference between
  - Ship vertical motion w(x,t)
  - Wave height ζ(x,t)

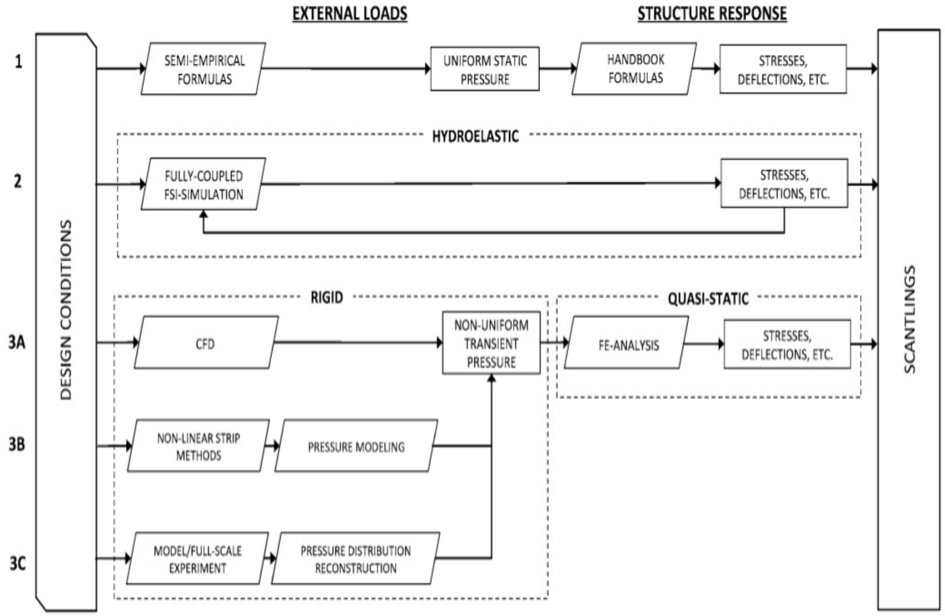
$$z(x,t) = w(x,t) - \zeta(x,t)$$

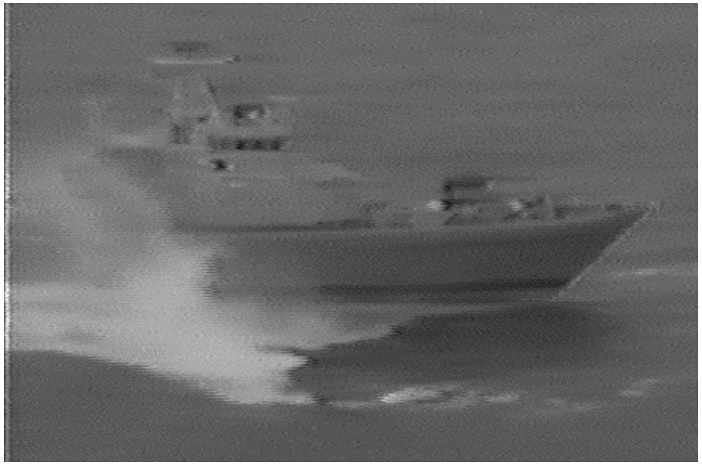
- The notation
  - z(x,t)>T, the bottom is in the air → possible slamming occurs
  - z(x,t)<-F, the deck gets submerged → shipping of green water occurs
- For slamming to conditions need to be fulfilled
  - The bow has to be in the air, z(x,t)>T
  - The vertical speed of bow or stern has to exceed certain tresshold value

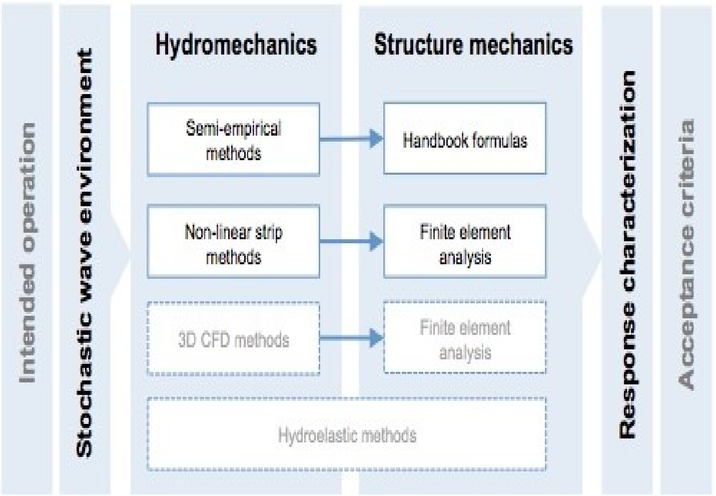


Slamming Assessment...(cont.)

- Highly coupled, nonlinear problem
- Fast process
- The structure and flow solutions can be strongly coupled (pressure distribution)
- The number of peaks must be assessed during ship operations







(cont.)...Slamming Assessment

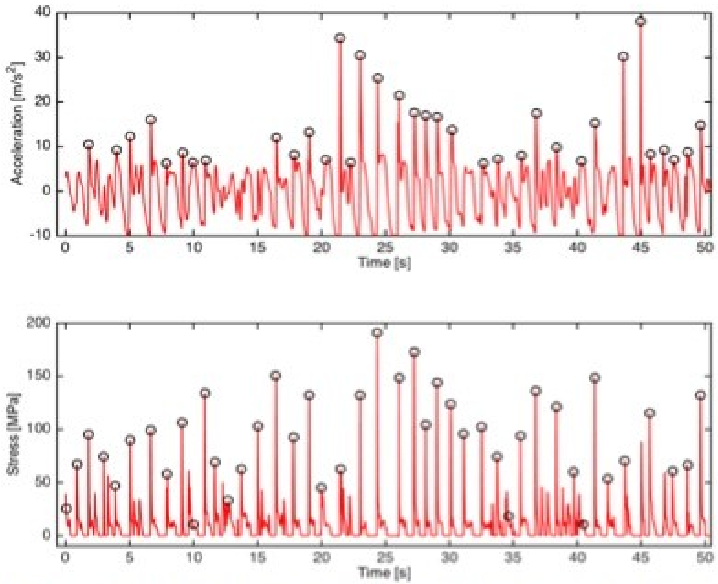
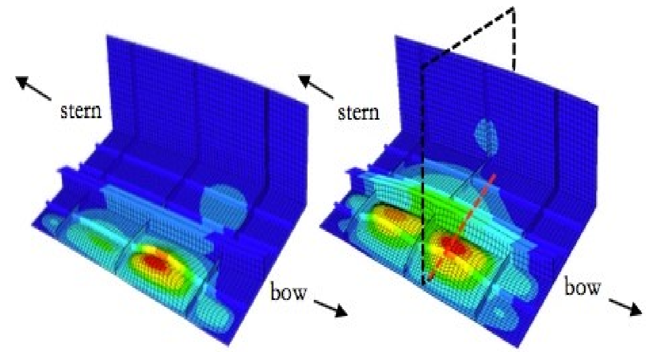
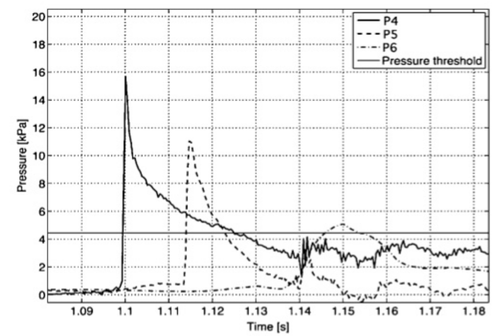
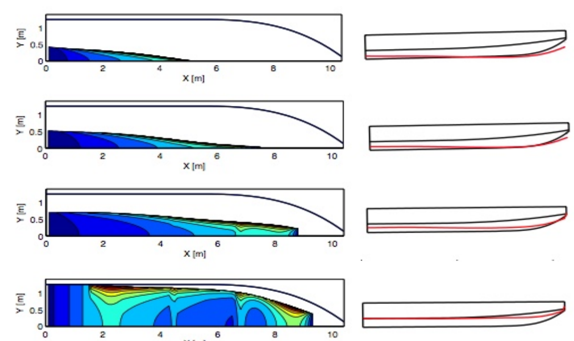


