Technical Committee on Stability in Waves

2017-2021

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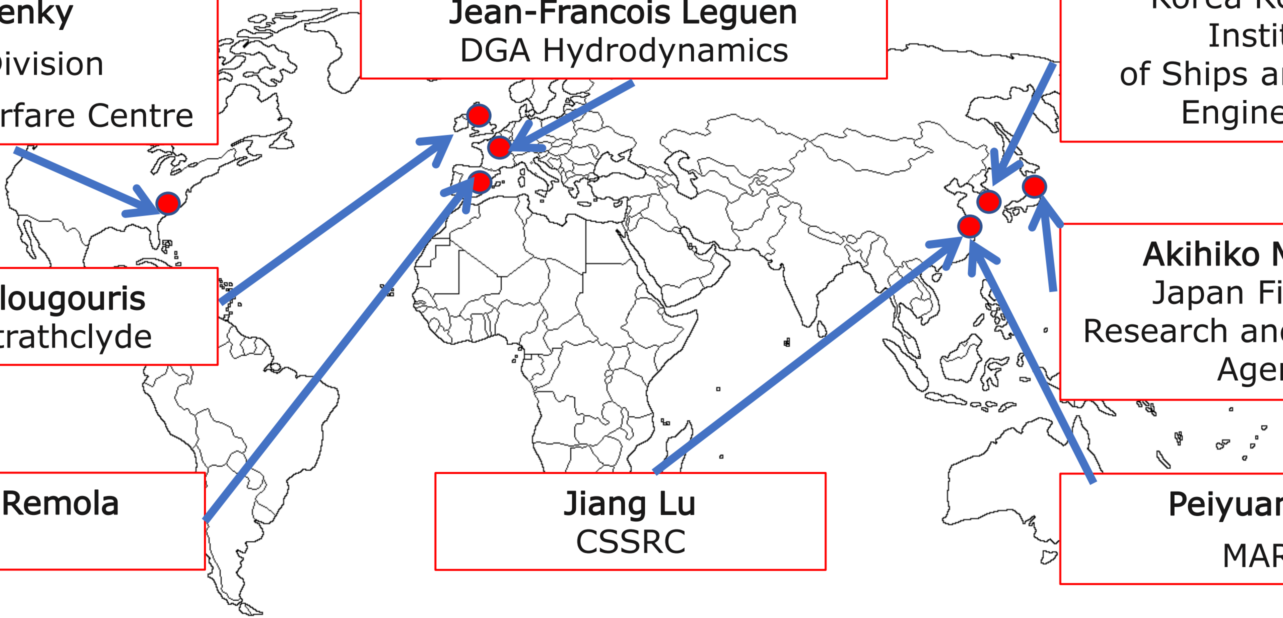
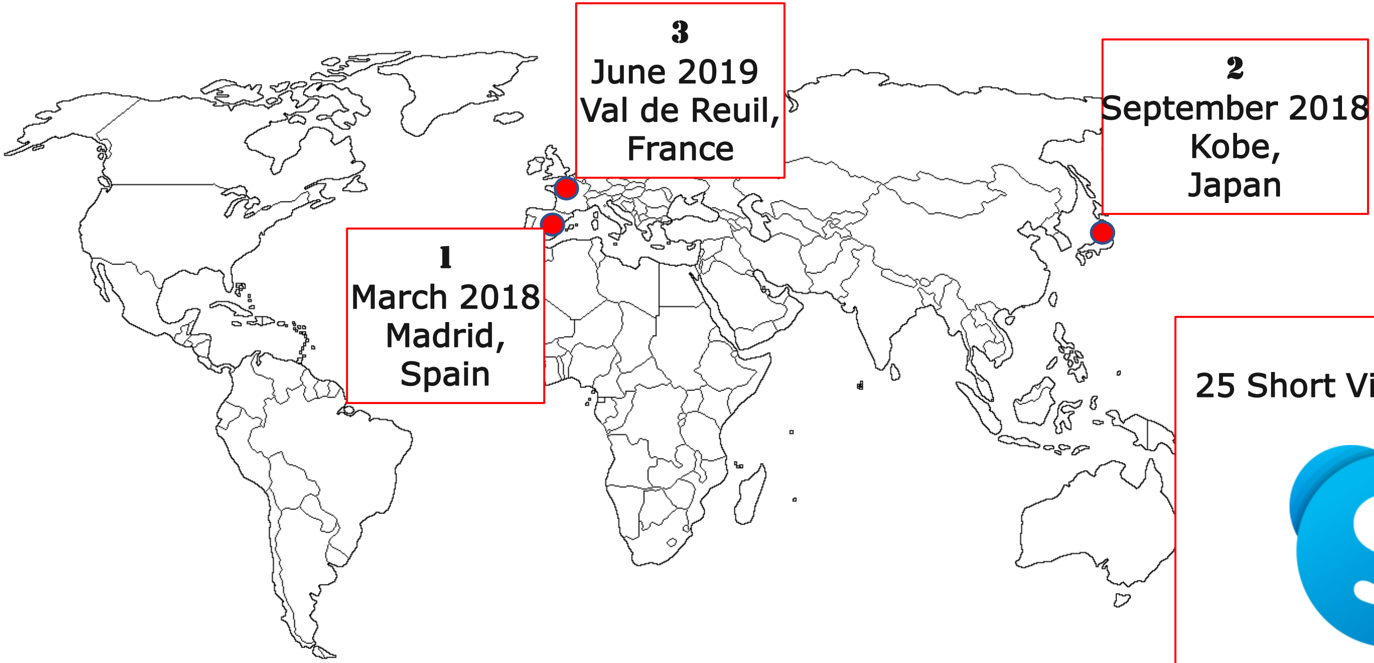
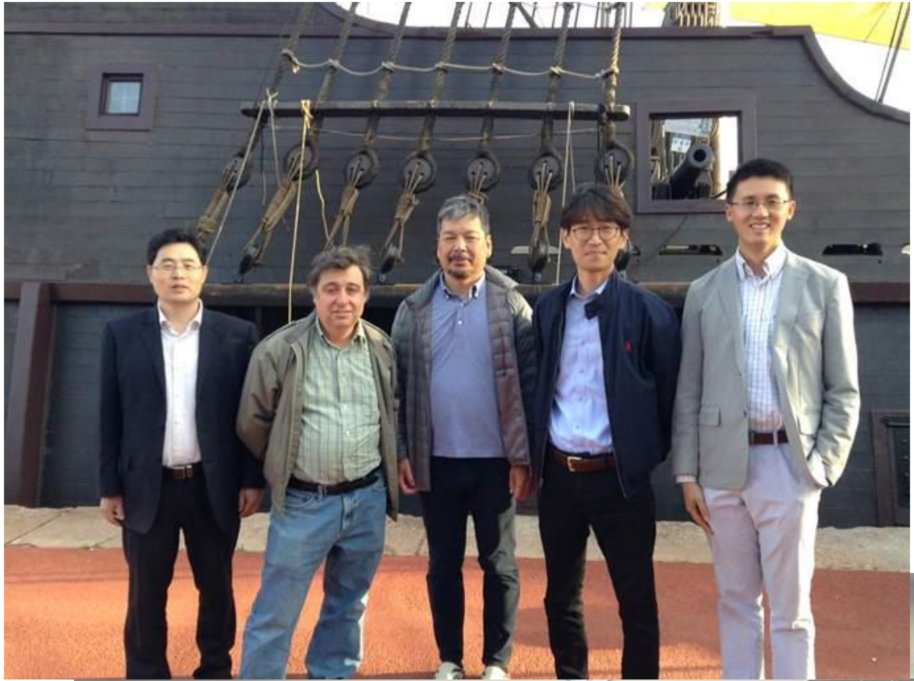


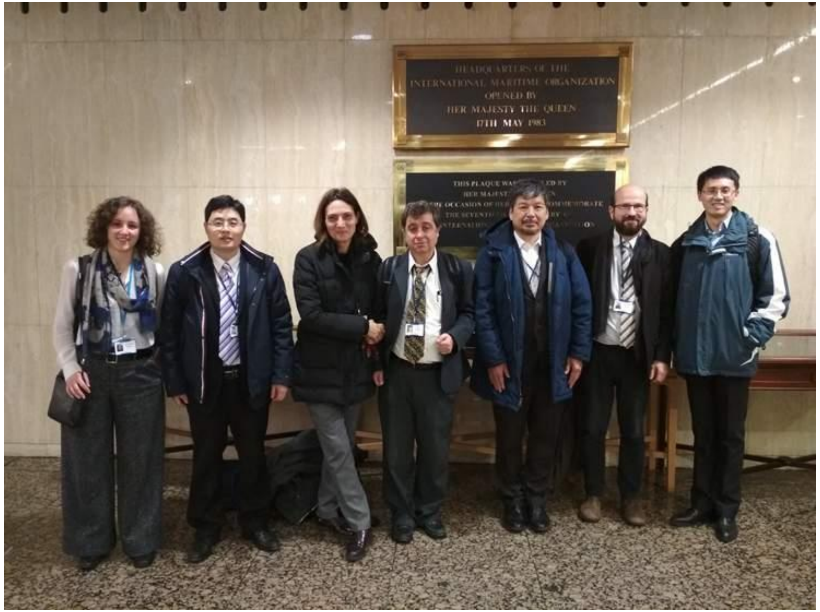
Meetings:



4
25 Short Video meetings

ROUEN





At IMO in LONDON with Paola Gualini, the previous chairman

KOBE

Tasks

1. Review the State-of-the-Art on stability of ships in adverse weather
2. Review ITTC Recommended Procedures
3. Review the IMO 2nd Generation Intact Stability Criteria (SGISC)
4. Provide a recommendation on developing procedures for Direct Stability Assessment for SGISC
5. Review the State-of-the-Art on Estimation of Roll Damping
6. Update Procedure 7.5-02-07-04.5 Estimation of Roll Damping
7. Update Guideline 7.5-02-07-04.3 on Parametric Roll towards a procedure
8. Update Procedure 7.5-02-07-04.4 Numerical Simulation of Capsize Behaviour of Damaged Ships in Irregular Beam Seas
9. Develop a method for estimating time to capsizing and/or sinking
10. Continue the identification of benchmark data
11. Develop a procedure for undertaking inclining tests

Task 1

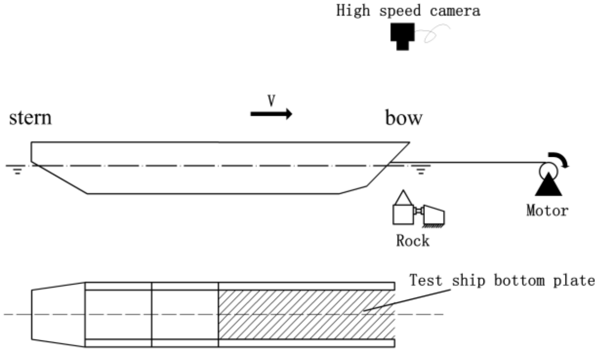
Update the state-of-the-art for evaluating the stability of ships in adverse weather conditions, emphasizing developments since the 2017 ITTC conference. The committee report should include sections on:

a. the potential impact of new technological developments on the ITTC;
b. new experimental techniques;
c. new benchmark data;
d. practical applications of computational methods to predication and scaling;
e. the need for R&D for improving methods of model experiments, numerical modelling;
f. wind and current effects on stability assessments (intact and damaged ship, experimental and numerical methods);
g. review the effect of flooding on non-watertight bulkheads due to fire fighting for example.

