MARSTRUCT

Analysis and Design of Marine Structures

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AN OVERVIEW OF SHIP HYDROELASTICITY

Ivo Senjanović, Nikola Vladimir

University of Zagreb,
Faculty of Mechanical Engineering
and Naval Architecture
Croatia

Šime Malenica

Bureau Veritas, Research Department
Paris, France

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Introduction

➢ HYDROELASTICITY

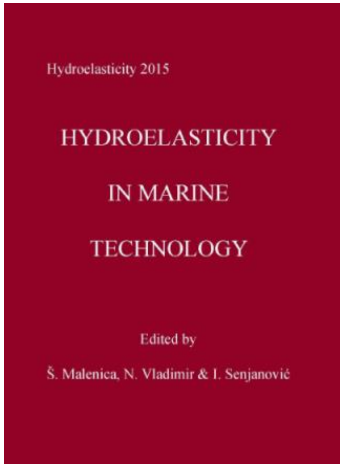
- ✓ *A branch of science concerned with the motion and distortion of deformable bodies responding to environmental excitations in the sea* (Chen et al., 2006).
- ✓ *A discipline concerned with phenomena involving interaction between inertial, hydrodynamic and elastic forces* (Heller and Abramson, 1959).
- ✓ According to Heller and Abramson (1959): *the naval counterpart to aeroelasticity - the fluid pressure acting on the structure modifies its dynamic state and, in return, the motion and distortion of the structure disturb the pressure field around it*.
- ✓ ***Hydroelasticity of Ships*** was brought to the attention of the Naval Architecture community in the 1970s through the work of Bishop and Price, culminating with the publication of the synonymous book in 1979.

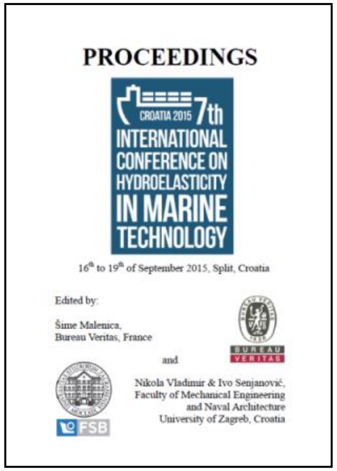
➢ Comprehensive reviews of advances in ship hydroelasticity

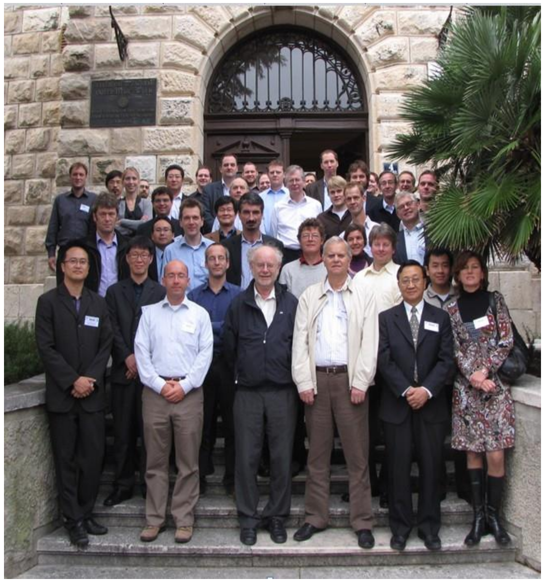
- ✓ Jensen and Madsen (1977), Wu (1987, 1994), Suo and Guo (1996), Kashiwagi (2000), Chen et al. (2006), Hirdaris and Temarel (2009)...
- ✓ ISSC reports regularly review advances in numerical approaches, model tests and full-scale measurements with hydroelastic effects included.

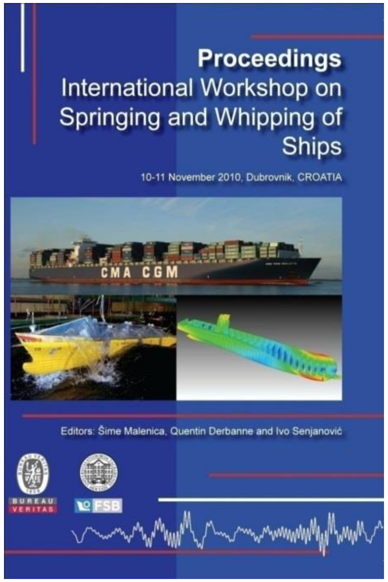
Specialized events dedicated to ship hydroelasticity

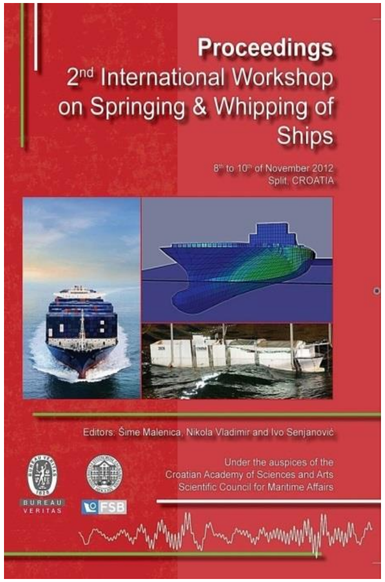
➢ Conferences, workshops...





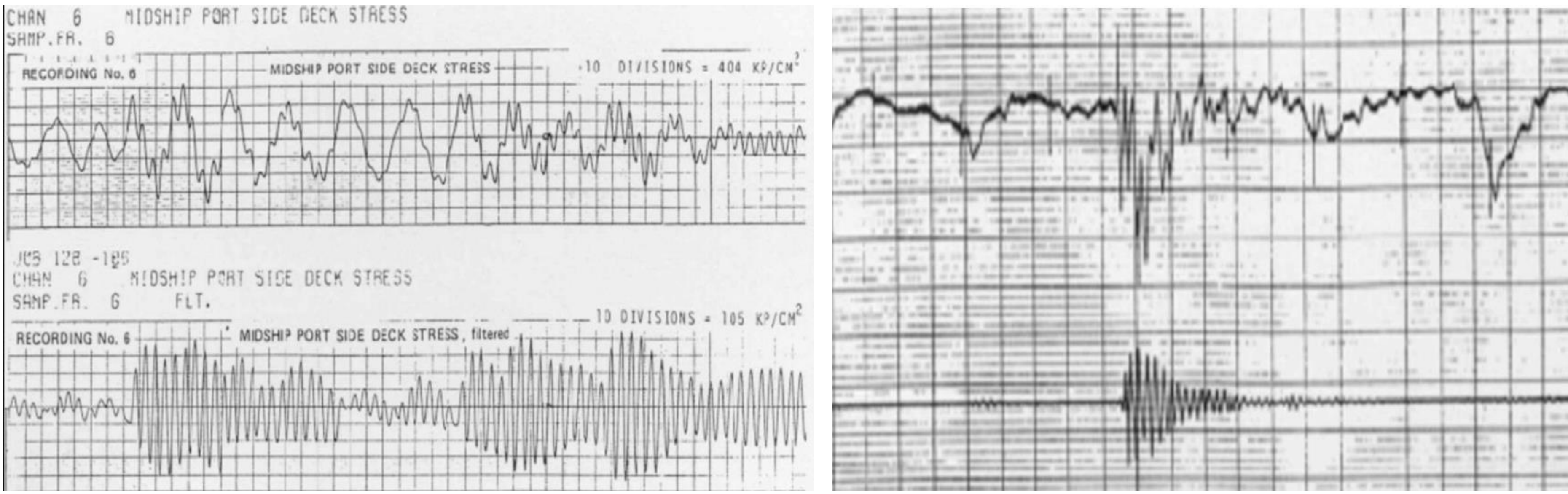






SPRINGING & WHIPPING

- Springing is usually defined as the continuous global ship structural vibrations induced by water waves. Springing is a resonant phenomenon in contrast to the whipping which is the transient ship vibrational response induced by impulsive loading (slamming, green water, underwater explosion,...).



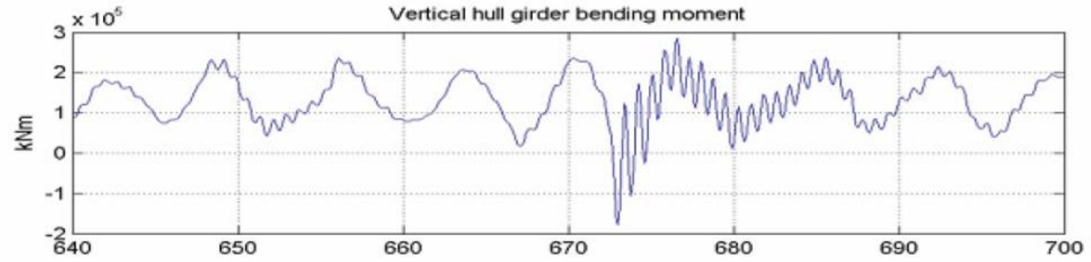
Typical springing (left) and whipping (right) ship structural response;
Top - total signal, bottom - filtered signal (Malenica et al., 2008)

Background

- **Existing rules of Classification societies cover only limited size and types of structures**
  - ✓ Mainly quasi-static approach
  - ✓ High frequency hydroelastic contribution either neglected either included empirically

S \ H	Linear	Weakly nonlinear	Impulsive nonlinear
Quasi static	X	X	X
Dynamic	X	X	X

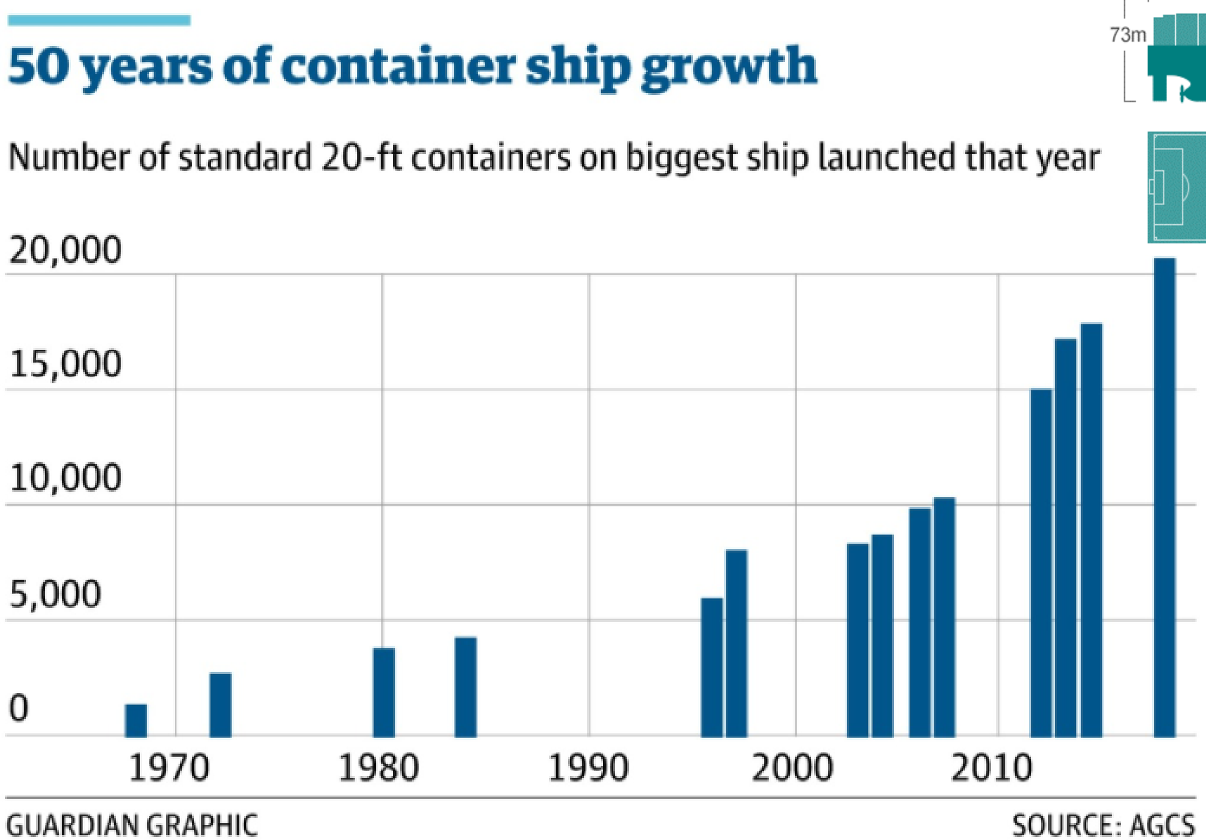
- **Methodology for inclusion of hydroelastic effects still "open"**
  - ✓ Reliability of different hydroelastic models
  - ✓ Realistic operational profile
  - ✓ Statistical post-processing
    - *Extreme*
    - *Fatigue*

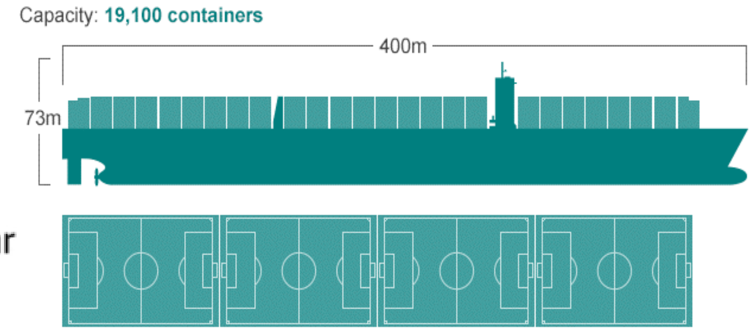


- **Harmonization of rules and direct calculation approaches**
  - ✓ Design methodology within direct calculation approach should not contradict the existing rule values for existing ships!
    - *Choice of reasonable operating conditions?*
    - *Choice of representative probability levels?*

Motivation - why to investigate ship hydroelasticity?

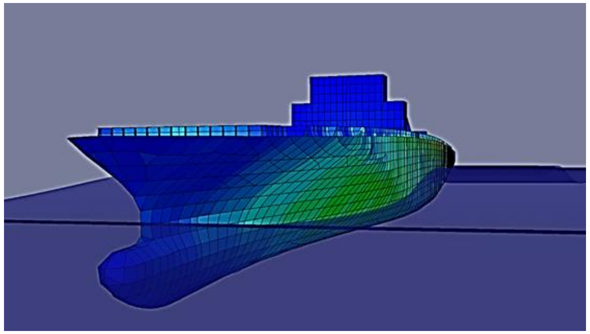
- ✓ Mainly influenced by the building of large ships – particularly container ships.
- ✓ Due to their flexibility, natural frequencies of ULCS are close to encounter frequencies. Such conditions are not covered by present CR – direct calculations mandatory.





Motivation - why to investigate ship hydroelasticity?

Research techniques


➢ Model tests

- ✓ Expensive
- ✓ Limited number of cases
- ✓ Problem of similitude (hydroelasticity, viscosity...)

➢ Numerical simulations

- ✓ Numerical modelling difficulties
- ✓ Lack of full validation
- ✓ CPU time

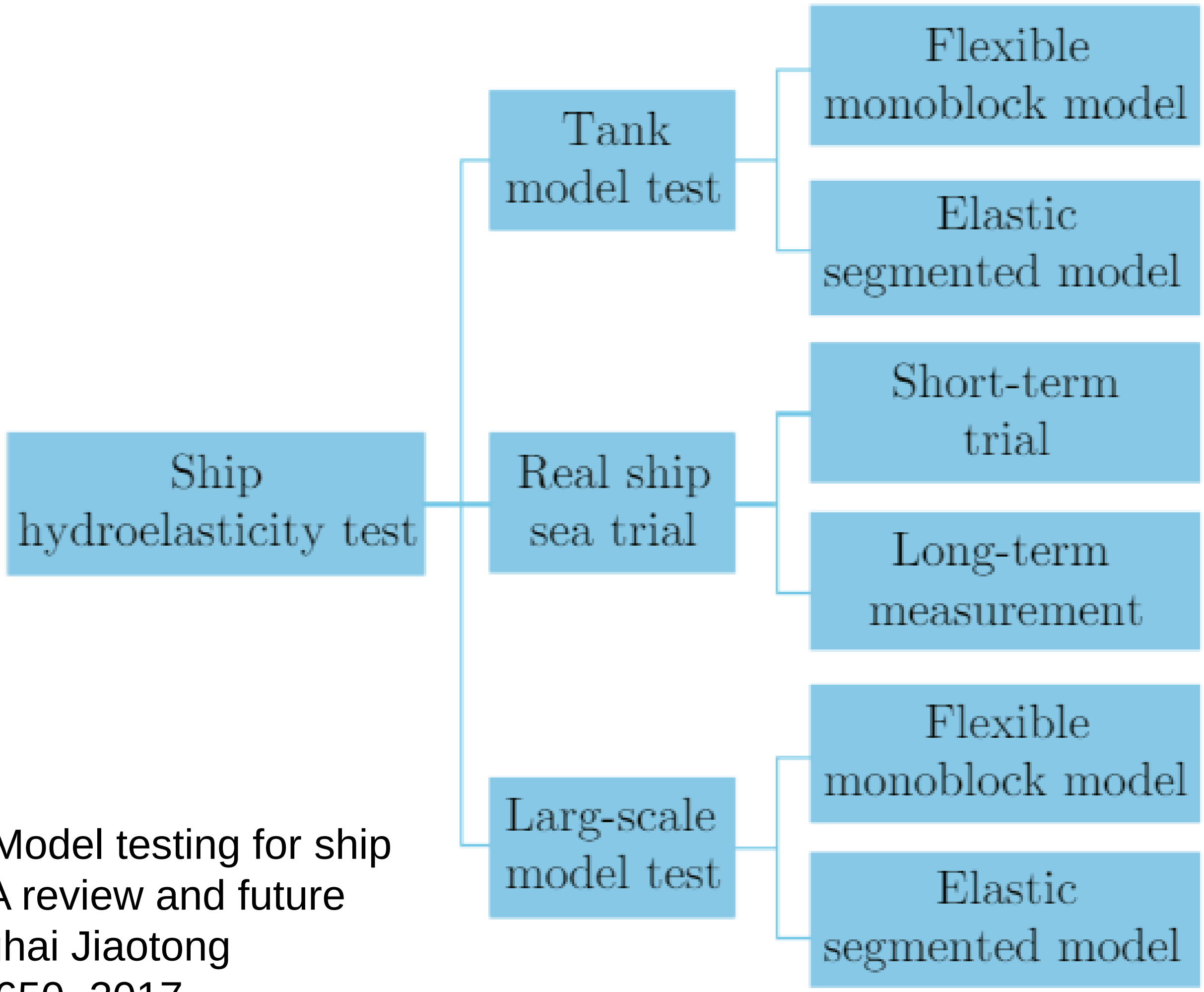
➢ Full-scale measurements

- ✓ Limited number of operating conditions
- ✓ Difficulties related to the measurement of the sea states

➢ Overall

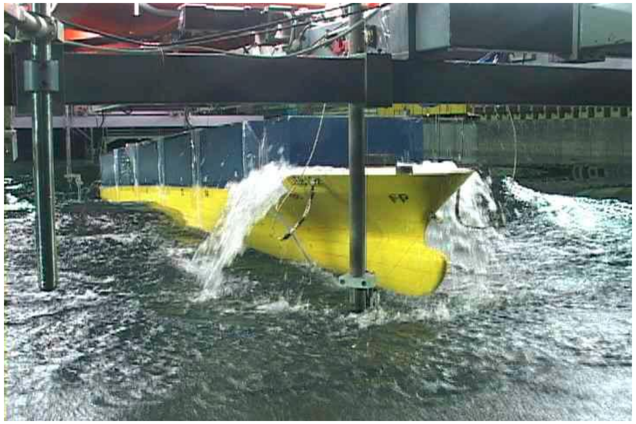
- ✓ Selection of the representative conditions (ship speed, loading conditions, scatter diagram, probability levels…)