Figure 9. Illustration of the vertical acceleration at the craft center of gravity (*top*) and bending stress (*bottom*) at a single point in a hull bottom panel for the same time sequence, for a high-speed craft in irregular waves.







Slamming Pressure – Simple Model

- The slamming pressure is derived assuming that the pressure *p* is proportional to square of relative speed

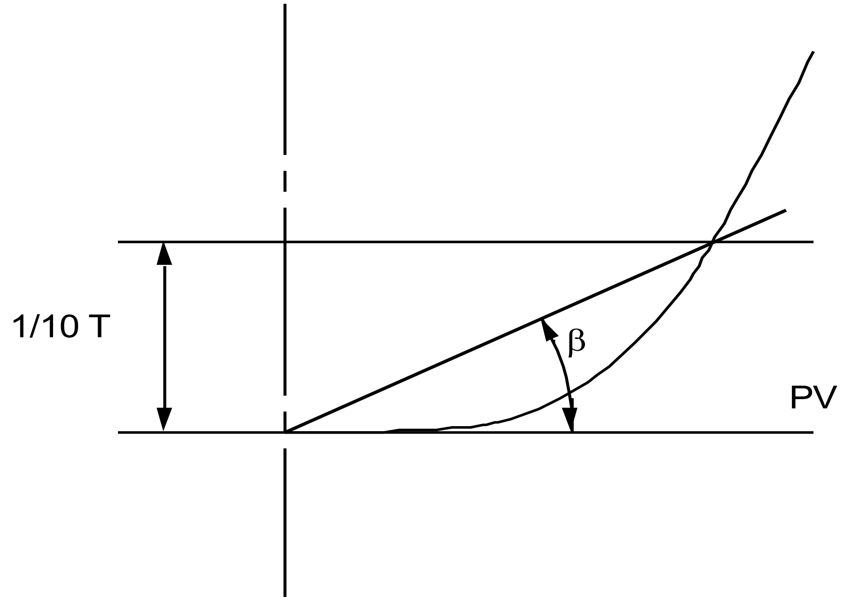
$$p = \frac{1}{2}\rho k \dot{z}^2$$

- The distribution for slamming pressure is

$$k = \frac{\pi}{\tan\beta}$$

- The ultimate value for pressure is

$$P\left(p_{slam} > p\right) = \exp\left[-\left(\frac{T^2}{R_{z}} + \frac{2p}{\rho k R_{\dot{z}}}\right)\right]$$



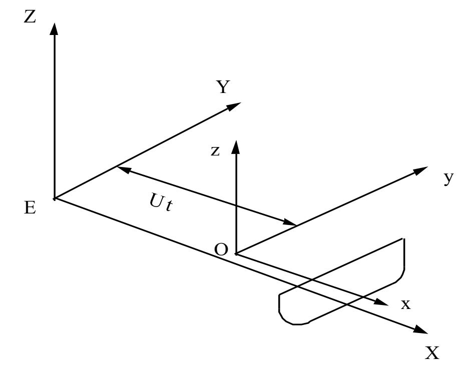
$$\hat{y}_n = \sqrt{\ln\frac{n}{\alpha}}\sqrt{R}$$

$$\hat{y}_n = \sqrt{\frac{1}{2}\rho k R_{\dot{z}} T^2 + R_{z} p}$$

$$R = \frac{1}{2}\rho k R_{z} R_{\dot{z}}.$$

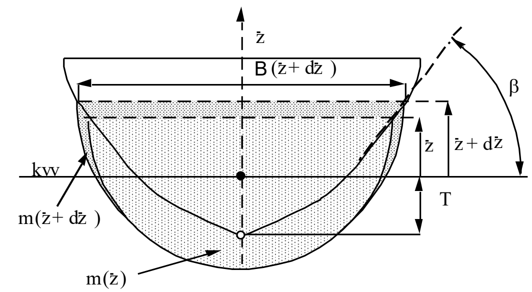
$$\hat{p}_n = \frac{1}{2}\rho k R_{\dot{z}}\left(\sqrt{\ln\frac{n}{\alpha}} - \frac{T^2}{R_{z}}\right)$$

Total Time Derivative & Forces



- E (X, Y, Z) is fixed ground coordinate system ; O (x,y,z) is moving coordinate system
- $X_E = U\,t + x$
- where U is ship speed defined as : $\dfrac{dx}{dt} = -U$
- Total time derivative $\dfrac{D}{dt} = \dfrac{\partial}{\partial t} + \dfrac{\partial}{\partial x}\dfrac{dx}{dt} = \dfrac{\partial}{\partial t} - U\dfrac{\partial}{\partial x}.$
- Inertia component

$$F_I = \frac{D}{dt}(m\dot{z}) = \frac{\partial}{\partial t}(m\dot{z}) + \frac{\partial}{\partial x}(m\dot{z})\frac{dx}{dt} = m\ddot{z} + \dot{z}\frac{\partial m}{\partial t} - U\dot{z}\frac{\partial m}{\partial x},$$



- Buoyancy $F_\nabla = \rho g(T + \bar{z})B(\bar{z}).$

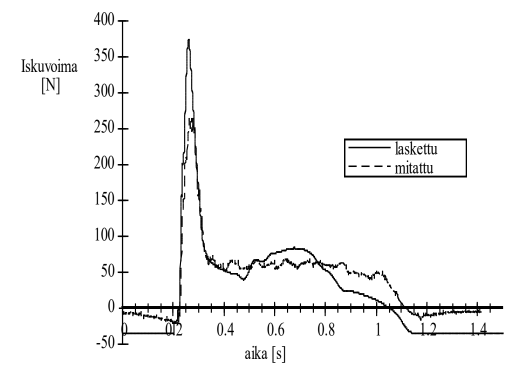
- The total force $F = F_I + F_\nabla$

since $\dot{z}\dfrac{\partial m}{\partial t} = \dot{z}\dfrac{\partial z}{\partial t}\dfrac{\partial m}{\partial z} = \dot{z}^2\dfrac{\partial m}{\partial z}$, we obtain