Task 1.a - The potential impact of new technological developments on the ITTC

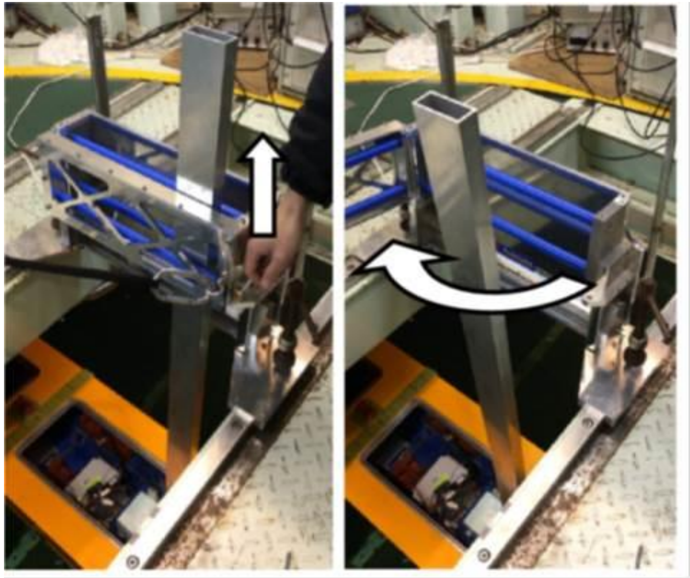
- **Active measures for flooding accidents are now demonstrable**
  - Inflatable devices
  - Highly expandable foam
- **Critical parameter**
  - Accurate capturing of their impact to floatability & stability during the event
    - Proper numerical simulation models are required
- **They are not covered under the existing SOLAS**

Task 1b - New experimental techniques



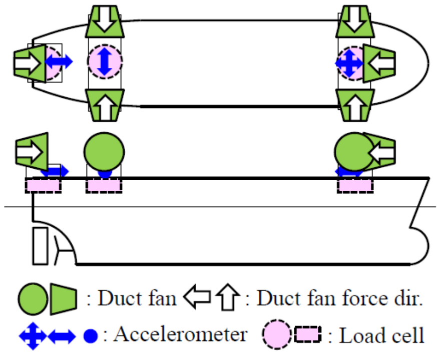
Zhu et al. (2018) performed model grounding experiments in a water tank to study the coupling effects of both internal mechanics and external dynamics. The influence of surrounding water on ship motions during grounding is taken into account. During their testing, varying rock penetrations are considered to study the grounding damage. Experimental results such as the horizontal grounding forces and damage extents are measured and analysed.

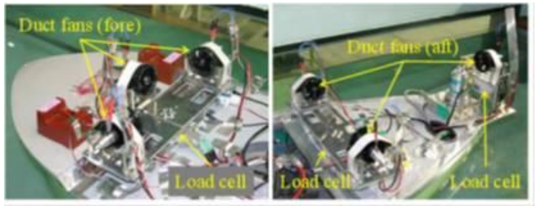
Task 1b - New experimental techniques



Hashimoto et al. (2019) designed and constructed a purpose-built device to obtain high-quality experimental data of roll decay motions for the quantitative validation of CFD methods. A certain initial heel angle was given to the ship model via the long square pipe as shown in Figs. 2 and 3. The square pipe can freely move in heave and pitch directions even when being held, thus, the change of ship attitude owing to the change of underwater ship volume and buoyancy balance is allowed. To start the roll decay test, the heel constraint is released momentarily by very swiftly open the aluminium frame through the strong tension of the connected rubber rope. As the rolling energy is consumed during the consecutive swings, the square long pipe will not reach the initial angle, thus will never hit the apparatus

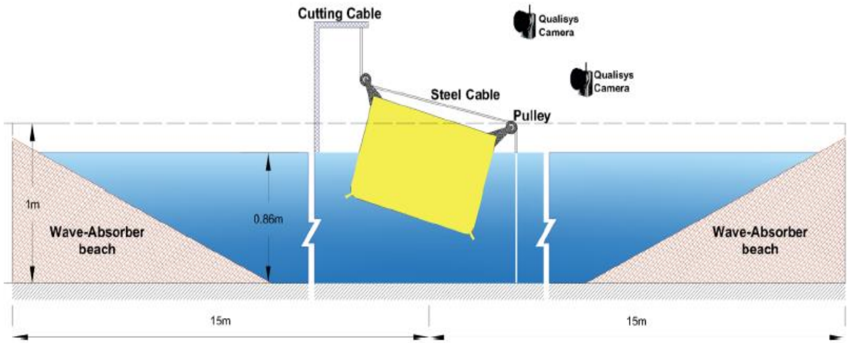
Task 1b - New experimental techniques





Tsukada et al. (2017) and Ueno et al. (2019) have developed a wind loads simulator (WiLS) that enables us to carry out free-running model tests for investigating wind effects on ship performance. WiLS provides a free-running model ship with simulated wind loads taking into account the supposed true wind speed and direction, and instantaneous model ship speed, drift angle, and heading angle. It does not generate environmental wind but exerts forces and moment on a model ship using three pairs of duct fans. A control PC calculates time-varying longitudinal and lateral wind forces and yaw moment using wind loads coefficients estimated beforehand and ship motion data, and distribute them to the three pairs of duct fans. Feedback control ensures the intended wind loads using data from load cells on which the duct fans are mounted and those from accelerometers for correcting inertia forces of the duct fans.

Task 1b - New experimental techniques



Asgari et al. (2020) investigated the Instantaneous Rotation Centres (IRC) and Most Often Instantaneous Rotation Centres (MOIRC) behaviour during the free roll decay tests of an FPSO by following the time series of the IRC. A static pure couple is applied to the hull to initiate the rolling. The motions during the test were tracked by an optical system using two Qualisys cameras, which measures the trajectory of the model, calculates the velocities, and transfer them into the non-inertial body-fixed coordinate system with the origin at the centre of gravity. It is demonstrated through the experiment that IRC behaviour leads to distinct damping values. Two categories of IRC locus were devised according to observations. Category-I corresponds to a tangent type IRC locus. Category-II corresponds to a double parabolic IRC locus. The effect of the MOIRC on roll damping explains why the damping is different from the clockwise to the counter clockwise oscillation.

Task 1c - New benchmark data

The committee has identified the following references to new benchmark data:

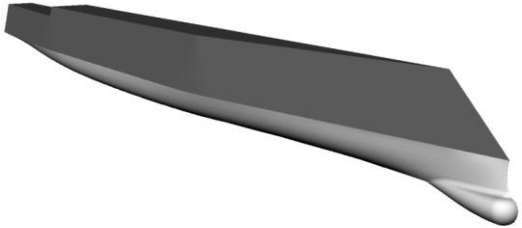
- Telste and Belknap 2008
- Irkal, Nallayarasu and Bhattacharyya 2019
- Hashimoto,Yoneda, Omura, Umeda, Matsuda, Stern, Tahara 2018

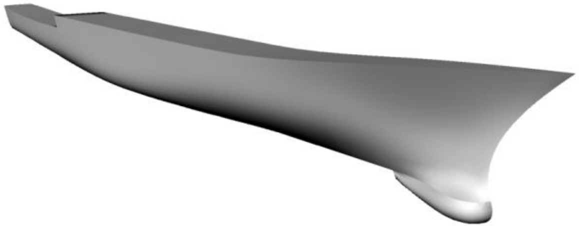
See also Task 10

Task 1c - New benchmark data

Telste and Belknap 2008

Comparative analysis of several existing computer codes in their ability to calculate potential flow forces and moments acting on hulls (ONR tumblehome and model 5514) in motions



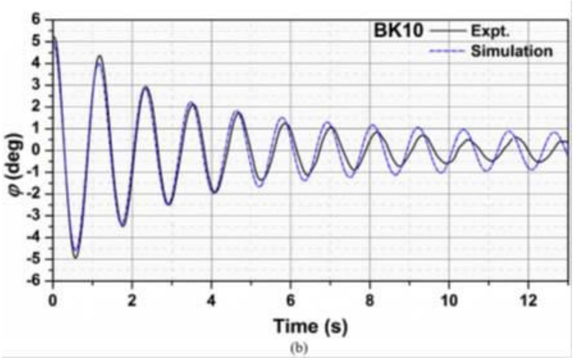


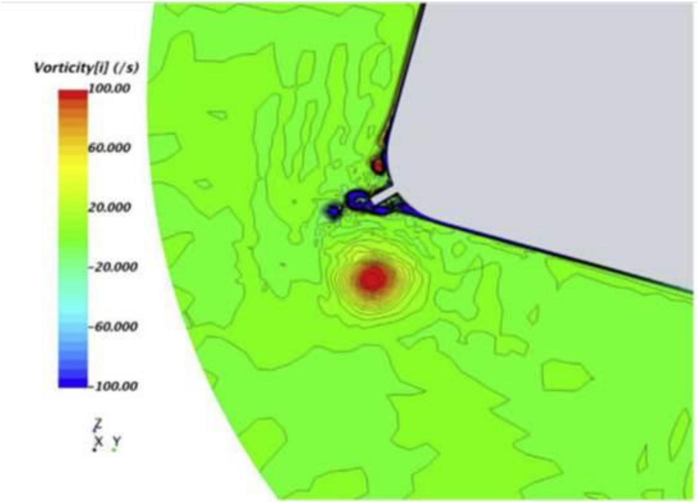
Data available on : ShipStab
Ship Stability, Dynamics and Safety

Task 1c - New benchmark data

Irkal, Nallayarasu and Bhattacharyya 2019

Three-dimensional simulations of roll decay of a barge ship model, both with and without bilge keel, with experimental validation.

