Report of the 27th ITTC Seakeeping Committee

Presented by
Yonghwan Kim
SKC Chairman
ITTC SK Members (27th Term)

- Dariusz Fathi (MARINTEK, Norway)
- Dan Hayden (NSWC-CD, United States), Secretariat
- Greg Hermanski (National Research Council Canada (NRC), Canada)
- Dominic Hudson (University of Southampton, United Kingdom)
- Pepijn de Jong (Delft University of Technology, The Netherlands)
- Yonghwan Kim (Seoul National University, Korea), Chairman
- Quan Ming Miao (CSSRC, China, a new member will replace in Oct.)
- Katsuji Tanizawa (National Maritime Research Institute, Japan)
- Giles Thomas (University of Tasmania, Australia)
1. Update the state-of-the-art review
2. Review/Revise ITTC Recommended
3. Liaise with ISSC and other ITTC committees
4. Update existing ITTC Recommended Procedure 7.5-02-07-02.5 for V&V of computational codes
5. Investigate methodology for V&V of fully non-linear seakeeping viscous flow codes.
6. Develop a guideline for hydroelastic seakeeping codes.
7. Jointly organize and participate in the joint ISSC/ITTC workshop
8. Establish a numerical and experimental process for estimating $f_{\text{FW}}$ in the EEDI calculation.
9. Develop a unified method for sloshing experiments
The Seakeeping Committee is primarily concerned with the behavior of ships underway in waves. The Ocean Engineering Committee covers moored and dynamically positioned ships, including the modeling and simulation of waves, wind and current.
Highlights

• Procedures
  – Updates to four
  – Decision of no change for one
  – One withdrawn for revision

• State of the art review with emphasis on sloshing, added resistance, and viscous codes

• Underpin a common approach to predicting added resistance and a basic concept of $f_w$ computation for EEDI formula

• Joint organization for the 1st and 2nd ITTC-ISSC Joint Workshops
Committee meetings

• 1st Meeting: University of Southampton, Southampton, United Kingdom, January 2012
• 2nd Meeting: National Maritime Research Institute, Tokyo, November 2012.
• 3rd Meeting: David Taylor Model Basin, West Bethesda, USA, July 2013
• 4th Meeting: Delft University of Technology, Delft, Netherlands, February 2014

Additional meetings

• 1st ISSC-ITTC Joint Workshop, Rostock, Germany, September 2012
• 2nd Joint ITTC-ISSC Joint Workshop, Copenhagen, Denmark, August 2014
ITTC-ISSC Joint Workshops

1st Joint Workshop
Understanding uncertainty modelling and its impact on model tests, full scale measurement, load prediction, and loads computation.

2nd Joint Workshop
Loads in ocean waves as a common technical issue of ITTC and ISSC, including nonlinear wave-induced motion, ocean environments, and resultant loads on ships and offshore structures. Benchmark test for a segmented model ship.
New Experimental Facility

Actual Sea Model Basin: NMRI, Japan

- LBD: 80m x 40m x 4.5m
- 382 flap type wave makers with multidirectional absorbing control
- Max synthesis speed of towing carriage: 4.6m/s
- Max wind speed: 10m/s

New Wavemaking in Manoeuvring and Seakeeping Basin (MASK): CDNSWC, USA

- 216 paddles at a 0.658 m spacing
- 108 paddles along the long wall of the tank, 60 paddles in the curve, and 48 paddles along the short wall
- Hinge depth at 2.5 meters
New Wavemaker in Depressurized Wave Basin: MARIN, Netherlands

- 24 dry-back paddles with a 2.5m hinge depth and a 0.6m width along the short wall
- 200 dry-back paddles with a 1.8m hinge depth and 0.6m width along the long edge

Sloshing Platform: CSSRC, China

<table>
<thead>
<tr>
<th></th>
<th>Displacement</th>
<th>Speed</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surge</td>
<td>± 40 cm</td>
<td>± 100 cm/s</td>
<td>± 0.6g</td>
</tr>
<tr>
<td>Sway</td>
<td>± 40 cm</td>
<td>± 100 cm/s</td>
<td>± 0.6g</td>
</tr>
<tr>
<td>Heave</td>
<td>± 50 cm</td>
<td>± 140 cm/s</td>
<td>± 0.8g</td>
</tr>
<tr>
<td>Roll</td>
<td>± 45°</td>
<td>± 50°/s</td>
<td>± 150°/s²</td>
</tr>
<tr>
<td>Pitch</td>
<td>± 25°</td>
<td>± 25°/s</td>
<td>± 150°/s²</td>
</tr>
<tr>
<td>Yaw</td>
<td>± 15°</td>
<td>± 15°/s</td>
<td>± 80°/s²</td>
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</table>
Sloshing Platform: Seoul National University, Korea

- 3 platforms
  - 1.5, 5, 14 tons capacities
- Largest facility in the world
- 500 dyn. pressure channels
- 2D and 3D PIV systems
- Impact test facility

<table>
<thead>
<tr>
<th>14-ton platform</th>
<th>Displacement</th>
<th>Speed @1500 rpm</th>
<th>Speed @2000 rpm</th>
<th>Acceleration</th>
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</thead>
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<tr>
<td>Surge</td>
<td>±144 cm</td>
<td>155 cm/s</td>
<td>200 cm/s</td>
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<tr>
<td>Sway</td>
<td>±138 cm</td>
<td>138 cm/s</td>
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<td>Heave</td>
<td>±84 cm</td>
<td>84 cm/s</td>
<td>110 cm/s</td>
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<tr>
<td>Roll</td>
<td>±33°</td>
<td>34°/s</td>
<td>45°/s</td>
<td>&gt; 250°/s²</td>
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<tr>
<td>Pitch</td>
<td>±33°</td>
<td>37°/s</td>
<td>49°/s</td>
<td>&gt; 250°/s²</td>
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<tr>
<td>Yaw</td>
<td>±33°</td>
<td>56°/s</td>
<td>74°/s</td>
<td>&gt; 250°/s²</td>
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</tbody>
</table>

Tanks under construction

- UoS: New towing tank, scheduled to complete in Sep. 2014
  138m x 6m x 3.5m with max speed 12m/sec
- KRISO: 100m x 50m x 15m (45m pit) under design
- NUS: Ocean basin for offshore experiment
- A few organizations are in design or plan stage to build new facilities.
Experimental Techniques: Added Resistance / Speed Loss in Waves

The prediction of added resistance or speed loss of a ship in waves is essential to evaluate the ship performance in a seaway.