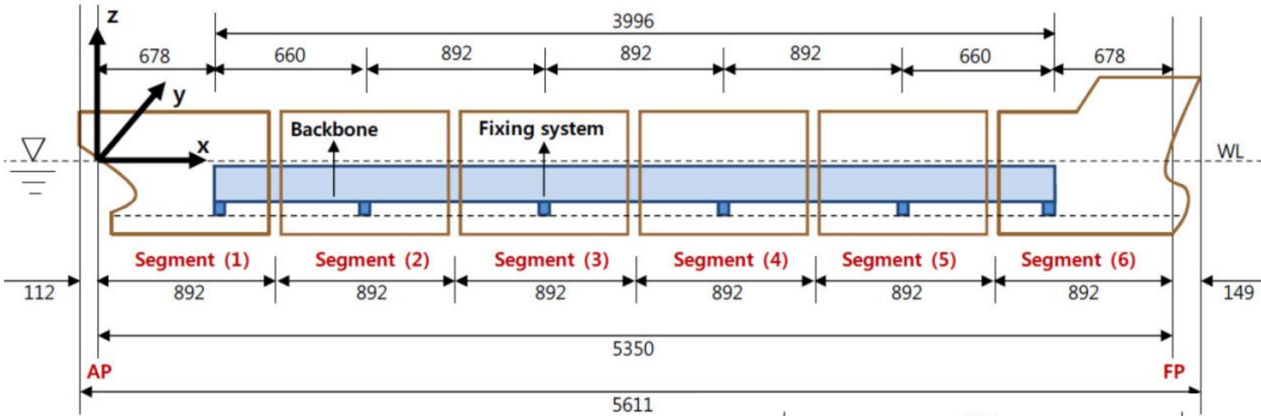
Classification of ship hydroelasticity tests

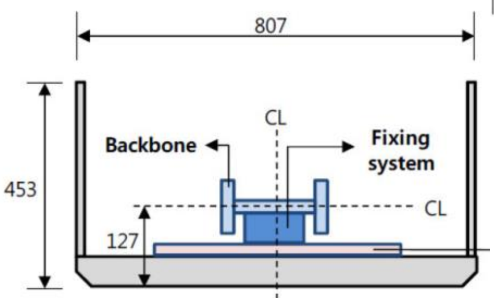


Ref. Jiao et al.: Model testing for ship hydroelasticity: A review and future trends, J. Shanghai Jiaotong Univ. 22(6):641-650, 2017

- **Detailed reviews regularly given in ISSC Reports**
- Earlier review of model tests – Wu (2003)
- **Recent tests with segmented models (reviewed in ISSC 2018)**
  - ✓ 321 m long 10000 TEU container ship (Kim et al., 2015; Hong et al., 2015) – WILS JIP Project







  - ✓ 425 m long 500000 DWT ore carrier (Li et al., 2016)
  - ✓ 350 m long 450000 DWT ore carrier (Kim et al., 2015)
  - ✓ 112 m long catamaran (Lavroff et al., 2017; Davis et al., 2017)

Model tests

➢ Model types

- ✓ Segmented, flexible backbone models
- ✓ Hinged models
- ✓ Fully flexible models (difficulties...)

Segmented barge, experiments in BGO First, Toulon, France

Experiments in CEHIPAR, Madrid, Spain, Project TULCS

Full-scale measurements

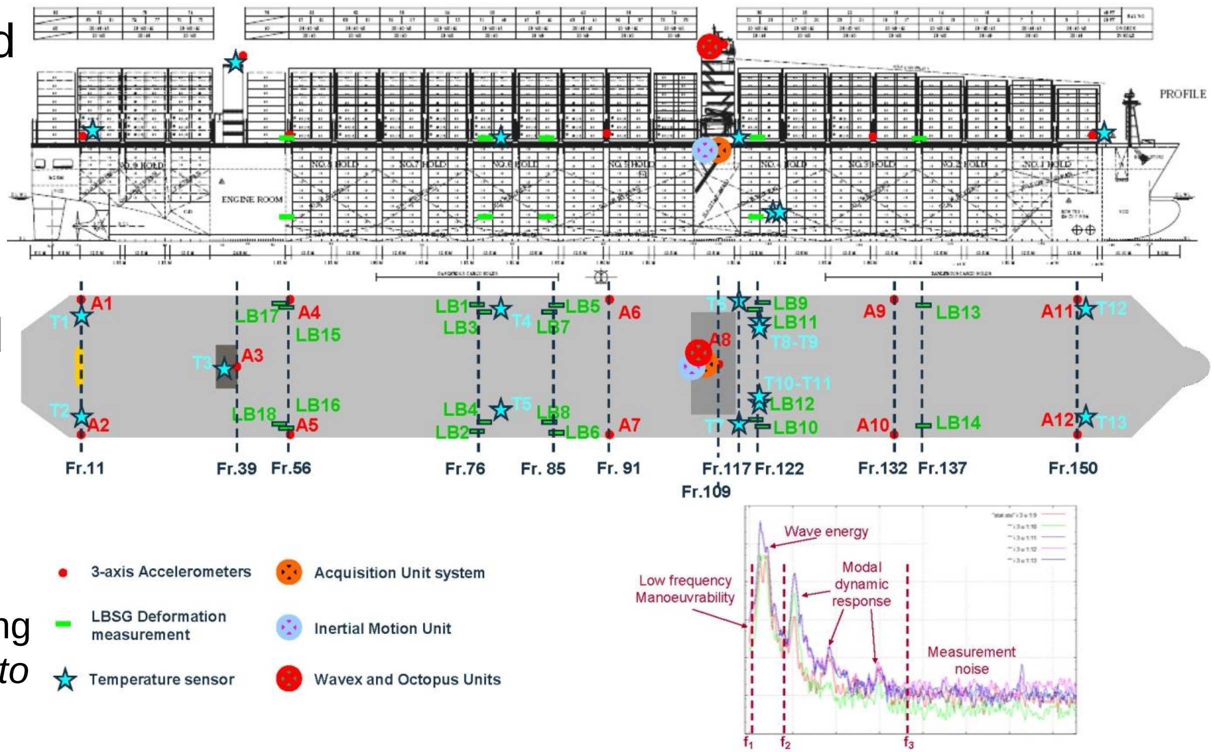
- **Detailed reviews also regularly given in ISSC Reports**

- **Full-scale measurements reported in ISSC 2018**
  - ✓ 2800 TEU container ship (Gaidai et al., 2016)
  - ✓ 2800 and 4440 TEU container ships (Mao et al., 2015)
  - ✓ 4400, 8600, 9400 and 14000 TEU container ships (Andersen, 2014)
  - ✓ 8400 and 8600 TEU container ships (Storhaug & Kahl, 2015)
  - ✓ 8600 TEU container ship (Barhoumi & Storhaug, 2014)
  - ✓ 14000 TEU container ship (Ki et al., 2015)
  - ✓ 4600 and 14000 TEU container ships (Kahl et al., 2015)
  - ✓ 8600, 9400 and 14000 TEU container ships (Andersen & Jensen, 2015)
  - ✓ 4600 and 14000 TEU container ships and a LNG carrier (Kahl et al., 2016)
  - ✓ 56 m naval high speed light craft (Magoga et al., 2016)
  - ✓ Several container ships and blunt ships (Storhaug et al., 2017)
  - ✓ 210 m Ro-Lo ship (Orlowitz & Brandt, 2014)

Full-scale measurements

➢ ISSC 2018 conclusions on full-scale measurements

- ✓ Full-scale measurements and model tests in recent years have been focused on unconventional ships such as VLCS and ULCS (probably influenced by MSC Napoli and MOL Comfort cases)
- ✓ The effects of sea state, heading, speed, size, loading condition, trade and structural location are often discussed
- ✓ Most studies are related to vertical vibration
- ✓ Recommended to pay more attention to torsional vibrations and other topics, such as acceleration levels for cargo securing



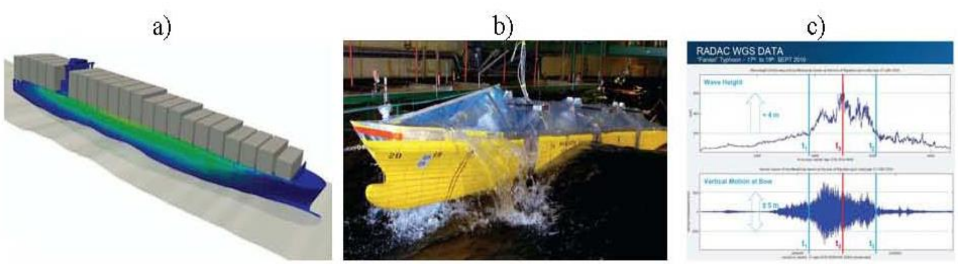
Schematic presentation of measuring points on the container ship *Rigoletto* (EU FP7 Project TULCS)

Selected projects on ship hydroelasticity

- **EU FP7 Project TULCS (June 2009 – November 2012)**
- **Goal**
  - ✓ … to deliver clearly validated design tools and guidelines, capable of analysing all hydro-structure interaction problems relevant to ULCS
- **Main physical problems**
  - ✓ Global quasi-static loading and responses
  - ✓ Global hydroelastic wave loading and responses
  - ✓ Local hydrodynamic loading and responses

TULCS

Tools for Ultra Large Container Ships



Numerical simulation | Model test | Full-scale measurement

TULCS Partners:

Bureau Veritas, France (coordinator)
MARIN, The Netherlands
CMA-CGM, France
CEHIPAR, Spain
Ecole Centrale Marseille, France
Technical University Delft, The Netherlands
University of Zagreb, Croatia
Technical University of Denmark, Denmark
University of East Anglia, United Kingdom
SIREHNA, France
WIKKI, United Kingdom
HYDROCEAN, France
Brže Više Bolje, Croatia
Hyundai Heavy Industries, Korea

Background

- ASERC (Advanced Ship Engineering Research Center) at PNU
- Center of Excellence designated by Korean government in the Naval Architecture and Ocean Engineering field in 2002 (Period 2002 – 2011)

GCRC-SOP (Global Core Research Center for Ships and Offshore Plants)

- Establish the world premier research center at PNU through the succession of ASERC and the strategic international collaboration with world-renowned researchers in the field of Ship & Offshore Plant Engineering (Period 2011-2021)

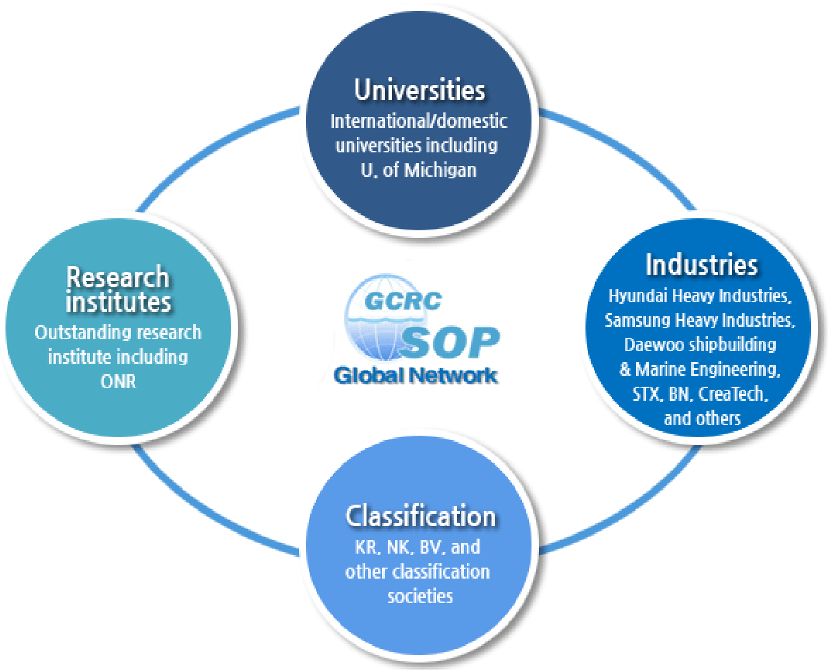
GCRC-SOP Participants

- National Research Foundation of Korea, Pusan National University, Pusan Metropolitan City, Shipyards (HHI, DSME, SHI, STX , BNC, CreaTech), Classification societies (ABS, BV, NK, KR)

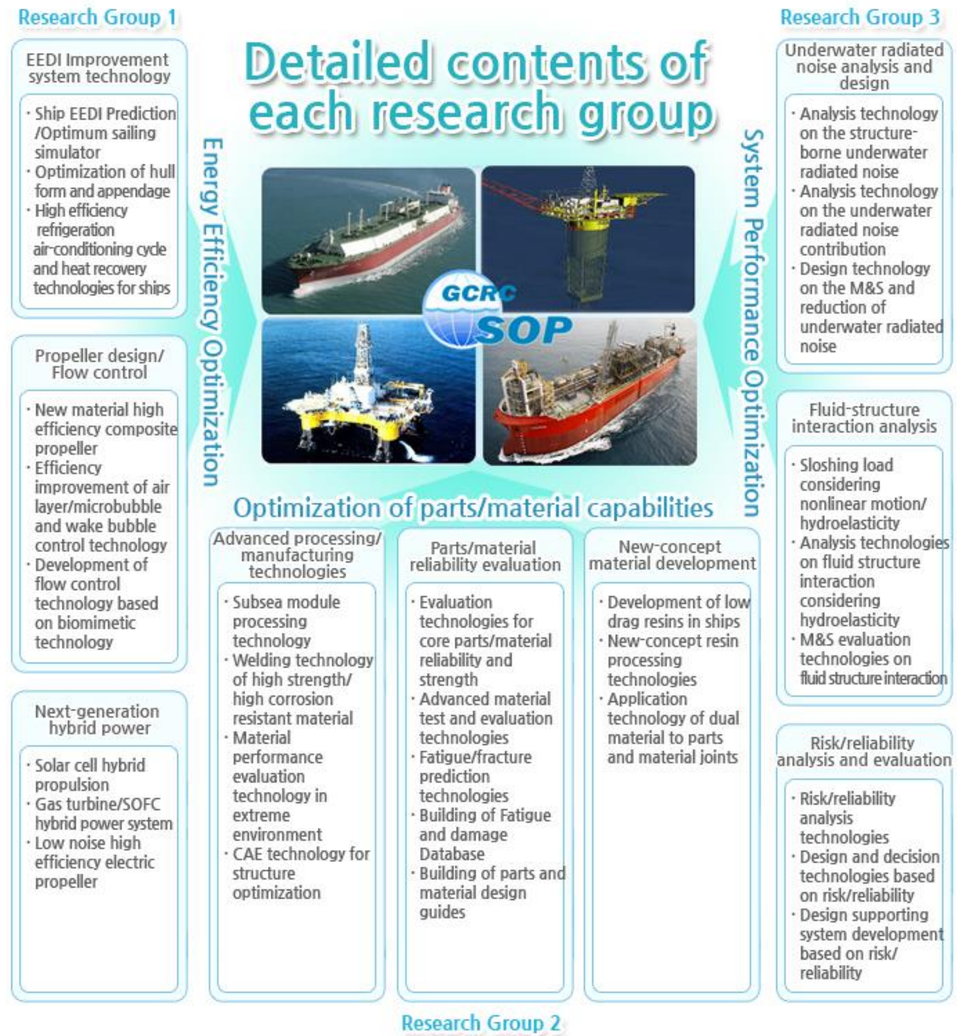
4 External Universities

- University of Michigan, University of Maryland, University of New Orleans, UNIZAG FSB (with Bureau Veritas, Paris, France)

GCRC-SOP

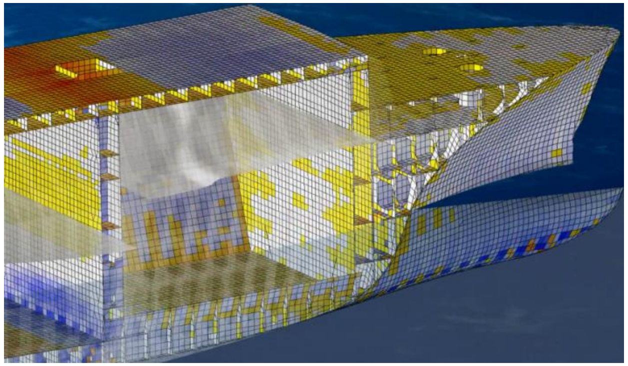


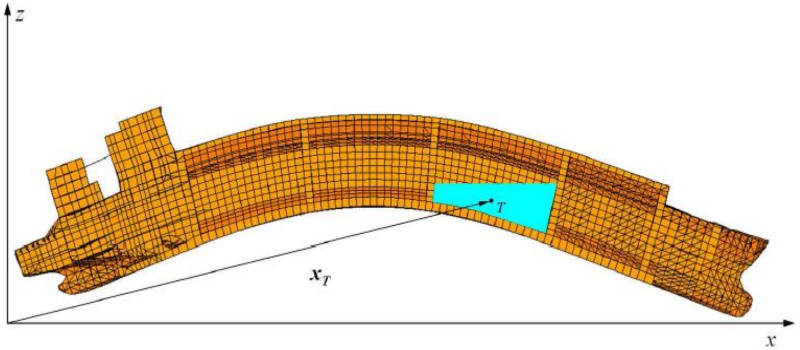
GCRC SOP Cooperative Network

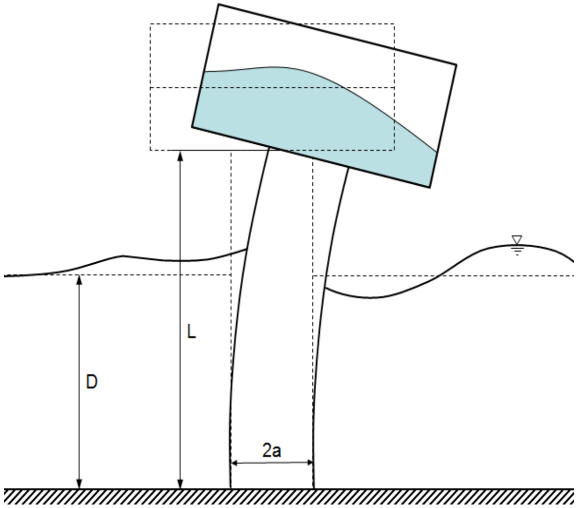


➢ Global hydroelastic response of LNG ships

- ✓ Joint Development Project (PNU, BV, UNIZAG FSB & HHI)
- ✓ Goal: to develop hydroelastic model for ships with internal liquid (LNGC, Tankers…)
  - *Beam structural model*
  - *3DFE structural model*
- ✓ Scope of work:
  - *Example ship provided by HHI*
  - *UNIZAG FSB - beam hydroelastic model*
  - *BV & UNIZAG FSB - 3D FEM hydroelastic model*
  - *PNU - semi analytical solution for validation purposes*