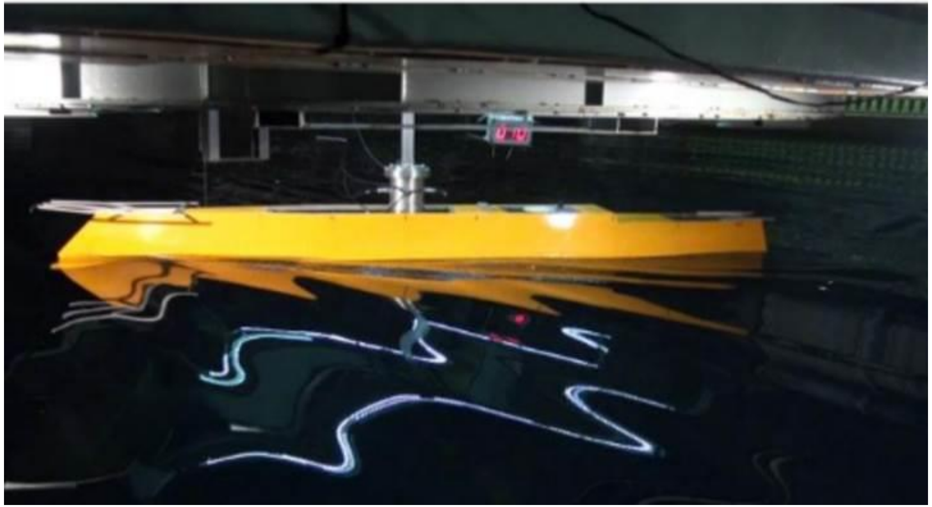




Task 1c - New benchmark data

Hashimoto, Yoneda, Omura, Umeda, Matsuda, Stern, Tahara, 2018

Numerical simulation predict wave-induce forces on ONR-tumblehome in irregular stern-quartering seas and are compared to model experiments



Task 1d - Practical applications of computational methods to prediction and scaling

- Surf-Riding and Broaching-to
  - Improving mathematical models with system identification method (Mizumoto et al. 2018), (Araki et al 2019) and regression (Aram & Silva 2019)
  - Progress in dynamics: influence of hull shape above waterline (Htet et al. 2018), analytical solution
- Parametric Roll
  - Averaging method for predicting magnitude (Sakai et al. 2018)
  - Encounter period for Grim effective wave (Sakai et al. 2019)
- Direct Counting and Simulation Requirements
  - Applicability issues of Poisson process (Shigunov 2019); requirement for total duration of simulation (Reed 2019a)
- Statistical Extrapolation
  - Block maxima method and cross-method benchmarking (Wandji 2019); Envelope Peak over Threshold – EPOT procedure description (Weems et al. 2019b)
  - Statistical validation: procedure (Smith 2019) and fast simulation method (Weems et al 2018)

Task 1e - The need for R&D for improving methods of model experiments, numerical modelling

The study of the stability of ships in a stochastic sea state

- Choi et al. (2017) adopt the First Order Reliability Method (FORM) to define possible combined critical wave and wind scenarios leading to capsize and achieve the calculation of capsizing probability at a much lesser computational effort.
- Jensen et al. (2017) show that the FORM can be an efficient method for estimation of outcrossing rates and extreme value statistics for stationary stochastic processes, suitable for the bifurcation type of processes such as a parametric roll.
- Sclavounos et al. (2019) develop a new methodology for the modelling of the nonlinear responses and stability of ships in stochastic steep waves, where a state-space stochastic differential equation is derived for the states governing the vessel nonlinear responses and a linear Fokker–Planck partial differential equation is obtained for the joint probability density function of the vessel motions, allowing the direct evaluation of the joint probability density function of the responses via the solution of the Fokker–Planck equation.

Task 1e - The need for R&D for improving methods of model experiments, numerical modelling

Physics of a stability-in-waves-related phenomenon at Irregular waves

- Results on the computation of celerity of irregular waves are reviewed in Spyrou et al. (2019).
- Kontolefas and Spyrou (2018) related the Lagrangian coherent structure with “high runs” (instantaneous speed above the normally expected fluctuations) and the estimated probability of surf-riding.

Quantification of uncertainty

- It is considered in Brown and Pipiras 2019.

Task 1e - The need for R&D for improving methods of model experiments, numerical modelling

A method for estimation of the probability of instantaneous values of roll motions:

- First, the shape of the distribution is obtained by subjecting a dynamical system to white noise excitation; it is further scaled with variance estimate(Maki, 2017).
- Further study of the method, including application, comparison and experimental validation is described in Maki et al. (2018, 2019a, 2019b)

Others

- Macé et al. (2019) developed a method for estimation of capsizing probability by extrapolation of an estimate of roll exceedance rate.
- Chai et al. (2019) compared path integration method (Kougioumtzoglou and Spanos 2014) with the averaging method (Dostal et al. 2012; Dostal and Kreuzer 2014) and formulated recommendations for application based on the advantages of both methods.

Task 1e - The need for R&D for improving methods of model experiments, numerical modelling

Probabilistic methods based on extreme value theory

- The extreme value theory states that the largest value in a sample of independent identically distributed variables tends to Generalized Extreme Value (GEV) distribution (the first extreme value theorem also referred to as Fisher-Tippet-Gnedenko theorem).
- It also states that a distribution above some large threshold can be approximated with Generalized Pareto Distribution (GPD) - the second extreme value theorem, referred as Pickands-Balkema-de Haan theorem (see e.g. Coles, 2001).
- Pipiras (2020) examined issues associated with using GPD for modelling extreme roll motions.
- Anastopoulos and Spyrou (2019a) found that while GPD works for large roll angle, it is not applicable for a description of escapes (capsizing).
- The issues of GPD may be resolved with "physics-informed model" where physical information is included into a statistical model in order to decrease the uncertainty (Glotzer et al. 2017).

Task 1e - The need for R&D for improving methods of model experiments, numerical modelling

Probabilistic methods based on extreme value theory

- Belenky et al. (2019a) proved that the response of a dynamical system with softening nonlinearity has a heavy tail of the distribution using a piecewise linear approximation of the restoring term.
- Belenky et al. (2018a) described a new version of EPOT using Pareto distribution to model a heavy tail.
- Belenky et al. (2018a, 2018b) described a new version of the split-time method using an exponential distribution for capsizing metric.
- Estimation of probability of capsizing caused by broaching with the split-time method is described in Belenky et al. (2017) and Weems et al. (2020) using an approximation of the boundary of Lagrangian coherent structures describing surf-riding states in irregular waves (Kontolefas and Spyrou, 2016; 2018).

Task 1e - The need for R&D for improving methods of model experiments, numerical modelling

Probabilistic methods based on wave group approach

- Anastopoulos and Spyrou (2017) described further development of a realistic wave group model with a variation of amplitudes and periods (Anastopoulos and Spyrou, 2016).
- All the cited papers use Markov chain to model a wave group, originally proposed by Kimura (1980) and applied for probabilistic assessment of dynamic stability in waves by Themelis and Spyrou (2007).
- Mohammad and Sapsis (2018) used a combination of an envelope of wave elevations and Gaussian-shape functions (Cousins and Sapsis, 2016; Farazmand and Sapsis, 2017) for detecting the wave groups.
- Adaptive sequential sampling was applied; the central idea is to use Gaussian process regression (GPR) that enables an optimization algorithm to drive the selection of critical wave groups that define the tail of the response distribution. The method offers sufficient computational efficiency to be used with advanced panel code (Stevens, 2018; Rathore, 2019) and CFD (Mohammad and Sapsis 2018; Gong et al. 2020) to evaluate the extreme roll response.

Task 1e - The need for R&D for improving methods of model experiments, numerical modelling

Probabilistic methods based on wave group approach

- Originally developed for the assessment of extreme wave-induced loads (e.g. Alford and Troesch, 2009), the Design Load Generator (DLG) was extended to extreme motions (Kim and Troesch, 2013; 2019). Xu and Maki (2018, 2019a), Xu et al. (2020) integrated DLG with RANS solution, using FOAM.

Task 1f - Wind and current effects on stability assessments (intact and damaged ship, experimental and numerical methods)

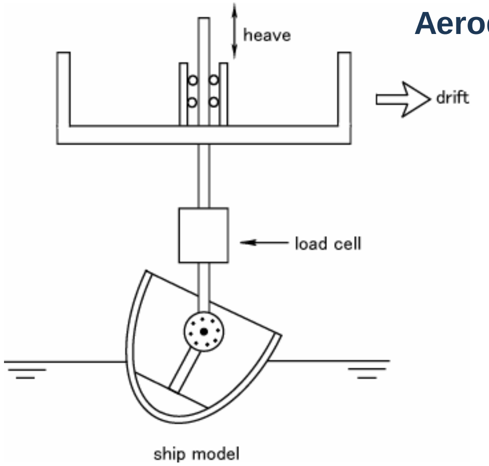
WIND is an important parameter to evaluate stability in waves

- One of the first used in rules comes from PIERROTTET in 1935
- OMI Weather criteria in 1977 for fishing vessels
- Dead Ship Conditions of the SGISC of OMI in 2020

CURENT is not pointed out but essential for estimation of drift forces

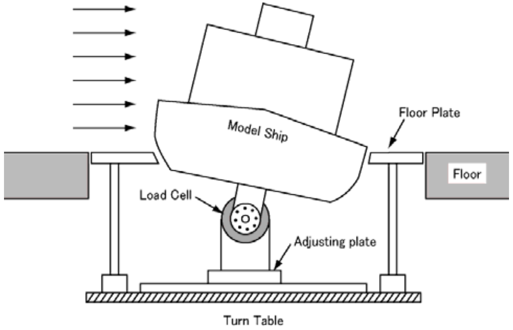
Task 1f - Wind and current effects on stability assessments (intact and damaged ship, experimental and numerical methods)

Circular 1200 and 1227 of OMI describe experimental setup



Aerodynamic forces

Hydrodynamic forces
(similar to transverse current)



Task 1f - Wind and current effects on stability assessments (intact and damaged ship, experimental and numerical methods)

In rules wind and current are parameters like any others

- Comparisons of regulations must includes all the process from the initial situation chosen to the criteria, including wind speed
- Wind speed chosen in IMO is not related to a physical operational wind speed

Task 1g - review the effect of flooding on non-watertight bulkheads due to fire fighting for example

- **Non-watertight, firefighting bulkheads have an effect on flooding survivability of a ship**
  - They create asymmetries >> Increase vulnerability to capsizals
- **Methodologies (Ruponen, Dankowski)**
  - The fire doors at the staircases and escape trunks that allow up and down-flooding and all doors on the bulkhead deck could be considered open
  - The doors in longitudinal bulkheads under the bulkhead deck should be considered closed
- **Results**
  - Enormous effects on the progress of flooding
  - Reduction of TTC

Task 2 - Review ITTC Recommended Procedures

a) identify any requirements for changes in the light of current practice, and, if approved by the Advisory Council, update them;

b) identify the need for new procedures and outline the purpose and contents of these.

Task 2a - Identify any requirements for changes in the light of current practice, and, if approved by the Advisory Council, update them

Procedure 7.5-02-05-07 (Dynamic Instability Tests from high-speed marine vehicles domain) was reviewed and no change is proposed by the committee.

Task 2a - Identify any requirements for changes in the light of current practice, and, if approved by the Advisory Council, update them

Procedure 7.5-02-07-04.1 (Model Tests on Intact Stability) was reviewed and no change is proposed by the committee.

Task 2a - Identify any requirements for changes in the light of current practice, and, if approved by the Advisory Council, update them

Procedure 7.5-02-07-04.2 (Model Tests on Damage Stability in Waves).

The procedure was written and submitted by the previous Stability in Waves committee. No comments were received by previous and actual committee no improvement is requested by this committee.

Task 2a - Identify any requirements for changes in the light of current practice, and, if approved by the Advisory Council, update them

Procedure 7.5-02-07-04.3 (Predicting the Occurrence and Magnitude of Parametric Rolling) was submitted:

- Three levels-structure was adopted. Each level describes methods of prediction of different fidelity and thus complexity;
- Recommendations on assessment of parametric roll in irregular waves was added;
- List of references was updated.

See also Task 7

Task 2a - Identify any requirements for changes in the light of current practice, and, if approved by the Advisory Council, update them

Procedure 7.5-02-07-04.4 (Numerical Simulation of Capsize Behaviour of Damaged Ships in Irregular Beam Seas) was submitted.