- Segmented model test (Guo and Steen, 2011): added resistance of KVLCC2 in short waves. Ship model was divided into three segments: fore-segment, aft-segment, and parallel mid-body.
- The effect of oblique waves on ocean-going vessel behavior in realistic sea states (Chuang and Steen, 2013): a free running model in oblique waves.
- Sadat-Hosseini et al. (2013): Experiment with KVLCC2 in surge free and fixed condition.
- Lee et al. (2013): Observation on different bow shapes.
Experimental Techniques
Water on Deck and Slamming

Most studies have focused on slamming.

- A synergic 3-D experimental investigation was conducted for wave-ship interactions involving the water-on-deck and slamming phenomena. (Greco et al. 2012)
- Slam events experienced by high-speed catamarans in irregular waves were investigated through experiments using a hydroelastic segmented model. (Thomas et al., 2011, Lavroff et al., 2013)
- Green water from side wall: Buchner & van den Berg (2013)
Experimental Techniques
Ship Structural Hydroelasticity

Measurement of springing and whipping.

- WILS II, III (Hong et al., 2012, 2013): Segmented model test for springing measurement (WILS II) and slamming-whipping (WILS III), a 10,000 TEU containership.
- SHI’s segmented model test (Lee et al, 2013): Segmented mode test for 18,000 TEU containership.
Experimental Techniques

Sloshing

- **SLOSHEL project** (Brosset et al., 2012, 2013, Lafeber et al., 2012): organized by GTT and MARIN, participating several organizations for real-scale sloshing in shallow depth

- **Benchmark tests for single impact case**, organized by GTT (2013, 2014)

- Model tests for IMO B-type LNG cargo system (Song et al., 2012, Kim et al., 2013): LNG cargo with internal members

- Model tests for anti-sloshing blanket system (Chung et al., 2012): blanket system with connected segmented foams

- Sloshing-ship motion coupling (Wang et al., 2012, )

- ISOPE Sloshing Dynamics Symposium (2009~2014)
The slamming behavior of large high-speed catamarans (Jacobi et al., 2013): full-scale measurements, US Navy conducted the trials in the North Sea and North Atlantic region on a 98m wave piercer catamaran.

A measurement campaign on board a 9,300 TEU container vessel (Koning and Kapsenberg, 2012)

A series of captive model tests for the broaching prediction of a wave-piercing tumblehome vessel with twin screws and twin rudders (Hashimoto et al., 2011)
Numerical Methods
Frequency-Domain Methods

- Quick and efficient solutions
  - Allowing evaluation of large amount of design alternatives in early design
- Overall: **shift from FD methods towards TD methods**
  - TD methods now superseding FD methods to large extend, especially in R&D
- FD methods still very relevant for:
  - Early design slow-speed applications
  - Mooring and multi-body analysis
Numerical Methods
Time-Domain Methods (1)

- Slowly displacing FD methods also in practical applications
  - Intuitive extension towards nonlinear motions and loads
  - Ease of incorporating external forces and coupling with flexible structural modes and sloshing problems
- Increased computational demand compared to FD methods
- Nonlinear approaches rely on continuous re-panelization of body and free surface
- Many alternative approaches exist and are in development
- Applications also include combined topics such as Ocean Engineering and Manoeuvring and Stability in Waves
- CFD is expanding from resistance to manoeuvring, and then seakeeping. Potential codes are still leading in inertia-dominant problems, and CFD codes are applicable for violent flows which potential codes are limited.
Numerical Methods
Time-Domain Approach (2)

2D time domain techniques
- Relatively efficient and less complex in development
- Often based on FD extended to TD with retardation functions
- Can be combined with for instance manoeuvring models for 6DoF approaches (Chuang and Steen 2013)
- In some cases nonlinear radiation solutions (Mortola et al. 2011)
- High speed craft planning: separate class based on impacting wedge theory (Faltinsen and Sun 2011)

3D time domain Green Function Methods
- Only for linearized FS condition
- Often intermediate approaches combined with nonlinear hydrostatics and Froude-Krylov pressures
- Allows for direct inclusion of forward speed effects and used for semi-displacement vessels (Walree and De Jong 2011)
Numerical Methods
Time-Domain Approach (3)

3D time domain Rankine Panel Methods

- Much more simple singularities than GFM, but now also required on FS
- Explicit dealing with radiation condition necessary
- FS panels allow for easy extension to weakly (Song et al. 2011) or fully nonlinear analysis (Kim & Kim 2013, You & Faltinsen 2012)
- Attention paid to wave reflections on the artificial boundary (Xu and Duan 2012) and to inclusion of m-terms (Nan and Vassalos 2012)
Further developments:

- Higher Order Boundary Element Method (HOBEM)
  - Allow smoother representation of the velocity potential and its derivatives, therefore require much less elements
  - e.g. He and Kashiwagi (2013), Shao and Faltinsen (2012)

- Finite Element Methods (FEM)
  - Hong and Nam (2010): second order wave forces
  - e.g. Yan and Ma (2011): fully nonlinear potential flow with an Langrangian-Eulerian FEM

Hybrid methods: RPM+GFM, CFD+BEM,...