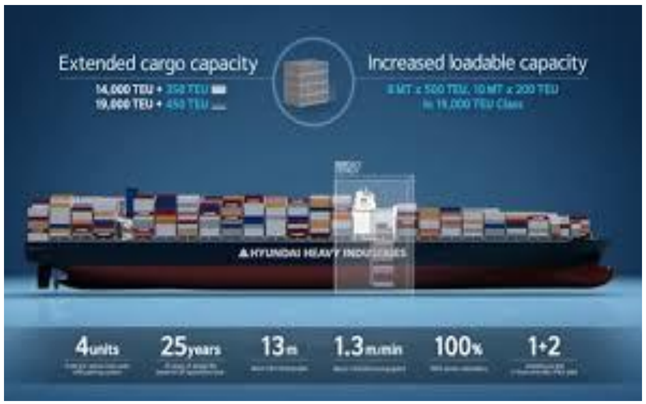


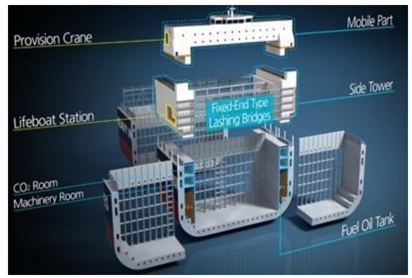


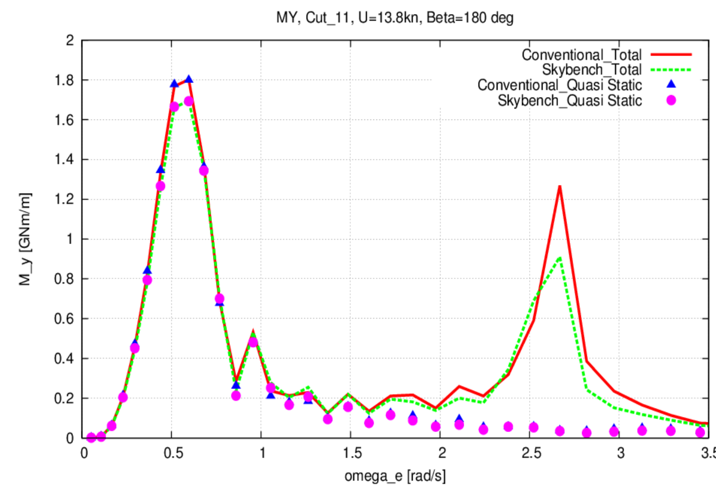


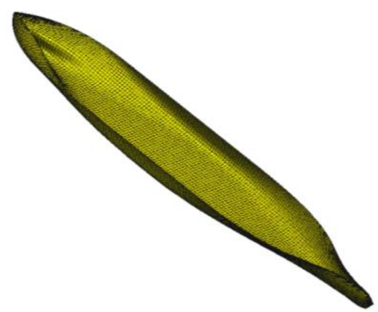
➢ Springing & Whipping Analysis of HHI SkyBench™ container carrier

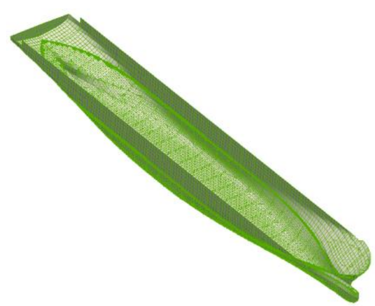
✓ Joint Research Project (UNIZAG FSB & HHI)

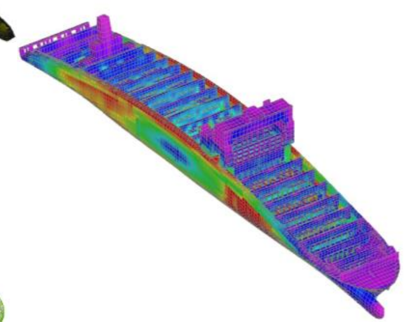


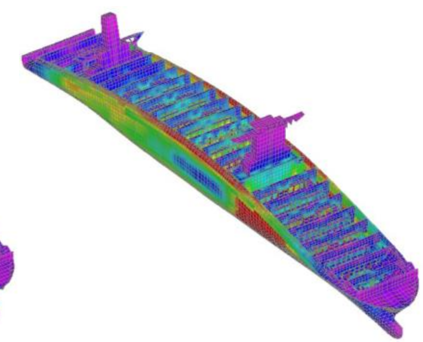






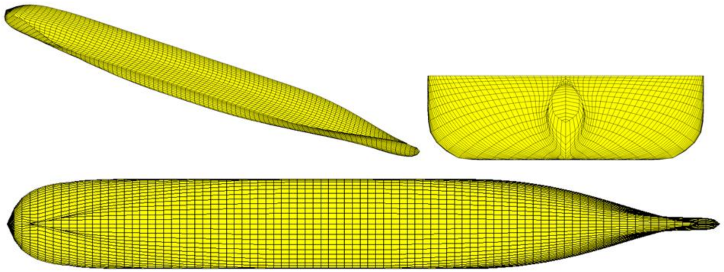


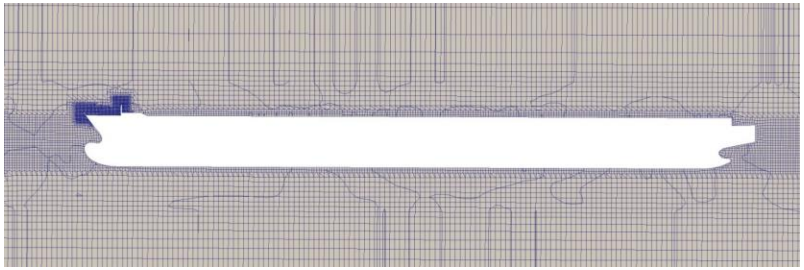


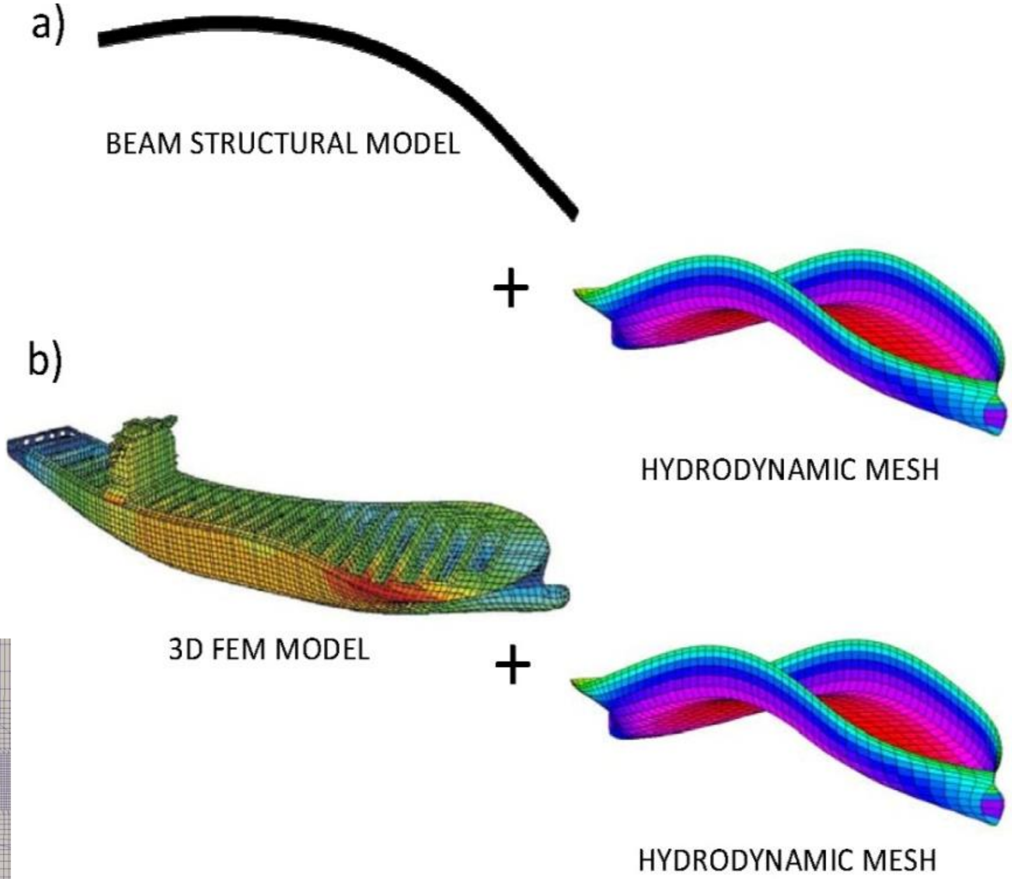


Numerical simulations

- **Solving hydroelastic problem at different levels of complexity and accuracy**
  - ✓ Structural models
    - *Beam structural model*
    - *3D FEM structural model*
  - ✓ Hydrodynamic models
    - *Potential flow theories*
    - *CFD*







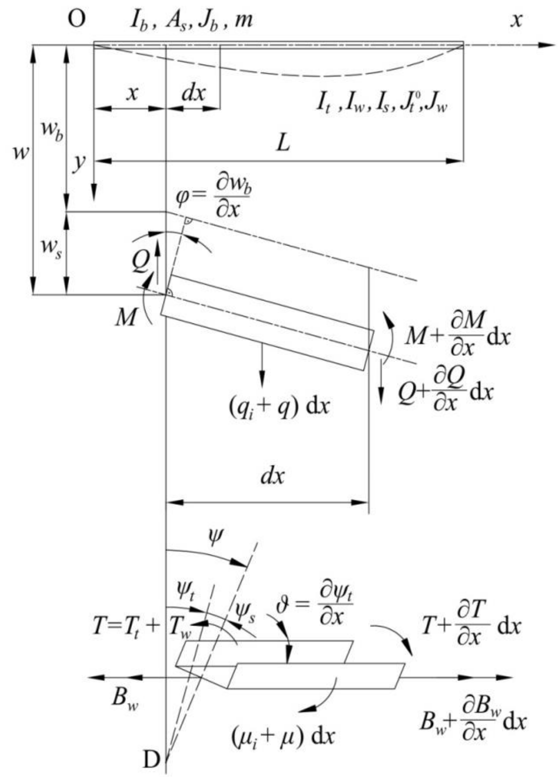
➢ Beam model can give accurate results at global level

- ✓ Based on the advanced thin-walled girder theory
  - *shear influence on bending and torsion*
  - *accounting for contribution of transverse bulkheads to hull stiffness in a reliable way*
  - *accounting for closed engine room structure segment in a proper way*

- ✓ Shear influence on torsion
  - *Analogy with shear influence on bending*

$$w = w_b + w_s, \qquad w_s = -\frac{EI_b}{GA_s}\frac{\partial^2 w_b}{\partial x^2}$$

$$\psi = \psi_t + \psi_s, \qquad \psi_s = -\frac{EI_w}{GI_s}\frac{\partial^2 \psi_t}{\partial x^2}$$

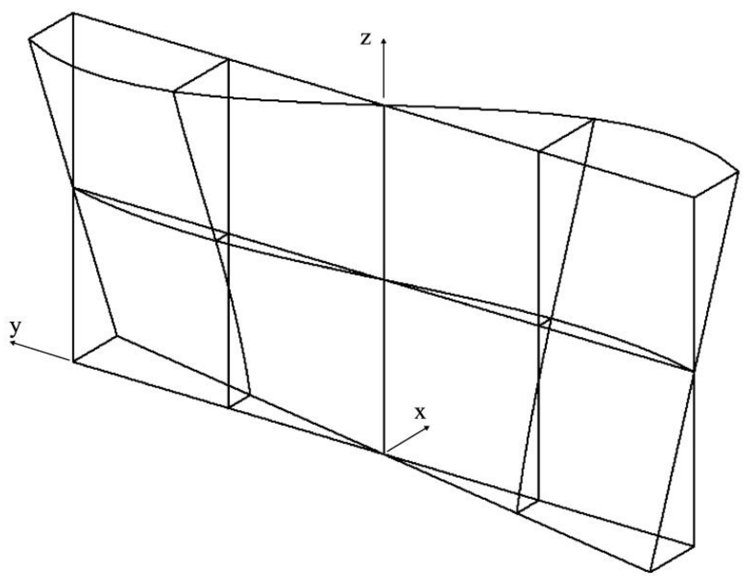


Refs. Pavazza (2005), Senjanović et al. (2009)

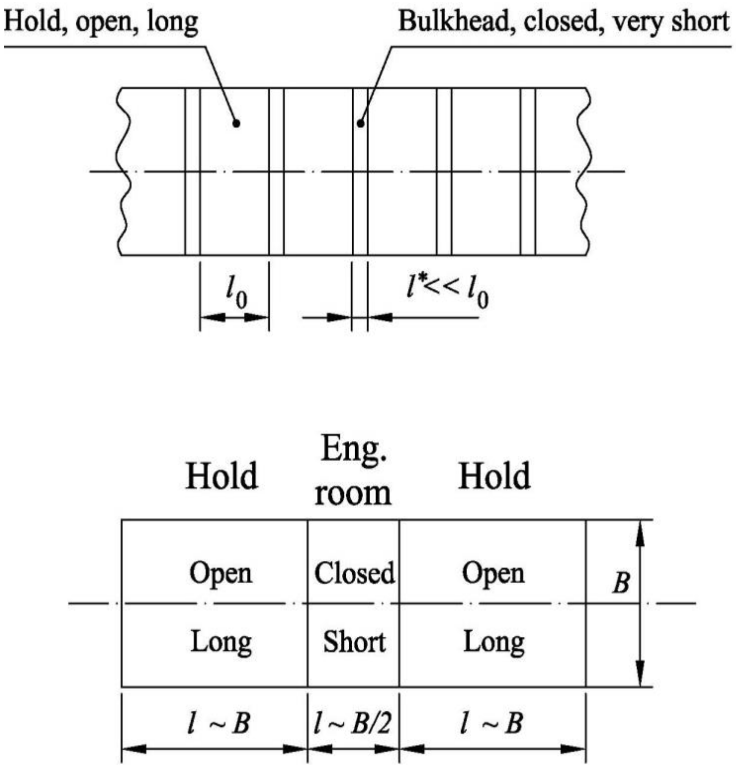
Sophisticated beam structural model

✓ Contribution of transverse bulkheads to the global hull stiffness

- *Theory of torsion of thin-walled girders*
- *Theory of bending of an ortothropic plate*
- *Core idea: Increase St. Venant torsional modulus of open hull cross-section*



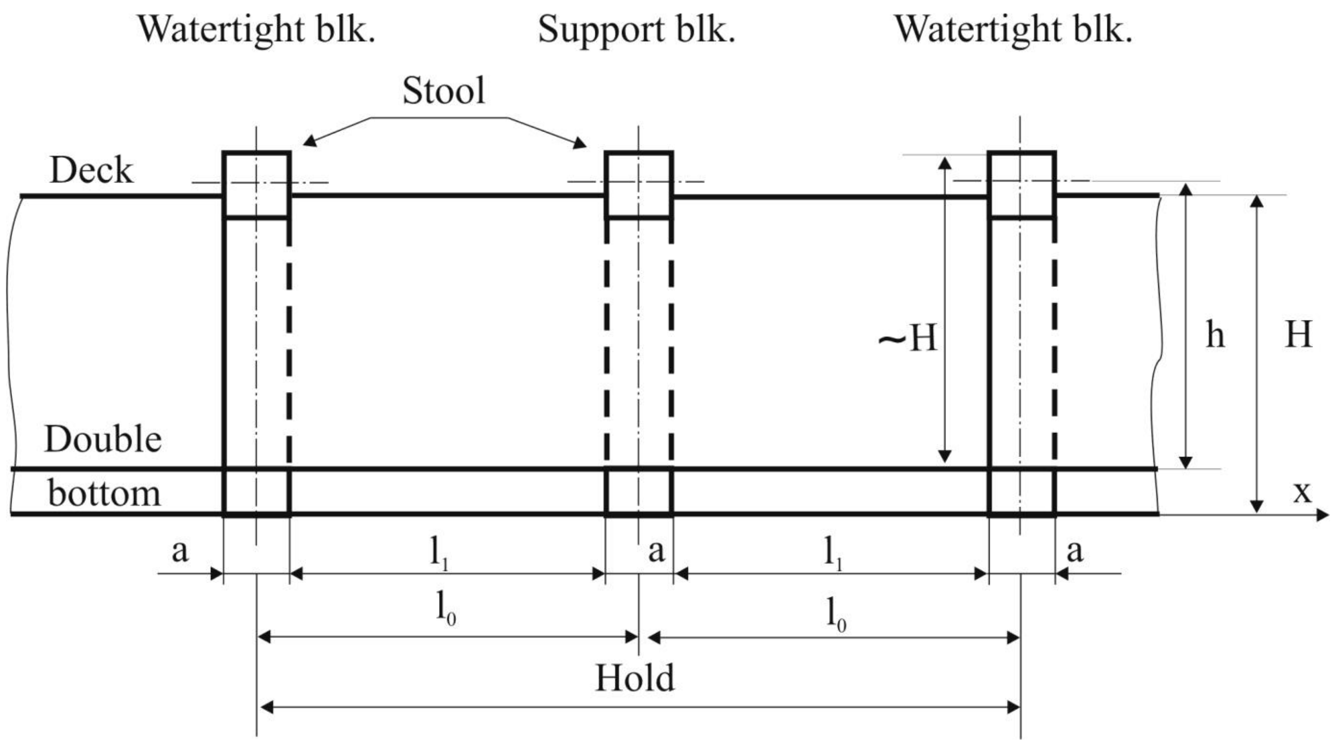
Bulkhead deformation due to hull cross-section warping