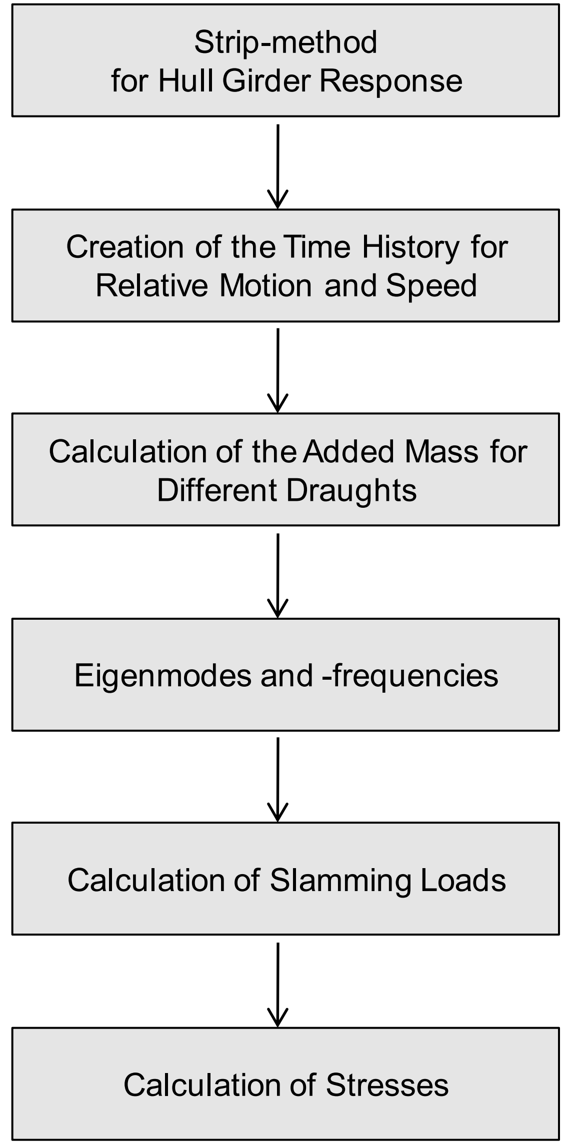
$$F(x,t) = \begin{cases} \rho g \Delta A_r, & \dot{z} < 0 \\ \dot{z}^2\dfrac{\partial m}{\partial z} + \rho g \Delta A_r, & \dot{z} > 0 \end{cases}$$

$\dot{z} < 0$: Bow separates from water (emmersing)

$\dot{z} > 0$: Bow enters water (immersing)



The influence of Bow Shape

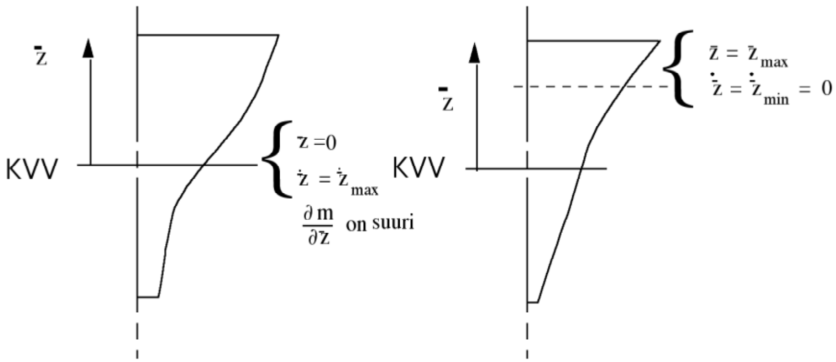


Bad design

huono kaaren muoto

Good design

hyvä kaaren muoto



The total response is obtained by summing the impact and normal wave bending responses

$$y(x, t) = \sum_{i=1}^{N} \phi_i(x)\, p_i(t) + \sum_{k=1}^{M} a_k [|H_h|(\omega_k) - x\, |H_\theta|(\omega_k)] \sin(\omega_k t + \alpha_k)$$

M is the number of regular waves, a_k is the amplitude of wave component and H_h and H_q are the response functions of heave and pitch

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Example – The Rauma Class

L_{OA}= 48.0 m
B = 8.00 m
Displacement 215 tons
T = about 2 m
v = 30+ knots.

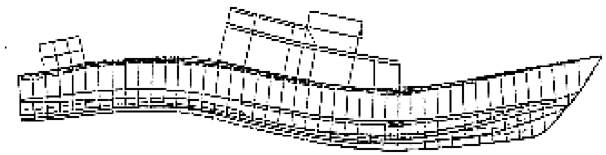
- Usually beam model is sufficient for whipping calculations since we need only the hull girder bending modes (s_1-level)

- In present case 3D-FEM was used since
  - Significant influence of superstructure
  - Discontinuities
  - Bulkheads

- The mass of water was included (added mass) by FEM analysis (infinite and finite size)

- Only the most significant modes are presented
  - The modes with large displacements at bow are important since then the force works (W=F*u)
  - Two first modes are beam modes while the 5th mode includes also the superstructure deformations

I ominaismuoto



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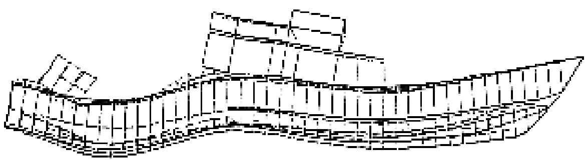

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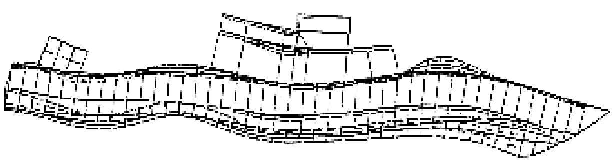
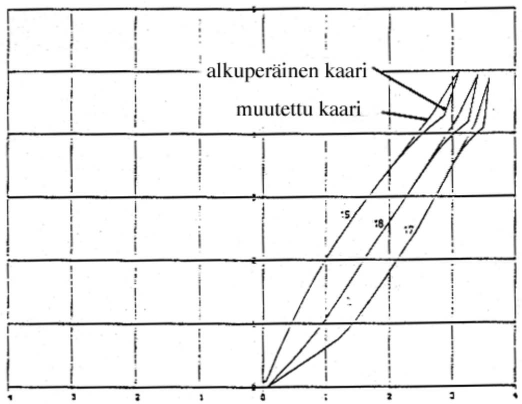
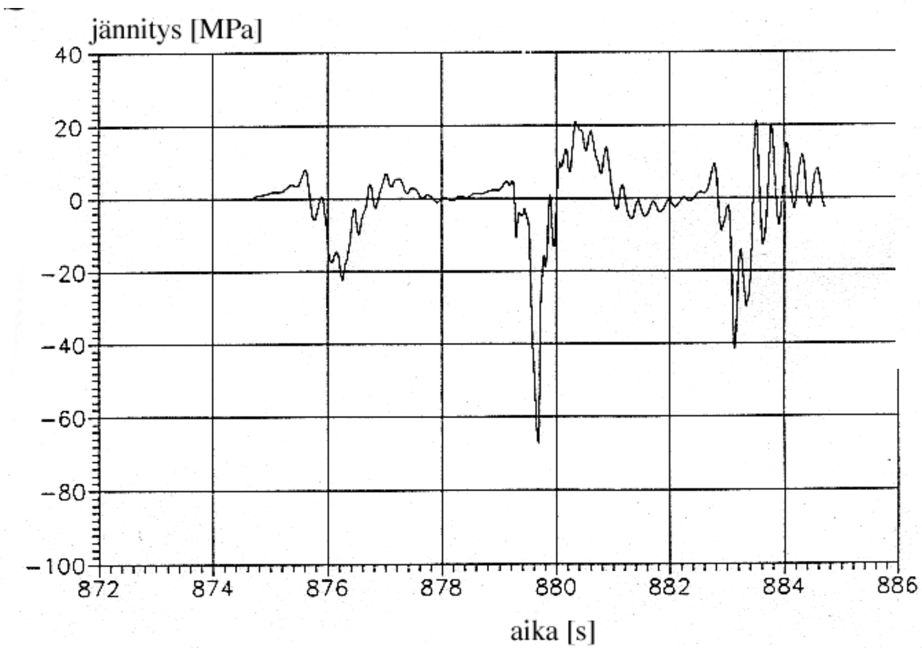