- Usually a combination of a sophisticated inner domain solution combined with a more efficient outer domain solution
  - Tong et al. (2013): inner domain RPM with outer domain GFM
  - Guo et al. (2012): inner domain VOF with outer domain BEM

- Physics-based modeling by Weymouth and Yue (2013):
Numerical Methods
Ship Structural Hydroelasticity

- Required to solve the seakeeping and structural problem at the same time
- **Springing**
  - Frequency domain approach with beam based modal superposition
  - Time domain approach with beam or 3D whole FE models
  - 3D panel or CFD methods with direct integration for ship structure
  - Zhu, Wu & Moan (2011)
- **Whipping:**
  - Requires slamming force
  - Typically 2D sectional force by GWM or wedge approximation
  - e.g. Derbanne et al. (2010), Tuitman (2010), Oberhageman & Moctar (2011), Kim et al. (2013), Ćorak et al. (2013)
- **TULCS Project** (Tools for Ultra Large Container Ships): 2009-2012 by BV and other organizations
- **Hydroelasticity Conference:** Tokyo, 2012
- **Int. Workshop on Springing and Whipping:** Split, 2012
Analysis Procedure for Ship Design

Hydro.
Strip/3D panel (Rankine or Green function)/CFD

Coupling
Modal/Direct

Fatigue Analysis Module
(Rainflow Counting / Miner’s Rule)

Long-Term Prediction

Computation (WISH-FLEX 2.5D) vs Experiment (MOERI WILS2)
Process for the Estimation of Ship Speed Reduction Coefficient $f_w$ in Waves

Calculation flow of the ship speed reduction

\[ V_{\text{ref}} \]

\[ R_T \]

\[ R_{T_w} = R_T + \Delta R_w \]

\[ P_{B_w} = R_{T_w} V / (\eta_D, \eta_S) \]

find $V_w$ at the point where $P_B$ at $V_{\text{ref}} = P_{B_w}$ at $V_w$

\[ f_w = V_w / V_{\text{ref}} \]

- $V$: Speed
- $R_T$: Total resistance in calm sea condition
- $\Delta R_w$: Added resistance due to wind and waves
- $P_B$: Brake power
- $\eta_D$: Propulsion efficiency
- $\eta_S$: Transmission efficiency
- Subscript $w$ refers to wind and wave

\[ \int f_w \, dV = V_w / V_{\text{ref}} \]
Process for the Estimation of Ship Speed Resistance in Seaways

Total resistance in seaways: \( \Delta R_w \)

\[
R_{Tw} = R_T + \Delta R_w
\]

\[
R_T = R_T + \Delta R_{wind} + \Delta R_{wave}
\]

Added resistance due to wind: \( \Delta R_{wind} \)

\[
\Delta R_{wind} = \frac{1}{2} \rho_a A_T C_{Dwind} \left( \left( U_{wind} + V_w \right)^2 - V_{ref}^2 \right)
\]

\( C_{Dwind} \) should be calculated by a formula or measured through experiment.

Added resistance due to waves: \( \Delta R_{wave} \)

\[
\Delta R_{wave} = 2 \int_0^{2\pi} \int_0^\infty \frac{R_{wave}(\omega, \alpha; V)}{\zeta_a^2} \cdot E(\omega, \alpha; H, T, \theta) d\omega d\alpha
\]

Key for the accurate estimation of \( f_w \)
# Process for the Estimation of Ship Speed

## Methods for Added Resistance Prediction

<table>
<thead>
<tr>
<th>Approaches</th>
<th>Numerical method</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slender-body theory</td>
<td>Direct pressure integration: Added resistance = (Total Resistance in waves) – (Resistance in cal water)</td>
</tr>
<tr>
<td>Added resistance computation</td>
<td>3D panel method</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Momentum conservation method</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Direct pressure integration (e.g. Faltinsen et al,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1980, Kim &amp; Kim, 2011)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Radiated energy method (e.g. Salvesen, 1978)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wave-pattern analysis (e.g. Kashwagi, 2013)</td>
<td></td>
</tr>
<tr>
<td>Methodology</td>
<td>Strip method, (enhanced) unified theory</td>
<td>Commercial or in-house codes</td>
</tr>
<tr>
<td></td>
<td>Green-function method, Rankine panel method</td>
<td>Surge-fixed or surge-free tests</td>
</tr>
<tr>
<td>Short-Wave Approximation</td>
<td>Linear formulation for seakeeping.</td>
<td>Fully nonlinear formulation.</td>
</tr>
<tr>
<td></td>
<td>Faltinsen’s approximation, NMRI’s empirical formula</td>
<td>Fully nonlinear</td>
</tr>
<tr>
<td>Remarks</td>
<td>Quick computation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Different formulations for time- and frequency-domain methods.</td>
<td>A lot of computational time</td>
</tr>
<tr>
<td></td>
<td>Grid dependency should be observed in short waves.</td>
<td>Expensive</td>
</tr>
<tr>
<td></td>
<td>Strong grid dependency in short waves.</td>
<td>Scale dependency and repeatability should be observed.</td>
</tr>
</tbody>
</table>
Process for the Estimation of Ship Speed
Experiment for Added Resistance

KVLCC2
Process for the Estimation of Ship Speed
Comparison of Different Methods

Strip method

RPM & Cartesian grid method
Overall status of the art of CFD schemes for free surface flow: Field equation solvers

**Grid Methods**
- Finite Difference Method (FDM)
- Finite Volume Method (FVM)
- Finite Element Method (FEM)

**Gridless Methods**
- Smoothed Particle Hydrodynamics (SPH)
- Moving Particle Semi-implicit (MPS)

**Field Equations**
**Incompressible**
- Velocity-Pressure Coupling (SIMPLE, PISO, Fractional step...)

**Compressible**
- Contact Discontinuity
- Equation of State (sound of speed)

**Global Flow and Force**
- Global Ship Waves and Motion
- Global Force/Moment in a Computational Domain
- Mass Conservation (~natural frequency)
- Free Surface (~topology change)

**Local Flow and Pressure**
- Local Flow Simulation
- Local Pressure/Load Computation
- Observation on Local Flows
- Compressibility, Hydroelasticity, Gas interaction