Discontinuities of ship hull

Sophisticated beam structural model

- ✓ Equivalent torsional modulus

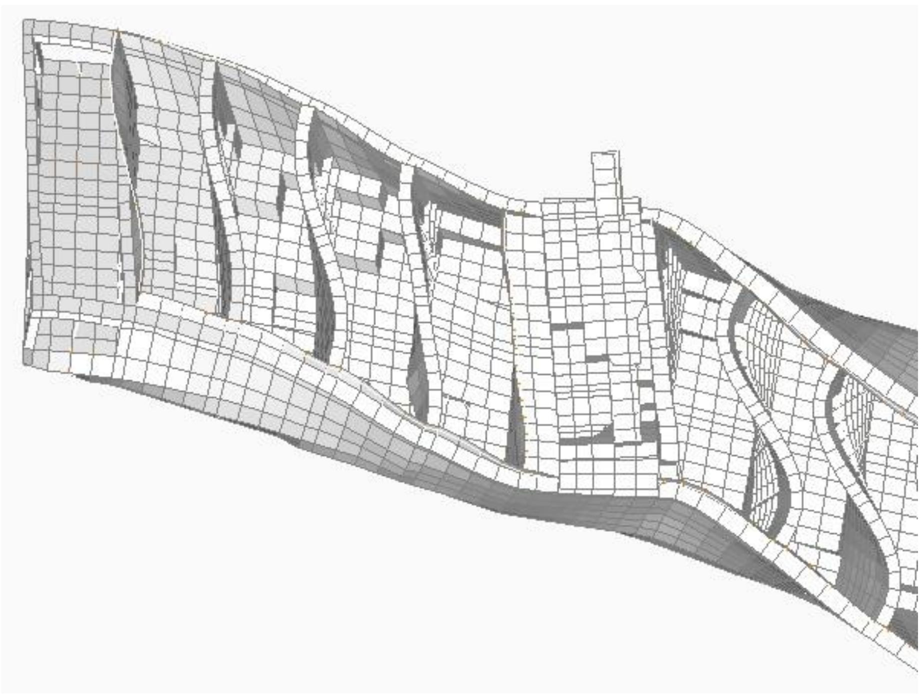


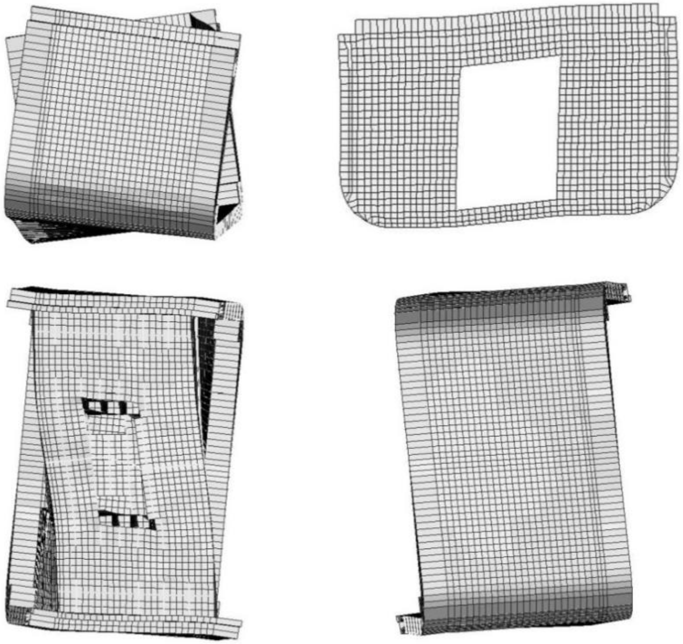
Longitudinal section of container ship hold

$$I_t^* = \left[1 + \frac{a}{l_1} + \frac{4(1+\nu)C}{I_t l_0}\right] I_t \qquad C = \frac{U_g + U_s}{E\psi'^2} \qquad \left(I_t^* \approx 2.4 I_t\right)$$

Sophisticated beam structural model

- ✓ Contribution of engine room structure to the hull stiffness (relatively short closed segment)
- ✓ Solution: Modelling of engine room structure as an open segment of increased torsional stiffness due to influence of the decks





Sophisticated beam structural model

✓ Basic expressions

$$U = |U_D| + |U_B| = \left(|w_D| + |w_B|\right)\psi_t'$$

$$u_b = \frac{y}{2b}\left[3 - \left(\frac{y}{b}\right)^2\right]U_b$$

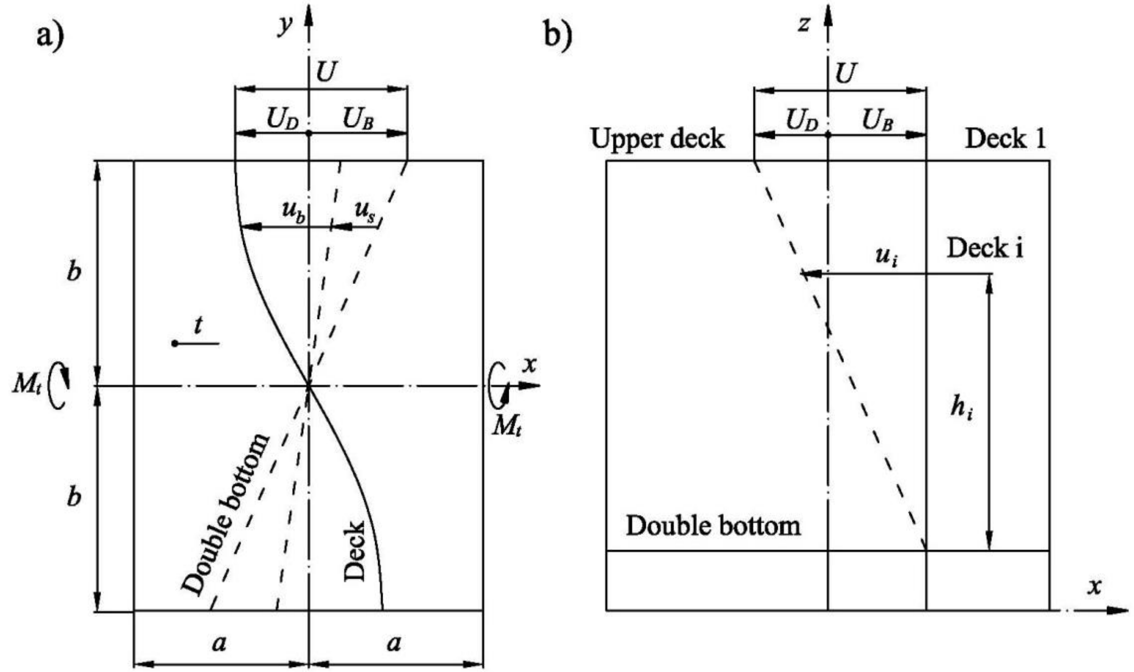
$$u_s = -\frac{EI}{GA}\frac{\mathrm{d}^2 u_b}{\mathrm{d}y^2} = 2(1+\nu)\left(\frac{a}{b}\right)^2\frac{y}{b}U_b$$

$$E_1 = \frac{1}{2}EI\int_{-b}^{b}\left(\frac{\mathrm{d}^2 u_b}{\mathrm{d}y^2}\right)^2\mathrm{d}y + \frac{1}{2}GA\int_{-b}^{b}\left(\frac{\mathrm{d}u_s}{\mathrm{d}y}\right)^2\mathrm{d}y$$

$$\tilde{I}_t = (1+C)I_t^\circ$$

$$C = \frac{\sum E_i}{E_t^\circ} = \frac{4(1+\nu)t_1\left(\frac{a}{b}\right)^3\left(|w_D| + |w_B|\right)^2 k}{\left[1 + 2(1+\nu)\left(\frac{a}{b}\right)^2\right]I_t^\circ a}$$

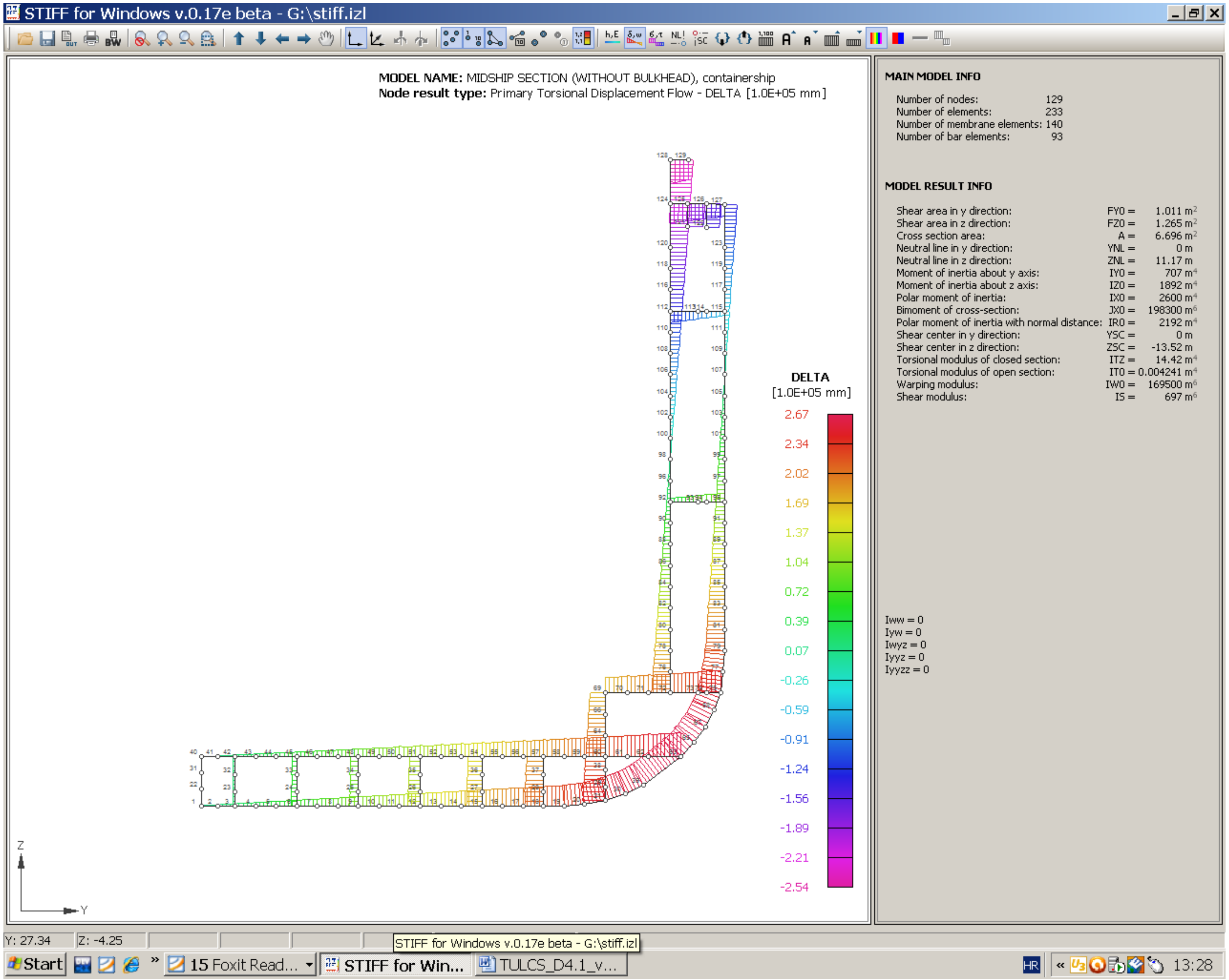
$$k = \sum\frac{V_i}{V_1}\left(\frac{h_i}{h_1}\right)^2$$



Upper deck deformation and double bottom rotation, a – bird's eye view, b – lateral view

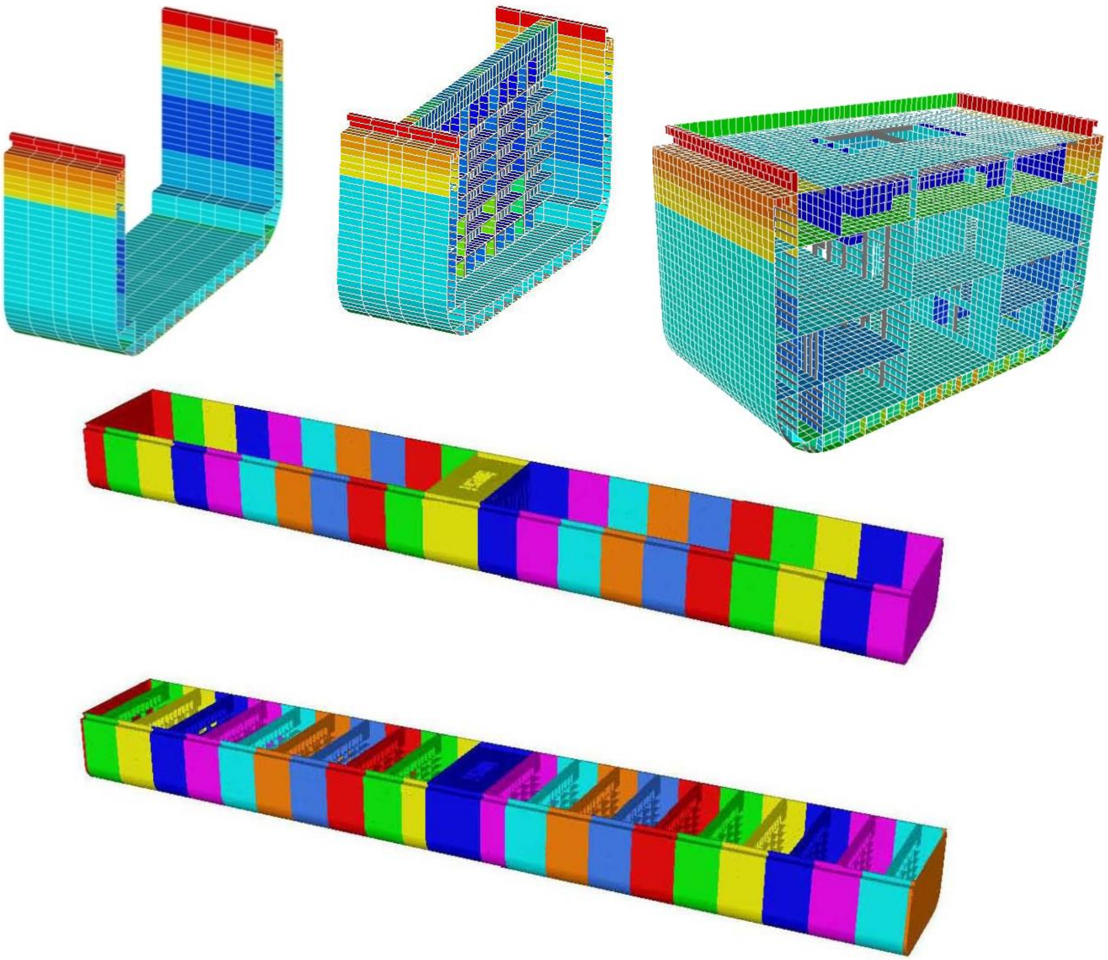
Refs. Senjanović et al. (2010, 2011)

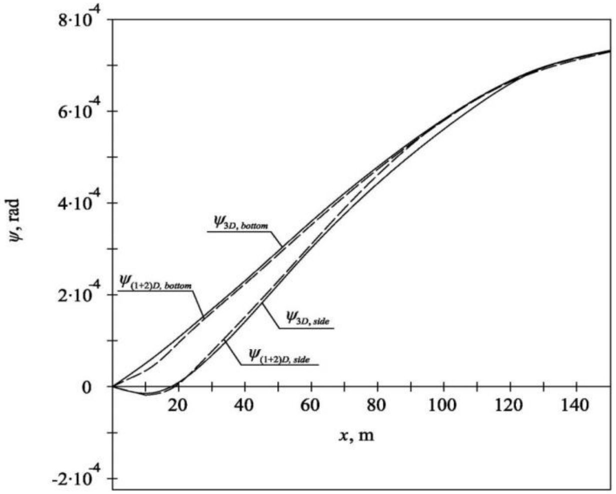
Assessing cross-sectional parameters (STIFF software)

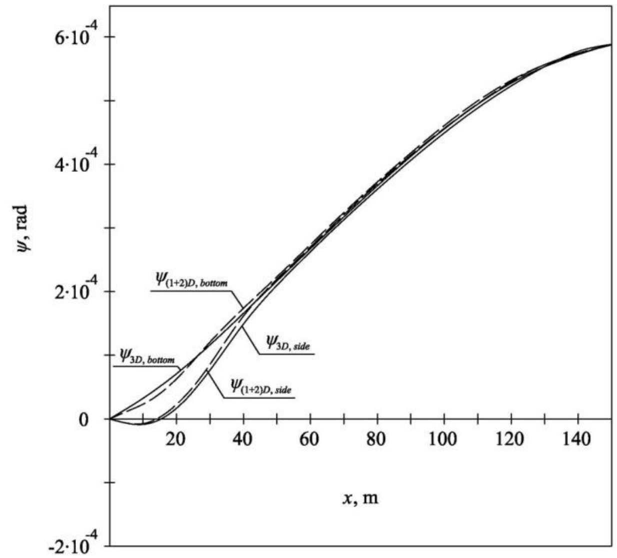


Validation of beam structural model

- ✓ Comparison of twist angles for segmented pontoons with and wihout bulkheads (Beam & 3D FEM models)

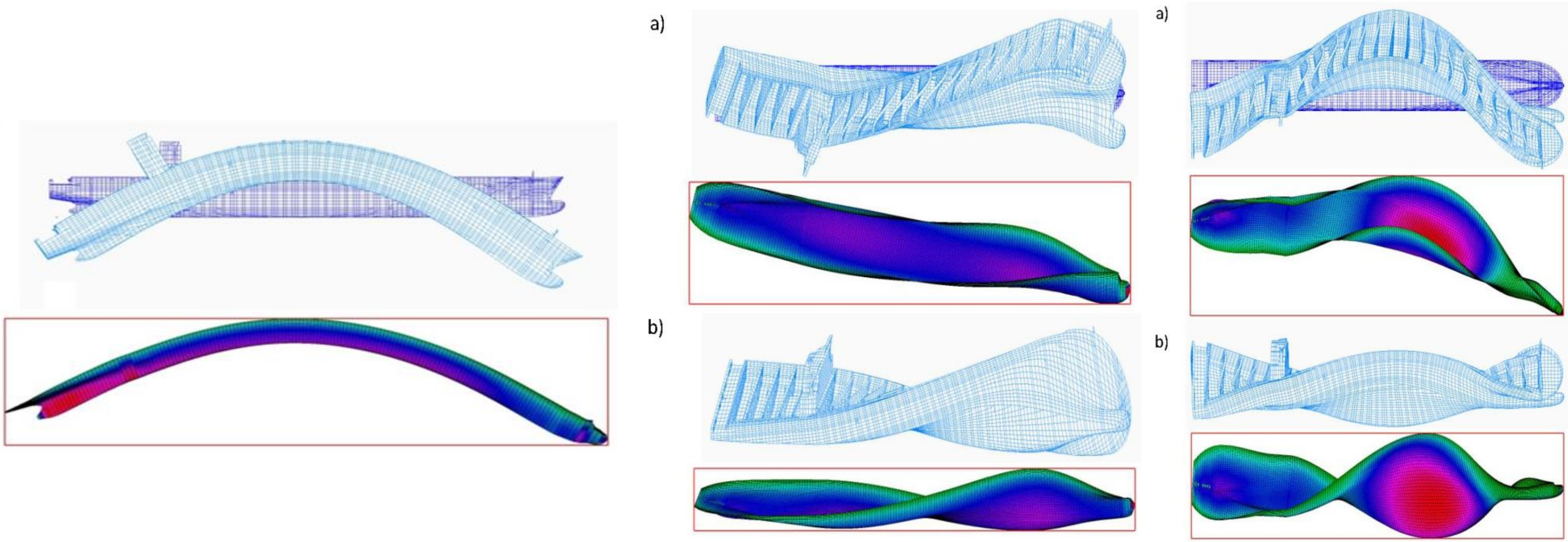






Validation of beam structural model

- ✓ Comparison of natural vibrations of 11400 TEU CS obtained by beam model and 3D FEM model



Dry natural frequencies of the light container ship, ω_i[Hz]

	1D		3D		Discrepancy, %	
No.	Vertical	Coupled	Vertical	Coupled	Vertical	Coupled
1	1.149	0.640	1.159	0.639	-0.86	0.16
2	2.318	1.053	2.328	1.076	-0.43	-2.14
3	3.694	1.738	3.654	1.750	1.09	-0,69

Equation of motion in frequency domain

- The governing matrix differential equation for coupled ship motions and vibrations in frequency domain

$$\left[\mathbf{k}+\mathbf{C}-i\omega\left(\mathbf{d}+\mathbf{B}(\omega)\right)-\omega^2\left(\mathbf{m}+\mathbf{A}(\omega)\right)\right]\boldsymbol{\xi}=\mathbf{F}$$

$\mathbf{k}$, $\mathbf{d}$, $\mathbf{m}$ - structural stiffness, damping and mass matrix