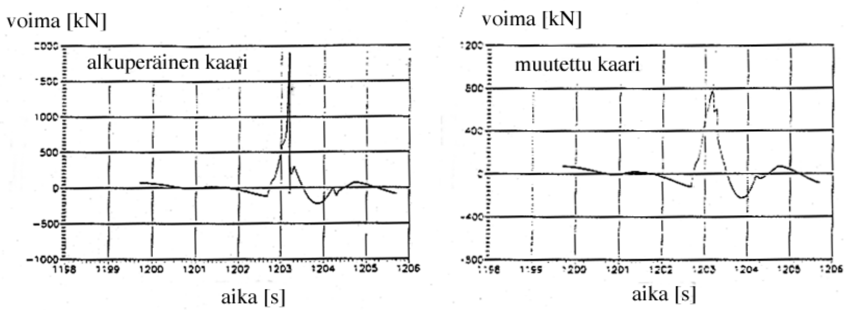
V ominaismuoto

Whipping-Analysis

- Changes in bow halved the load
- Normal stress presented in the figure below shows significant increase in the sagging moment

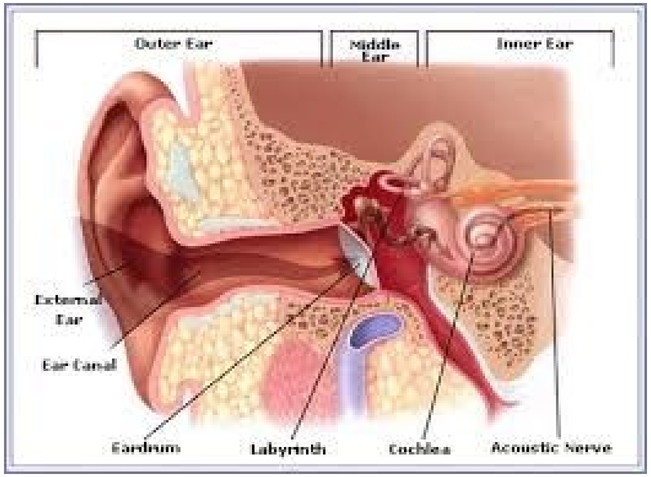






Motion Sickness - Introduction

- Balance organs are located in the inner ear and can detect both magnitude and direction of gravity and motion effects.
- Excessive stimulation of this organ may lead to motion sickness
- The organ is linked to signals coming from the eye
  - Motion sickness can be caused without movement
  - Blocking signal from eyes can cause motion sickness
- Seeing the horizon helps to reduce motion sickness as the “conflicting signals” will be in agreement (rigid body motion)
- Anxiety, hunger, fatigue and smells can promote motion sickness
- Motion sickness decreases in couple of days typically (adaptivity)



Measures of Ship Performance - MSI

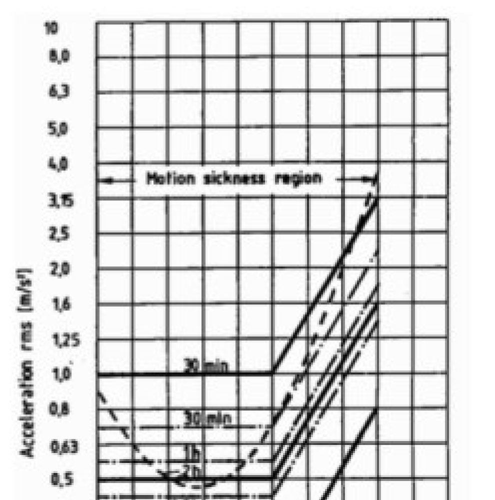
- **Motion Sickness Incidence (MSI).** Experience shows that the principal cause of sea sickness appears to be a result of vertical accelerations. Experiments carried out in the 70s with 300 male volunteers in the USA positioned in a cabin subject to sinusoidal vertical motion with amplitude up to 3.5 m. MSI has been defined as the percentage of participants who vomited in the first 2 hrs of the experiment. The MSI was expressed in the form

$$MSI = 100\left[0.5 + erf\left(\frac{\log_{10}(\ddot{w}/g) - \mu}{0.4}\right)\right]$$

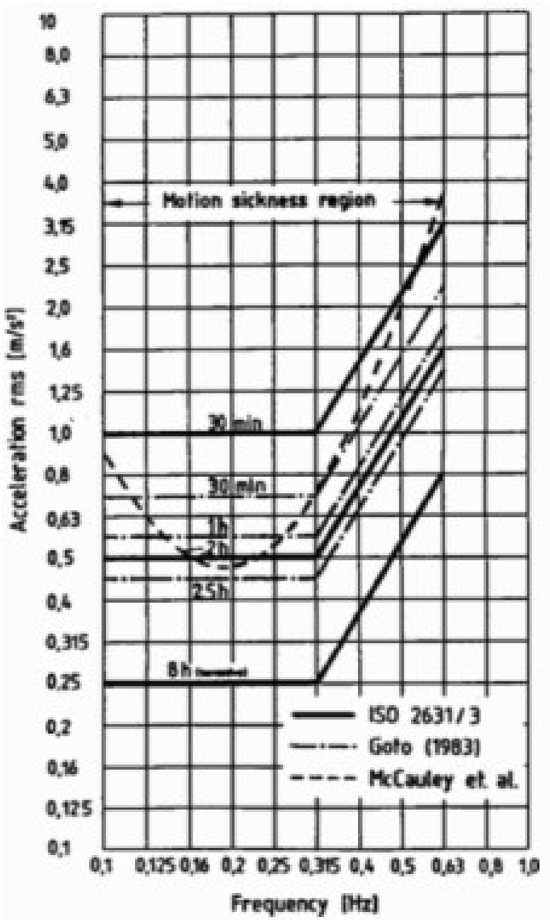
- Hypothesis is that the vertical acceleration causes the motion sickness
  - Other motion components are typically very small in ships to cause this
  - Location on ship affects this as the rotations will add to the vertical accelerations through rigid body motions – worst place bow and stern

- The error function is expressed as $erf(x) = \frac{1}{\sqrt{2\pi}}\int_0^x \exp(-0.5z^2)\, dz$

