Report of the 26th ITTC Seakeeping Committee

Presented by Paul Crossland

Brazil, September 2011

Membership

- Paul Crossland (Chairman), QinetiQ,UK
- Dariusz Fathi (Secretary), Marintek, Norway
- Dan Hayden, Carderock Division, Naval Surface Warfare Center, USA
- Greg Hermanski, Institute for Ocean Technology, Canada
- Lex Keuning, Delft University of Technology, The Netherlands
- Yonghwan Kim, Seoul National University, South Korea
- Rumen Kishev, Bulgarian Ship Hydrodynamic Centre, Bulgaria
- Koichiro Matsumoto, Universal Shipbuilding Corporation, Japan
- Quanming Miao, China Ship Scientific Research Center, China

Seakeeping Committee meeting at the V&V workshop

Committee meetings

- January 2009, Delft University of Technology, The Netherlands
- October 2009, China Ship Scientific Research Center, China
- May 2010, Institute for Ocean Technology, Canada
- February 2011, QinetiQ Ltd, United Kingdom

Additional meetings

- October 2010 - V&V Workshop South Korea
- November 2010 - Joint ISSC/ITTC meeting, United Kingdom

Set up an e-room hosted by MARINTEK to upload, store and download information

Presentation outline

- Recommendations of 25th ITTC
- Cooperation with ISSC
- Highlights
- State of the art review
- Verification and validation workshop
- Recommended procedures
- Recommendations for further work
- Discussion

Recommendations of 25th ITTC

1. State-of-the-art review

2. ITTC Recommended Procedures

- Review existing pertinent procedures
- Amend Procedure 7.5-02-07-02.1, “Seakeeping Experiments” to bring uncertainty analysis into line with ISO GUM
- Assess whether Recommended Procedure 4.2.4-01, “Standard Format for Exchange of Seakeeping Data on Computer-Compatible Media” shall be retained.
- Develop a new procedure on the prediction of global wave loads.
- Develop a new procedure for the prediction of power increase in waves from model tests.

Recommendations of 25th ITTC

4. Organize a workshop on the verification and validation of non-linear seakeeping codes. The results of the workshop will be used to develop the procedure on validation and verification of non-linear seakeeping computer codes.

5. Liaise with the ISSC and the Ocean Engineering Committee.

Cooperation with ISSC

- Importance of cooperation recognised by 25th ITTC
- Further cooperation mandated by ITTC and also by the pertinent ISSC committees
- Joint meeting hosted by Lloyds Register in Portsmouth in November 2010
- Attended by representatives from the ITTC SC and OEC and ISSC Loads and Responses and Environment committees
- Possible level of cooperation
  - Joint Project represents a high level of commitment complicated by the one year phase difference of the two committees
  - Joint workshop seemed preferred level of cooperation

Aim of understanding uncertainty modelling and its impact on:

- Model testing
- Full scale measurements
- Load prediction techniques
- Experimental validation techniques
- Utilization of satellite measurements
- Extreme environmental phenomena
- Risk assessment and mitigation
- Goal based standardisation

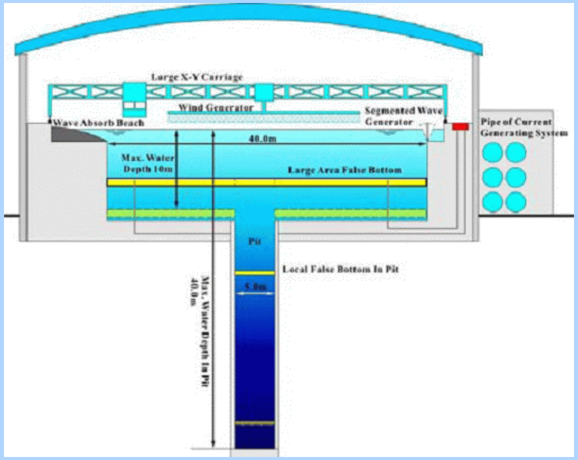
Highlights

- Procedures
  - Developed two new procedures
  - Major updates to two
  - Minor corrections to one
  - One withdrawn
- State of the art review with emphasis on sloshing, hydroelasticity and added resistance
- Underpin a common approach to predicting added power
- Workshop on V&V of non-linear seakeeping codes

State of the art review

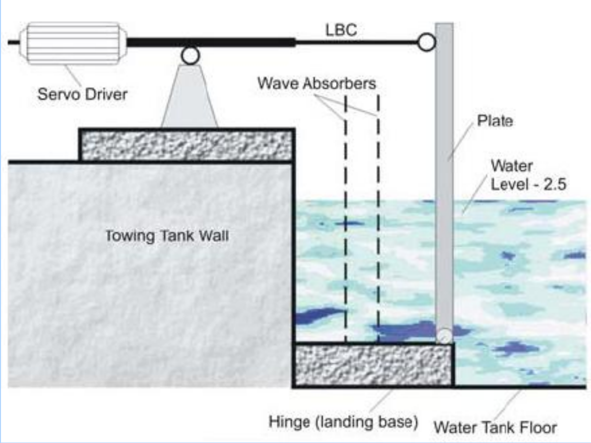
- New experimental facilities
- Experimental techniques
- Numerical methods (frequency and time domain)
- Rarely occurring events
- Sloshing
- Hydroelasticity (hull girder loads)
- Added resistance and power
- CFD applications

New experimental facilities



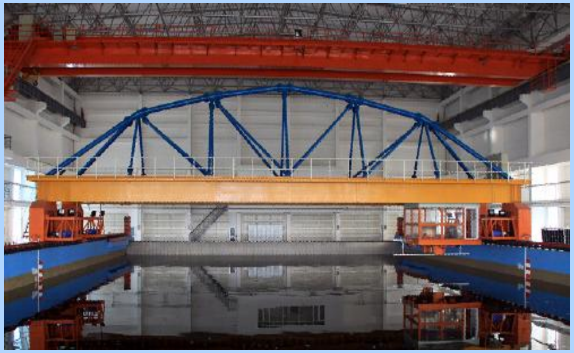
- Deepwater offshore basin in Shanghai Jiao Tong University (50m long, 40m wide, with a water depth of 10m and a 40m deep pit)

- Upgrade to the wavemaker at the Bulgarian Ship Hydrodynamics Centre. System has been developed based on AC servomotors and ball-screw pairs.

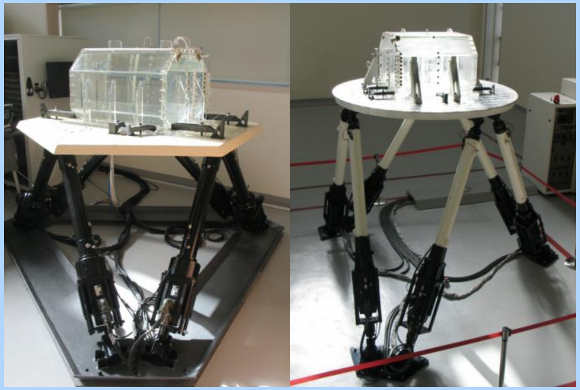


New experimental facilities

- Ocean Basin at Harbin Engineering University (50m long x 30m wide and 10m deep). Main carriage speed up to 3 m/s (with a sub-carriage capable of 2m/s).



- Sloshing Test Facility at Seoul National University. 1.5 tonne and 5 tonne capacity platforms in operation; a large 10 tonne platform is under construction



Experimental techniques - waves

- Generation of irregular waves using linear and second order statistical models to fit the crests and heights of observed waves, (Petrova and Guedes Soares, 2008).

- Development of a multi-peaked directional spectral approach that allows the fitting of spectral models to measured or Hindcast data, (Petrova and Guedes Soares, 2009)

- Development of a technique to generate design rogue wave sequences in extreme seas, (Clauss, 2008). The method is suited for investigating the mechanisms of specific extreme events.

Experimental techniques – Model tests

- Investigation of structural loading in extreme seas, (Roused *et al*, 2010). Investigated different configurations in irregular, unidirectional and bi-directional waves.

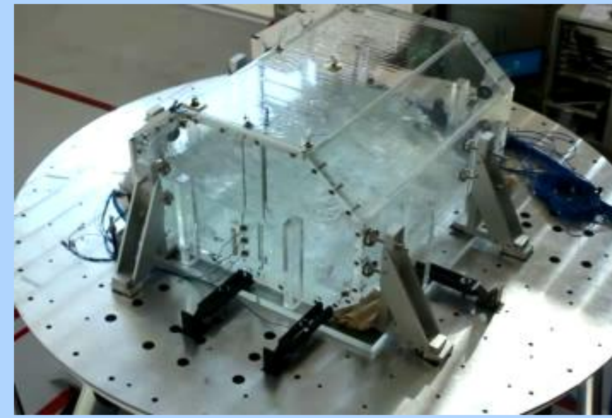
- Measurement of hull surface pressure in the alternately wet and dry areas near the water line and near the bow of a high speed vessel in irregular head waves, (Chiu *et al*, 2009). The model had a high deadrise angle so was subjected to impacts and bow wave effects

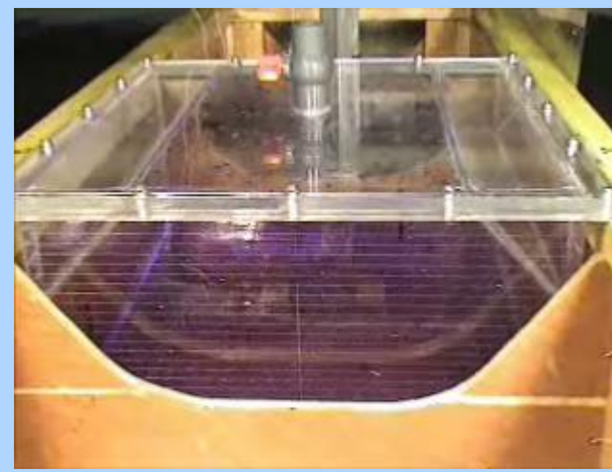
- Experiments to evaluate the performance of a submarine operating on surface with focus on modelling the effect of free flow under the casing on the roll response, (Hermanski and Kim, 2010).