TOR 8: Update Procedure 7.5-02-07-04.4 (1)

- **Added concepts:**
  - Modelling methods for free surface in tanks
  - Flooding open spaces
  - Capsize band
  - Capsize rate
  - Critical wave height and
  - Time to capsize (TTC) vs. Time to Evacuate (TTE)
  - Fusing real-time sensor information for real-time risk assessment during uncontrolled flooding incidents.
- **Technological innovations**
  - Area of active buoyancy & stability recovery systems

TOR 8: Update Procedure 7.5-02-07-04.4 (2)

- **Applicability of CFD:**
  - Increasing interest for capturing with CFD the behaviour of the damaged ship in waves
  - Challenges of:
    - high computational power
    - Sensitivity to mesh quality
    - Experience from the end-user <u>important</u>
- **Not mature yet for general use**
- **Nevertheless, they provide valuable input for hybrid or blended methods**
- **Their performance improves fast**
- **Future opportunities can be clearly identified**

Task 2a - Identify any requirements for changes in the light of current practice, and, if approved by the Advisory Council, update them

Procedure 7.5-03-02-03 (Practical Guidelines for ship CFD application) was reviewed.

<u>Proposal:</u> modify “Section 3.6 Time Step” by adding the recommended time interval when an overset mesh is used, i.e., if an overset mesh is used, use at least 500 time steps per period.

Task 2a - Identify any requirements for changes in the light of current practice, and, if approved by the Advisory Council, update them

Procedure 7.5-02-07-04.5 (Numerical Estimation of Roll Damping) was completely reviewed and significantly updated by the committee.

See also Task 6

Task 2b - Identify the need for new procedures and outline the purpose and contents of these

Proposal for Guidance on Avoiding Self- Repetition Effect During Numerical Simulation of Ship Motions was submitted.

- Purpose of the Guidance is to formulate a process for verification of the absence of self-repetition effect and statistical validity of irregular waves in numerical simulation of ship motions
- An inappropriate choice of frequency discretization of the spectrum may lead to self-repetition effect, compromising statistical validity of the model. It may result in an incorrect assessment of statistical uncertainty of SSA and other estimates, required by procedure 7.5-02-01-08

See also Task 4

Task 2b - Identify the need for new procedures and outline the purpose and contents of these

Procedure on Extrapolation for Direct Stability Assessment in Waves was submitted.

The procedure contains description of two extrapolation methods for estimation of probability of large roll angles and capsizing in waves:

- Peak-over-Threshold / Envelope Peak-over-Threshold (POT/EPOT) Method
- Split-Time Method
- The procedure supports the second generation IMO intact stability criteria

See also Task 4

Task 2b - Identify the need for new procedures and outline the purpose and contents of these

Proposal for Procedure of Estimation of Frequency of Random Events was submitted.

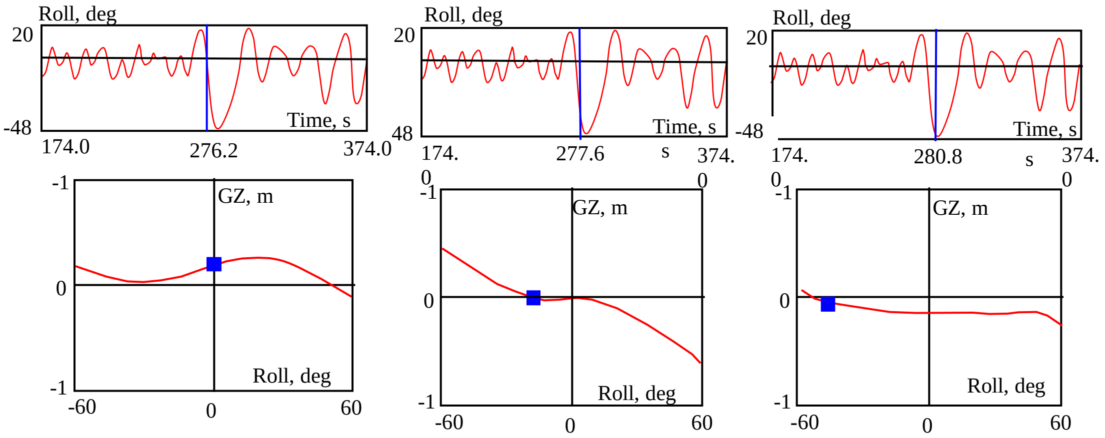
- Purpose of the procedure is to formulate a process for estimating the statistical frequency and rate of rare events
- Input data are time series resulted from model test or numerical simulation
- Supports second generation IMO intact stability criteria

See also Task 4

Task 2b - Identify the need for new procedures and outline the purpose and contents of these

Proposal for Computational Procedure for Predicting the Instantaneous $\overline{GZ}$ Curve during Time-Domain Numerical Simulation was submitted.

- Purpose of Procedure is to describe a process for computation of the instantaneous $\overline{GZ}$ curve in irregular waves to enhance the analysis of large roll angles
- Knowing the form of the instantaneous $\overline{GZ}$ curve in irregular waves may help to explain large roll excursions



Task 2b - Identify the need for new procedures and outline the purpose and contents of these

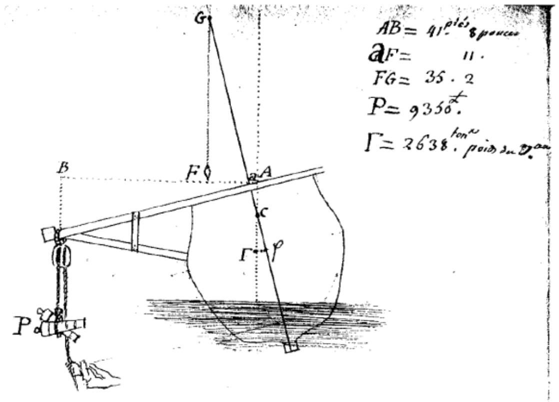
Proposal for Procedure "Statistical Validation of Extrapolation Methods for Time Domain Numerical Simulation of Ship Motions and Loads" was submitted.

- Purpose of the procedure: to formulate a process for validation of extrapolation methods for time domain numerical simulation of ship motions and loads
- The is idea is to generate a large-volume sample, estimate an event rate, and then compare it with a result of extrapolation using a small subset of this large-volume sample.
- Supports the second generation IMO intact stability criteria

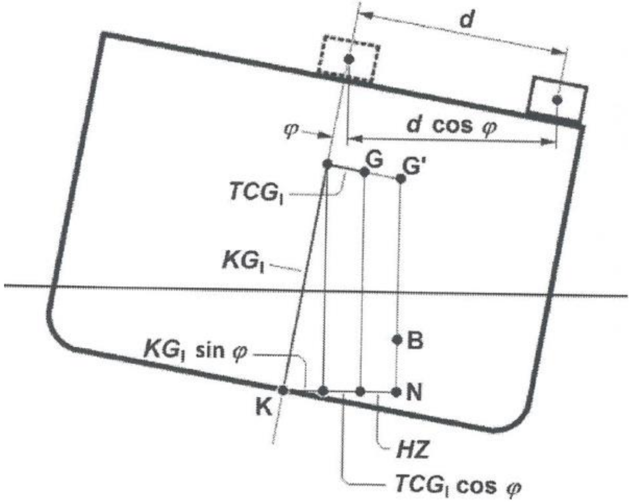
See also Task 4

Task 2b - Identify the need for new procedures and outline the purpose and contents of these

Proposal for Procedure on inclining test was submitted.

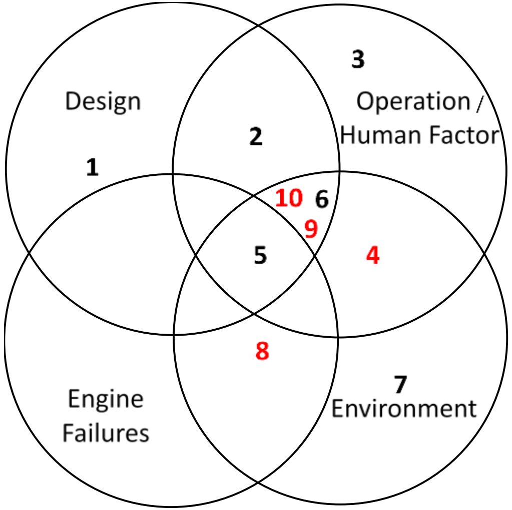


Since 1748 until today, many methods and procedures have been published but not from ITTC



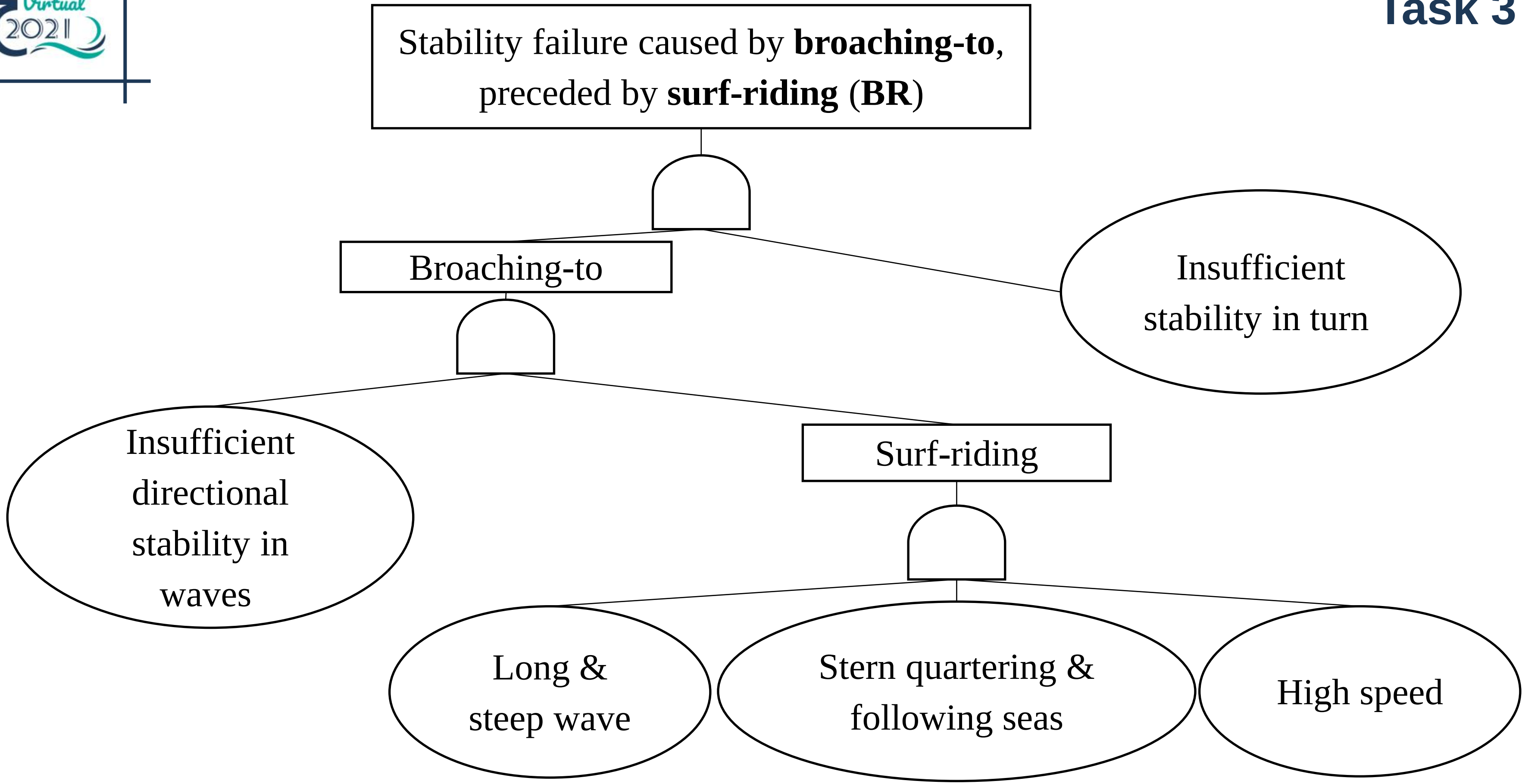
See also Task 4

Task 3 - Review the IMO 2nd Generation Intact Stability Criteria and standards with a particular focus on the physics and background for each of the stability failure modes. It may be useful to develop a fault tree to better identify each of the stability failure modes.