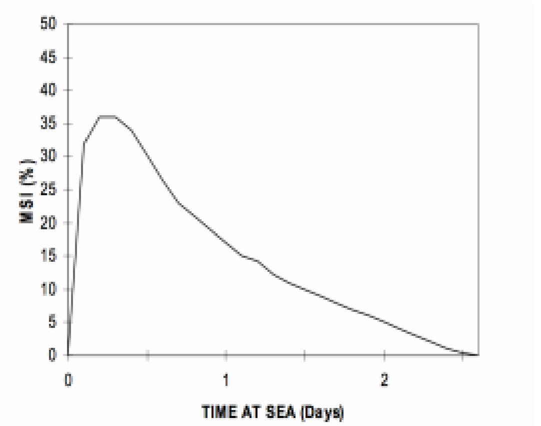
- The method assumes that ship accelerations are expressed as gauss acceleration is $\ddot{w} = 0.798\sqrt{m_{\ddot{w}}}$ in (ms^{-2}), where $\sqrt{m_{\ddot{w}}}$ is the RMS valu



Measures of Ship Performance - MSI



MSI criteria from ISO, Goto and McCauley (NORDFORSK 1987)



Adaptation to MSI for time spent at sea (Pattison and Sheridan 2004)

Measures of Ship Performance - SM

Subjective Magnitude **(SM)**. In mid 70s a number of pilots were subjected to an experiment of sinusoidal vertical motions using a chair capable of amplitudes up to 1.5m. The objective of the experiment was to quantify the influence of motions on their ability to work effectively. A reference motion at 1 Hz with acceleration of 0.6g was assigned an SM (10).A motion judged to be twice as severe was assigned SM (20), half as severe SM (5) etc. The data obtained were expressed in the form

$$SM = A\left(\frac{\ddot{w}}{g}\right)^{1.43}$$

The acceleration amplitude can be taken $A=[\,75.6 - 49.61\log_e(\omega_e) + 13.5\,\{\log_e(\omega_e)\}^2]\,[1-\exp(-1.65\,\omega_e^2)]$.

Practically speaking the acceleration amplitude can be taken as half of the significant acceleration namely $\ddot{w}=2\sqrt{m_{\ddot{w}}}$, where $m_{\ddot{w}}$ is the mean square of the vertical acceleration. Using this assumption a plot of SM against RMS acceleration can be generated and the subjective regions are :

- Moderate **SM (5)**
- Serious **SM (10)**
- Severe **SM (15)**
- Hazardous **SM(20)**
- Intolerable **SM(30)**

Measures of Ship Performance - MII

Motion Induced Interruption **(MII)**. This is a reasonably adequate parameter for judging the severity of motion for passengers derived form research carried out in 80s and 90s. However, it is not very relevant to the ability of crew to function effectively. It is based on the frequency that a member of the crew has to stop work and hold on to a suitable anchorage to prevent loss of balance due to sliding or tipping *e.g. roughly SM(10). The no of MIIs per minute can be expressed as

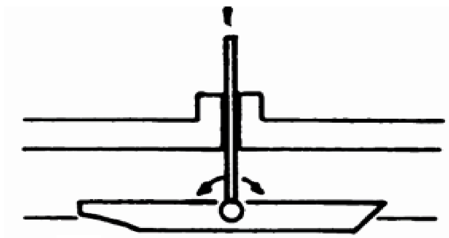
$$MII = \frac{60}{T_z} \exp\left[-\frac{(\nu\, g)^2}{2\, m_{\ddot{\alpha}}} \right] \quad (\text{min})^{-1}$$

where *Tz* is the average zero crossing period of the seaway and *Mxx* is the MS value of the total acceleration including both lateral and vertical accelerations. The later are evaluated at the right or left foot of the crew member depending on whether there is siding or tripping to port or starboard. The MIIs to port and starboard are added together.

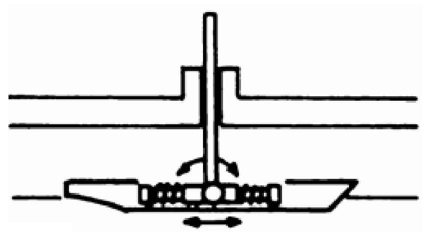
The afore mentioned equation is valid for either sliding where *v* is the friction coefficient between the deck floor and the crew $m_{\ddot{w}}$ is the RMS value of the total acceleration. The equation is valid for sliding or tripping and $\nu = l/h$ (h is the distance from deck floor to crew members COG and *l* is half stance distance)

Seakeeping tests – Free models classification

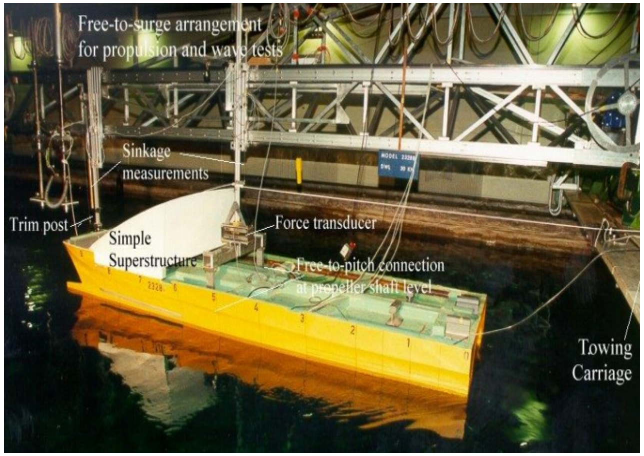
- Seakeeping tests are carried out to reveal possible seakeeping problems with a new design, to determine operational limits, optimise and validate the design, to validate R&D, measure design loads , understand capsize and loading effect sequences, carry out safety studies or to develop and test damping systems.

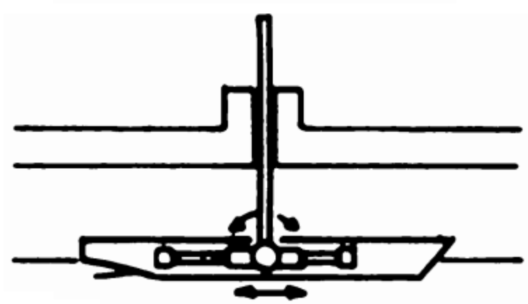


Free to heave and pitch (unpowered model)



Free to surge, heave and pitch (unpowered model restrained by springs)