**Capturing** (Level Set, VOF, MAC...)
**Interface**
**Tracking**
## CFD Application for Seakeeping

**The State of the Art**

<table>
<thead>
<tr>
<th>Discretization for convective term</th>
<th>C. Hu et al. (Kyushu Univ.)</th>
<th>D.G. Dommermuith et al. (SAIC)</th>
<th>J. Yang et al. (Univ. of Iowa)</th>
<th>P. Queutey et al. (ECN)</th>
<th>R. Löhner et al. (George Mason Univ.)</th>
<th>H. Miyata et al. (Univ. of Tokyo)</th>
<th>Y. Kim et al. (Seoul National Univ.)</th>
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</thead>
<tbody>
<tr>
<td>Body motion</td>
<td>IBM Particle</td>
<td>IBM Triangle panel</td>
<td>IBM Triangle panel</td>
<td>Mesh Deformation</td>
<td>ALE</td>
<td>Overlapping Grid</td>
<td>IBM Triangle panel</td>
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<tr>
<td>Free surface</td>
<td>THINC (VOF)</td>
<td>CLSVOF</td>
<td>CLSVOF</td>
<td>VOF</td>
<td>VOF</td>
<td>Density Function (QUICK)</td>
<td>THINC (VOF)</td>
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<tr>
<td>Remark</td>
<td>LES</td>
<td>LES</td>
<td>Ghost Fluid Method</td>
<td>RANS</td>
<td>RANS</td>
<td>RANS</td>
<td>Euler eq. solver</td>
</tr>
</tbody>
</table>
CFD Application for Seakeeping
To be considered...

Computational Efficiency
- Need parallelize, otherwise it is too slow for practical use
- Seakeeping analysis requires more time consuming than resistance or maneuvering problems.
- Need to compromise with accuracy

Accuracy
- Acceptable for global motion prediction
- In general, sensitively dependent on mesh resolution and time segment, particularly in violent local flows

Robustness and Applicability
- Robustness is dependent on program, but so far in a low degree.
- Still limited applicability for engineering problems in seakeeping

In-house or Commercial?
- Commercial code is getting popular.
- In-house codes can be applied for specific interests.

Eulerian grid-based or Lagrangian Particle Method?
- Still grid-based volume approach is popular.
Recent trend of LNGC capacity

Potential of structural damage on LNG CCS is increased.

Experiment is most reliable so far.
Sloshing Experimental Procedure

Technical Issues

Model Test with LNG or Similar Fluid
Sensor Sensitivity: Reliability, Thermal Shock, Sensing Diameter
Experimental Procedure: Time Window, Wave and Motion Conditions
Hydroelasticity Effects of Insulation Structure
Scale Law
Statistical Analysis of Impact Loads
Modeling of Impulsive Pressure for Structural Analysis: Space and Time
Validation of FE Analysis for Dynamic Structural Responses
Reliable and Stable CFD Computation with Small CPU Time
Effects of Coupling with Ship Motion: Guidance for Design
Local Structural Damage: Leakage, Debonding, Delamination,…
## Sloshing Experimental Procedure
### Example: Pressure Sensors

<table>
<thead>
<tr>
<th>Group</th>
<th>Maker</th>
<th>Model</th>
<th>Diameter (mm)</th>
<th>Reference</th>
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<tr>
<td>Ecole Centrale Marseille</td>
<td>PCB</td>
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<td>Loysel et al. (2012)</td>
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<td>Exxon Mobile</td>
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<td>Yung et al. (2009)</td>
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<td>M106B</td>
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<td>XCL-8M-100-3.5BARA</td>
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<td>Pistani and Thiagarajan (2012)</td>
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</table>
Sloshing Experimental Procedure
Pressure Sensors: Sample Case

Piezoresistive and piezoelectric sensors

Time histories of pressure signals measured in a 2D tank under surge motion with 20% H filling (Ahn et al., 2013)
Effects of Density Ratio

Synchronized movement of the liquid with pressures – case 1

$$\frac{\rho_{\text{gas}}}{\rho_{\text{liquid}}} = 0.0012$$
Effects of Density Ratio

(a) Amplitude = 40 mm               (b) Amplitude = 15 mm

Measured sloshing pressure of 2D harmonic test with 70%H filling level varying the frequency and the density ratio (Ahn, et al. 2012)
Procedure 7.5-02-07-02.1
Seakeeping Experiments

- All-in-all a mature procedure that required only limited updates
- Changes:
  - Editorial corrections: misspellings, missing references recovered, inconsistent and incorrect symbols corrected
  - Sections on Regular Waves, Transient Waves, and Irregular Waves were updated with some additional information, guidelines, and references
  - A number of new symbols are proposed for Appendix A on uncertainty assessment (until ITTC-QG proposes something more consistent):
- Difficult to find the source of Fig.3 for blockage effect
- Adopted QG’s recommendation for minor corrections
Procedure 7.5-02-07-02.2
Predicting Power Increase in Irregular Waves from Model Experiments in Regular Waves

• **Change in procedure:** Inclusion of a section to address directional spectrum with short crested component

• There was a discussion with regards to applicability of various simulation efforts to calculate added resistance. The thought was whether there would be a future area of the procedure that might incorporate simulation combined with experimental results to determine added resistance. Based on this discussion, some sentences are revised, particularly for the wave spectrum.
Procedure 7.5-02-07-02.3  
Experiments on Rarely Occurring Events

- **Task:** Include the definition of slamming
- **Question:** Is Ochi’s formula appropriate?
  - Ochi’s formula principally looked at slamming velocity.
  - It was thought that bow flare and hull shape should also be an included factor.
  - Might need to break slamming into manageable pieces to provide a proper definition.
  - ABS, ISSC and other classification rules should be reviewed for applicability to slamming and rarely occurring events.
- **Include the description of slamming in section 2.4.3**
Procedure 7.5-02-07-02.5
V&V of Linear and Weakly Nonlinear Seakeeping Computer Codes

• Task: update procedure with outcomes of the Workshop on V&V for Non-linear Seakeeping Analysis

• There was an important comment that the current state of art shows that most authors do not include details of their V&V activities in publications other than straightforward comparison between experimental and computed data, be it RAOs, signal statistics, or direct time trace comparison. This issue should be considered for any future revision

• Based on this the SK committee proposes to keep to current procedure ‘as is’
Procedure 7.5-02-07-02.6
Prediction of Global Wave Loads

• Needed to look at incorporation of hydroelastic computation into procedure
  - Current procedure concentrates on experimental procedure. Need to consider how computations can be used as interface, guide, and interpretation of experimental results.
  - Changes might be more appropriate as state of art review first, but should consider appropriate changes.