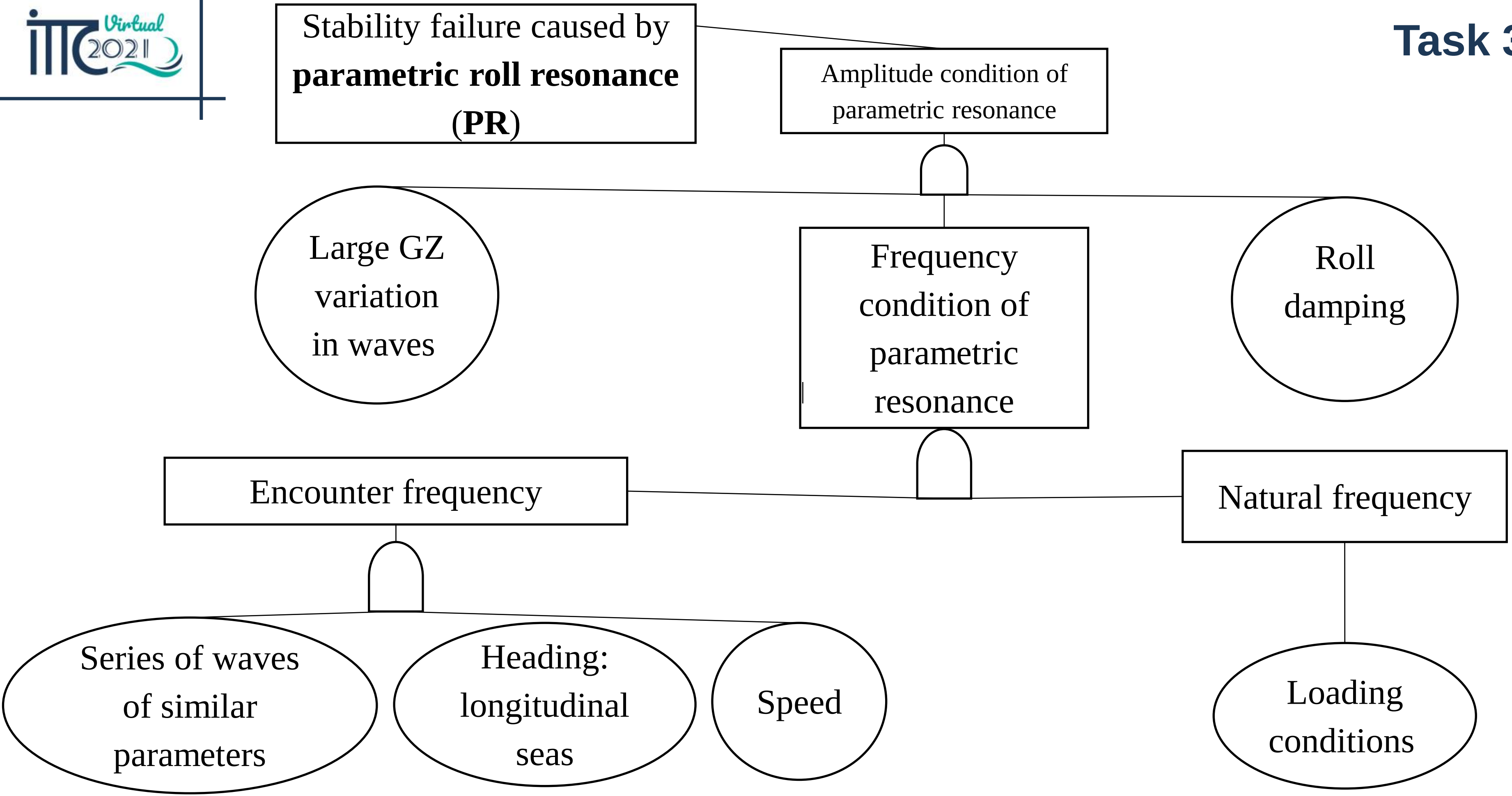


1. When launched due to faulty design
2. Turning at high speed
3. Overloading
4. High speed in following sea – broaching and pure loss of stability
5. Bad weather + lack of knowledge + low stability + subsystem failure
6. Excessive water on deck
7. Heavy icing combined with heavy sea preventing clearing off the ice
8. Dead Ship Condition
9. Parametric Roll
10. Excessive Acceleration

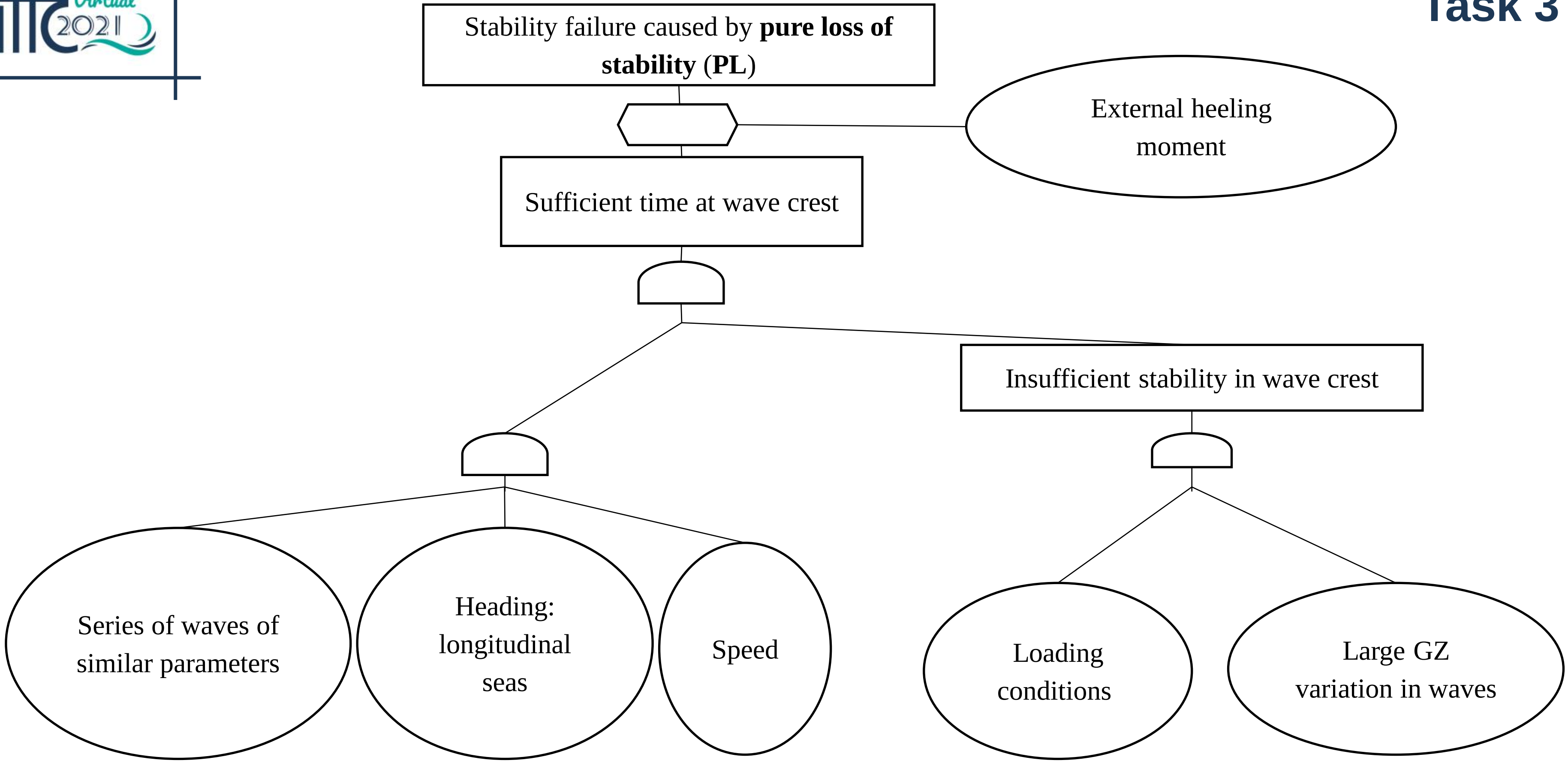
For each failure modes of IMO a fault tree was developed

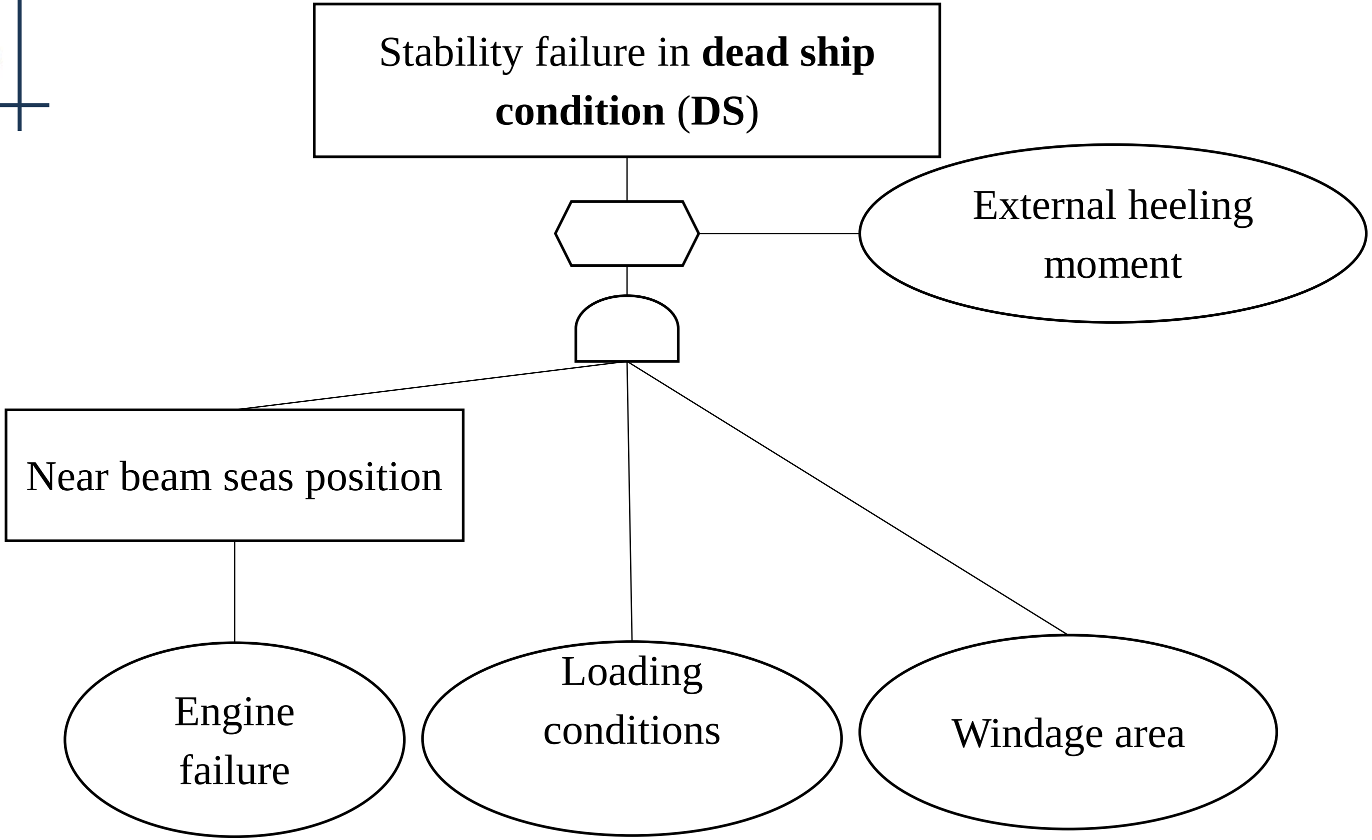

Stability failure caused by **broaching-to**, preceded by **surf-riding** (**BR**)
Broaching-to
Insufficient stability in turn
Insufficient directional stability in waves
Surf-riding
Long & steep wave
Stern quartering & following seas
High speed