Experimental techniques – LNG tests

The greater demand for safety in LNG carrier design results in the emergence of new experimental facilities and R&D projects investigating sloshing phenomena.

- Understanding the coupling effect of LNG containers on ship motion
- Understanding of local behaviour of sloshing on the LNG containment systems.
- Influence of fluid/gases to replicate full scale behaviour
- Deriving full-scale design loads from model experiments





Model –scale tank test and sloshing-motion coupling test (Seoul National University)

Experimental techniques – Full scale trials

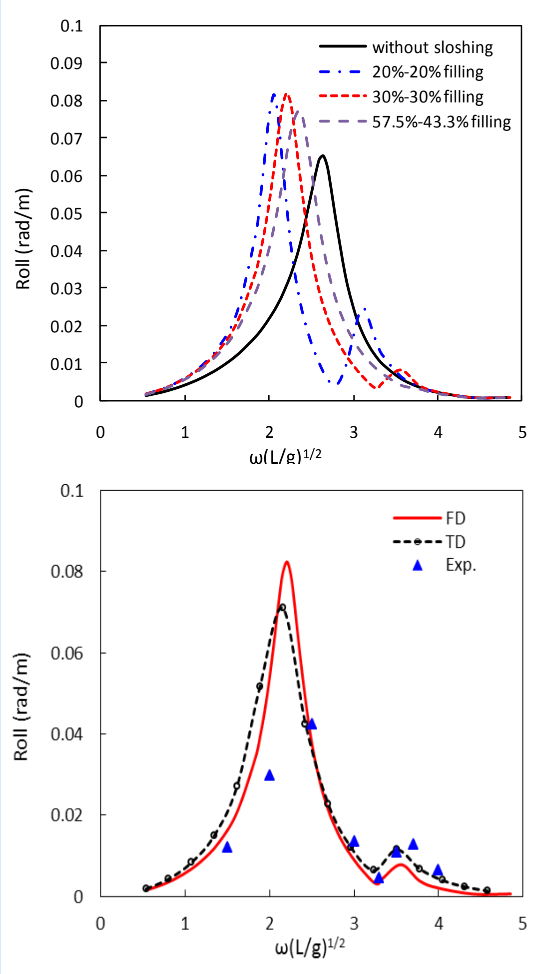
Sea trials are considered to provide the most pertinent source of data; though the uncertainty must be considered when examining the results.

- Derivation of methods for estimating the waves from vessel motion, (Pascoal and Guedes Soares, 2009). Used motion sensor data as input and provides an estimation of sea conditions and spectra.
- Lee *et al*, 2010, presented the results from a hull stress monitoring system installed on a container ship. They recorded the hull girder loads during a storm in the Mediterranean Sea.
- Methods developed to estimate waves and wave spectra from shipboard radar, (Lyzenga and Nwogu, 2010)

Numerical techniques - Frequency domain

Less developments in frequency domain analysis. Advances are quite targeted

- Fluid-structure interaction, e.g., establishing correlation between modal accelerations on an elastic segmented model to back estimate the model loading, (Coppotelli *et al*, 2008)
- Coupled ship motion and sloshing, e.g., investigating the ship resonance as a result of sloshing interaction.
- Multi-body, two ships in close proximity, problems such as Underway Replenishment, (Li, 2009) studied two ship interaction in deep and shallow water.



Frequency-domain solution of sloshing-motion coupling for a 285m LNG-FPSO (Gou *et al.)*

Numerical techniques - Time domain

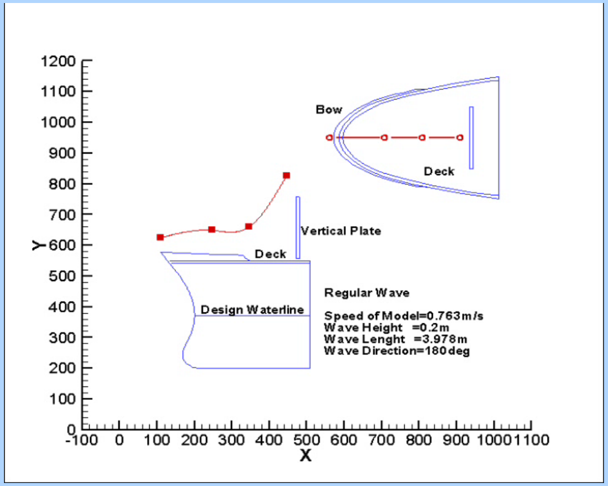
Computational methodology for time-domain approaches

Numerical Method	Advantage	Disadvantage	CPU capacity and time
Impulse-Response-Function approach	Easy to implement, fast computation require small computer memory	Need pre-computed hydrodynamics coefficients Limited applicability	Minimal
Strip/sectional-based approach	2D BVP Fast computation require small computer memory	Limitation as 2D sectional method Poor accuracy in low frequency	Minimal
Transient wave Green function approach	Radiation condition is automatically satisfied. Panel distribution on only body surface	Hard to compute Green function for non-zero speed Limited application	Moderate
Rankine panel method	Good practicality Easy extension to nonlinear analysis Good overall accuracy	Difficulty in 3D geometric modelling and panel generation Need a numerical method for radiation condition	Moderate
CFD method solving field equation(s)	Capability for violent ship motion Can include viscous effects	Huge computational time and effort Poor accuracy in memory flow	Heavy
Hybrid method combing two methods	Taking advantages of combined method	No benefits in many combinations Additional effort for combinations	(Varying)

Numerical techniques – Green water

Increasing use of CFD is these applications

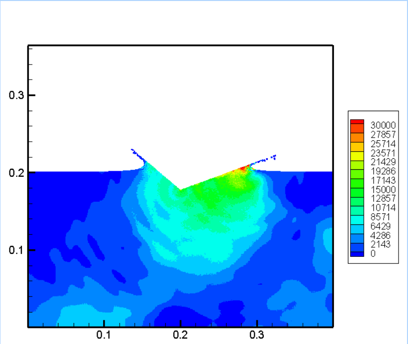
- A combined/coupled approach with traditional potential flow seakeeping analysis and CFD methods.
  - Grid methods such as Navier-Stokes for 3D water-on-deck problems, (Colicchio *et al*, 2010), for example.
  - Gridless methods such as Moving Particle Semi-implicit (MPS) and Smooth Particle Hydrodynamics (SPH) for impact pressures and violent free-surface flows, (Lee *et al*, 2009) and (Le Touzé *et al*, 2010)



Numerical techniques – Slamming

Focus of slamming research is tailored toward practical applications

- Slamming analysis is still largely empirically based
  - Statistical properties of impact loads based on Wagner theory, (Kapsenberg and Thornhill, 2010) method of long term simulation to derive impact loads
  - Coupled time domain strip theory with the Wagner formulation, (Hermundstad and Moan, 2009) presented ship motion and slamming pressures of a Ro-Ro ferry.
- Alternative approaches include CFD largely on simple 2D shapes, (Veen and Gourlay, 2009).

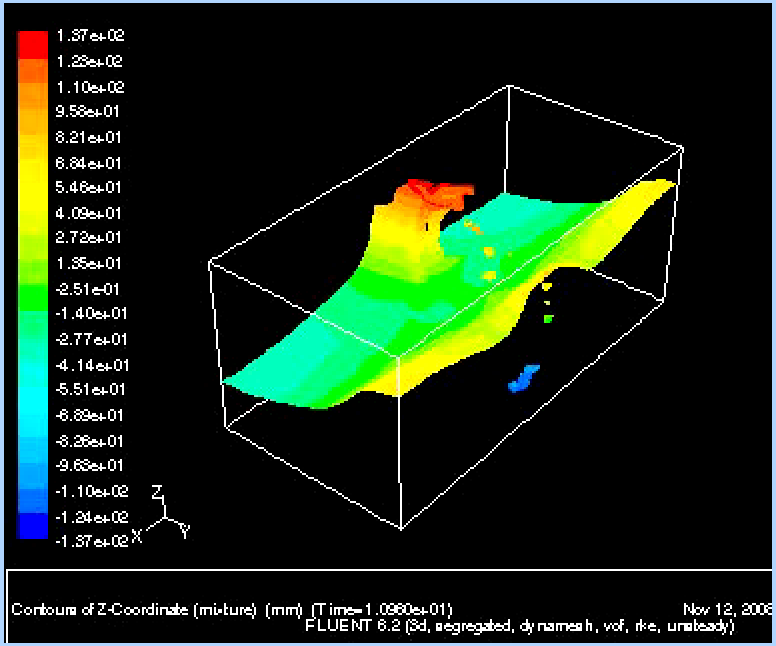


SPH simulation for wedge impact

Sloshing

Complex phenomena of fluid movement showing strong non-linearity and apparent randomness.