• This was not completed in the 27th term.

• Computational procedure can be included in 7.5-02-07-02.5 (V&V of Linear and Weakly Nonlinear Seakeeping Computer Codes) or can be a separate procedure.
Procedure 7.5-02-05-04
HSMV Seakeeping Tests

• Task: Review the procedure and revise if needed

• Changes
  - Include references (none in the previous version)
  - Add paragraph on placement of ‘free to pitch’ fitting for catamaran vessels
  - Add requirement to measure pitch inertia
  - Updated planning craft testing to include requirement to consider sample rate for human factors measurements
  - Updated free-running model testing to recognise that onboard digital storage is now possible and commonly used.
  - Removed S175 from suggested benchmark/database of ship. This hull cannot be considered as an HSMV.
Recommendation for Future Works

- It is recommended that **ITTC has a combination of pure technical committees and special committee(s) for external needs.**

- It is recommended to survey and/or **collect benchmark data** for seakeeping problems, such as motions, loads, sloshing, slaming and full-scale measurements.

- It is recommended to **write a new section for the V&V of ship hydroelasticity codes** in the procedure 7.5-02-07-02.5, Verification and Validation of Linear and Weakly Non-linear Seakeeping Computer Codes.

- It is recommended to **strengthen the collaboration with ISSC committees**, including, Loads and Responses and Environment Committees.

- It is recommended to **liaison with Propulsion and Manoeuvring Committees** for seakeeping/motion effects.

- It is recommended to **create a unified procedure for sloshing experiment.**
ITTC-ISSC Joint Workshops

• Importance of cooperation recognised by 25th ITTC and continued in 26th and 27th terms.

• Further cooperation mandated by ITTC and also by the pertinent ISSC committees.

• 1st joint workshop was held in one day before ISSC Conference at Rostock in 2012, and 2nd joint workshop was held in one day before this ITTC Conference.

• Attended by representatives from the ITTC SC and OEC and ISSC Loads and Environment committees.

• Presentations of the 1st workshop were written into the technical papers which were published in a special edition of Ocean Engineering. The same is scheduled for the 2nd workshop.
<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Session Chair</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00 - 09:30</td>
<td>Registration</td>
<td></td>
</tr>
<tr>
<td>09:30 - 09:40</td>
<td>Welcome from the Chairs of ITTC &amp; ISSC</td>
<td></td>
</tr>
<tr>
<td>09:40 – 10:20</td>
<td>Prediction of Wave Induced Loads on Ships: Progress and Challenges by Pandeli Temarel, ISSC Loads Committee</td>
<td>Gerhard Strasser</td>
</tr>
<tr>
<td>10:20 - 11:00</td>
<td>Emerging Problems of Nonlinear Seakeeping and Loads by Yonghwan Kim, ITTC Seakeeping Committee</td>
<td></td>
</tr>
<tr>
<td>11:00 - 11:20</td>
<td>Coffee Break (supported by DNV-GL)</td>
<td></td>
</tr>
<tr>
<td>11:20 – 12:00</td>
<td>Nonlinear Loadings on Ocean and Offshore Structures by Wei Qui, ITTC Ocean Engineering Committee</td>
<td>Paul Crossland</td>
</tr>
<tr>
<td>12:00 - 12:40</td>
<td>Sea state conditions for marine structures’ analysis and model tests</td>
<td></td>
</tr>
<tr>
<td>12:40 - 14:00</td>
<td>Lunch (supported by Lloyd’s Register Group)</td>
<td></td>
</tr>
<tr>
<td>14:00 – 14:50</td>
<td>Results of Benchmark Test for a Containership</td>
<td>Carlos Guedes Soares</td>
</tr>
<tr>
<td>14:50 – 15:05</td>
<td>Benchmark Test 1 : Lloyd’s Register</td>
<td></td>
</tr>
<tr>
<td>15:05 - 15:20</td>
<td>Coffee Break (supported by MARIN)</td>
<td></td>
</tr>
<tr>
<td>15:35 - 15:50</td>
<td>Benchmark Test 3 : University of Duisburg-Essen</td>
<td></td>
</tr>
<tr>
<td>15:50 - 16:15</td>
<td>Benchmark Test 4 : Seoul National University</td>
<td></td>
</tr>
<tr>
<td>16:15 - 16:30</td>
<td>Coffee Break</td>
<td></td>
</tr>
<tr>
<td>16:30 - 17:30</td>
<td>Panel Discussion for Environmental Loads and Ship Responses</td>
<td>Yonghwan Kim</td>
</tr>
<tr>
<td>17:40 -</td>
<td>Dinner (Hosted by AMEC, Seoul National University)</td>
<td></td>
</tr>
</tbody>
</table>
Discussions

• Need to have terms of references
• Create joint committee(s) of ITTC and ISSC
• Open to all committees of ITTC and ISSC
• Topics to be considered: loads, uncertainty, ...
• A common archive can be shared by two organizations, e.g. benchmark test, ...
• Review reports each other can be considered.
• Short-term and long-term plan should be defined.
• ......
Benchmark Test: Ship Model