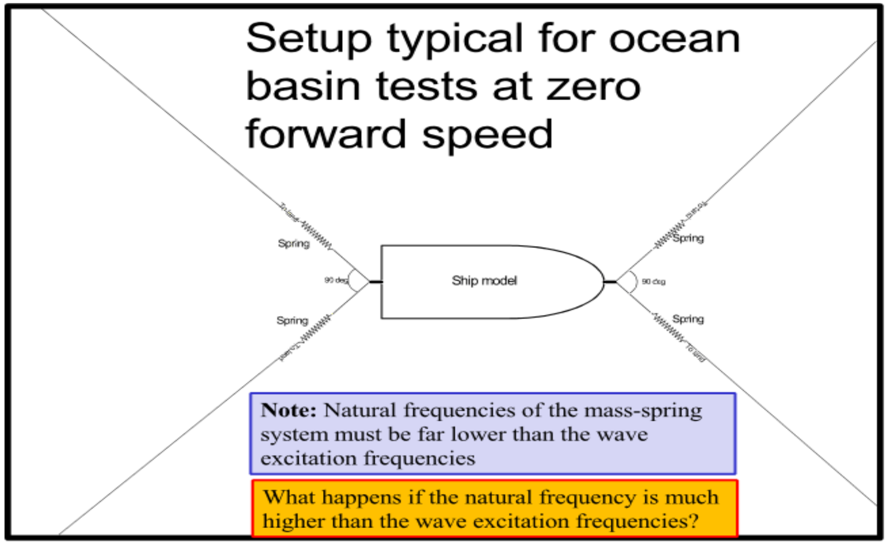


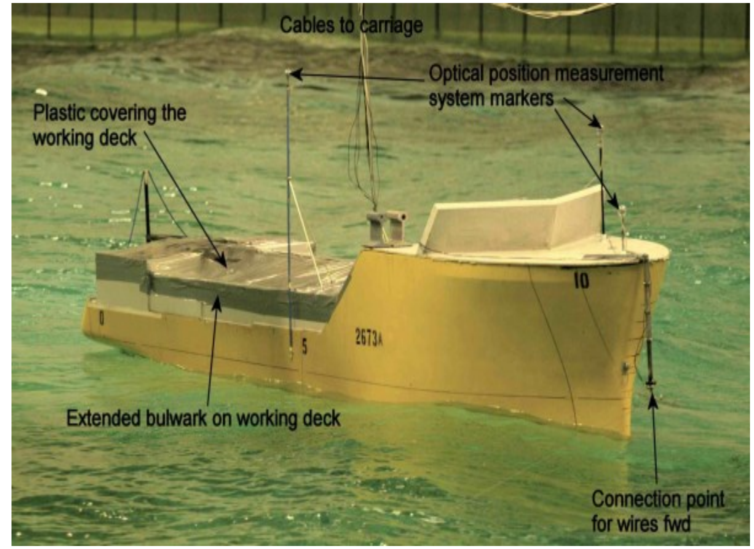


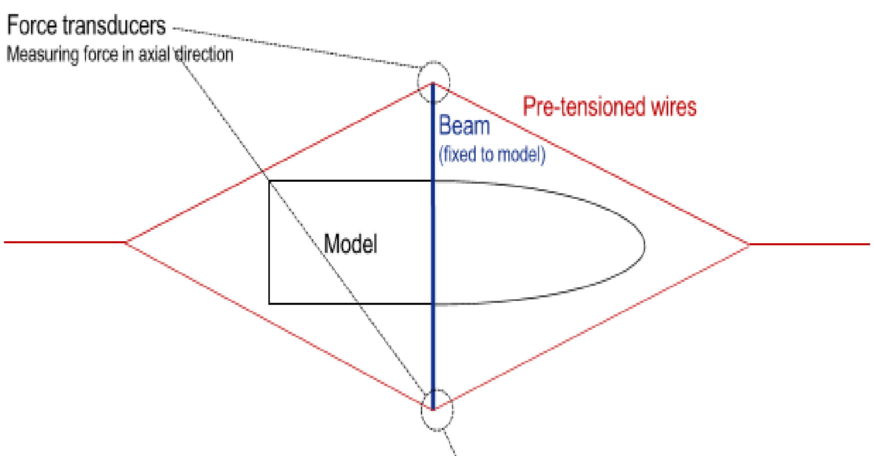
Free to surge, heave and pitch (powered model)

A free model is a model that is free to heave, pitch and possibly surge. In some occasions we allow for the model to have restricted horizontal motions. In other occasions the model may be completely free

Seakeeping tests – Restricted Horizontal motions

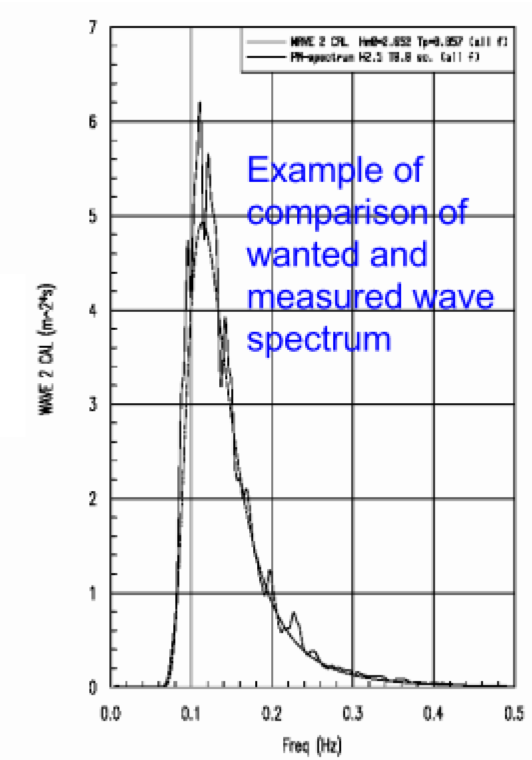


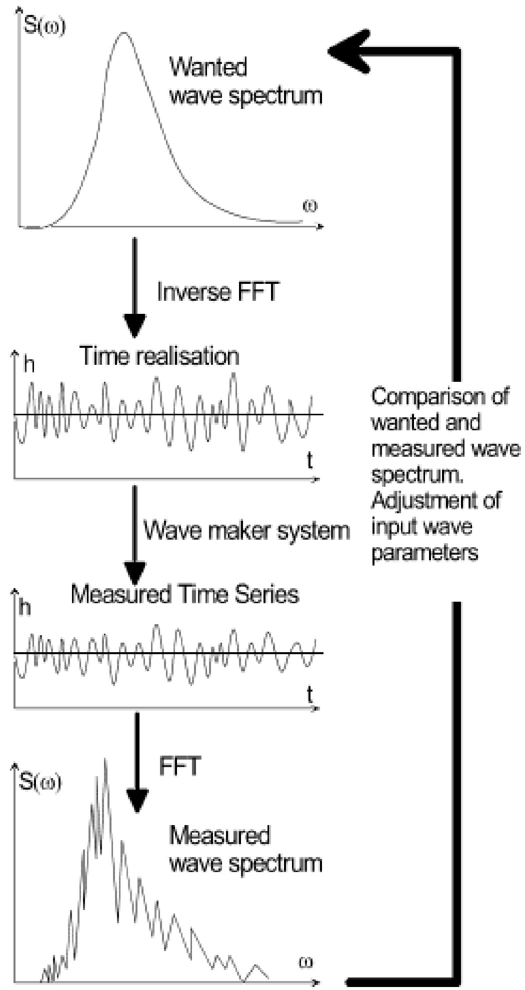




Model suspended in a system of thin wires and springs. Seakeeping tests at all headings, with or without fwd speed in a towing tank or seakeeping basin. We can measure motions, loads accelerations drift forces etc. etc.