$\mathbf{C}$ - restoring stiffness matrix

$\mathbf{B}(\omega)$ - hydrodynamic damping

$\mathbf{A}(\omega)$ - added mass

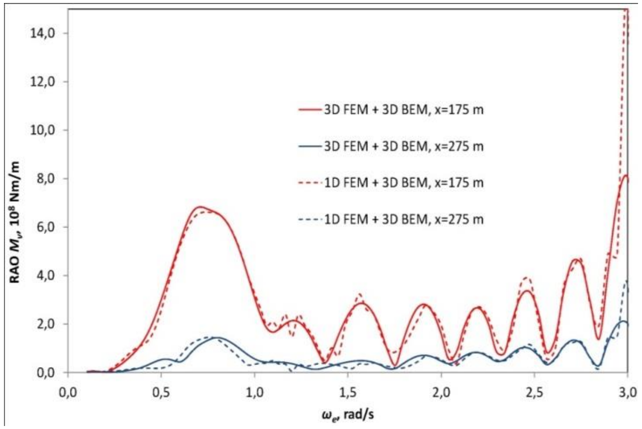
$\boldsymbol{\xi}$ - modal amplitudes

$\mathbf{F}$ - wave excitation

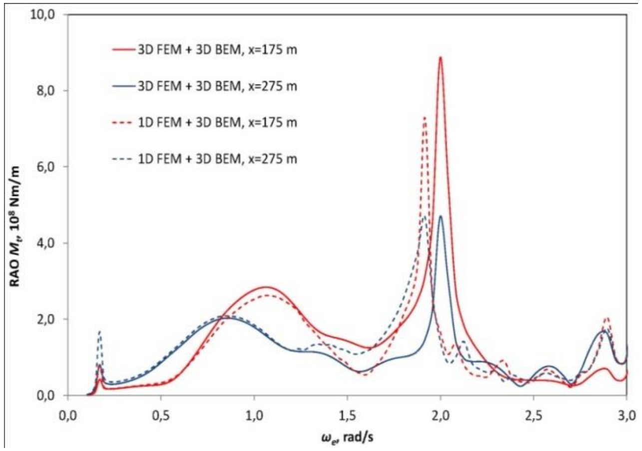
ω - encounter frequency

Validation of beam structural model

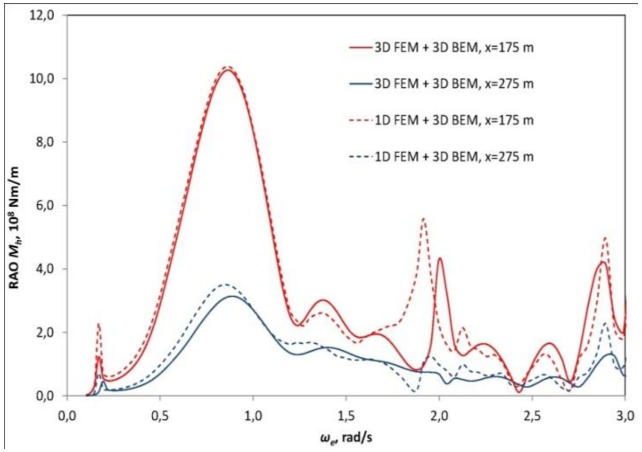
- ✓ Comparison of transfer functions obtained by beam hydroelastic model and 3D hydroelastic model (in both cases hydrodynamic potential flow model)



Transfer function of vertical bending moment, χ=120°, V=15.75 kn



Transfer function of torsional moment, χ=120°, V=15.75 kn



Transfer function of horizontal bending moment, χ=120°, V=15.75 kn

Time domain simulation models

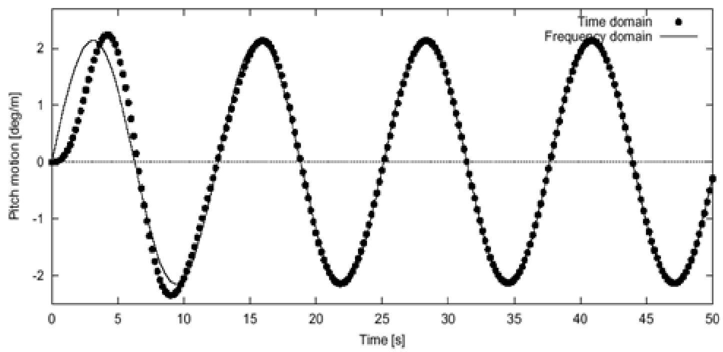
- **Hybrid method proposed by Cummins is adopted**
  - ✓ **Frequency domain**

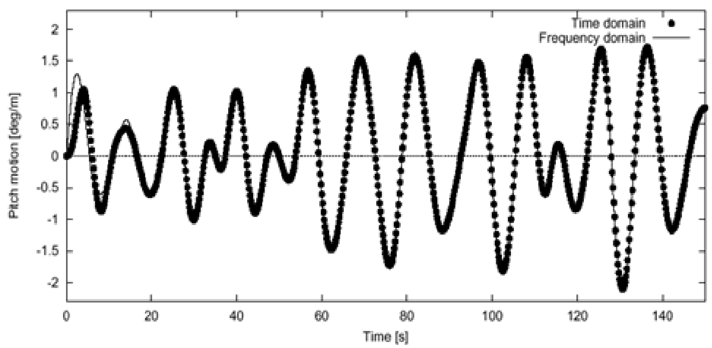
$$\{-\omega^2([\,\mathbf{m}\,]+[\,\mathbf{A}\,])-i\omega[\,\mathbf{B}\,]+([\,\mathbf{k}\,]+[\,\mathbf{C}\,])\}\{\xi\}=\{F^{DI}\}$$

  - ✓ **Time domain**

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

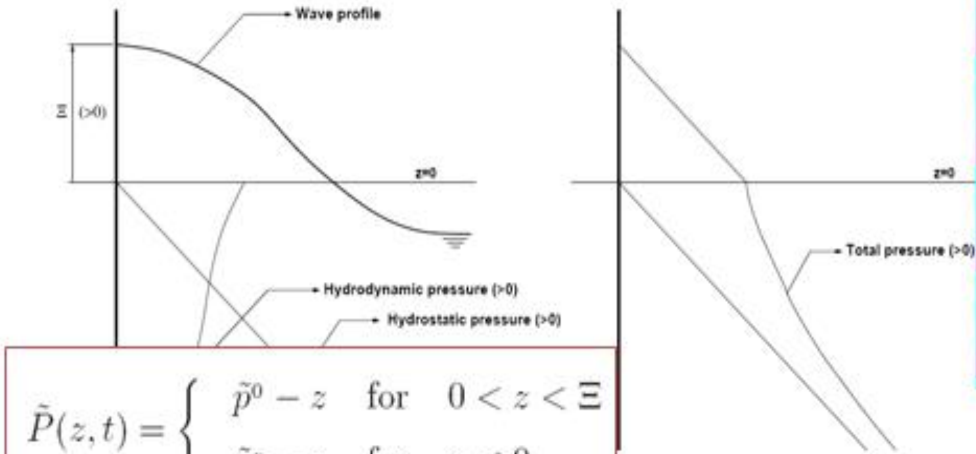
  - ✓ **Preliminary verifications for regular and irregular waves in linear conditions**

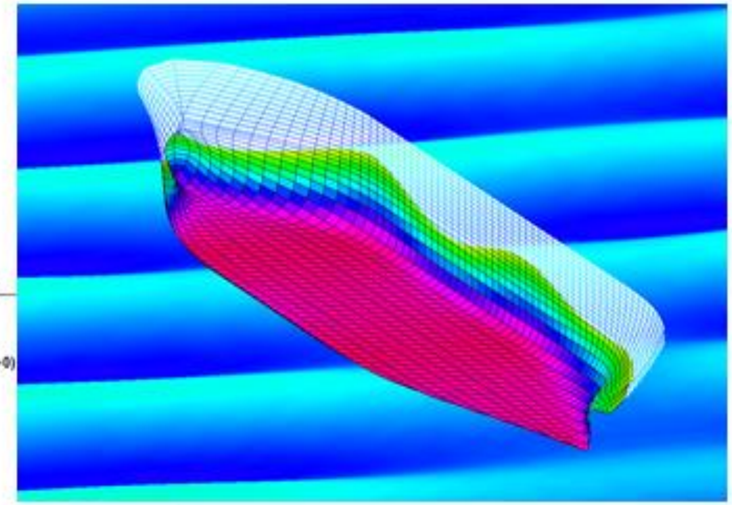




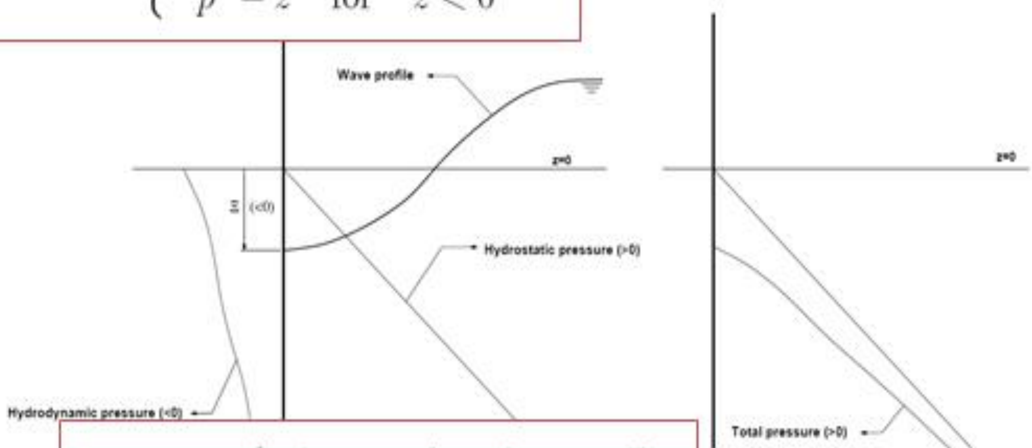
- **Once the linear model verified the nonlinearities are included in the right hand side**
  - ✓ **Froude Krylov**
  - ✓ **Nonlinear hydrostatics and large motions**

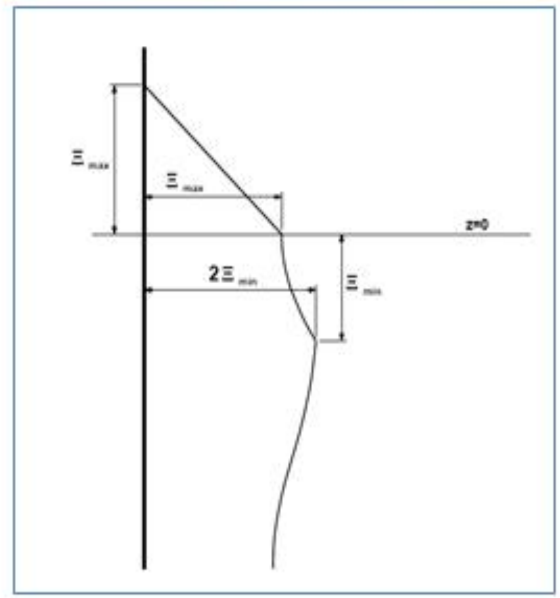
➢ Froude Krylov approximation





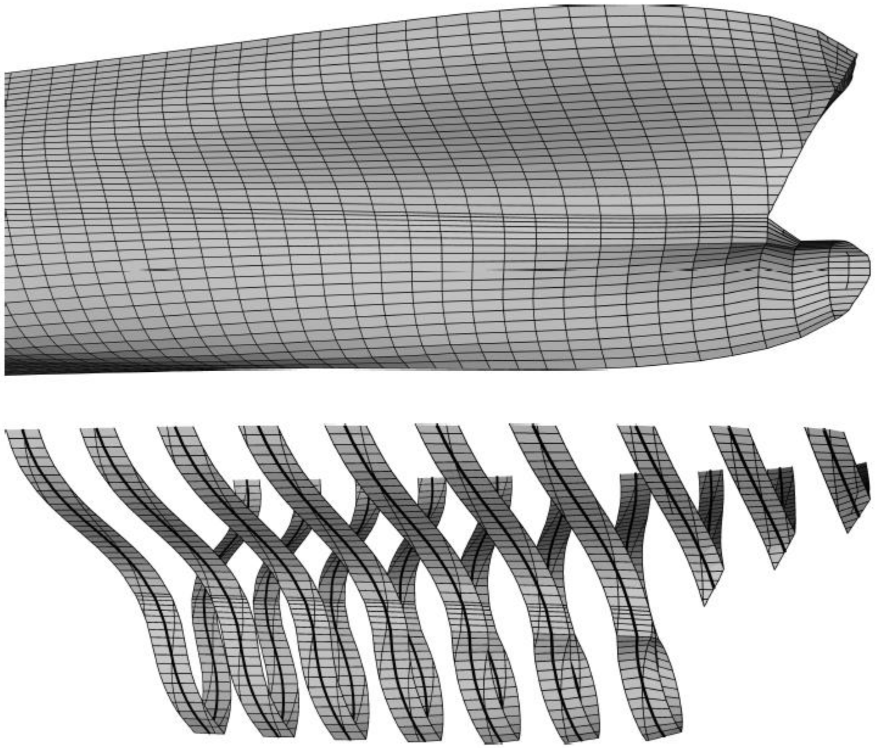
$$\tilde{P}(z,t) = \begin{cases} \tilde{p}^0 - z & \text{for} \quad 0 < z < \Xi \\ \tilde{p}^z - z & \text{for} \quad z < 0 \end{cases}$$





$$\tilde{P}(z,t) = \begin{cases} 0 & \text{for} \quad 0 > z > \Xi \\ \tilde{p}^z - z & \text{for} \quad z < \Xi \end{cases}$$

➢ Slamming (strip approach)



$$F^i = \iint_S p\boldsymbol{h}^i \boldsymbol{n} dS$$

$$F^i = \sum_{i=1}^{N_s} \iint_{S_s} p_s \boldsymbol{h}_s^i \boldsymbol{n}_s dS_s$$

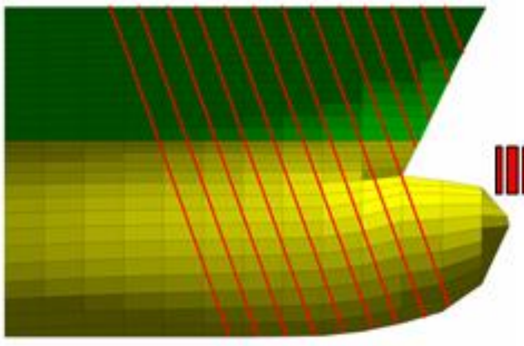
$$dS_s = b_s(l) dl_s$$

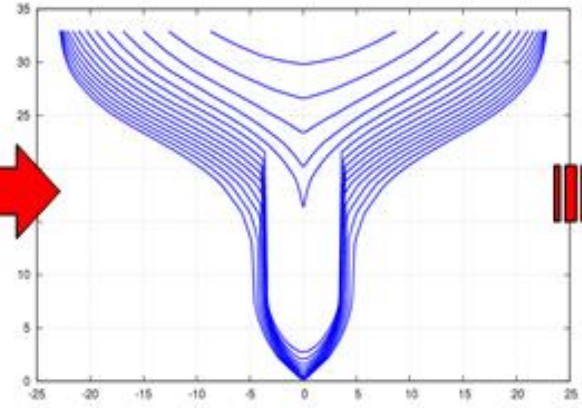
$$b_s(l) = \frac{dS_s}{dl_s}$$

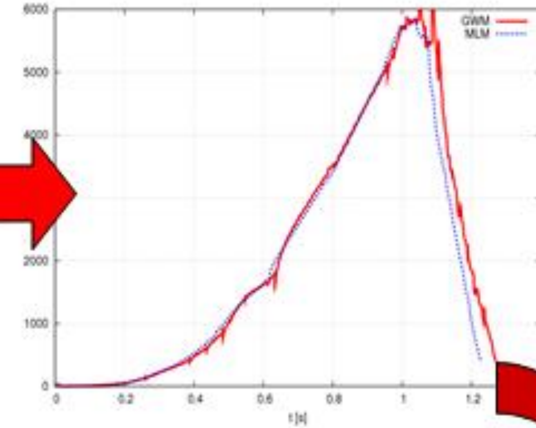
✓ Two slamming models:

- **Generalized Wagner**
- Modified Logvinovich

$$F^i = \sum_{i=1}^{N_s} \int_{L_s} p_s \boldsymbol{h}_s^i \boldsymbol{n}_s b_s dl_s$$

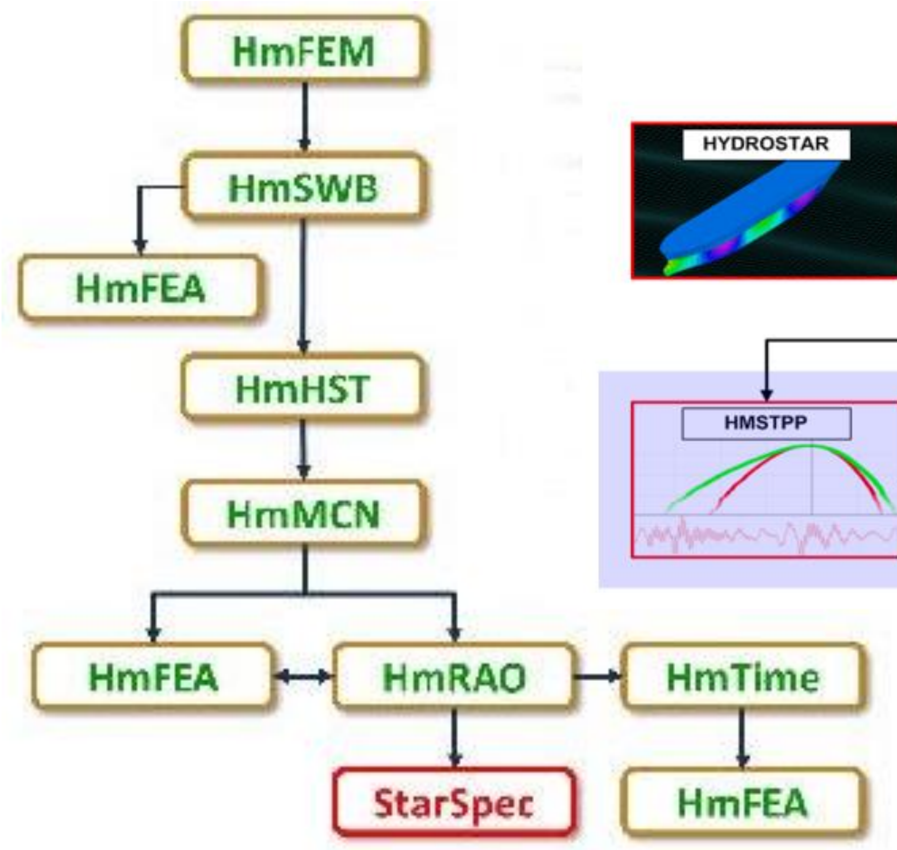


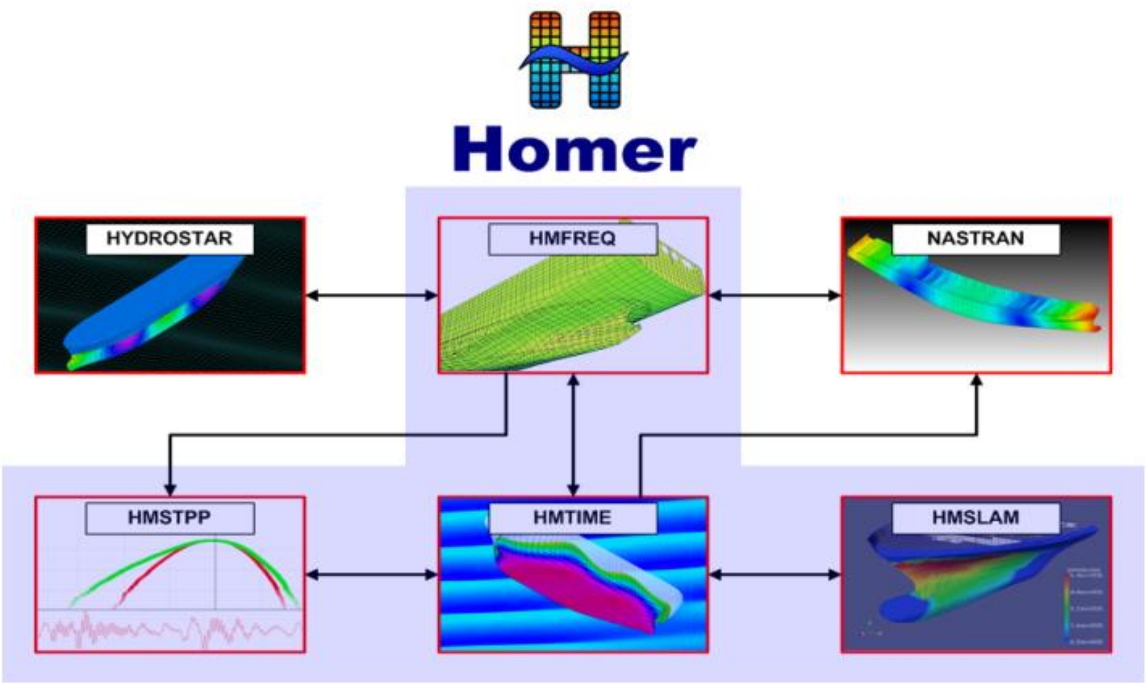




$$([\ \mathbf{m}\ ]+[\ \mathbf{A}^{\infty}\ ])\{\ddot{\xi}(t)\} + ([\ \mathbf{k}\ ]+[\ \mathbf{C}\ ])\{\xi(t)\} + \int_0^t [\ \mathbf{K}(t-\tau)\ ]\{\dot{\xi}(\tau)\}d\tau = \{\boldsymbol{F}(t)\} + \{Q(t)\}$$