KRISO 6750-TEU Containership

**Design/Model Test:** designed by DSME and KRISO

**Model Test:** KRISO (2009)

**Body Type:** 8-segmented flexible ship with rectangular bar backbone

<table>
<thead>
<tr>
<th>Item</th>
<th>Prototype</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>1/1</td>
<td>1/70</td>
</tr>
<tr>
<td>LOA (m)</td>
<td>300.891</td>
<td>4.298</td>
</tr>
<tr>
<td>LBP (m)</td>
<td>286.6</td>
<td>4.094</td>
</tr>
<tr>
<td>Breadth (m)</td>
<td>40</td>
<td>0.571</td>
</tr>
<tr>
<td>Height (m)</td>
<td>24.2</td>
<td>0.346</td>
</tr>
<tr>
<td>Draft (m)</td>
<td>11.98</td>
<td>0.171</td>
</tr>
<tr>
<td>Displacement</td>
<td>85562.7 ton</td>
<td>249.454 kg</td>
</tr>
<tr>
<td>KM (m)</td>
<td>18.662</td>
<td>0.267</td>
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<tr>
<td>GM (m)</td>
<td>2.1</td>
<td>0.03</td>
</tr>
<tr>
<td>KG (m)</td>
<td>16.562</td>
<td>0.237</td>
</tr>
<tr>
<td>LCG from AP (m)</td>
<td>138.395</td>
<td>1.977</td>
</tr>
<tr>
<td>kxx (m)</td>
<td>14.6</td>
<td>0.206</td>
</tr>
<tr>
<td>kyy (m)</td>
<td>70.144</td>
<td>1.002</td>
</tr>
<tr>
<td>kzz (m)</td>
<td>70.144</td>
<td>1.002</td>
</tr>
<tr>
<td>Natural Period of Roll (sec)</td>
<td>20.5</td>
<td>2.45</td>
</tr>
<tr>
<td>Neutral axis from keel (m)</td>
<td>7.35</td>
<td>0.105</td>
</tr>
</tbody>
</table>
Backbone Property

A tubular backbone of rectangular cross-section

<table>
<thead>
<tr>
<th>Backbone</th>
<th>Real scale (m)</th>
<th>Model scale (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>7.000</td>
<td>100.000</td>
</tr>
<tr>
<td>H</td>
<td>3.500</td>
<td>50.000</td>
</tr>
<tr>
<td>t</td>
<td>0.161</td>
<td>2.300</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Young Modulus</th>
<th>Real scale (TPa)</th>
<th>Model scale (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14 (TPa)</td>
<td>200 (GPa)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Neutral axis from keel</th>
<th>Real scale (m)</th>
<th>Model scale (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.350</td>
<td>105.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode</th>
<th>Natural frequency of 2-node vertical bending</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Real scale (Hz)</td>
</tr>
<tr>
<td>Dry mode</td>
<td>0.785</td>
</tr>
<tr>
<td>Wet mode</td>
<td><strong>0.645</strong></td>
</tr>
</tbody>
</table>

*Damping ratio is approximately 2.0% of critical damping.*
## Test Cases

- Linear RAOS of motion and load in head sea (Linear)
- Nonlinear motion and load in head sea (NL1, 2, and 3)
- Longitudinal distribution of sagging and hogging moment (NL1, 2, and 3)
- Forward speed effect (NL1 and 3)
- Nonlinear springing and whipping due to a large wave (NL2)

<table>
<thead>
<tr>
<th>Objective</th>
<th>Test ID</th>
<th>Wave Frequency (rad/s), $\lambda/L$</th>
<th>Wave Height (m)</th>
<th>Heading angle (degree)</th>
<th>Forward speed (m/s), Froude No.</th>
<th>Output Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear RAO</td>
<td>RAO</td>
<td>0.242<del>0.628, 0.54</del>3.68</td>
<td>small value</td>
<td>180</td>
<td>0</td>
<td>RAO of Heave, pitch, VBM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Optional objective</th>
<th>Test ID</th>
<th>Wave Frequency (rad/s), $\lambda/L$</th>
<th>Wave Height (m), $H/\lambda$</th>
<th>Heading angle (degree)</th>
<th>Forward speed (m/s), Froude No.</th>
<th>Output Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonlinear load &amp; whipping</td>
<td>NL1</td>
<td>0.449, 1.07</td>
<td>6.118, 1/50</td>
<td>180</td>
<td>2.572, 0.05</td>
<td>Time series of heave, pitch, and VBM</td>
</tr>
<tr>
<td></td>
<td>NL2</td>
<td>0.449, 1.07</td>
<td>10.926, 1/28</td>
<td>180</td>
<td>2.572, 0.05</td>
<td>Longitudinal distribution of VBM</td>
</tr>
<tr>
<td></td>
<td>NL3</td>
<td>0.449, 1.07</td>
<td>6.118, 1/50</td>
<td>180</td>
<td>6.173, 0.12</td>
<td></td>
</tr>
</tbody>
</table>
### Participants: 17 programs from 11 organizations

<table>
<thead>
<tr>
<th>Institutes</th>
<th>Codes</th>
<th>Method</th>
<th>RAO</th>
<th>NL1</th>
<th>NL2</th>
<th>NL3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSSRC (China Ship Scientific Research Center)</td>
<td>THAFTS</td>
<td>3D BEM</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>DNV GL (Det Norske Veritas Germanischer Llyod)</td>
<td>GL Rankine1</td>
<td>3D BEM</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
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<tr>
<td></td>
<td>GL Rankine2</td>
<td>3D BEM</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>HEU (Harbin Engineering University)</td>
<td>COMPASS-WALCS-LE/NE</td>
<td>3D BEM</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>IST (Instituto Superior Tecnico)</td>
<td>In-house</td>
<td>Strip</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>LR (Llyod’s Register)</td>
<td>CRS PRECAL, PRETTI, TDWHIP</td>
<td>3D BEM</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>MUN (Memorial University of Newfoundland)</td>
<td>MAPS0</td>
<td>Panel-Free Method</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NMRI (National Maritime Research Institute)</td>
<td>NMRIW</td>
<td>Strip</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>NTUA (National Technical University of Athens)</td>
<td>NEWDRIFT</td>
<td>3D BEM</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>HYBRID</td>
<td>IRF</td>
<td>X</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>SNU (Seoul National University)</td>
<td>WISH</td>
<td>3D BEM</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>WISH-FLEX 2.5D</td>
<td>3D BEM</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>WISH-FLEX BEAM</td>
<td>3D BEM</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>UDE (University of Duisberg-Essen)</td>
<td>COMET</td>
<td>RANSE</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>UZUR (University of Zagreb and University of Rijeka)</td>
<td>Waveship</td>
<td>Strip</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>HydroSTAR</td>
<td>3D BEM</td>
<td>O</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Gretel</td>
<td>Strip</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>
Participants Analysis