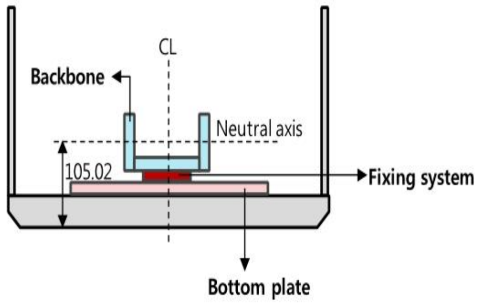
Seakeeping tests – hydroelastic models

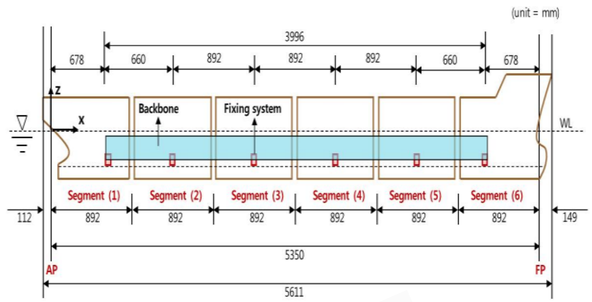


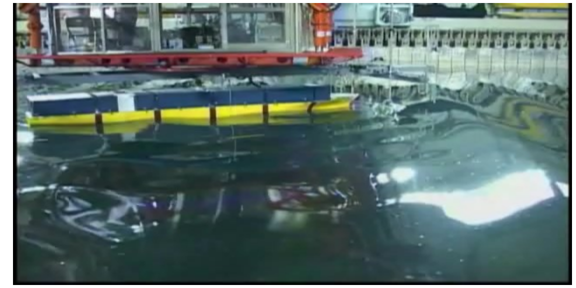


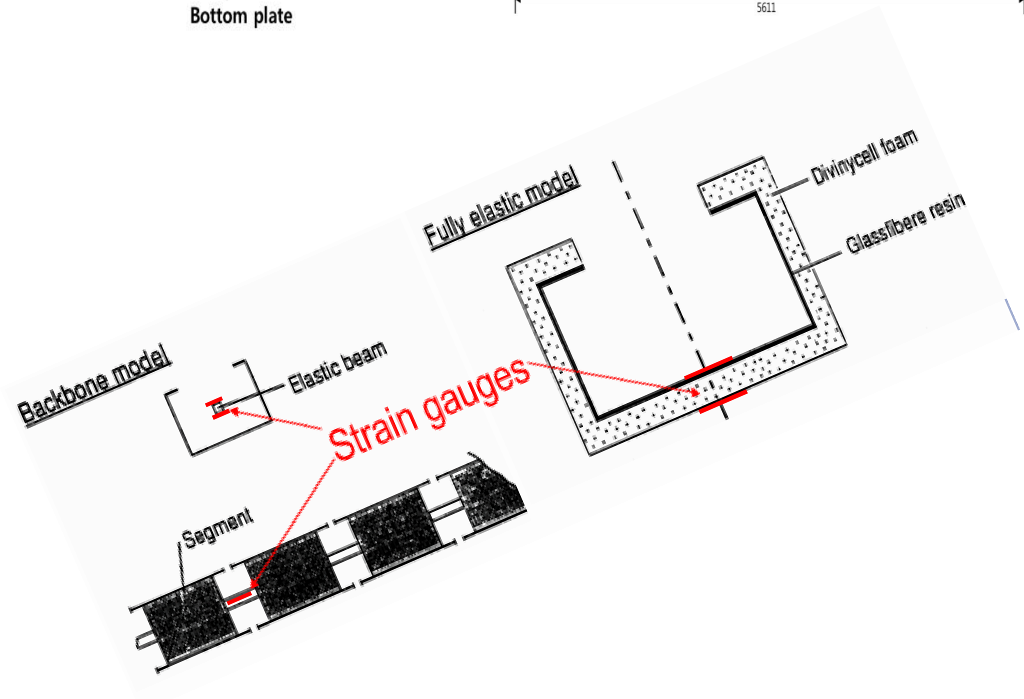
The model must be self propelled with an active rudder and steering system And an autopilot. Battery power may be used and some cabling will be necessary.

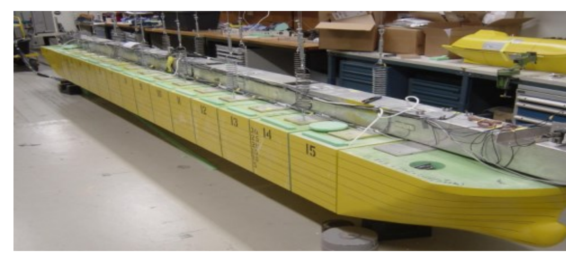
Seakeeping tests – Hydroelastic models (segmented)











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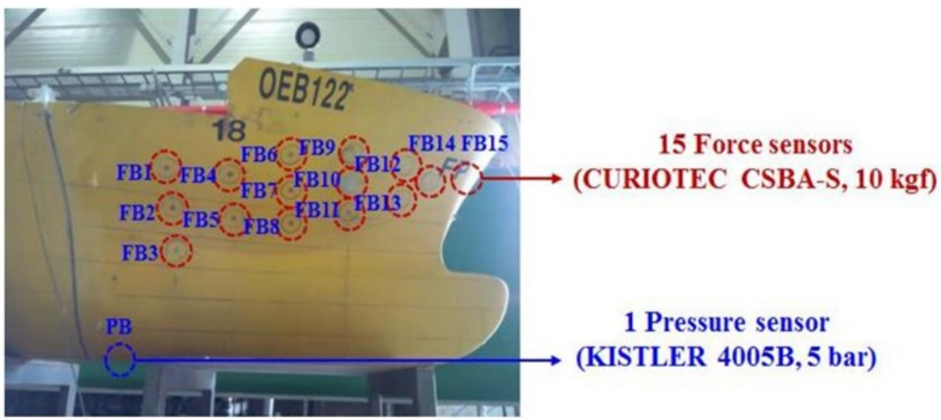
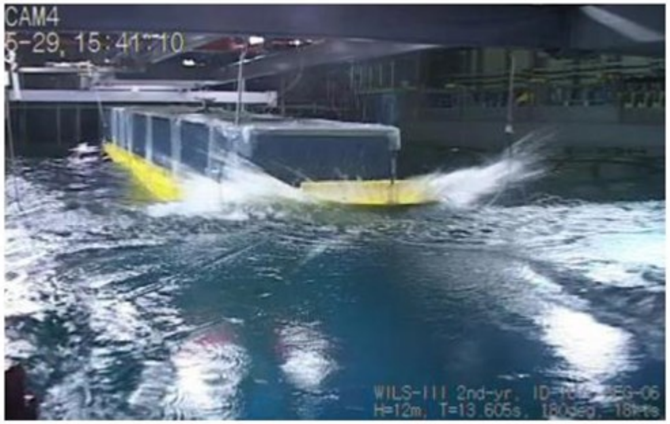
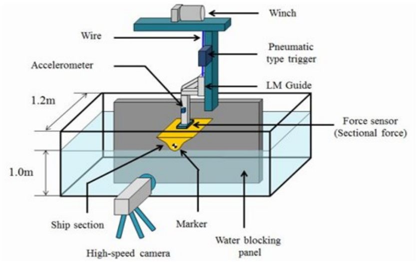
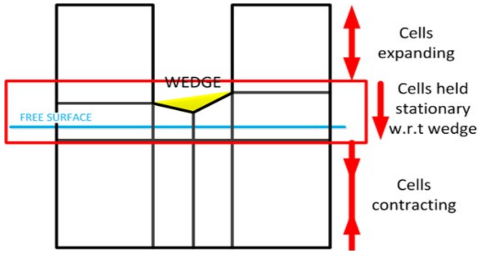
Lee, Y., Nigel White, N., Wang, Z., Hirdaris, S.E. and Zhang, S. Comparison of springing and whipping responses of model tests with predicted nonlinear hydroelastic analyses. The International Journal of Offshore and Polar Engineering (IJOPE), 22(3), pp. 1-8.