- The knowledge of the sloshing problem has reached unprecedented levels:
  - Significant numbers of papers related to the effect of liquid sloshing
  - A number of papers related to the coupling effects of sloshing
- Despite the numerical and experimental modelling, there is no fully consistent solution to determining full scale sloshing loads



Numerical techniques – Sloshing

- Work summarised in Tables 3 and 4 of report
- Overview of sloshing problem, Gavory and de Seze (2009)
- Overview of coupled ship motion/sloshing problem Faltinsen and Timokha (2009a)
- Impact loads are highly localised requiring simplified hydrodynamic models to define the shape of the wave front
  - Wagner-type impact
  - Steep wave-type impact
  - Bagnold-type impact
  - Aerated fluid impact
- CFD methods (RANS, SPH, CIP, MPS *et al)* are used to characterize the free surface and predict impact pressures

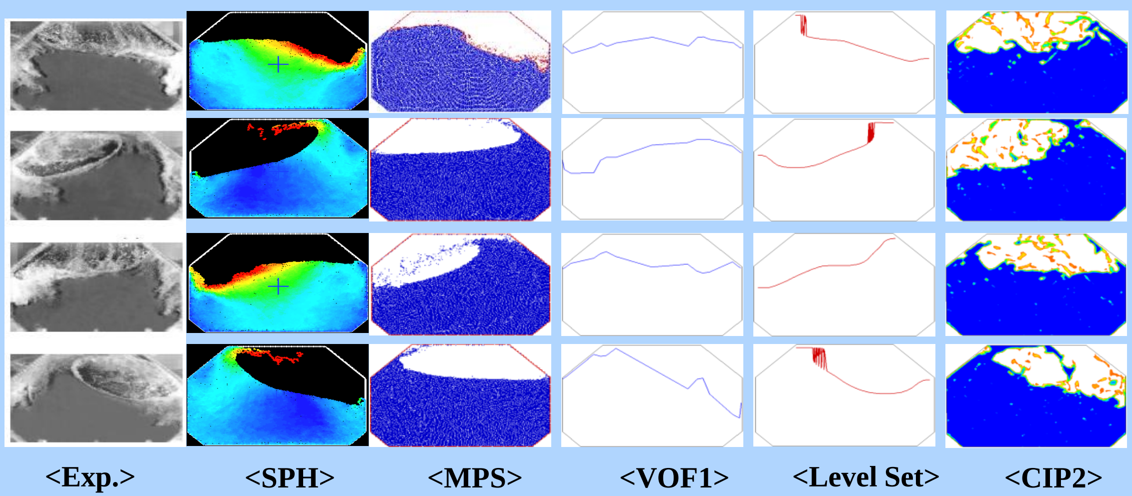
Numerical and experimental techniques – Sloshing

- Research on sloshing
  - ExxonMobil covering development of sloshing related procedures
  - GTT developed sloshing assessment procedure and developed mathematical models
  - Class Societies have developed procedures for predicting the sloshing loads and to evaluate structural strength
  - Joint Industry Project SLOSHEL aimed at collecting data from full-scale experiments.

Experiment in SLOSHEL JIP

Numerical and experimental techniques – Sloshing

- Three Sloshing Dynamics and Design Symposia (held in 2009~2011) as a part of the ISOPE conference
  - 1st included a comparative study on CFD
  - 2nd included a comparative study investigating impulsive pressure during the impact of a free-fall water column.

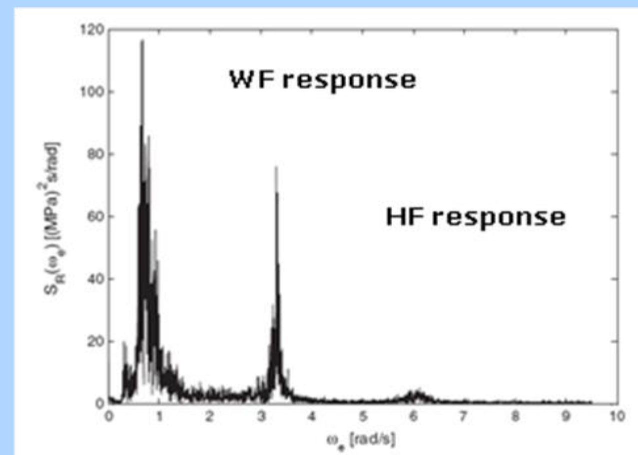


Comparative study of sloshing simulation (ISOPE, 2009)

Hydroelasticity (hull girder loads)

Very large modern ships can be susceptible to springing and slamming-induced whipping - hydroelasticity represents an area where there has been the most significant activity related to the development of time-domain seakeeping analysis.

There are two major contributions to loads: one in the frequency range of the ocean waves, and the other in the high frequency range. The high-frequency response is due to the hydroelastic effect of ship structure.

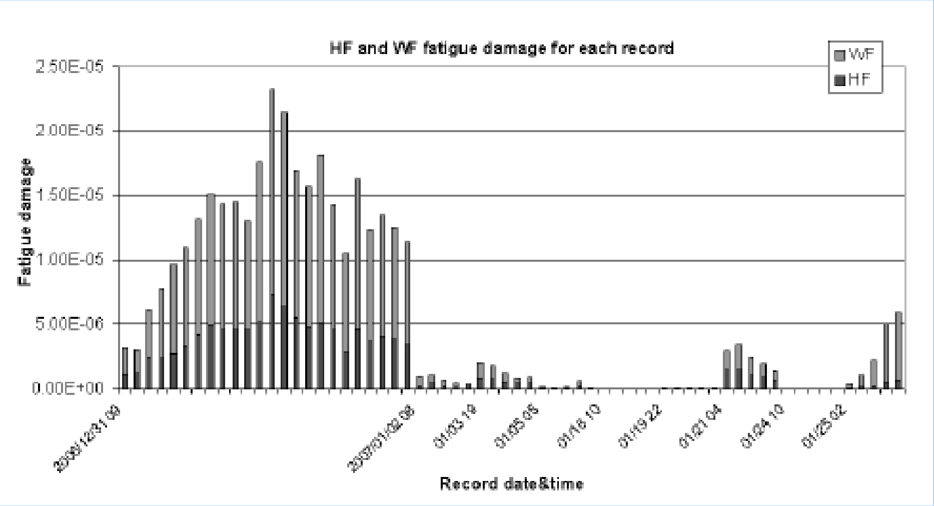


Stress response spectrum measured on a real ship (Vidic-Perunnovic, 2005)

Hydroelasticity (hull girder loads)

The potential for structural damage due to springing and whipping is significant in large modern ships.

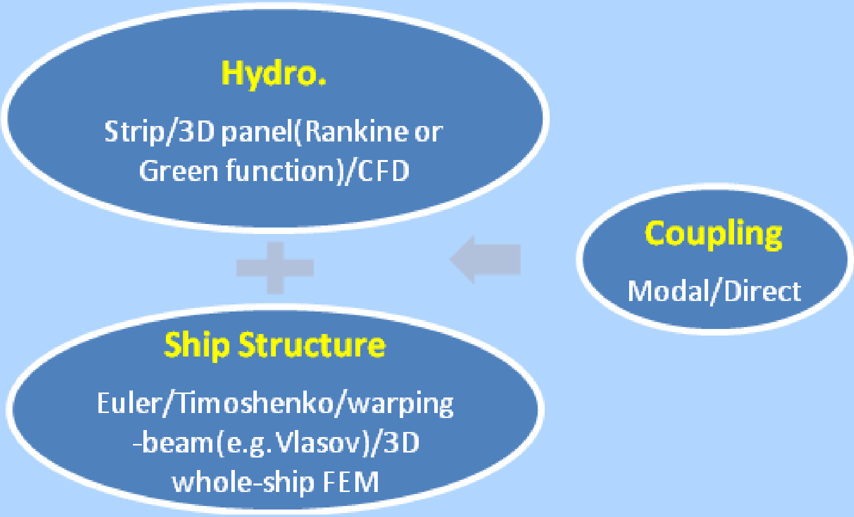
- The high-frequency (HF) component contributes about 20~30% of the total amount of estimated fatigue.
- Recent studies have predicted over 50% increase in fatigue damage.