Nonlinear Computation
- Linear: 12
- Nonlinear: 5

Frequency domain or Time domain
- Frequency domain: 12
- Time domain: 5
Participants Analysis

Analysis Method
- WGF: 6
- RPM: 4
- Strip: 4
- Others: 3

Commercialization
- Commercial: 13
- In-house: 4

*Others (3): CFD (1), IRF (1), Panel-Free-Method (1)
Linear RAO - Heave

| Linear RAO | λ/L = 0.54~3.68 | Small amplitude | 180° heading angle | Fn=0 | Heave |

Graph showing linear RAO for Heave with various symbols representing different models: 01-CSSRC(THAFTS), 02-DNVGL(GL_Rankine1), 03-DNVGL(GL_Rankine2), 04-HEU(WALCS), 05-IST(in-house), 06-LR(CRS), 07-MUN(MAPS0), 08-NMRI(NMRIW), 09-NTUA(NEWDRIFT), 11-SNU(WISH), 12-SNU(WISH-FLEX_2.5D), 13-SNU(WISH-FLEX_BEAM), 14-UDE(COMET), 15-UZUR(Waveship), 16-UZUR(Hydrostar), 17-UZUR(Gretel) and EXP.
Linear RAO - Pitch

<table>
<thead>
<tr>
<th>Linear RAO</th>
<th>$\frac{\lambda}{L}$=</th>
<th>Small amplitude</th>
<th>180° heading angle</th>
<th>Fn=0</th>
<th>Pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.55~3.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing Linear RAO for different models and simulations.](image)

- 01-CSSRC (THAFTS)
- 02-DNVGL (GL_Rankine1)
- 03-DNVGL (GL_Rankine2)
- 04-HEU (WALCS)
- 05-IST (in-house)
- 06-LR (CRS)
- 07-MUN (MAPS0)
- 08-NMRI (NMRIW)
- 09-NTUA (NEWDRIFT)
- 11-SNU (WISH)
- 12-SNU (WISH-FLEX_2.5D)
- 13-SNU (WISH-FLEX_BEAM)
- 14-UDE (COMET)
- 15-UZUR (Waveship)
- 16-UZUR (Hydrostar)
- 17-UZUR (Gretel)
- EXP
### Linear RAO - VBM

<table>
<thead>
<tr>
<th>Linear RAO</th>
<th>$\lambda/L =$</th>
<th>Small amplitude</th>
<th>$180^\circ$ heading angle</th>
<th>$Fn=0$</th>
<th>VBM at Section 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.55~3.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing Linear RAO for VBM](image)

- **01-CSSRC (THAFTS)**
- **02-DNVGL (GL_Rankine1)**
- **03-DNVGL (GL_Rankine2)**
- **04-HEU (WALCS)**
- **05-IST (in-house)**
- **06-LR (CRS)**
- **07-MUN (MAPS0)**
- **08-NMRI (NMRIW)**
- **09-NTUA (NEWDRIFT)**
- **11-SNU (WISH)**
- **12-SNU (WISH-FLEX_2.5D)**
- **13-SNU (WISH-FLEX_BEAM)**
- **14-UDE (COMET)**
- **15-UZUR (Waveship)**
- **16-UZUR (Hydrostar)**
- **17-UZUR (Gretel)**
- **EXP**
Linear RAO – Total Difference

![Graphs showing Total Diff. for Heave/A, Pitch/kA, and VBM4/\rhoAgL^2B](image)
Nonlinear - NL2, VBM

$$\text{VBM4}/\rho\text{AgL}^2B$$ (hogging: -, sagging: +)

- 04-HEU(WALCS)
- 05-IST(in-house)
- 06-LR(CRS)
- 08-NMRI(NMRIW)
- 10-NTUA(HYBRID)
- 11-SNU(WISH)
- 12-SNU(WISH-FLEX_2.5D)
- 13-SNU(WISH-FLEX_BEAM)
- 14-UDE(COMET)
- 17-UZUR(Gretel)
- EXP

Time*sqrt(g/L)

$\lambda/L=1.07$  $H/\lambda=1/28$  180° heading angle  $F_n=0.05$  VBM at midship
Nonlinear - NL2, VBM

<table>
<thead>
<tr>
<th>Time*sqrt(g/L)</th>
<th>Mean Amp.</th>
<th>SD</th>
<th>SD/Mean Amp. [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.0195</td>
<td>0.00562</td>
<td>28.9</td>
</tr>
<tr>
<td>0.23</td>
<td>0.0195</td>
<td>0.00485</td>
<td>24.9</td>
</tr>
<tr>
<td>0.46</td>
<td>0.0195</td>
<td>0.00502</td>
<td>25.8</td>
</tr>
<tr>
<td>0.69</td>
<td>0.0195</td>
<td>0.00678</td>
<td>34.8</td>
</tr>
<tr>
<td>0.92</td>
<td>0.0195</td>
<td>0.00573</td>
<td>29.4</td>
</tr>
<tr>
<td>1.15</td>
<td>0.0195</td>
<td>0.00265</td>
<td>13.6</td>
</tr>
<tr>
<td>1.38</td>
<td>0.0195</td>
<td>0.00353</td>
<td>18.1</td>
</tr>
<tr>
<td>1.61</td>
<td>0.0195</td>
<td>0.00377</td>
<td>19.4</td>
</tr>
<tr>
<td>1.84</td>
<td>0.0195</td>
<td>0.00388</td>
<td>19.9</td>
</tr>
<tr>
<td>2.07</td>
<td>0.0195</td>
<td>0.00296</td>
<td>15.2</td>
</tr>
</tbody>
</table>