- HOMER software (Bureau Veritas)





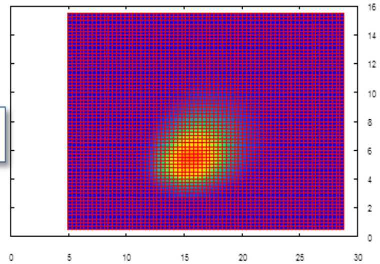
➢ WhiSp methodology (Bureau Veritas NR583)

➢ WHISP1

✓ **Fatigue including springing**

S \ H	LINEAR	WAVE NON LINEAR	IMPULSIVE NON LINEAR
QUASI STATIC	X		
DYNAMIC	X		

→ Spectral fatigue

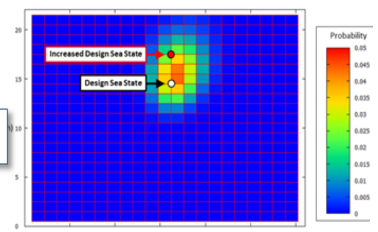


➢ WHISP2

✓ **Extreme (ultimate strength) including whipping**

S \ H	LINEAR	WAVE NON LINEAR	IMPULSIVE NON LINEAR
QUASI STATIC	X	X	
DYNAMIC	X	X	X

→ Design sea state

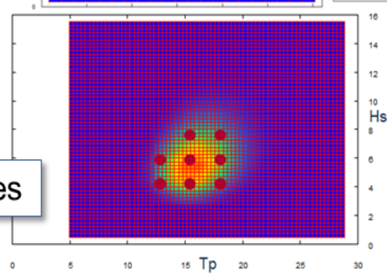


➢ WHISP3

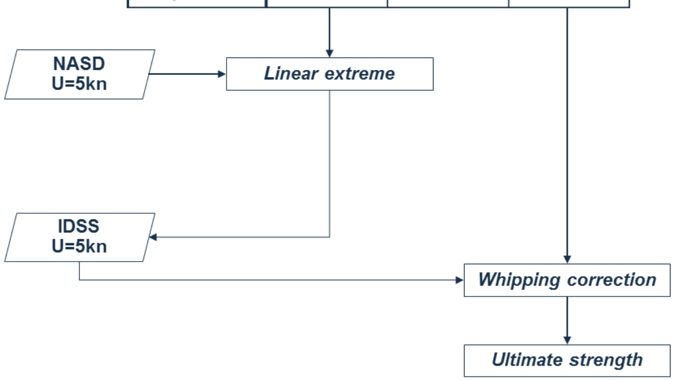
✓ **Fatigue including springing & whipping**

S \ H	LINEAR	WAVE NON LINEAR	IMPULSIVE NON LINEAR
QUASI STATIC	X	X	
DYNAMIC	X	X	X

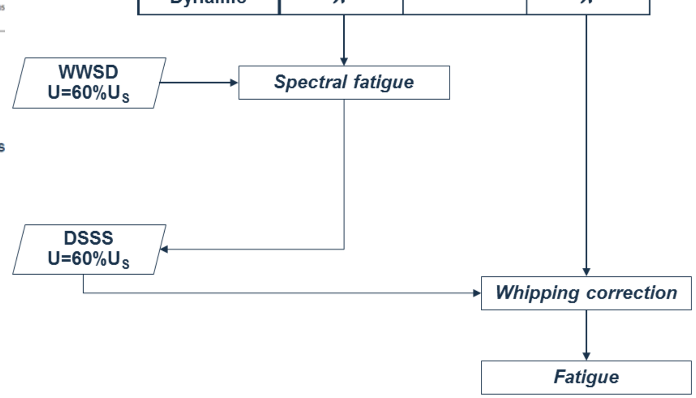
→ Design sea states



S \ H	Linear	Weakly nonlinear	Impulsive nonlinear
Quasi static	X		
Dynamic			X



S \ H	Linear	Weakly nonlinear	Impulsive nonlinear
Quasi static	X		
Dynamic	X		X

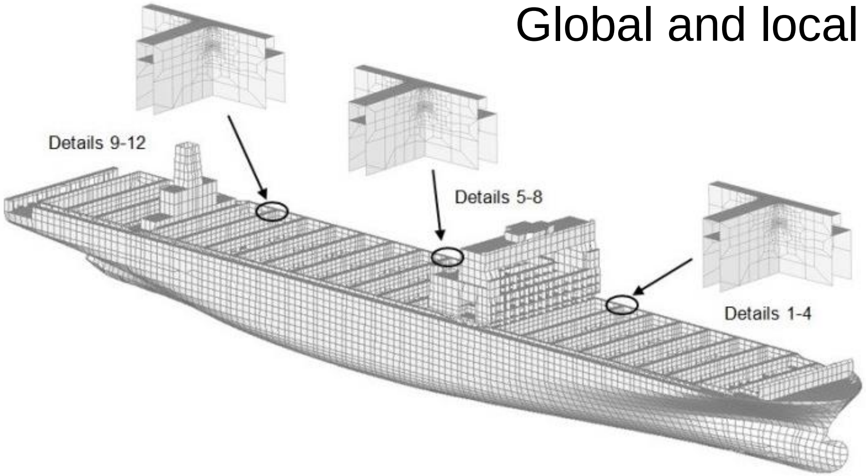


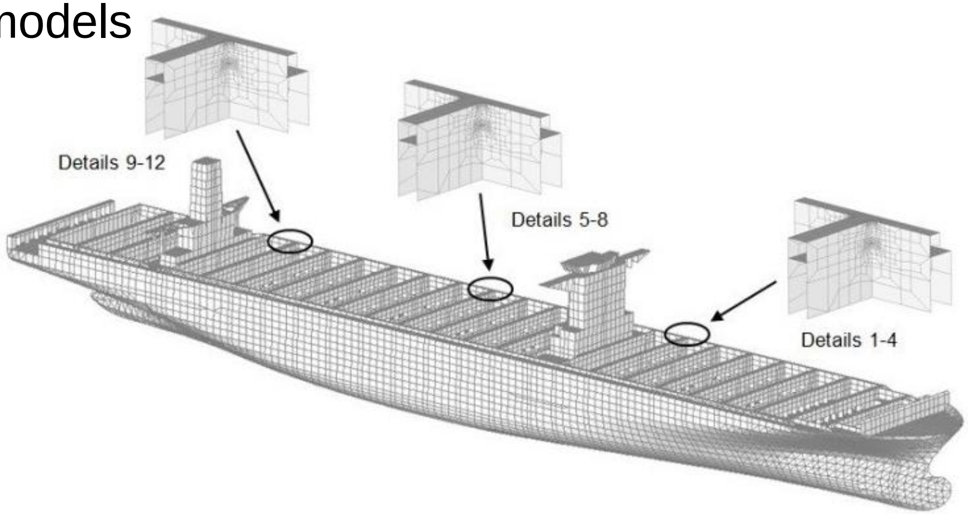
Evaluation of structural design of novel ULCS design on WhiSp 1, 2 and 3 levels

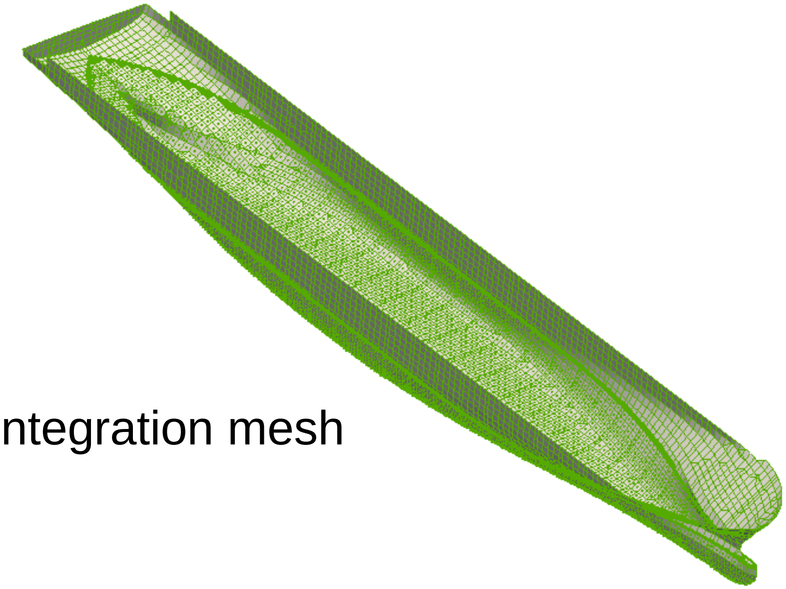
- ✓ comparison between conventional design and SkyBench™ of 19,000 TEU class container carrier
- ✓ ULS; evaluation of hull girder stress + additional points in SkyBench™ container carrier (connection part between hull and side towers, interface structures in way of securing devices and several square corners in way of bridge type mobile part)
- ✓ FLS; fatigue evaluation of hatch and bench corners + additional points in SkyBench™ container carrier
- ✓ Separation of quasi static and hydroelastic contributions in order to assess the relative influence of hydroelasticity.

Application of HOMER software

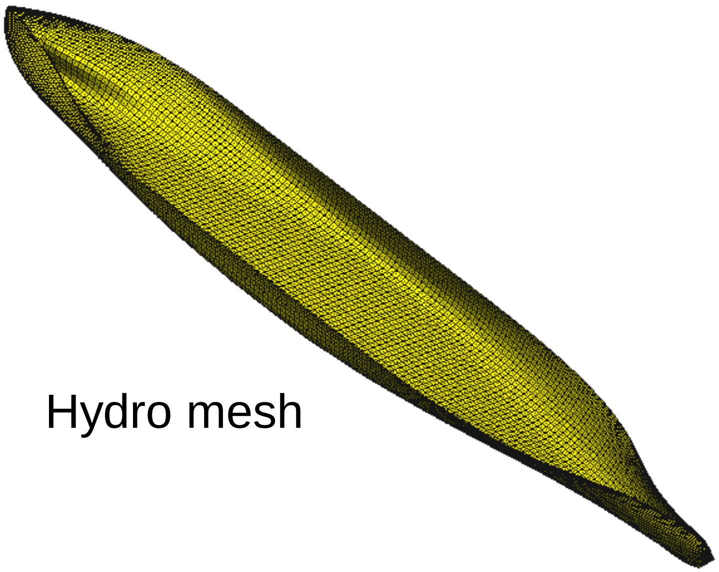
FE meshes
Global and local models





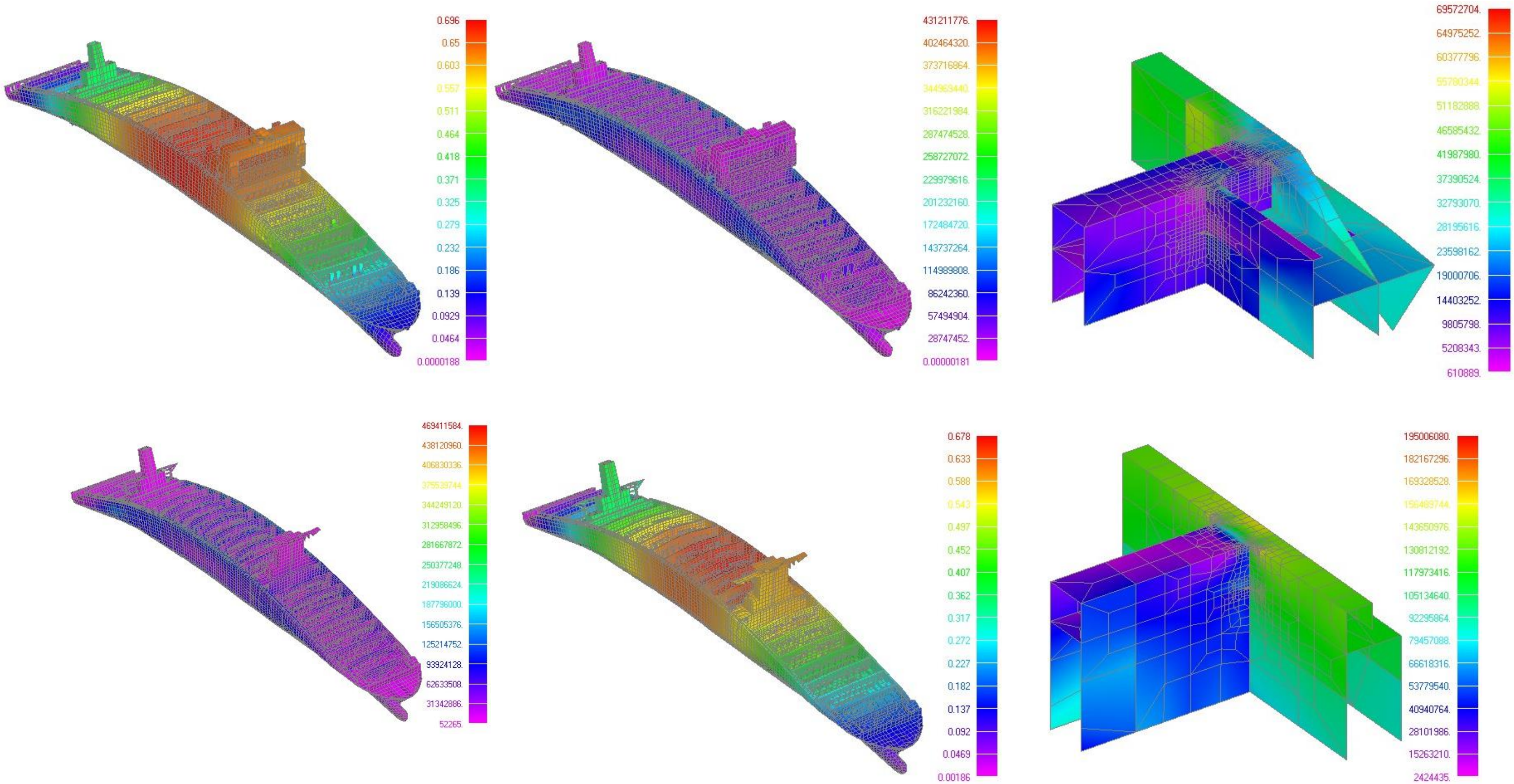


Integration mesh



Hydro mesh

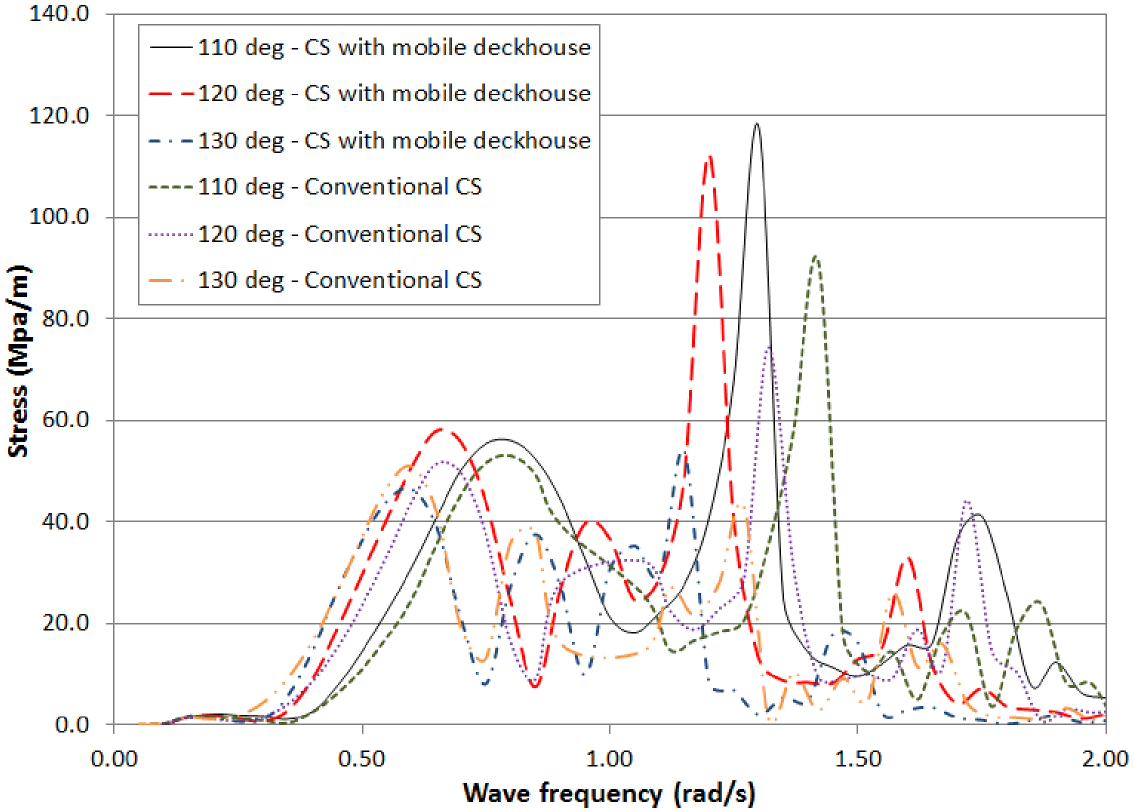
Application of HOMER software



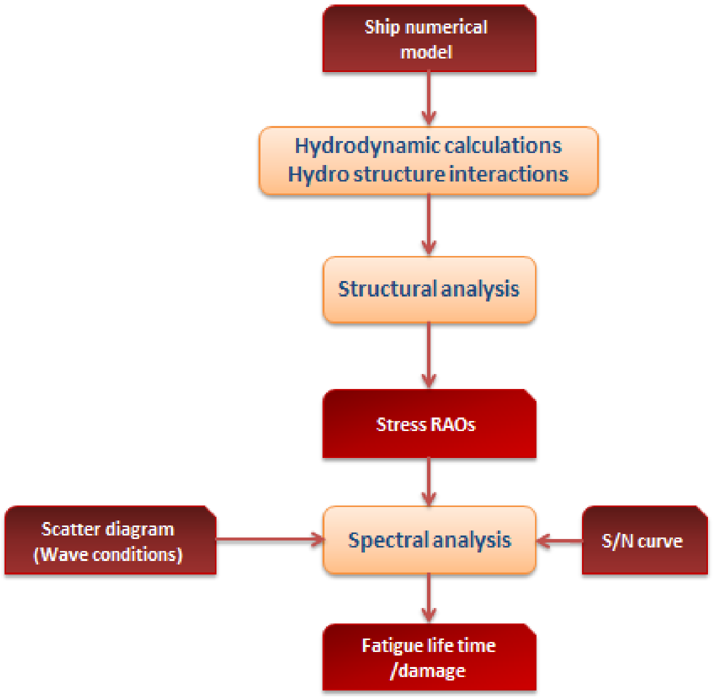
Still water deflections [m]