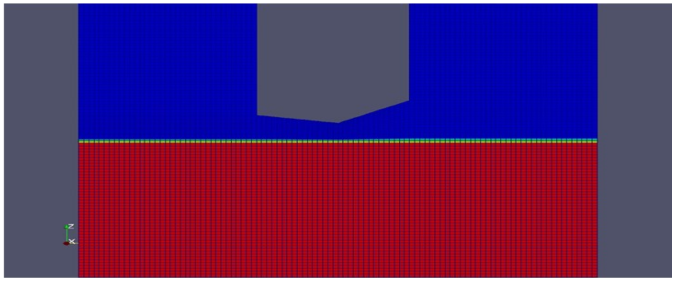
Seakeeping tests – slamming tests

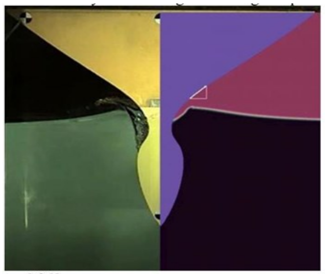




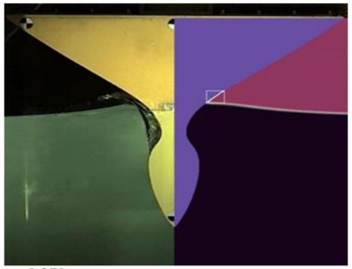




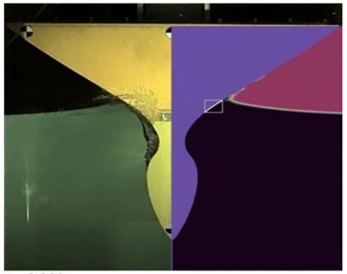




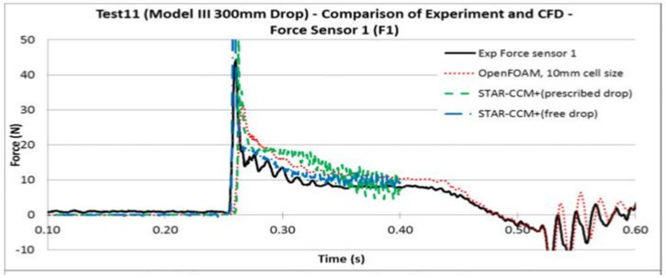
t = 0.260s



t = 0.270s



t = 0.280s



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Southall, N.R., Choi, S., Lee, Y., Hong, C., Hirdaris, S.E., White, N. Impact analysis using CFD – A comparative study, Proceedings of the 25th International Ocean and Polar Engineering Conference (ISOPE '15), 21-26 June 2015, Hawaii, USA.

Shipping operations – the relevance of seakeeping

- Motions can harm people's operations at sea
  - ➢ Instead of working people have to hang on
  - ➢ Moving around can become almost impossible
  - ➢ Sleeping gets difficult causing fatigue

- Normal operations may require better than normal hand-eye-coordination

- Excessive motions may cause landing of helicopter or airplane on the ship very challenging
  - ➢ Relative velocity between helicopter and flight deck might get too high
  - ➢ Touch down can happen unequally between different landing devices

- Green water on deck may cause pressure on the deck that
  - ➢ Damages the structures and equipment (e.g. glass in forepart)
  - ➢ Cause deck to be extremely slippery making operations very difficult

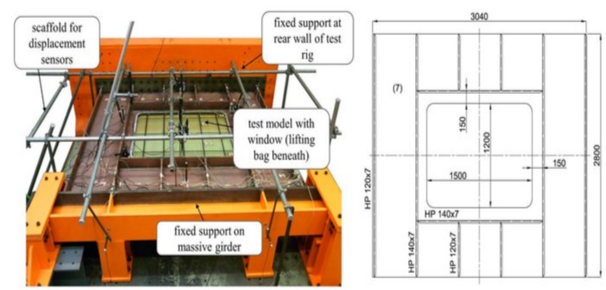


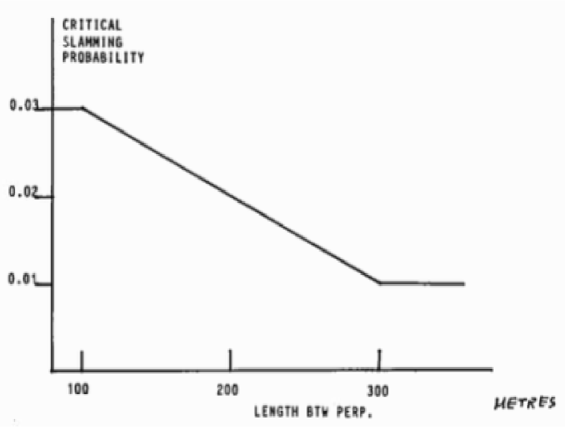
Figure 1: Model 1 mounted in the test rig (left) and steel structure of test models 1 through 3 (right)

Criteria for Voluntary Speed Loss

- The reasons to reduce the speed of the ship in rough weather are propeller emergence, slamming, ship motions, deck wetness
- Slamming and deck wetness can damage the bottom and side plating in case of slamming or the forecastle and superstructures in case of deck wetness
- In some cases blackout can occur due to the propeller emergence

Importance of physical location on the ship (NORDFORSK 1987)

Criterion	Hull safety	Equip. operat.	Cargo safety	Personnel safety and efficiency
Slamming	∅			
Deck wetness	∅			
Roll		∅	∅	∅
Vert. acceleration, FP	∅		∅	
Vert. acceleration, bridge		∅		∅
Lateral acceleration, bridge		∅	∅	∅



Critical slamming probability criteria (NORDFORSK 1987)

Operational Effectiveness

- Seakeeping is often relative issue
  - Two similar ships might be very close in terms of economics etc.
  - Seakeeping characteristics might be also some what similar
- However one is still better in terms of operations than the other
  - Less delays
  - More passengers without motion sickness
- We need to know for this the operation conditions and environment
- The operational effectiveness can be calculated analogously to the long term load on a ship, i.e. by looking at the successful missions over longer period

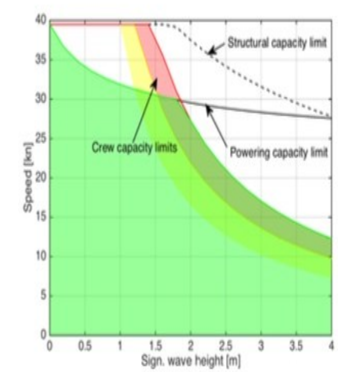


Figure 18. Illustration of operational restrictions due to powering, structure and crew capacities for a 22-meter high-speed rescue craft.

Summary

- Motion sickness and excessive motions that prevent normal operations on-board can be limiting factors for ship design

- Slamming, deck wetness, whipping etc. are phenomena associated with local loading and should be considered within the context of hydrodynamics for ship safety

- Model tests are necessary for design development, validation and R&D

- Limiting criteria for ship operations can be
  - Deck wetness
  - Propeller emergence
  - Slamming
  - Excessive motions that harm equipment or ship operations

- Often seakeeping is relative issue where we compare two similar designs – in operational effectiveness there is analogy to long term load analysis. Good design has less interruptions due to exceeded criteria.