Task 3

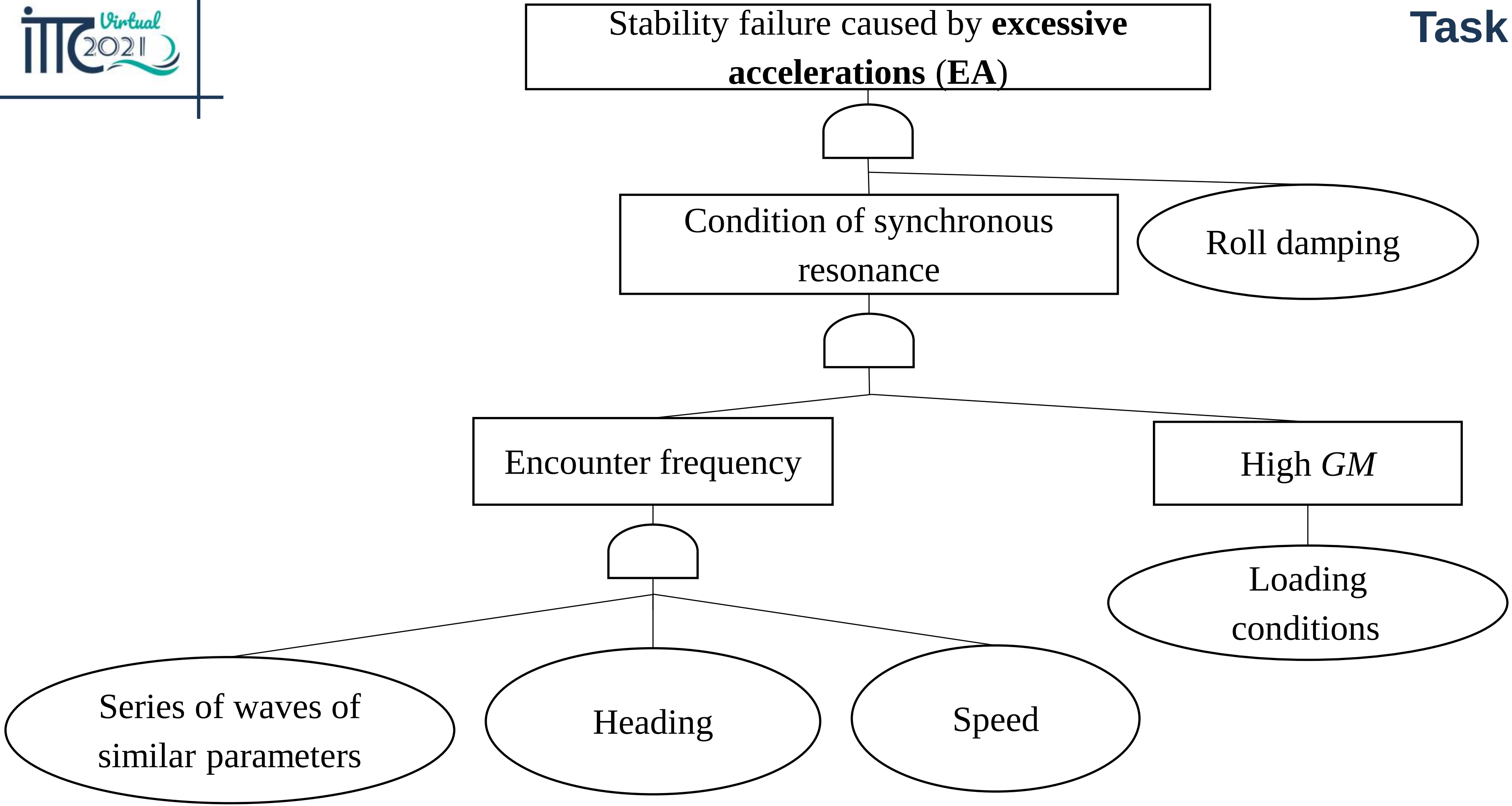

Stability failure caused by **parametric roll resonance (PR)**
Amplitude condition of parametric resonance
Large GZ variation in waves
Frequency condition of parametric resonance
Roll damping
Encounter frequency
Natural frequency
Series of waves of similar parameters
Heading: longitudinal seas
Speed
Loading conditions

Task 3


Stability failure caused by **pure loss of stability** (PL)
External heeling moment
Sufficient time at wave crest
Insufficient stability in wave crest
Series of waves of similar parameters
Heading: longitudinal seas
Speed
Loading conditions
Large GZ variation in waves


Stability failure in **dead ship condition** (DS)
External heeling moment
Near beam seas position
Engine failure
Loading conditions
Windage area

Task 3


Stability failure caused by **excessive accelerations (EA)**
Condition of synchronous resonance
Roll damping
Encounter frequency
High *GM*
Loading conditions
Series of waves of similar parameters
Heading
Speed

Task 4 - Provide a recommendation on developing a procedure, or a set of procedures, for the direct assessment (computational methods) of the IMO 2nd Generation Intact Stability Criteria five modes of intact stability failure.

Direct stability assessment (DSA) is the top-tier of the second generation IMO intact stability criteria (MSC.1/Circ.1627). It is an evaluation of dynamic stability of a ship in waves with the most up-to-date numerical simulation tools and/or model. The following procedures are envisioned in support of the DSA:

Procedure/Guidance	Status
Guidance on Avoiding Self- Repetition Effect During Numerical Simulation of Ship Motions	Proposed under Task 2
Procedure of Estimation of Frequency of Random Events	Proposed under Task 4
Procedure of Extrapolation for Direct Stability Assessment in Waves	Developed under Task 4
Statistical Validation of Extrapolation Methods for Time Domain Numerical Simulation of Ship Motions and Loads	Proposed under Task 4

Task 4 - Provide a recommendation on developing a procedure, or a set of procedures, for the direct assessment (computational methods) of the IMO 2nd Generation Intact Stability Criteria five modes of intact stability failure.

Proposed Procedure “Estimation of Frequency of Random Events”

Purpose: to formulate a process for estimating the statistical frequency and rate of rare events

Outline of the proposed procedure

- Estimate autocorrelation function based on all available data
- Estimate decorrelation time when the envelope of autocorrelation function falls below 0.05
- Count events for each realization, including only one within each decorrelation time period
- Estimate a rate of events as $\hat{\lambda} = n / \sum_i T_i$ where T_i is the duration of a simulation time history or model tank run
- Evaluate confidence interval of $\hat{\lambda}$ using binomial distribution for the random variable n or its normal approximation

Task 4 - Provide a recommendation on developing a procedure, or a set of procedures, for the direct assessment (computational methods) of the IMO 2nd Generation Intact Stability Criteria five modes of intact stability failure.

Procedure “Extrapolation for Direct Stability Assessment in Waves”

Purpose: **to provide detailed guidance on the extrapolation of ship motion data from numerical simulations in order to estimate probabilities of large roll angle and capsizing in irregular waves**

Outline of the procedure

- Theoretical background
- Estimation of roll exceedance rate with EPOT
- Estimation of capsizing rate with split-time method
- Calculation example

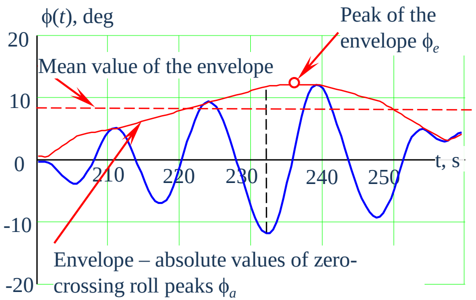
Task 4 - Provide a recommendation on developing a procedure, or a set of procedures, for the direct assessment (computational methods) of the IMO 2nd Generation Intact Stability Criteria five modes of intact stability failure.

Procedure “Extrapolation for Direct Stability Assessment in Waves”: Background

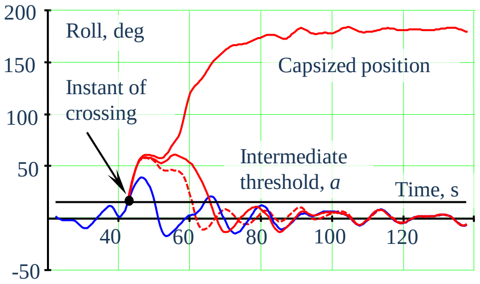
Theoretical background of EPOT and split-time method is the extreme value theory, describing probabilistic properties of the largest observation in a sample. The second extreme value theorem states that the distribution of this largest value can be approximated by a Generalized Pareto Distribution (GPD) above a large-enough threshold.

$$\mathrm{pdf}(y) = \begin{cases} \dfrac{1}{\sigma}\left(1+\xi\dfrac{y-u}{\sigma}\right)^{-\left(1+\frac{1}{\xi}\right)} & \xi \neq 0 \\ \dfrac{1}{\sigma}\exp\left(-\dfrac{y-u}{\sigma}\right) & \xi = 0 \end{cases}$$

The EPOT method is a generic extrapolation method using envelope to generate independent data



The idea of split-time method is to compute a metric of likelihood of a stability failure at an instant of crossing of an intermediate threshold and then extrapolate this metric for its critical value corresponding to the imminent failure.



Task 4 - Provide a recommendation on developing a procedure, or a set of procedures, for the direct assessment (computational methods) of the IMO 2nd Generation Intact Stability Criteria five modes of intact stability failure.