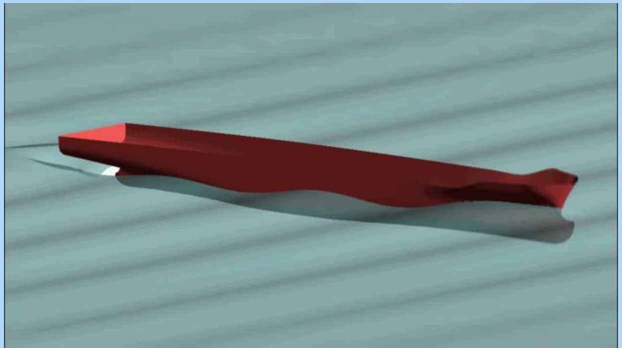
Estimated fatigue damage per hour for the wave frequency (WF) and the high frequency (HF) contributions, Ito, Nielsen and Jensen (2010)

Numerical techniques – Hydroelasticity coupled analysis

- Required to solve the seakeeping and structural problem at the same time
  - Frequency domain approach with beam based modal superposition
  - 3D panel or CFD methods with direct integration for ship structure



Typical analysis methods for ship springing



Numerical simulation of 2nd-order springing (Kim *et al.*, 2010)

Experimental techniques – Hydroelasticity

A hydro-structural model is made to be geometrically similar, hydrodynamically similar and structurally similar

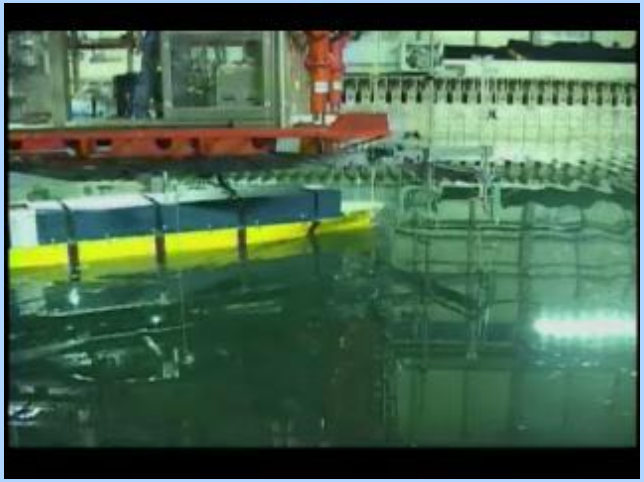
- Two types of model elastic and segmented
- Segmented is the most practicable
- Two types of segmented models
  - Rigid segmented
  - Elastic segmented

Elastic Segmented Model with Internal Backspline Beam (Miyake, 2009).

Flexible Connections for Non-Backspline Elastic Segmented Model (Drummen, 2007).

Experimental techniques – Hydroelasticity

- Hydroelastic models are very expensive to build
- Experimental data not readily shared
- Several European and Asian Joint industry projects
- Is there the potential for ITTC to engage with these partners?



WILS II JIP (MOERI/KORDI, 2009-2010).

Added resistance and power increase in waves

- Interim IMO guidelines for CO2 emissions, the Energy Efficiency Design Index (EEDI)
- EEDI is CO2 emission divided by transported cargo weight and velocity including speed loss at sea

$$\text{EEDI} = \frac{CO_2 \text{from propulstion} + CO_2 \text{ from Auxiliaries - Efficient use of energy}}{f_t \cdot (\text{DWT}) \cdot (\text{ship speed}) \cdot f_w}$$

- Includes *fw* which is a non-dimensional coefficient indicating the decrease of speed in a representative sea condition, e.g. Beaufort Scale 6.
- Emphasizes the need to provide reliable results of power increase in waves

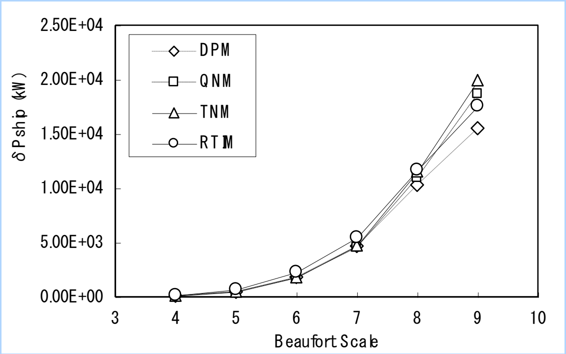
Added resistance and power increase in waves

- Four methods to predict increased powering in irregular waves from model tests in regular waves were investigated by the 25th ITTC SC
  - Torque and Revolution Method (QNM)
  - Thrust and Revolution Method (TNM)
  - Resistance & Thrust Identify Method (RTIM)
  - Direct Power Method (DPM)
- Recommendation was that DPM was unsuitable but 26th ITTC SC required to investigate further

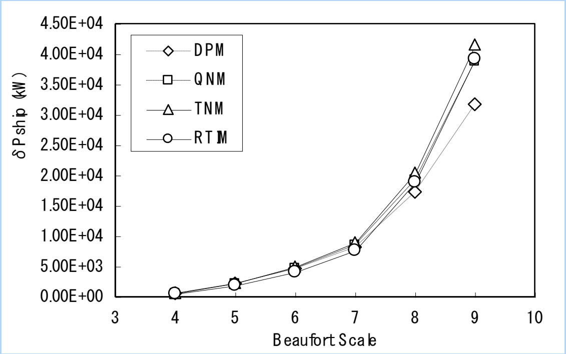
Added resistance and power increase in waves

- QNM, TNM and RTIM give close agreement and so DPM has been removed from the procedure

- Further comparison between QNM, TNM and RTIM is difficult due to the absence of a full set of data.



Power increase in irregular waves, Container ship (FULL)

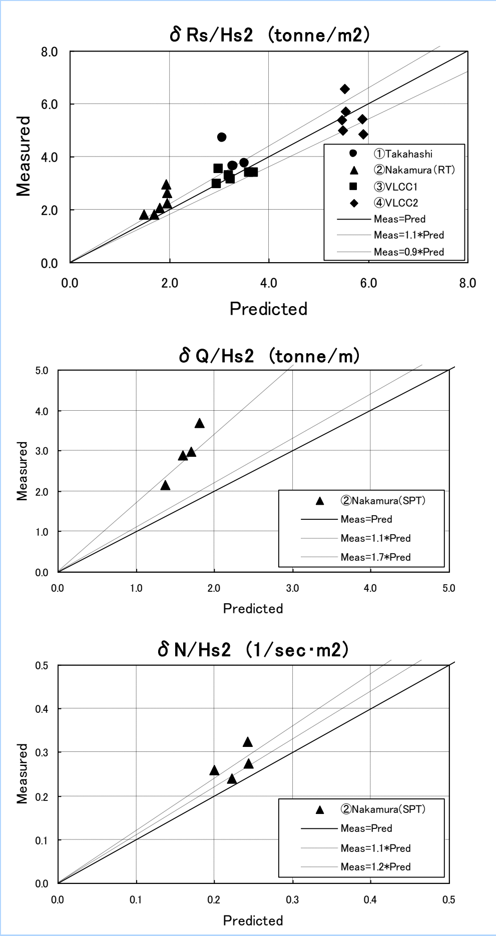


Power increase in irregular waves, VLCC (FULL)

Added resistance and power increase in waves

- Full set of data required to complete comparison
  - Still water resistance
  - Open water propeller tests (TNM and RTIM)
  - Tests in regular waves
  - Tests in irregular waves

- Identified published papers showing resistance increase, propeller torque and RPM increase