Still water stresses [Pa]

Application of HOMER software



Stress RAO sample with springing effect included



Procedure flowchart

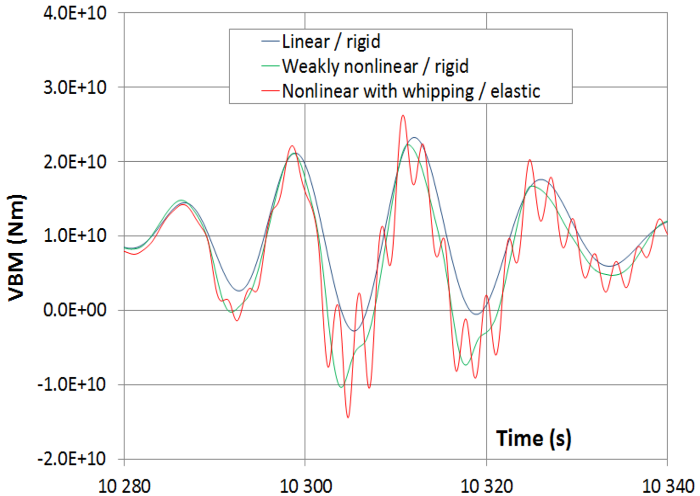
➢ Results

✓ WhiSp1 - Fatigue damage ratios

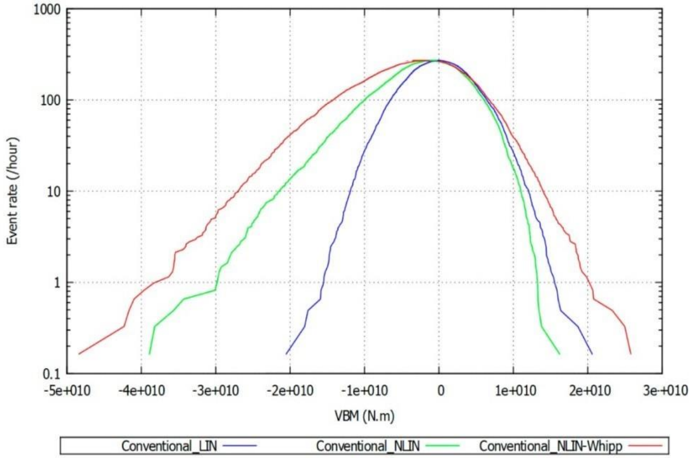
Detail	Damage ratio (Conventional CS/CS with mobile deckhouse)		Damage ratio (WhiSp1/Quasi-static linear)	
	Quasi-static linear	WhiSp1	CS with mobile deckhouse	Conventional CS
1	1.46	1.14	1.51	1.18
2	0.60	0.67	5.18	5.77
3	1.25	0.58	3.97	1.85
4	0.76	0.29	2.95	1.15
5	1.00	0.90	1.27	1.14
6	0.87	0.83	1.24	1.19
7	0.86	0.82	2.30	2.20
8	0.63	0.51	2.53	2.04
9	0.84	0.89	1.95	2.07
10	0.58	0.72	2.16	2.68
11	0.74	0.76	1.87	1.94
12	0.96	0.90	2.11	1.97

Application of HOMER software

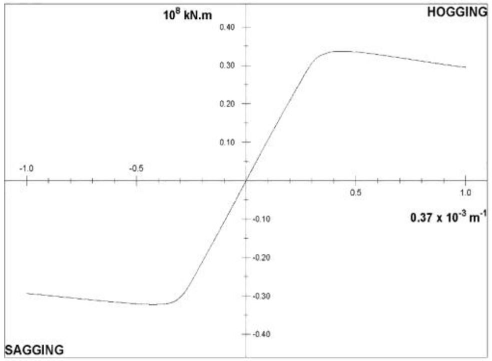
➢ Results



Typical VBM time history amidships

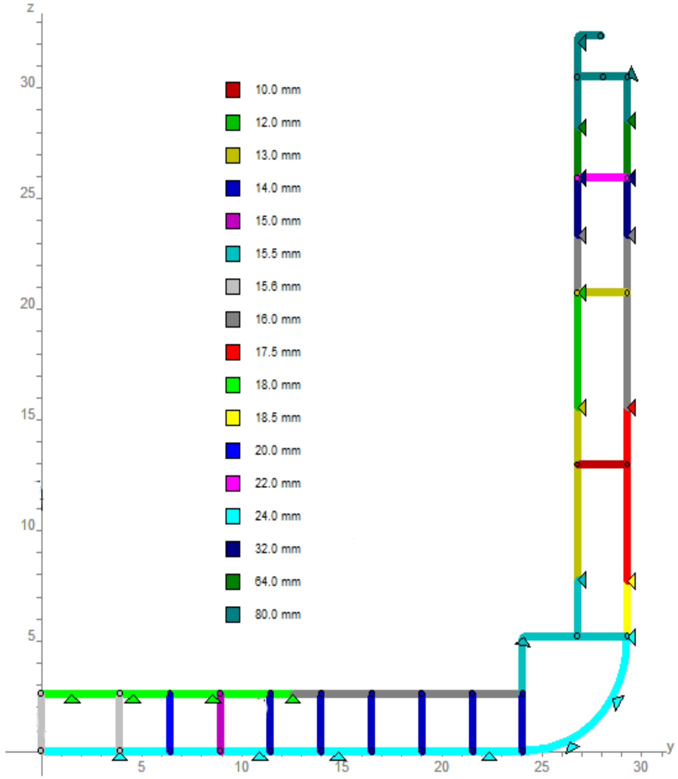


VBM upcrossing extrema distribution



Criterion

$$M \leq \frac{M_U}{\gamma_R}$$



Application of HOMER software

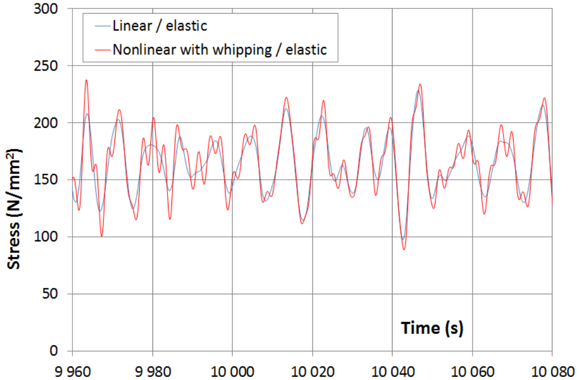
➢ Results

✓ Whisp 2 – Relative influence of whipping on VBM

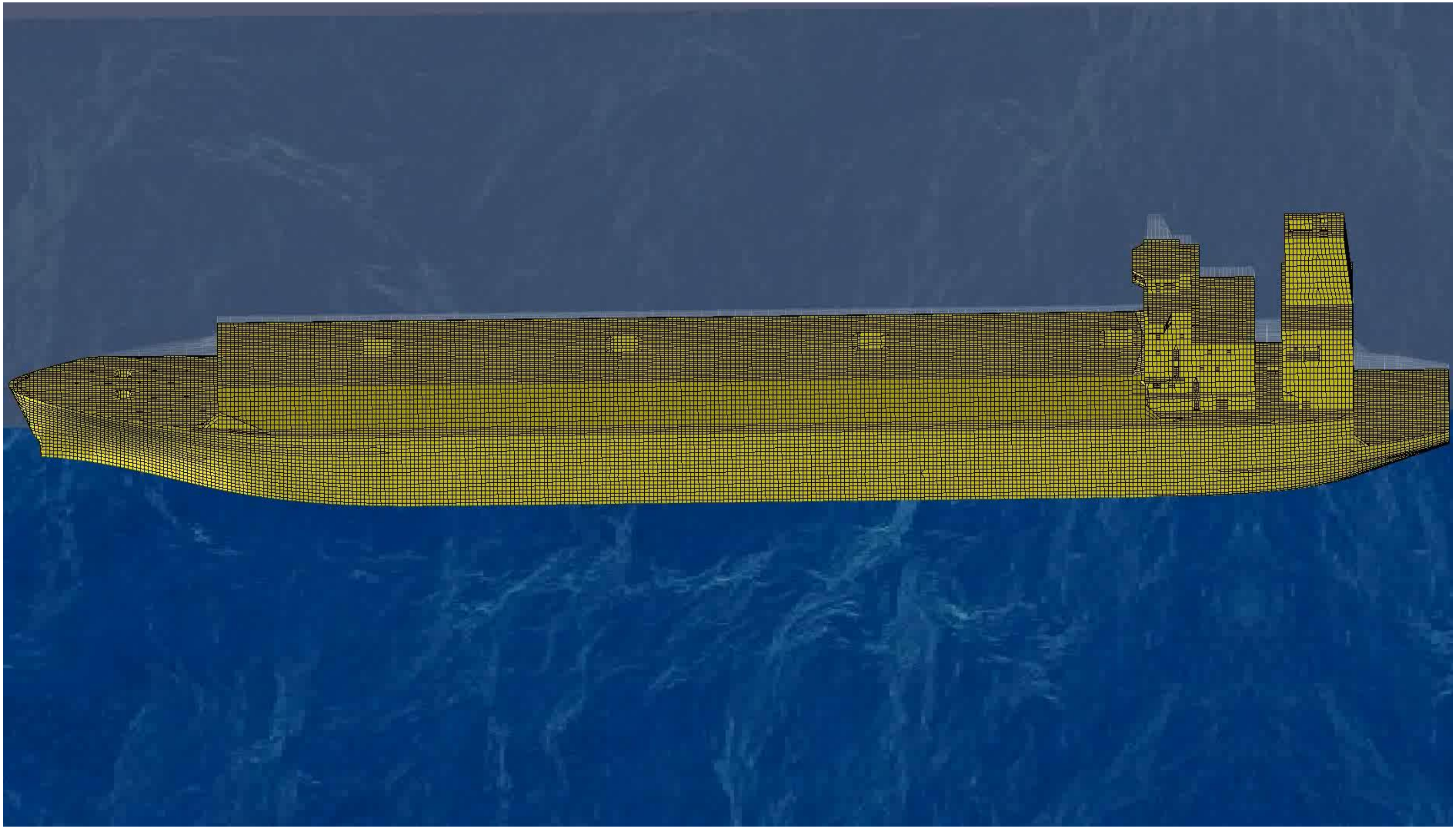
Item	CS with mobile deckhouse		Conventional CS	
	Sagging	Hogging	Sagging	Hogging
Still Water Bending Moment (SWBM)	1.023E+10		9.928E+09	
Quasi-static linear (without SWBM)	1.426E+10		1.494E+10	
Quasi-static nonlinear (without SWBM)	-2.542E+10	1.328E+10	-2.801E+10	1.309E+10
Whipping nonlinear (without SWBM)	-3.042E+10	1.743E+10	-3.434E+10	1.872E+10
Quasi-static total (with SWBM)	-1.519E+10	2.351E+10	-1.808E+10	2.302E+10
Whipping total (with SWBM)	-2.019E+10	2.766E+10	-2.441E+10	2.865E+10
Relative influence of Whipping	32.9%	17.7%	35.0%	24.5%

✓ WhiSp 3 – Relative influence of whipping on fatigue

Detail	Damage ratio (WhiSp3/Quasi-static linear)	
	CS with mobile deckhouse	Conventional CS
1	3.83	3.21
8	2.77	2.46
11	2.01	2.34



Application of HOMER software

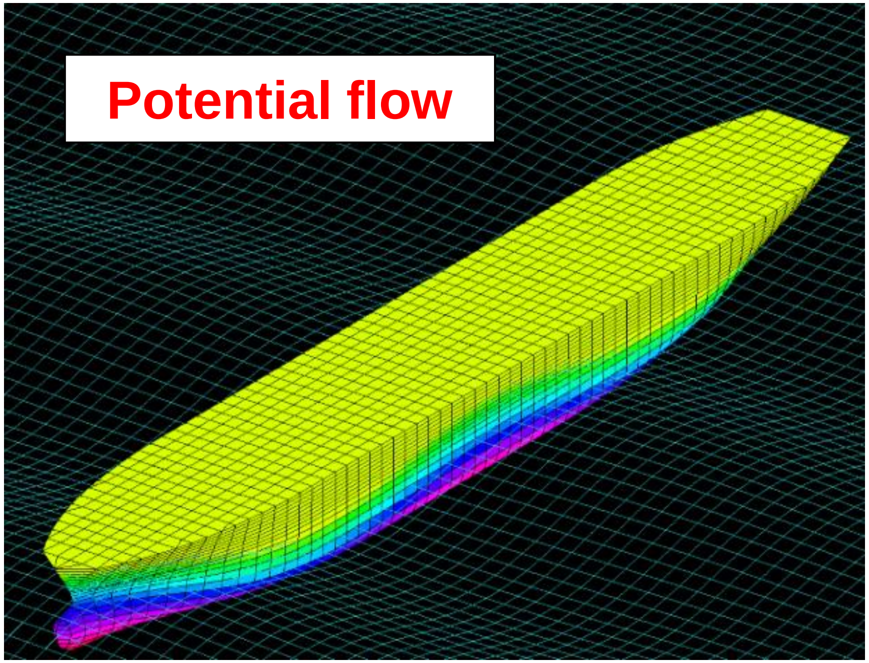


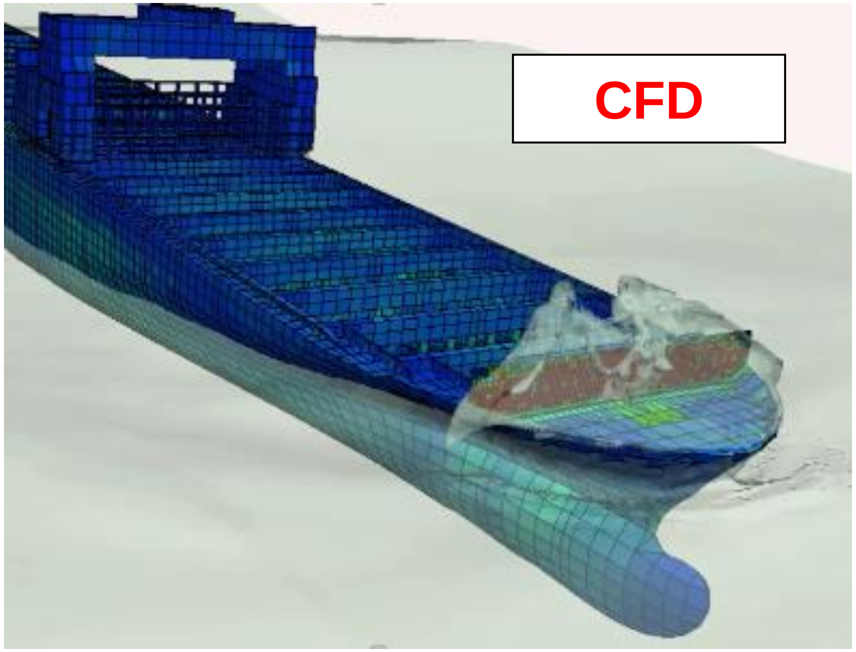
Response of LNG vessel (HHI) in waves, simulated by means of HOMER (BV)

Numerical models – current trends (Potential flow &/or CFD)

- **Advantages**
  - ✓ Very fast and very precise
- **Limitations**
  - ✓ Handling od nonlinear effects
    - *Global (large waves and motions,...)*
    - *Local (slamming, green water...)*

- **Advantages**
  - ✓ No limitations vs. nonlinear effects
- **Limitations**
  - ✓ Numerical issues
    - *Meshing*
    - *Convergence & stability*
  - ✓ CPU time

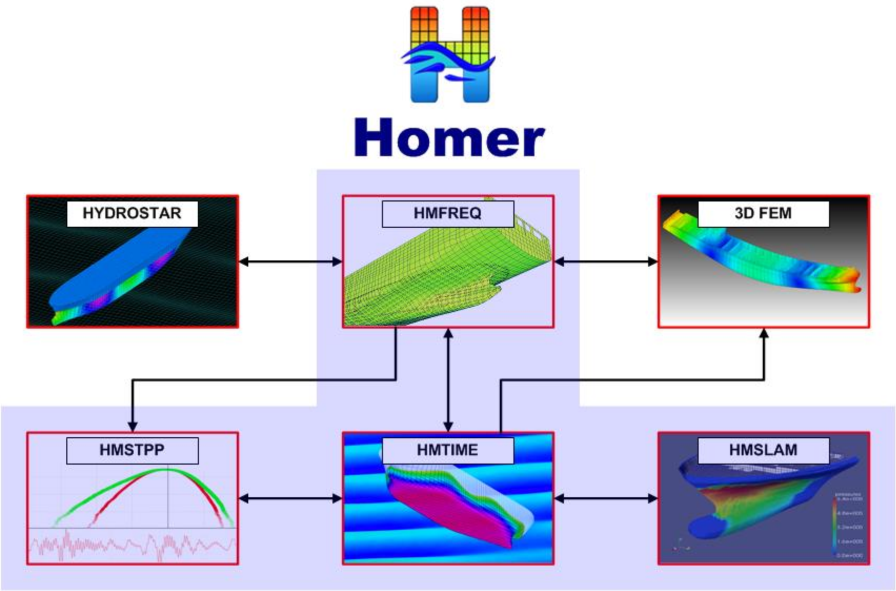




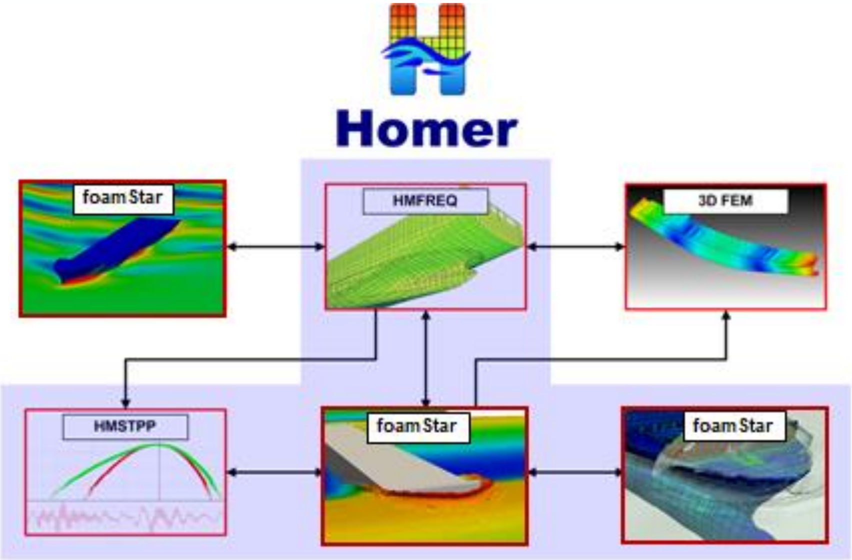
Numerical models – current trends (Potential flow &/or CFD)