Proposed Procedure “Statistical Validation of Extrapolation Methods for Time Domain Numerical Simulation of Ship Motions and Loads”

Purpose: **to formulate a process for validation extrapolation methods for time domain numerical simulation of ship motions and loads**

Outline of the procedure

- Production of a validation dataset with a mathematical model of reduced complexity
- Application of direct counting produces to obtain “correct value”. Note that estimation of the “correct value and its confidence interval is covered by the proposal “Procedure of estimation of frequency of random events”.
- Validation of the extrapolation procedure is performed for 50–100 statistically independent data sets, and evaluated for a number of ship speeds, relative wave headings and sea states.
- A comparison is made between the extrapolation and the "true value" for each data set. The comparison should be considered successful if the extrapolation confidence interval and the confidence interval of "true value" overlap.
- Validation should be considered successful if a specified number of individual data set comparisons were successful (88% for 50 sets, 90% for 100 — may be decreased by an “approximation allowance”)

Task 5 - Review the state-of-the-art for free roll decay, forced rolling and excited rolling tests

Generally speaking, there are two main types of tests devoted to the determination of roll damping, i.e., **roll decay tests** and **forced roll tests**.

Forced roll tests can be further categorized into:

- **Free running forced roll test**, where the roll moments are designated while the resulting roll motions are measured, and
- **(Semi-) captive forced roll test**, where the roll motions are designated while the roll moment to generate the motions are measured.

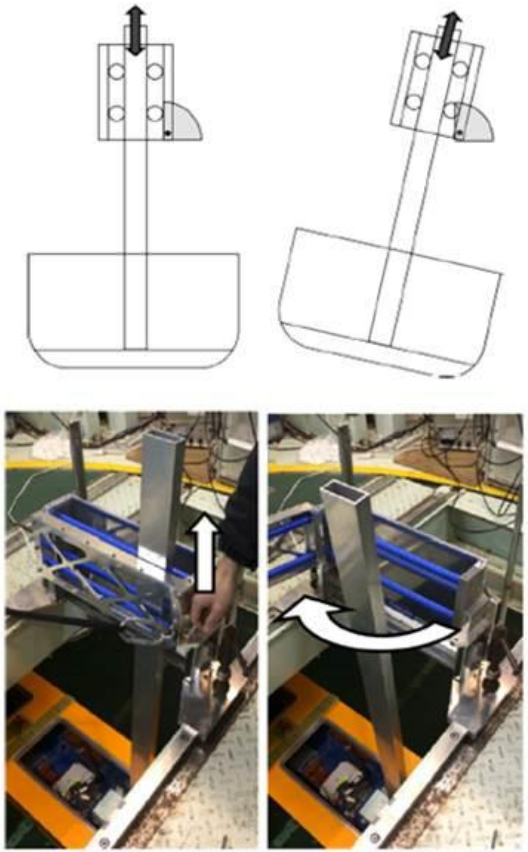
Task 5 - Review the state-of-the-art for free roll decay, forced rolling and excited rolling tests

Roll decay tests are based on inducing an initial heel to the ship model, releasing it and allowing the ship to roll freely, and then recording and analyzing the transitory roll motions.

The state-of-the-art focus is to reduce human interventions during the testing, i.e., to conduct the roll decay test in a sophisticated manner in order to obtain high-quality data which can withstand the quantitative validation of CFD.

Task 5 - Review the state-of-the-art for free roll decay, forced rolling and excited rolling tests

Hashimoto et al. (2019) proposed setup where a long aluminum pipe is attached to the ship model and a frame with rollers is used to induce a certain initial heel angle. To start the test, the heel constraint is released by swiftly open the aluminum frame through the strong tension of connected rubber rope. Using this kind of purpose-built device, it is possible to repeat the same roll decay test from a fixed angle/attitude.



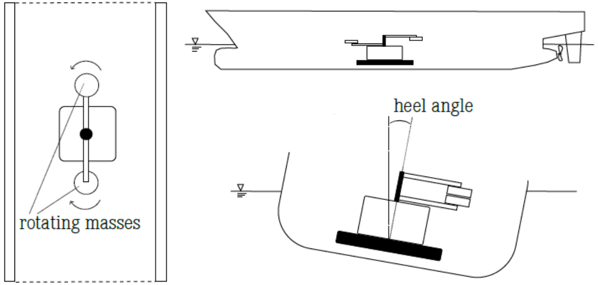
Hashimoto, H., Omura, T., et al., 2019, Several Remarks on EFD and CFD for Ship Roll Decay, *Ocean Engineering*, 186, 106082.

Task 5 - Review the state-of-the-art for free roll decay, forced rolling and excited rolling tests

Free running forced roll tests are based on exciting the ship to continuously rolling through internal roll moment generators (RMGs) or external waves, with the ship free to move in all degrees of freedom.

Several types of RMG are widely used, e.g., the gyroscopic type, the contra-rotating masses type and the moving mass type.

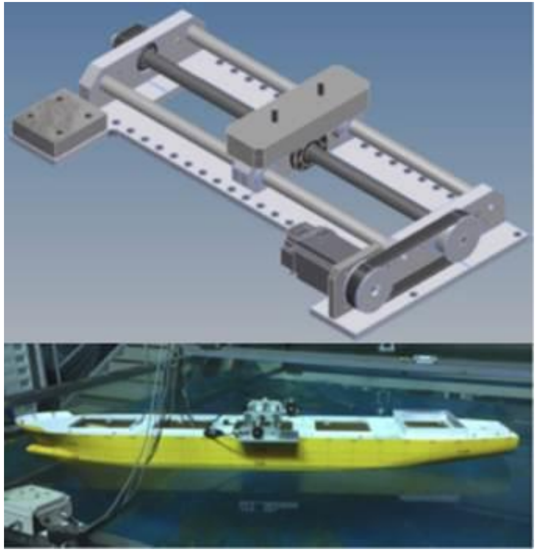
Gyroscopic Type (Grin et al, 2013)

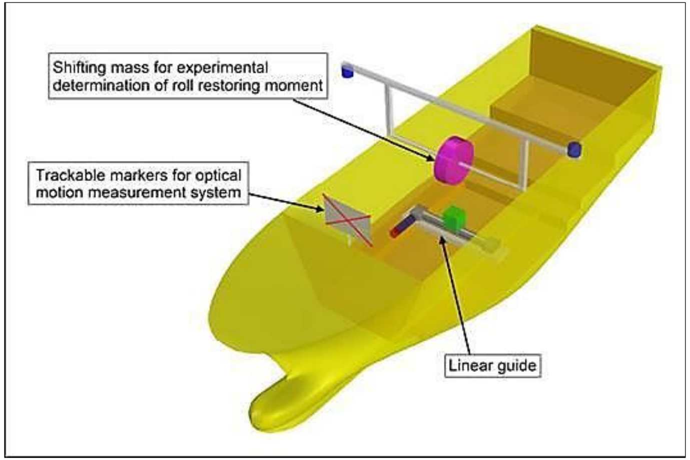


Contra-rotating Masses Type (Handschel et al, 2014)

Task 5 - Review the state-of-the-art for free roll decay, forced rolling and excited rolling tests

The gyroscopic type is preferable due to less interference on other degrees of motions. However, the capacity of such RMGs is usually limited. It is easier to design larger capacity RMGs of the moving mass type.





Moving Mass Type
(Left: Park et al, 2018; Right: Oliva-Remola, 2018)

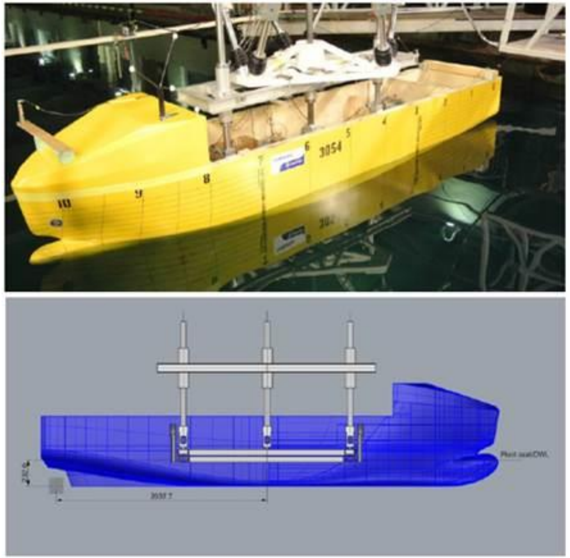
Task 5 - Review the state-of-the-art for free roll decay, forced rolling and excited rolling tests

Captive or semi-captive forced roll tests refer to ships being excited to continuously roll through an externally applied roll moment from an external oscillator between the towing carriage and the model.

In such tests, a fixed roll axis is typically being prescribed. Since there is no fixed roll axis during actual roll motions, this method should be applied with caution as the chosen position of the prescribed axis of rotation will influence the roll damping coefficients.

Task 5 - Review the state-of-the-art for free roll decay, forced rolling and excited rolling tests

Same as the free running forced roll tests, special instrumentation known as **forced roll mechanisms** are required, which should be able to generate the designated roll motions about the prescribed axis and measure the roll moment simultaneously.



SINTEF Ocean
(Kristiansen et al., 2014)

MARIC
(Feng et al., 2020)

Task 5 - Review the state-of-the-art for free roll decay, forced rolling and excited rolling tests

	Free Decay	Free-running Forced Roll	(Semi-) Captive Forced Roll
Steady Roll Ampl.	Impossible	Steady	Steadiest
Large Roll Ampl.	Temporarily	Depends on RMG	Easy
Forward Speed	Possible	Difficult	Easy
Memory Effect	Partially	Included	Included
CFD Validation Difficulty	Medium	Hard	Easy (1-DOF Case)
Roll Axis	Real/Time Varying	Real/Time Varying	Prescribed/Fixed
Time & Cost	Cheap	Expensive	Expensive

Task 6: Update Procedure 7.5-02-07-04.5 “Numerical Estimation of Roll Damping”

Name of the procedure has been changed from “Numerical Estimation of Roll Damping” to “**Estimation of Roll Damping**” because the scope of the procedure has been extended from purely numerical estimation based on an empirical formula to include also the relevant experimental approaches (including some IMO methodologies) to obtain the roll damping.

Task 6: Update Procedure 7.5-02-07-04.5 “Numerical Estimation of Roll Damping”

Section “2.1 Background equations” is added to give a clearer introduction of the subject.

Section “3. Procedure for estimating roll damping from experiments” is added, where sections “3.1 Roll decay tests in calm water”, “3.2 Free running forced roll tests” and “3.3 (Semi-) Captive forced roll tests” are discussed.

A new section of “4.3 Simplified Ikeda′s method” is added in the updated procedure.

Task 6: Update Procedure 7.5-02-07-04.5 “Numerical Estimation of Roll Damping”

Section “3.3 Decay coefficients” in the original procedure is deleted and rewritten as section “3.1.7 Data reduction and analysis”, where available methods are summarized into four categories:

(1) Logarithmic decrement method;
(2) Froude energy method;
(3) Roberts energy method;
(4) Least-squares iterative method.

The updated new procedure is more comprehensive compared with the original version.

Task 7 - Updating the guideline 7.5-02-07-04.3 for the prediction of the occurrence and magnitude of parametric rolling towards a procedure.