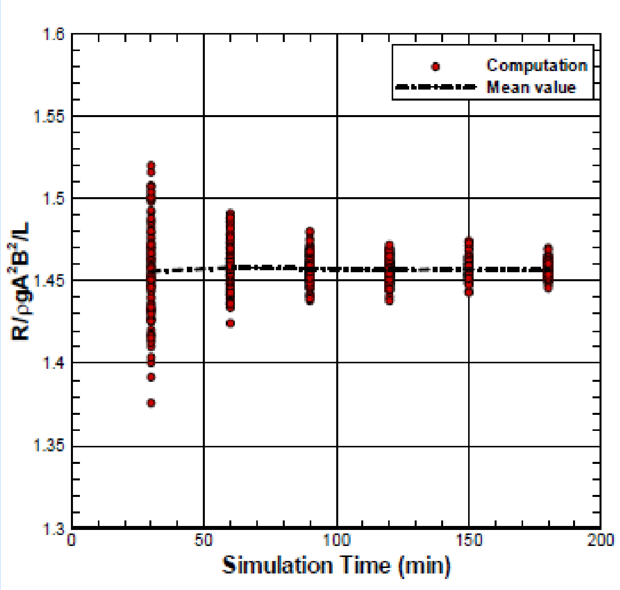
Resistance

Torque

RPM

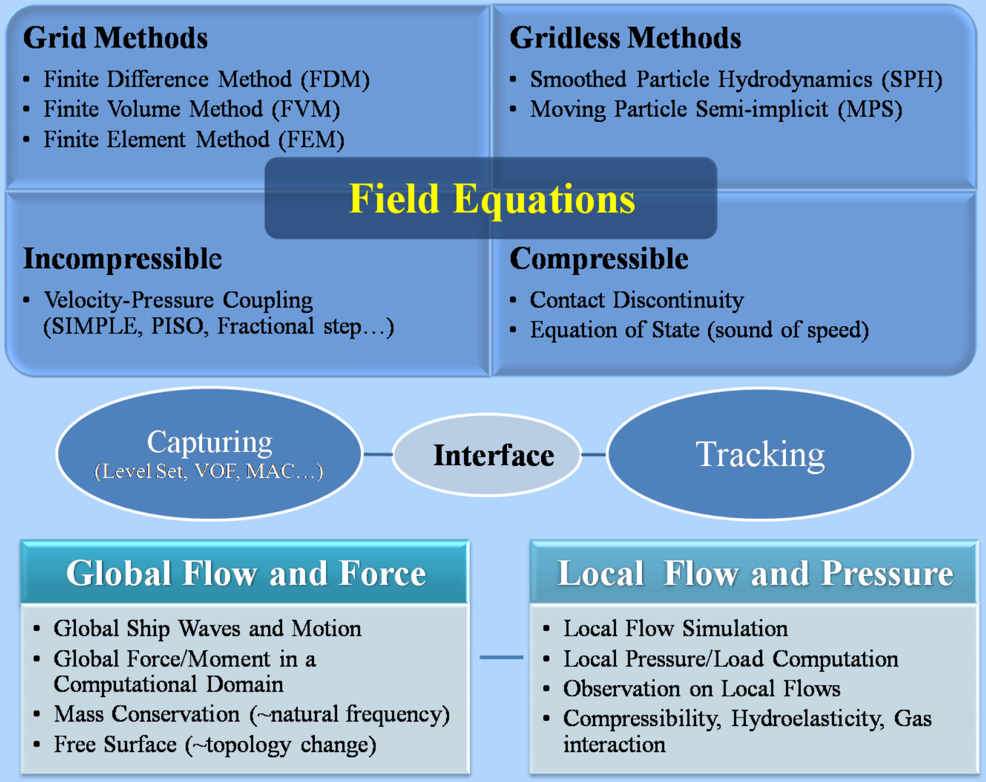
Added resistance and power increase in waves

- Numerical techniques are developing
  - Increase in run length (1.5 hours) to obtain stable statistics for added resistance
  - Common approach is to use RTIM to predict power increase
  - Main focus on prediction of added resistance



CFD applications

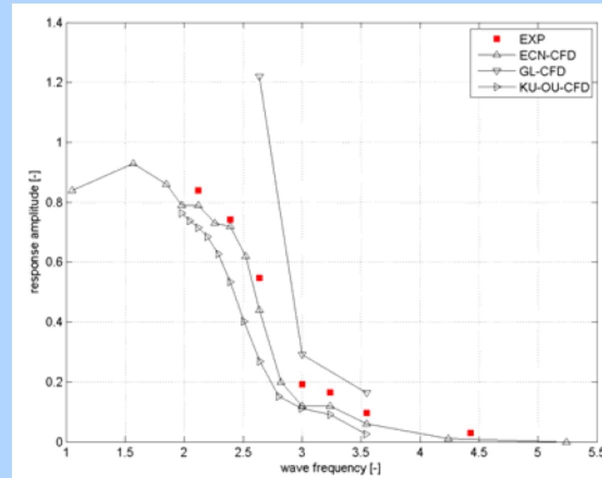
- CFD analysis becoming popular in a range of marine applications
- Viscous effects are mostly insignificant
- Primary difficulty in the implementation of the free surface



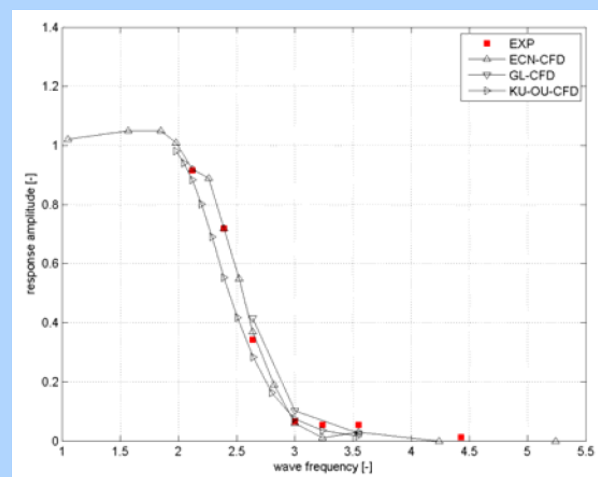
Overall status of the art of CFD schemes for free surface flow: Field equation solvers

Cooperative Research Ships (CRS) Comparative study

- Comparison of CFD methods, (Bunnik *et al*, 2010).
- Accurate computation of restoring properties is important



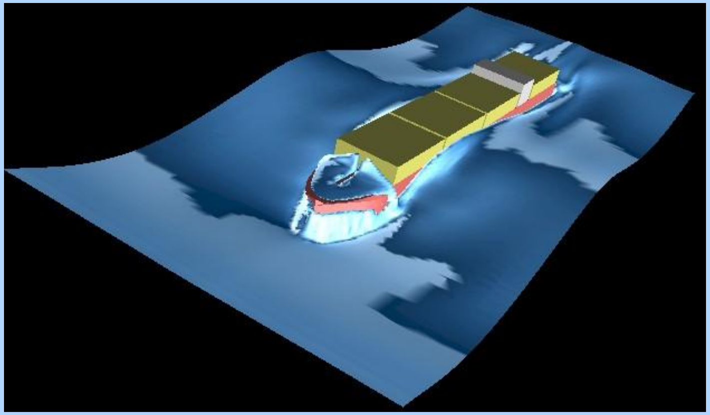
Heave



Pitch

CFD summary

- CFD requires still significant CPU time.
- Not practical for obtaining RAOs for a range of speeds and headings
- CFD are still relatively poor at predicting the far field radiated wave.
- Very good at predicting local flow phenomena.
- Focus of effort has been on extreme non-linear problems where potential theory is invalid



Seakeeping analysis using CIP method (Hu *et al.*, 2008, 2009)

Verification and validation workshop

- Seoul National University, 19th – 21st October 2010
- Jointly sponsored by
  - Office of Naval Research
  - Seoul National University
  - Daewoo Shipbuilding and Marine Engineering Co.
  - Samsung Heavy Industries
- Two day conference and one day workshop
- Aim to further develop the procedure on V&V of non-linear seakeeping computer codes.

Verification and validation definition

Verification of a computer code is the proof of its implementation. Establish that the code written echoes the intended operations and procedures. Its successful accomplishment means that the way the code emulates the theory in itself is correct

Was the software built correctly?

Validation of a computer code is the proof of its applicability. To validate a computer code one has to demonstrate that the mathematical model of the verified computer code is an adequate representation of the physical reality.

Was it the right software?

Verification and validation workshop

- Twenty papers related to
  - Developments in non-linear theories
  - Wave loads and hydroelasticity
  - Verification and validation activities
  - Parametric and resonant rolling
  - Navier Stokes formulations
  - Applications in design
- Perception was that V&V activities are too expensive and in some cases developers rely on their track record
- Key to V&V is that the process is streamline and targets key issues throughout the development process

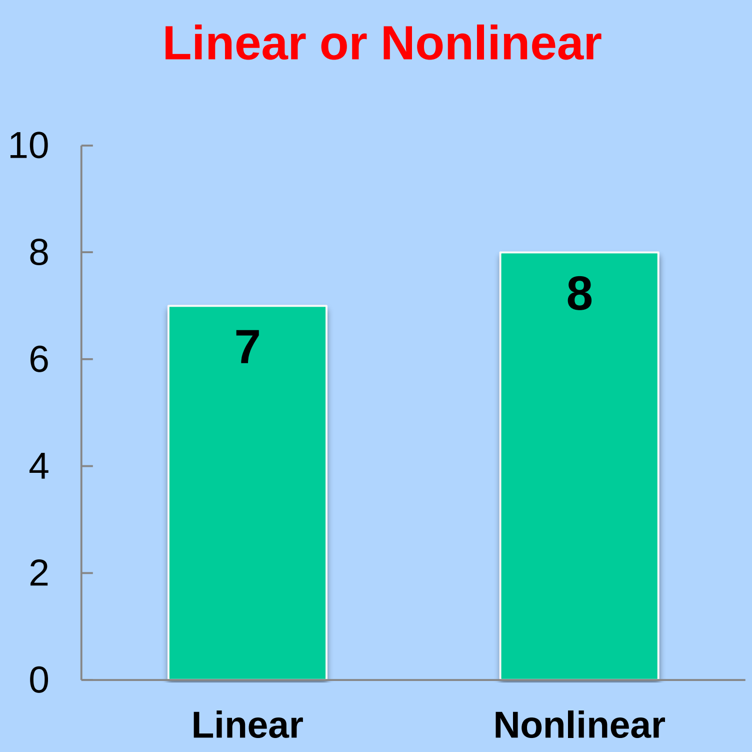
Author	Method	Wave excitation RAOs	Motion responses/Hydrodynamic loading						Exceedance probabilities	Added resistance
			Vertical plane RAOs	Lateral plane RAOs	Time histories	Harmonics	Variation with wave steepness	Spectra		
Liu et al	Body non-linear	✓	✓							✓
Bruzzone et al	Body non-linear		✓✓		✓	✓				
Kim et al,	Weak scatterer		✓✓	✓✓	✓✓	x✓	✓			
Qui et al	Body non-linear		✓✓	✓✓			✓✓			
Miyake et al	Non-linear strip		x✓		x✓				✓	
Wu et al	Body non-linear		✓✓						✓	
McTaggart	Body non-linear		✓	✓			✓			
Walree and Carette	Body non-linear				✓				✓	
Grigoropoulos et al	Linear, body non-linear, weak scatterer		✓		x✓					
Bulian et al	Mathieu equation			✓	✓	✓	✓	✓		
Matusiak	Body non-linear				✓					
Kim and Kim	Mathieu equation, body non-linear, weakly non-linear		✓	✓	✓	✓				
Kim	fully non-linear				x✓	x✓				
Orihara	fully non-linear		✓		✓					✓
Wu et al	fully non-linear		✓							✓
Kim et al	Body non-linear		x✓	✓						
Cho et al	Weak scatterer		✓	✓						
Comparative study			✓✓	✓	✓✓		✓			