➢ **Summary of coupling schemes**

✓ With Hydrostar



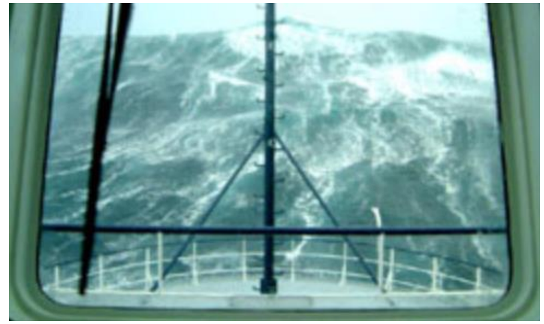
✓ With foamStar

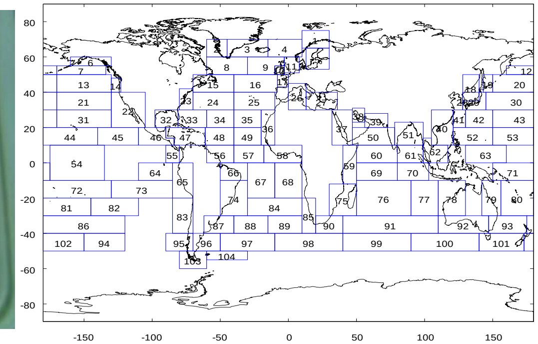


Numerical models – special application cases – green water

➢ Methodology

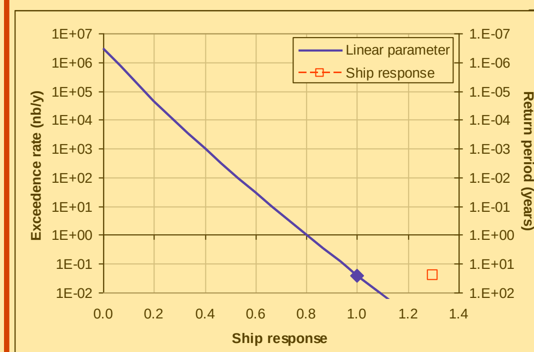
1 Definition of the representative operational profile

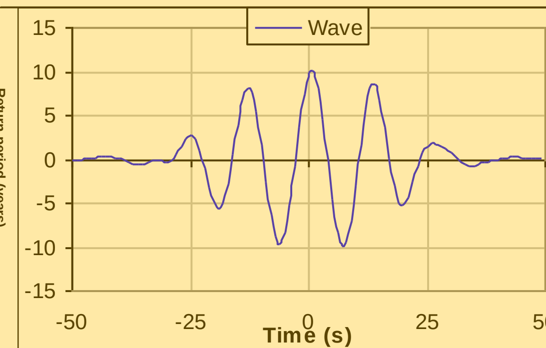




Potential flow

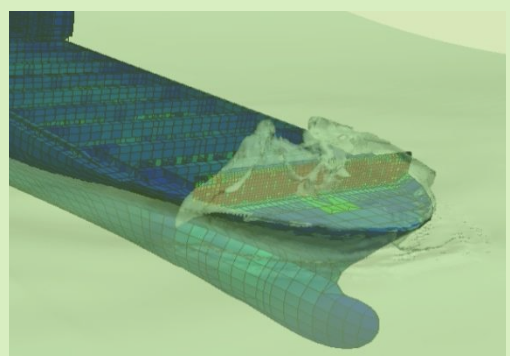
2 Identification of the representative design conditions

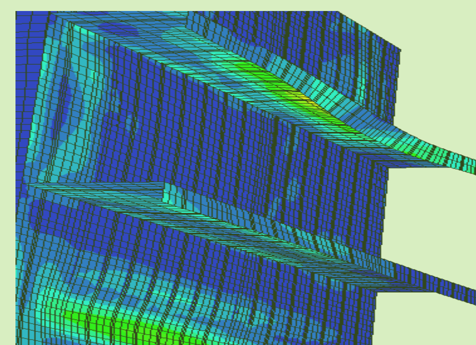




CFD

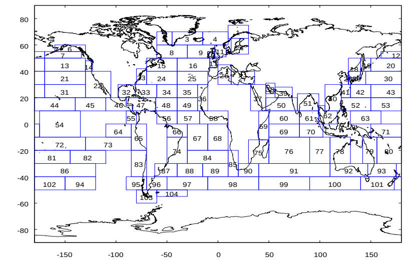
3 Hydro-structure simulations for design conditions



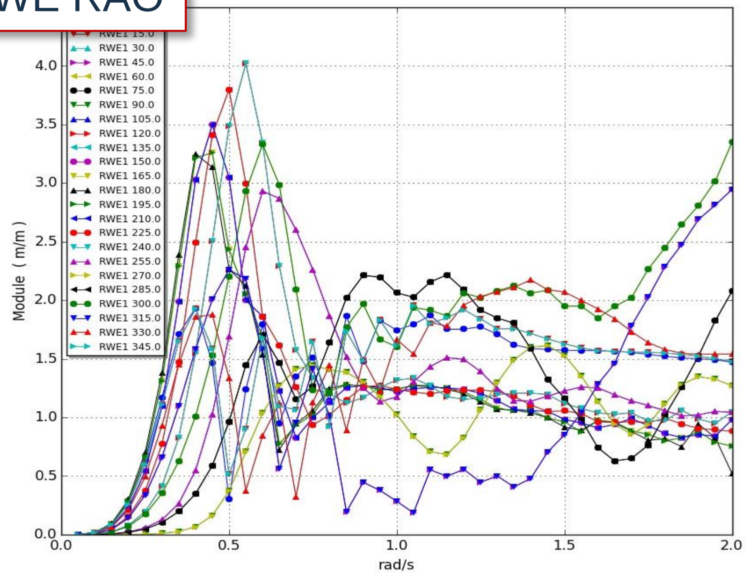


Design waves

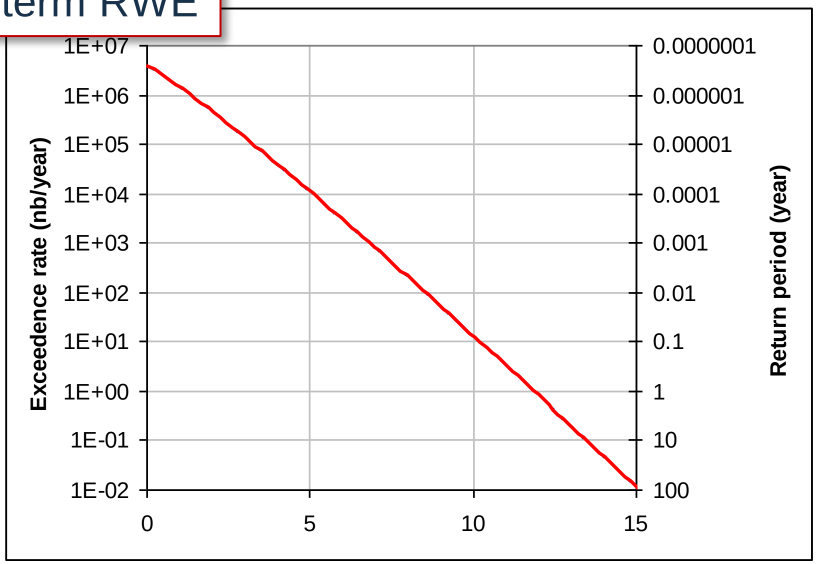
- ✓ Dominant loading parameter – relative wave elevation
- ✓ Bureau Veritas & UNIZAG FSB

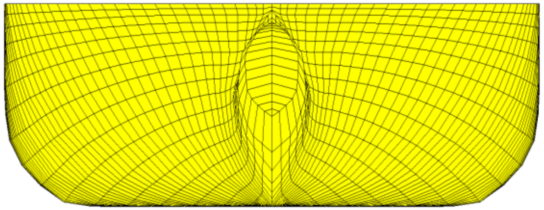


RWE RAO

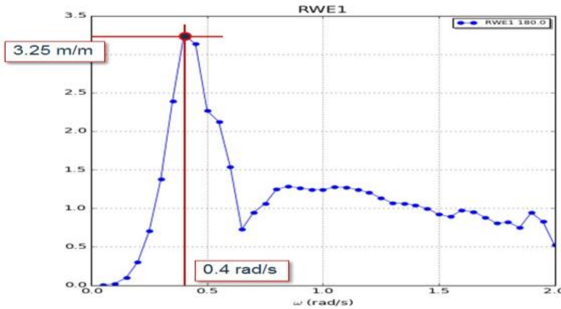


Long term RWE



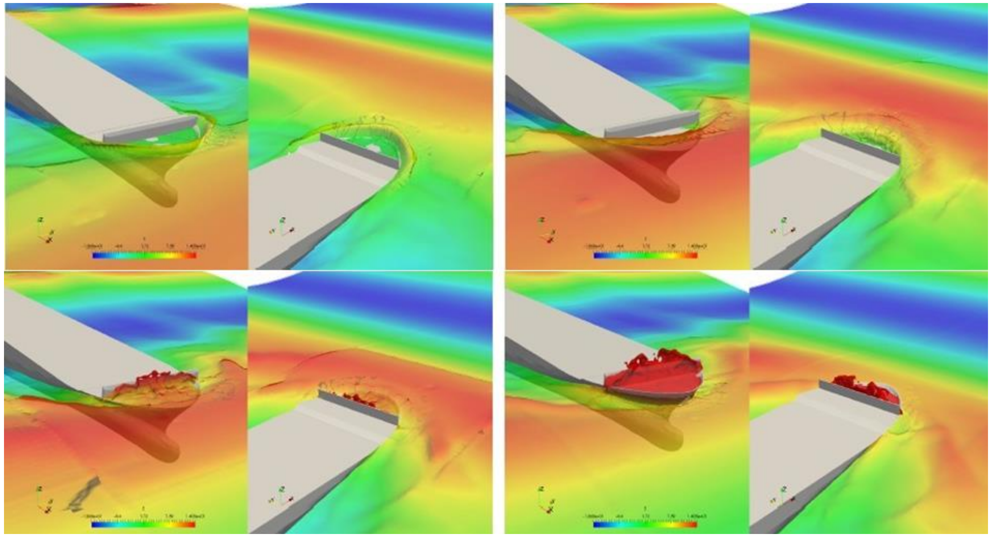


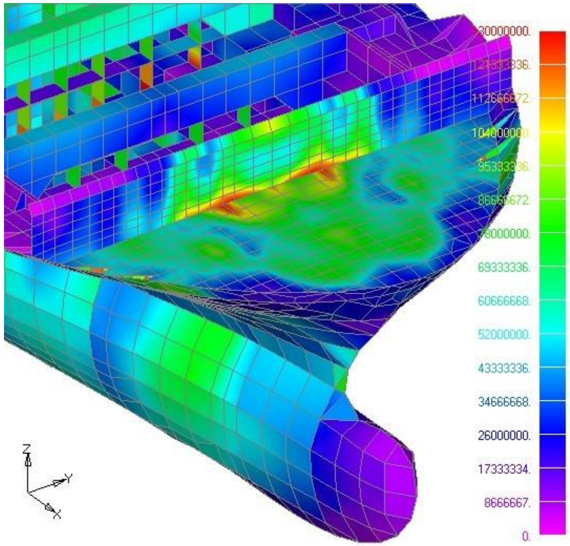
A=Long_Term / RAO_max

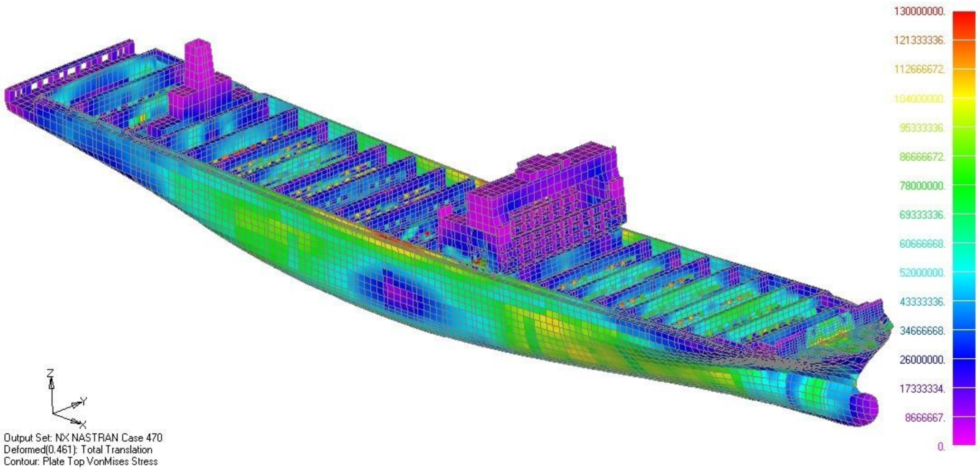


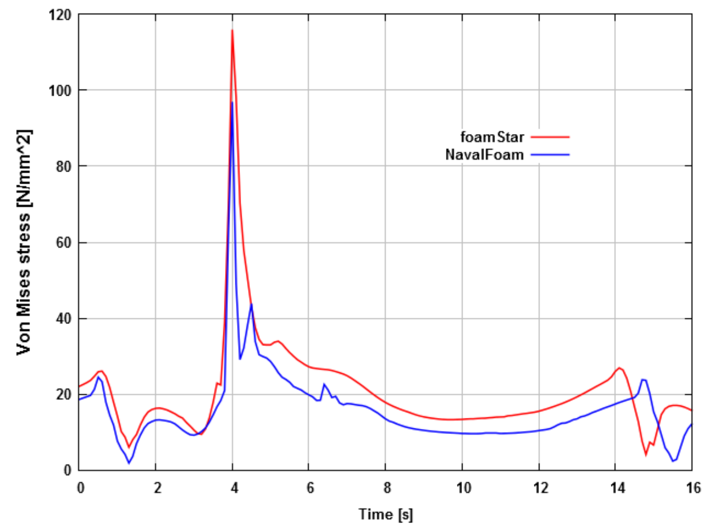
Numerical models – special application cases – green water

➢ Hydro-structure interactions



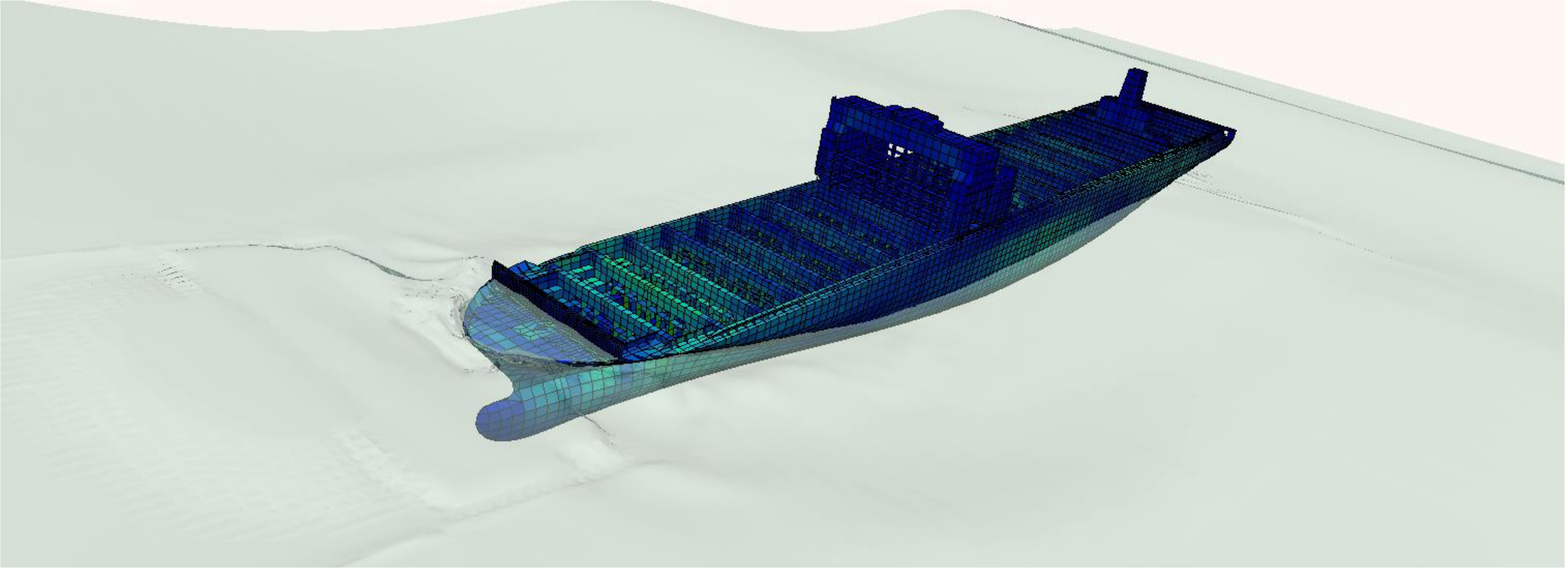






JRP within GCRC-SOP (BV, UNIZAG FSB, HHI)

- ✓ Determination of design waves (Hydrostar)
- ✓ CFD simulations (OpenFOAM)
- ✓ Structural analysis (NASTRAN)
- ✓ Coupling (HOMER coupling scheme)



Conclusion

➢ An overview of ship hydroelasticity is given

- ✓ Emphasis on numerical models developed within projects involving UNIZAG FSB and Partners (Bureau Veritas, Pusan Natl. Univ., Hyundai Heavy Industries, etc.) – particularly *TULCS* and *GCRC-SOP*
- ✓ Hydroelasticity of ships is still „open” issue – beside numerical codes still should be investigated by model tests and full-scale measurements
- ✓ Development of hydroelastic numerical codes and direct calculation methodologies should be done simultaneously (Example: HOMER & WhiSp)
- ✓ Trends in development of numerical codes: coupling of 3D FEM tools with CFD tools
- ✓ Application of hydroelastic theories becomes wider (simplified models including plates and stiffened panels, wedge-shaped bodies, ice-sheets, ships, very large floating structures, propellers, offshore structures, etc.)

Thanks for Your Attention!!!

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