NL2 $\lambda/L = 1.07$  
$H/\lambda = 1/28$  
180° heading angle  
Fn=0.05  
VBM at midship
Nonlinear - NL2, VBM

\[ \frac{VBM}{\rho A g L^2 B} \text{ (hogging:-, sagging:+)} \]

\[ \lambda/L = 1.07 \quad H/\lambda = 1/28 \quad 180^\circ \text{ heading angle} \quad Fn = 0.05 \quad \text{Longitudinal distribution of VBM} \]

Graph showing the distribution of VBM with various symbols and lines representing different models and simulations.
Nonlinear - NL2, VBM

NL2 $\lambda/L=1.07$  $H/\lambda=1/28$  180° heading angle  $F_n=0.05$  Longitudinal distribution of VBM

### Sagging

<table>
<thead>
<tr>
<th>$x/L$</th>
<th>Mean</th>
<th>SD</th>
<th>SD/Mean [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>0.0109</td>
<td>0.00489</td>
<td>44.9</td>
</tr>
<tr>
<td>0.23</td>
<td>0.0160</td>
<td>0.00461</td>
<td>28.8</td>
</tr>
<tr>
<td>0.33</td>
<td>0.0236</td>
<td>0.00470</td>
<td>20.0</td>
</tr>
<tr>
<td>0.43</td>
<td>0.0275</td>
<td>0.00508</td>
<td>18.5</td>
</tr>
<tr>
<td>0.53</td>
<td>0.0271</td>
<td>0.00488</td>
<td>18.0</td>
</tr>
<tr>
<td>0.63</td>
<td>0.0222</td>
<td>0.00419</td>
<td>18.9</td>
</tr>
<tr>
<td>0.73</td>
<td>0.0144</td>
<td>0.00346</td>
<td>24.1</td>
</tr>
</tbody>
</table>

### Hogging

<table>
<thead>
<tr>
<th>$x/L$</th>
<th>Mean</th>
<th>SD</th>
<th>SD/Mean [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>-0.0042</td>
<td>0.00357</td>
<td>-85.2</td>
</tr>
<tr>
<td>0.23</td>
<td>-0.0064</td>
<td>0.00141</td>
<td>-21.9</td>
</tr>
<tr>
<td>0.33</td>
<td>-0.0116</td>
<td>0.00231</td>
<td>-20.0</td>
</tr>
<tr>
<td>0.43</td>
<td>-0.0157</td>
<td>0.00249</td>
<td>-15.9</td>
</tr>
<tr>
<td>0.53</td>
<td>-0.0166</td>
<td>0.00236</td>
<td>-14.2</td>
</tr>
<tr>
<td>0.63</td>
<td>-0.0137</td>
<td>0.00221</td>
<td>-16.2</td>
</tr>
<tr>
<td>0.73</td>
<td>-0.0083</td>
<td>0.00164</td>
<td>-19.7</td>
</tr>
</tbody>
</table>
Nonlinear - NL2, VBM

NL2  \( \lambda/L=1.07 \)  \( H/\lambda=1/28 \)  180° heading angle  \( Fn=0.05 \)  Longitudinal distribution of VBM

![Graph showing the longitudinal distribution of VBM with participant IDs from 1 to 17. The graph displays the total differential for sagging and hogging across different participants, with bars indicating the percentage difference between NL2 and VBM for each participant.]
Comparison of SD – VBM4 (x/L=0.43)

<table>
<thead>
<tr>
<th>ID</th>
<th>LIN</th>
<th>LIN</th>
<th>LIN</th>
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<th>LIN</th>
<th>LIN</th>
<th>LIN</th>
<th>LIN</th>
<th>LIN</th>
<th>LIN</th>
<th>NL1</th>
<th>NL2</th>
<th>NL3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda/L$</td>
<td>3.68</td>
<td>2.82</td>
<td>2.52</td>
<td>2.29</td>
<td>1.77</td>
<td>1.48</td>
<td>1.07</td>
<td>0.85</td>
<td>0.66</td>
<td>0.55</td>
<td>1.07</td>
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<tr>
<td>$H/\lambda$</td>
<td>$\ll 1$</td>
<td>$\ll 1$</td>
<td>$\ll 1$</td>
<td>$\ll 1$</td>
<td>$\ll 1$</td>
<td>$\ll 1$</td>
<td>$\ll 1$</td>
<td>$\ll 1$</td>
<td>$\ll 1$</td>
<td>$\ll 1$</td>
<td>1/50</td>
<td>1/50</td>
<td>1/50</td>
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<tr>
<td>$F_n$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
<td>0.05</td>
<td>0.12</td>
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</table>
Comparison of SD – Sagging & Hogging

<table>
<thead>
<tr>
<th>x/L</th>
<th>0.16</th>
<th>0.23</th>
<th>0.33</th>
<th>0.43</th>
<th>0.53</th>
<th>0.63</th>
<th>0.73</th>
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<tbody>
<tr>
<td>H/λ</td>
<td>1/50</td>
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<td></td>
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<tr>
<td>Fn</td>
<td>0.05</td>
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<tr>
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<td>NL1</td>
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</tr>
</tbody>
</table>

**Notes:**
- SD: Sagging and Hogging
- Parameters: x/L, H/λ, Fn, ID
- Values: 0.16, 0.23, 0.33, 0.43, 0.53, 0.63, 0.73
- Displayed graphically with blue and red bars indicating positive and negative SD values.
Remarks for Benchmark Test

• 17 seakeeping analysis codes participated from 11 organizations. (12 nonlinear, 5 linear)

• The mean of all the numerical results show reasonable agreement with the experimental result.

• The numerical results are more scattered in VBM than motions.

• The numerical results are more scattered in the conditions of higher wave height, faster forward speed, or shorter wave length ($\lambda/L < 1.0$).

• The results of VBM near stern ($x/L < 0.2$) violently dispersed, whereas the results of VBM at mid-ship and bow are more convergent.
Thank you!

Q & A