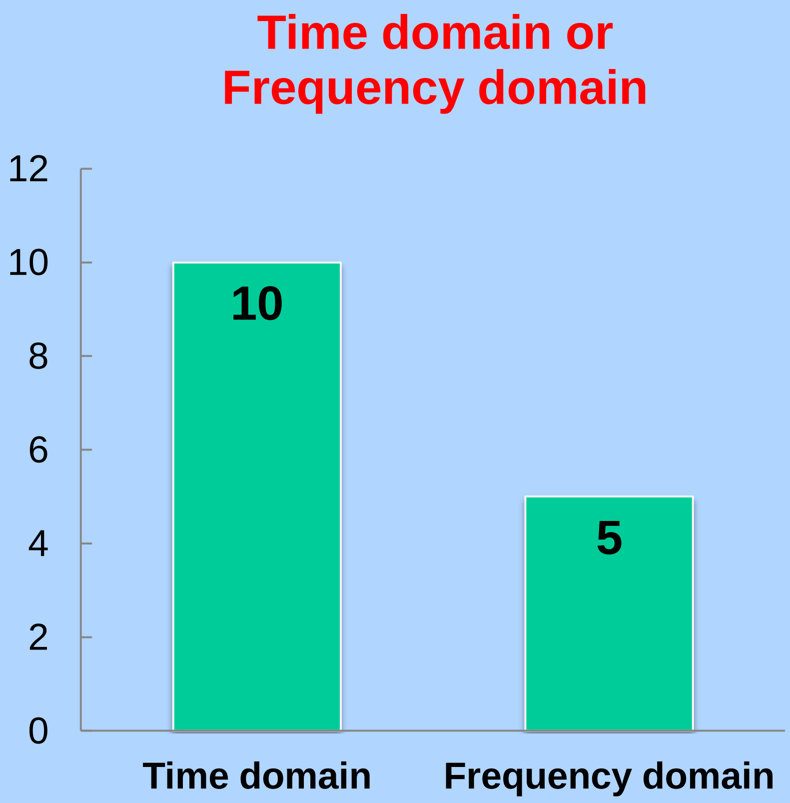
Key:
✓- Only motions,
x✓- Only loads,
✓✓- motions and loads

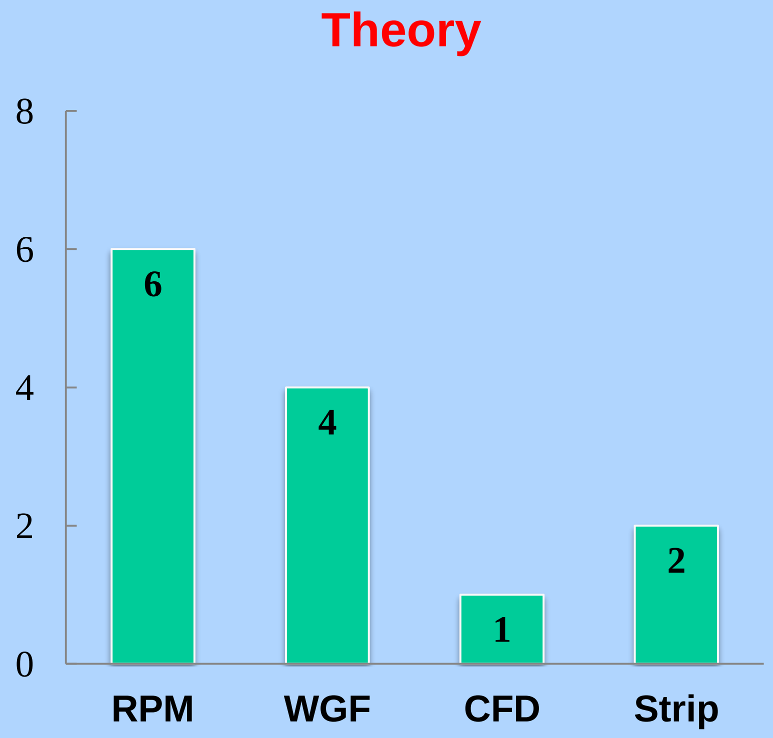
Comparative study

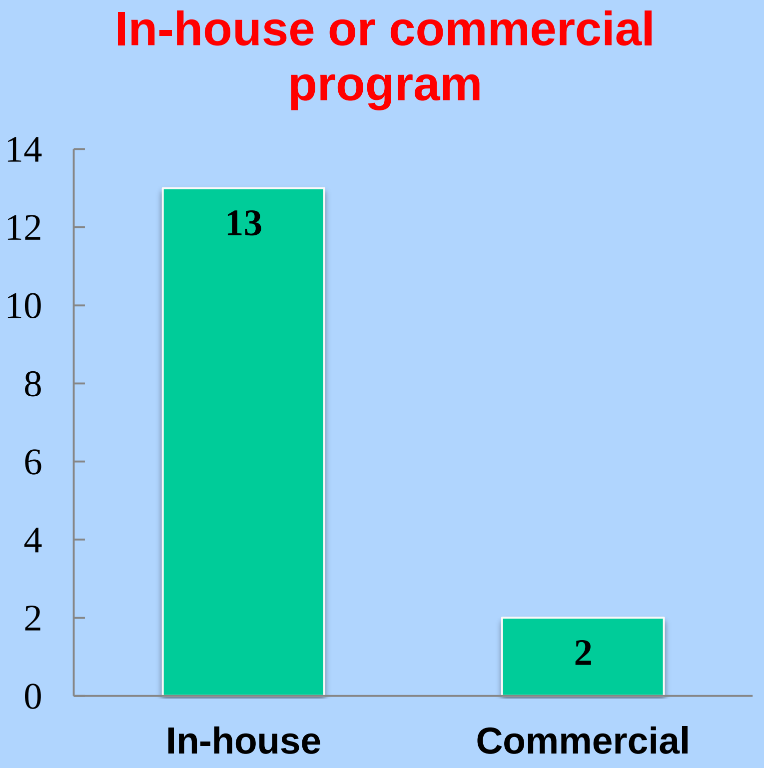
Affiliation	Methodology	Linear/Nonlinear
Defence Research and Development Canada-Atlantic, Canada	BEM	Linear
Harbin Engineering University, China	BEM	Nonlinear
Maritime & Ocean Engineering Research Institute, Korea	BEM, FEM	Linear, Nonlinear
National Maritime Research Institute, Japan	2D-BEM	Nonlinear
National Technical University of Athens, Greece	BEM	Linear, Nonlinear
Osaka University, Japan	CIP(CFD)	Nonlinear
Seoul National University, Korea	BEM	Linear, Nonlinear
University of Southampton, England	BEM	Linear

Methodology in ITTC SK Workshop in Seoul

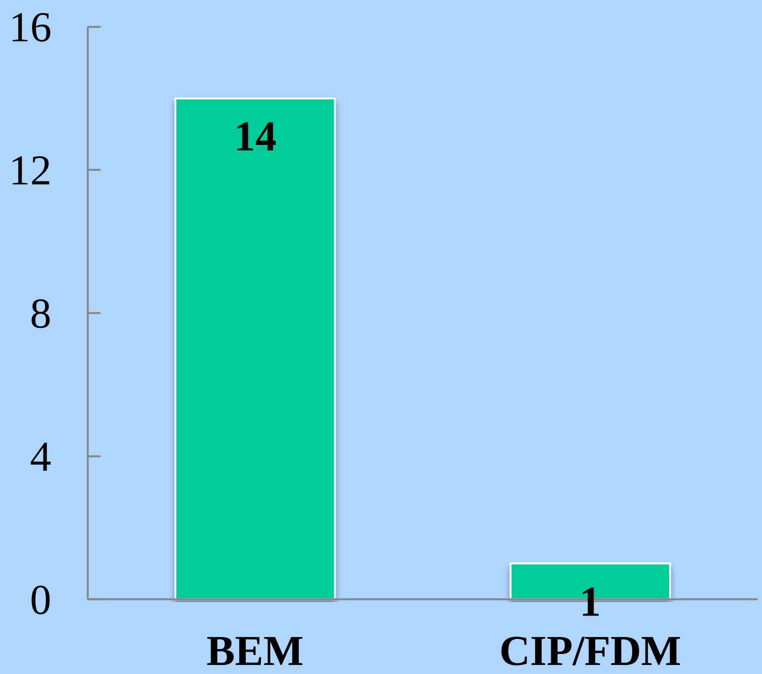




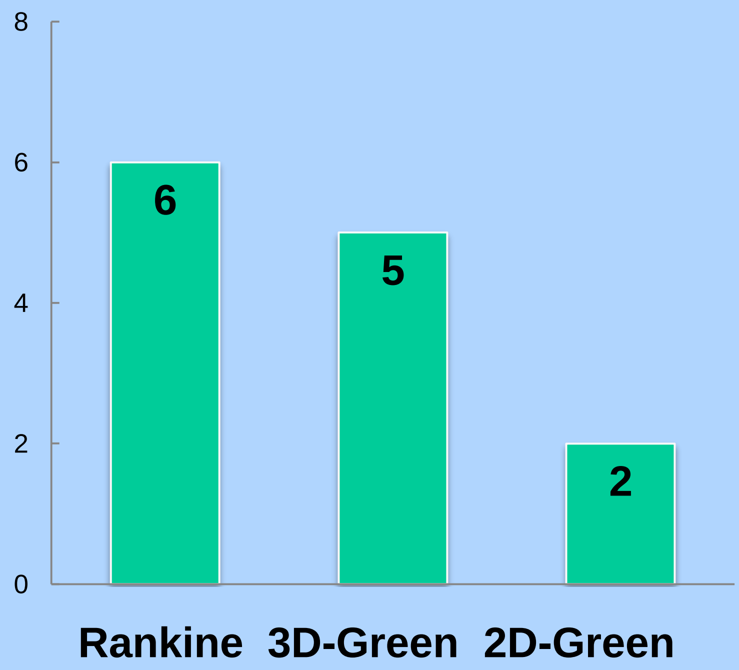

Theory
8
6
4
2
0
6
4
1
2
RPM
WGF
CFD
Strip


In-house or commercial program
14
12
10
8
6
4
2
0
13
2
In-house
Commercial

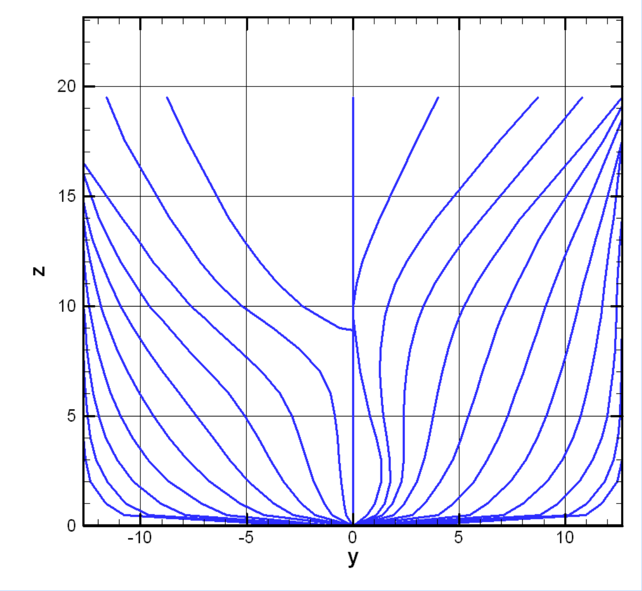
Numerical method



Green function type



Comparative study



Body plan of the
S175 containership

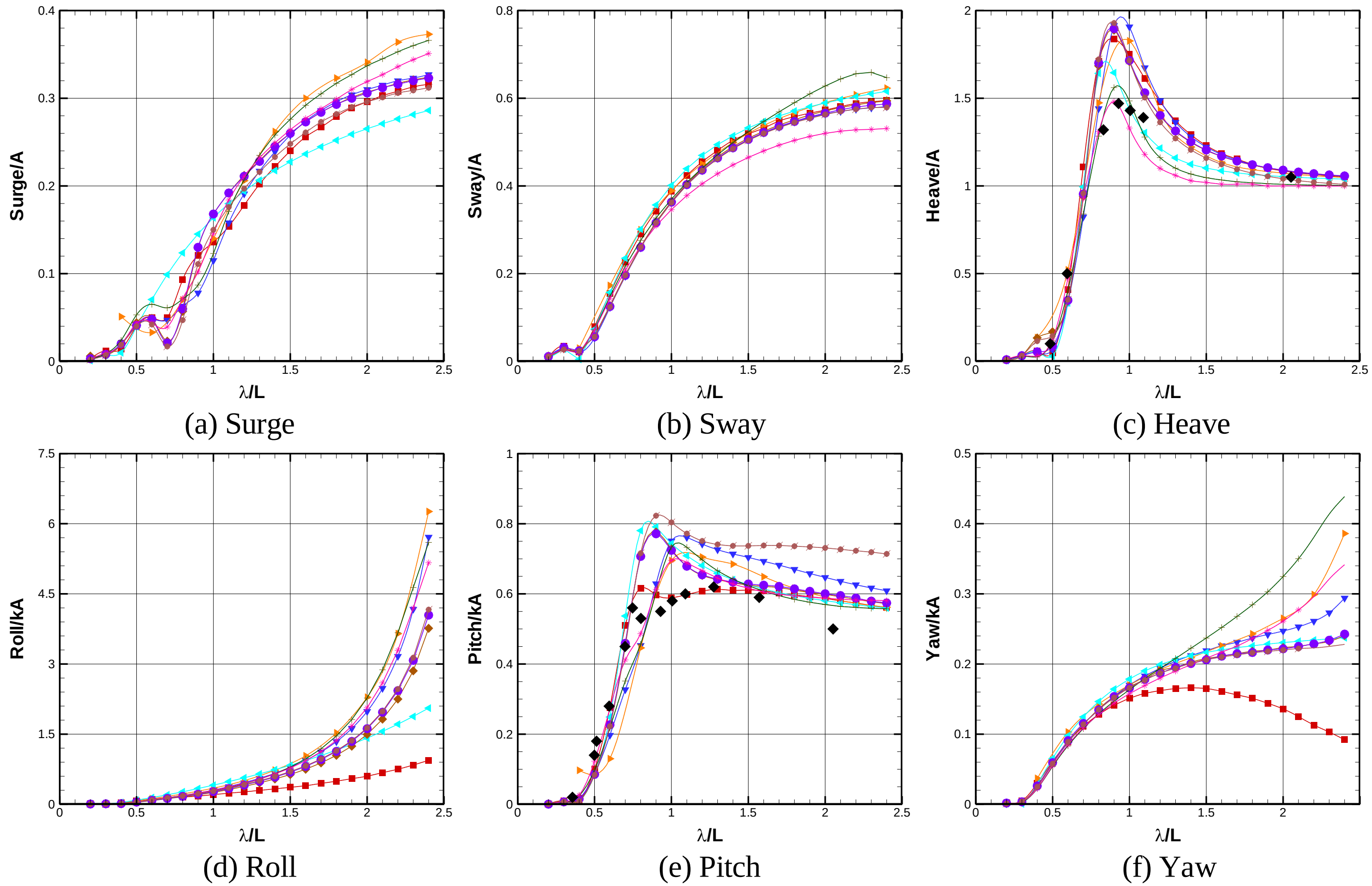
Linear analysis

Fn	Heading angle	λ/L	Motion	Load
0.275	180 deg	0.2~2.4	Heave, pitch	VSF, VBM
0.275	120 deg	0.2~2.4	Surge, sway, heave, roll, pitch, yaw	VSF, VBM, HSF, HBM
0.275	90 deg	0.2~2.4	Sway, heave, roll	
0.275	0 deg	0.2~2.4	Heave, pitch	VSF, VBM

Non-linear analysis

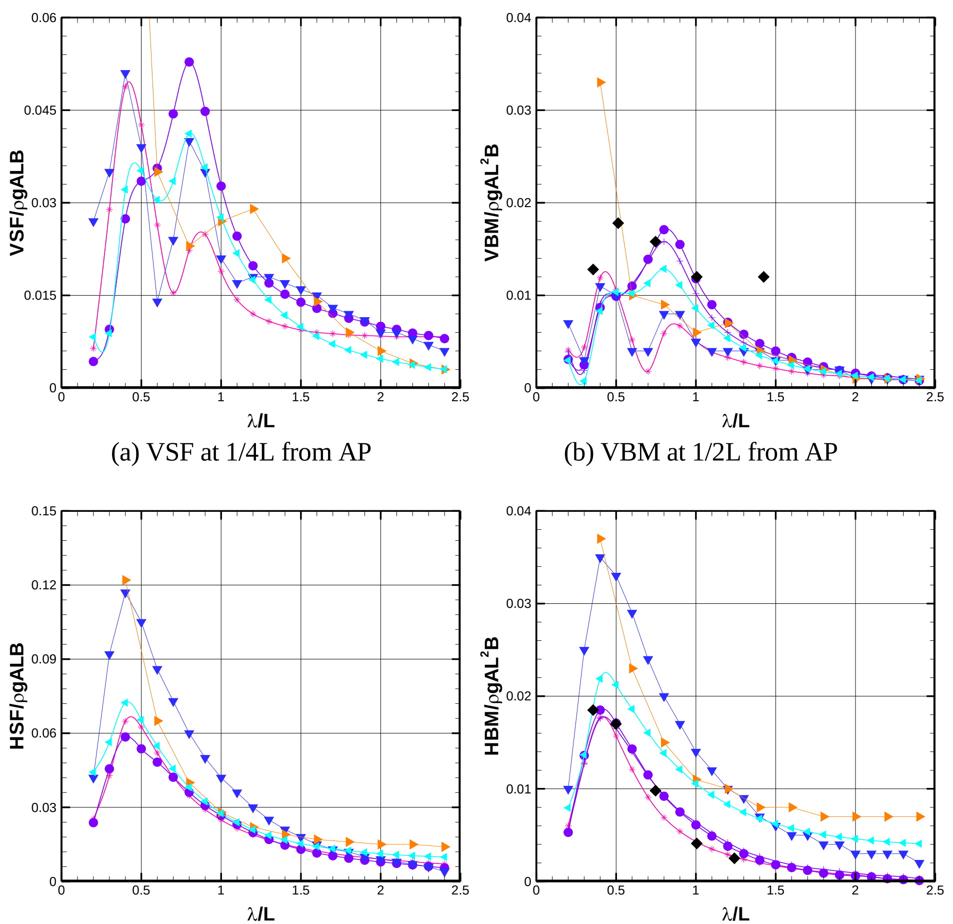
Fn	Heading angle	λ/L	kA	Motion	Load
0.20	180 deg	1.0 1.2 1.4	0.01, 0.04, 0.08, 0.12	Heave, pitch	VBM(hogging), VBM(sagging)
0.25	180 deg	1.0 1.2 1.4	0.01, 0.04, 0.08, 0.12	Heave, pitch	VBM(hogging), VBM(sagging)
0.275	180 deg	1.0 1.2 1.4	0.01, 0.04, 0.08, 0.12	Heave, pitch	VBM(hogging), VBM(sagging)

Comparative study



Motion RAOs (120 degrees)

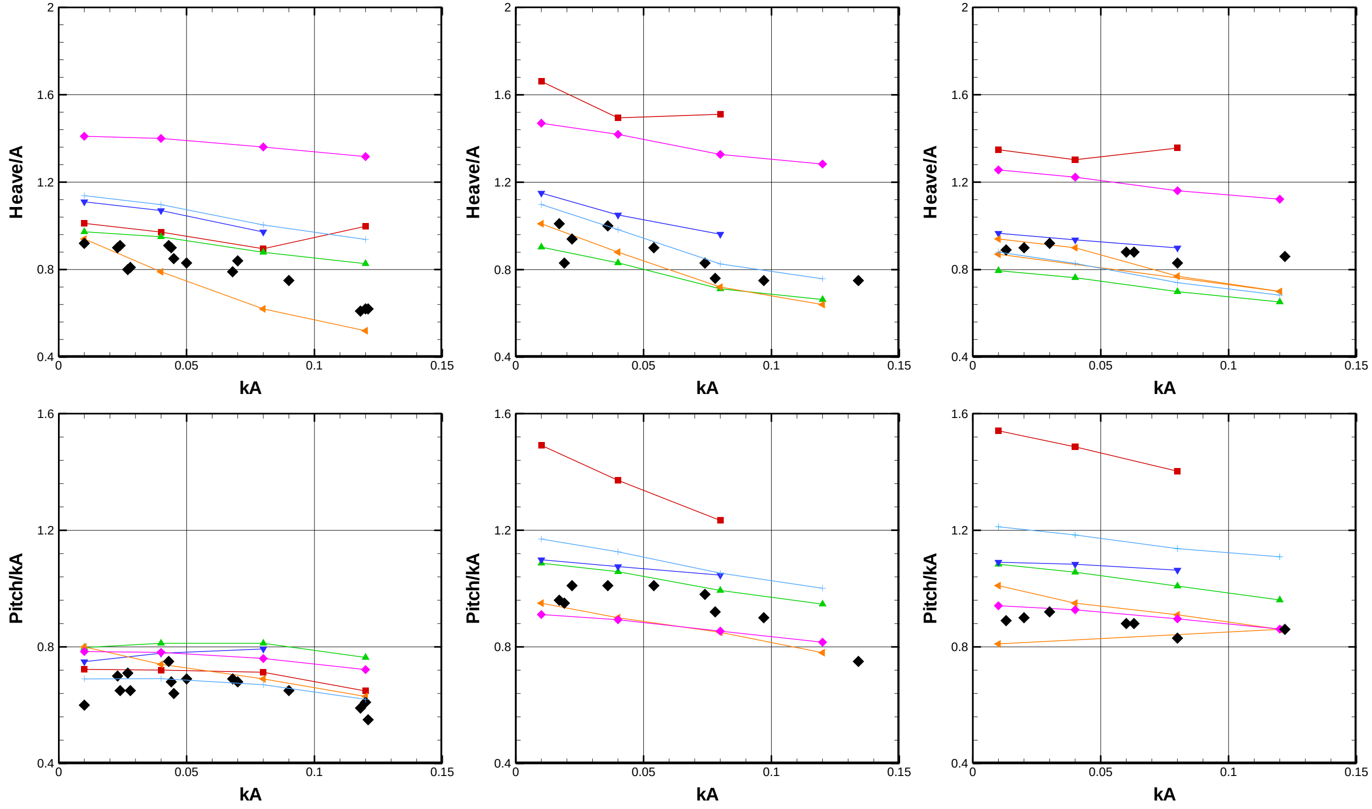
Comparative study



(a) VSF at 1/4L from AP
(b) VBM at 1/2L from AP
(c) HSF at 1/4L from AP
(d) HBM at 1/2L from AP

Structural load (120 degrees)

Comparative study



(a) λ/L=1.0 (b) λ/L=1.2 (c) λ/L=1.4

Heave (upper) and pitch (lower) motion responses (Fn=0.20, β=180°)

Most popular validation approaches

For motions:

- Vertical and lateral plane RAOs
- Harmonic analysis
- Variation of response with wave steepness

For loads:

- Vertical and lateral plane RAOs
- Variation of response with wave steepness
- Exceedance probabilities

Better outcome would have been achieved through the use of a more modern dataset

Comments on Non-linear V&V

- Verification activities should be more explicitly demonstrated by code developers than current practice
- Verification activities for CFD approaches should be based around grid resolution studies targeted towards 2D problems with analytic solutions
- Verification of CFD approaches for 3D problems is one of ensuring boundary conditions are matched
- Validation of fully non-linear codes generally follow the process for weakly non-linear.
- Requires greater definition such as sign convention for hogging and sagging
- Validation of CFD approaches give rise to the opportunity to compare with velocity data rather than pressure data

Recommended Procedures

ITTC Procedure 7.5-02-07-02.1, Seakeeping Experiments

- Minor editorial corrections
- ISO GUM approach to Uncertainty Analysis included as an Appendix
- Both Type A and B uncertainties are identified and explained
- Introduced concept of standard, combined and expanded uncertainties
- Explained by example

Recommended Procedures

ITTC Procedure 7.5-02-07-02.2, Predicting Power Increase in Irregular Waves from Model Experiments in Regular Waves

- The three methods for predicting power increase are described
- Data suggest RTIM is the best approach for predicting power increase
- Insufficient consistent data across all the require tests to undertake a full comparison

Recommended Procedures

ITTC Procedure 7.5-02-07-02.3, Experiments on Rarely Occurring Events

- Only updated with minor editorial corrections

ITTC Procedure 4.2.4-01 Standard Format for Exchange of Seakeeping Data on Computer-Compatible Media

- Recommended that procedure should be withdrawn
- The presentation of results and formatting of data is usually covered by the particular procedure

Recommended Procedures

ITTC Procedure 7.5-02-07-02.5, Verification and Validation of Linear and Weakly Non-Linear Seakeeping Computer

- Updated to include the V&V activities required for weakly non-linear seakeeping analysis
- Focussing on weakly or weak-scatterer-based nonlinear time domain analysis.
- Mandatory requirements are provided for the representation of the input and output data.
- Recommend further update to include outcomes of V&V workshop

Recommended Procedures

ITTC Procedure 7.5-02-07-02.6, Prediction of Global Wave Loads

- New procedure to outline the methods by which measurements of global wave loads can be made
- Expands the existing seakeeping procedure (7.5-02-07-02.1), outlining the additional considerations required for the measurement of global loads
- Describes the design of the experiment, the set-up of the model and instrumentation, the test, and the analysis.

Recommendations for further work

- Participate in a joint ITTC/ISSC workshop on uncertainty
- Engaged, where practicable, JIPs on hydroelasticity
- Establish a numerical and experimental process for estimating *fw* in the calculation of EEDI
- The current V&V procedure be extended to include the outcomes of the seakeeping workshop, with the potential to address specific aspects of global loads
- Investigate procedure for V&V of hydroelastic codes
- Review experimental procedures on sloshing currently under development by the Class Societies.

Thank you

Any questions?