Procedure "Predicting the Occurrence and Magnitude of Parametric Rolling"

Purpose: to **provide detailed guidance on the numerical methods for predicting the occurrence and magnitude of parametric rolling**

Outline of the procedure

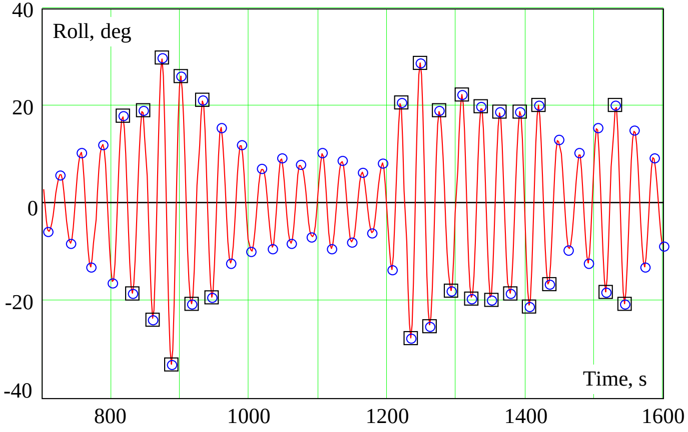
- Physical background
- Level 1 Formula prediction
- Level 2 Simple numerical prediction in regular waves
- Level 3 Advanced numerical prediction in regular and irregular waves
- Calculation example

Task 7 - Updating the guideline 7.5-02-07-04.3 for the prediction of the occurrence and magnitude of parametric rolling towards a procedure.

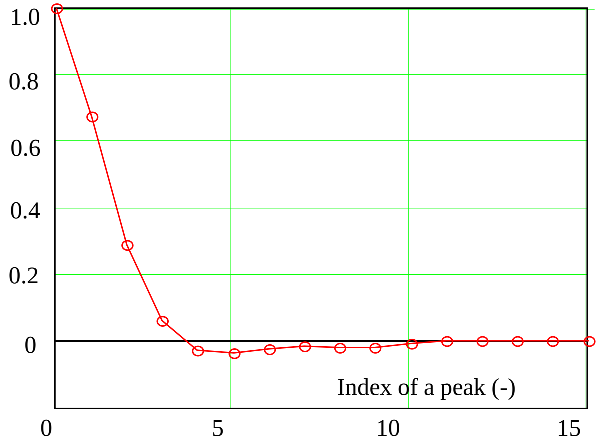
Procedure “Predicting the Occurrence and Magnitude of Parametric Rolling”

Example of application of the Procedure 7.5-02-01-08 for confidence interval of SSA of parametric roll

Extracting 1/3 largest peaks



Estimate of autocorrelation of 1/3 largest peaks



Task 8 - Update Procedure 7.5-02-07-04.4 Numerical Simulation of Capsize Behaviour of Damaged Ships in Irregular Beam Seas

- **Added:**
  - Modelling methods for free surface in tanks
  - Flooding open spaces

- **Technological innovations**
  - Area of active buoyancy & stability recovery systems

Task 9 Develop/suggest a method for estimating time to capsizing and/or sinking and include this in the report

- **The time interval between the start of the flooding of the vessel and its final capsizal determines the "time to capsize" (TTC).**
- **Similar concepts:**
  - "survival time" (Jasionowski, 1999)
  - "time to sink" (van Veer et al., 2002)
  - "time to flood" (Valando, 2006)
  - "time to ship loss" (Spanos, 2007)
- **Methodologies**
  - Jasionowski et al. (2002)
    - consideration of individual waves or groups as an integral element of the capsizing process.
    - The capsize event is identified from the presence of the incidence of the critical groups.
    - TTC is then calculated by the statistical analysis of the results.

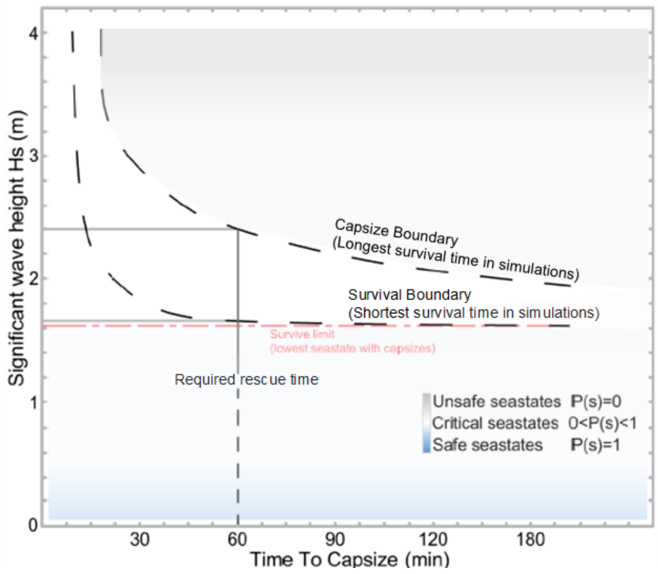
Task 9 Develop/suggest a method for estimating time to capsizing and/or sinking and include this in the report

- **Methodologies (cont'd)**
  - Spanos et al. (2007)
    - "time to ship loss" that corresponds to the loss of adequate floatability or stability
  - Valanto (2006)
    - Time from the initiation of the water ingress and the steady-state ensuing progressive flooding
  - Atzampos et al. (2019)
    - TTC is fundamentally linked to the critical wave height (HScrit) concept
    - It forms an upper boundary of the area where it is likely to observe capsizes
    - Conceptually it forms an asymptote of the TTC distribution

Task 9 Develop/suggest a method for estimating time to capsizing and/or sinking and include this in the report

- **Methodologies (cont'd)**

  - Atzampos et.al. (2019):
    - TTC is fundamentally linked to the critical wave height (H_{Scrit}) concept
    - It forms an upper boundary of the area where it is likely to observe capsizes
    - Conceptually it forms an asymptote of the TTC distribution
    - TTC will decrease with the increase of the encountered wave height.
    - TTC is inversely proportional to the difference between H_{Scrit} and the actual sea state.



Capsize and survival boundary concept with indication of the safe and unsafe regions with respect to change of the Time to Capsize as a function of the significant wave height. (Atzampos, 2019)

Task 9 Develop/suggest a method for estimating time to capsizing and/or sinking and include this in the report

- **Key characteristics:**
  - Monte Carlo sampled numerical simulations are used to determine the relationship between the TTC and the survivability
  - Atzampos (2019) used a direct approach based on time-domain simulations to estimate the expected probability of survival
  - TTC for a given group of damages is characterised by random damage locations, damage extent and sea-states
  - The direct approach derives from the non-zonal approach presented by Bulian et al. (2018) and Zaraphonitis et al. (2013)

Task 10 - Continue the identification of benchmark data for validation of stability in waves predictions.

Three new benchmark entries were added to the previous version of benchmark reference data spreadsheet

File is available on ITTC web site

Task 11 - Develop a procedure for undertaking inclining tests at full scale include estimates of the measurement uncertainty.

The proposed procedure:

- Is applicable only for conventional surface ships;
- Is focused on the inclining test itself and not on the inventory and on extrapolation to others displacements;
- It is strongly recommended to reproduce all the experiments with adequate numerical tools in order to improve post-treatments;
- Proposed an estimation of uncertainty of all parameters;
- List of important point to check for better accuracy is given;
- Similar procedures available in open literature is included as references.

See also Task 2b

IMO LIAISON

The ITTC Stability in Waves Committee representatives attended SDC 6 and SDC 7.

SDC6

At SDC 6, 4 to 8 February 2019, the ITTC Stability in Waves Committee representatives participated in the meeting of the Expert Group on Intact Stability.

The expert group agreed that these documents contain all necessary technical information and require editorial work by the Intersessional Correspondence Group. The final editing (SDC 7/WP.1) was done by the Drafting Group at SDC 7 in 2020. Upon completion, and subcommittee has forwarded the draft to Maritime Safety Committee (MSC) for their approval and publication in a form of MSC Circulars for test application by the Maritime Industry

IMO LIAISON

SDC7

At SDC 7, 3 to 7 February 2020, the ITTC Stability in Waves Committee representatives participated in the meeting of the Drafting Group on Intact Stability. Much of the effort of the Drafting group focused on the finalizing of Interim Guideline on the Second Generation Intact Stability Criteria.

The Drafting group recommended that the Intersessional Correspondence Group develop the draft Explanatory notes on the Second Generation Intact Stability Criteria coordinated by Dr. Umeda, Japan. The subcommittee agreed with this recommendation and created the Correspondence group. The final editing is expected to be done at SDC 8 in 2021. However, due to the COVID-19, SDC 8 has been postponed until 2022.

This IMO development is well aligned with a number of ITTC aims, making ITTC participation in this development very relevant. In particular, we start to try Interim Guideline on the Second Generation Intact Stability Criteria. The experience gained in implementing the Interim guidelines is very important for ITTC, so it will continue to stimulate improvement of methods for numerical modelling of extreme ship motions with model experiments. In pursue of this aim ITTC has a chance to have a positive impact on this international development that may improve ITTC's stance.

CONCLUSIONS AND RECOMMENDATIONS

Technical conclusions

The second generation IMO intact stability criteria

Interim guidelines on the second generation intact stability have been published by the IMO Maritime Safety Committee (MSC): MSC.1/Circ. 1627 on 10th of December 2020.

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MSC.1/Circ.1627
10 December 2020

INTERIM GUIDELINES ON THE SECOND GENERATION INTACT STABILITY CRITERIA

- The second generation of IMO intact stability criteria covers 5 failure modes: dead ship condition, excessive accelerations, pure loss of stability, parametric roll and surf-riding / broaching-to.
- All these modes are directly relevant to stability in waves; excessive accelerations are also relevant to seakeeping while broaching is also relevant to manoeuvring in waves.
- To avoid unnecessary costs, the assessment can be done in three different levels of complexity. Increase of complexity (and cost) of application is meant to be related to decrease of conservatism (if a ship found not to be vulnerable to a particular mode of failure, using lower complexity criteria, there is no need for further assessment)
- The second generation intact stability criteria also includes operational measures, as not all the stability-in-waves problems can be addressed during the design.

CONCLUSIONS AND RECOMMENDATIONS

Technical conclusions

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10 December 2020

INTERIM GUIDELINES ON THE SECOND GENERATION INTACT STABILITY CRITERIA

The second generation IMO intact stability criteria: Direct Stability Assessment (DSA)

- The core of the DSA is a state-of-the-art numerical simulation of extreme ship motions in severe weather conditions.
- DSA may require numerical simulation of ship motion in irregular waves, the resulted time histories should be of sufficient length to apply statistical processing
- **Correct statistical modelling of encounter waves** is a key technology for correct statistical estimates. In particular, the self-repetition effect is a concern
- DSA requires estimation of the statistical frequency of stability failures. The key technologies are an **assurance of independent of counted events** and **assessment of statistical uncertainty of the estimate**.
- If a sufficient number of stability failures cannot be observed during numerical simulation, methods of statistical extrapolation are meant to be used:
  - Extrapolation over wave heights,
  - Envelope peak over threshold (EPOT)
  - Split-time/ motion perturbation (MPM)
  - Critical wave method.
- Another key technology is a **validation of extrapolation methods**.

Per Task 4 this committee is proposing to develop ITTC procedures to address application of these key technologies

CONCLUSIONS AND RECOMMENDATIONS

Recommendations to the Conference

Adopt updated, reviewed and new procedures:

- Adopt the updated ITTC Procedure 7.5-02-07-04.5 “**Estimation of Roll Damping**”;
- Adopt the updated ITTC Procedure 7.5-02-07-04.3 “**Predicting the Occurrence and Magnitude of Parametric Rolling**” towards a Recommended Procedure;
- Adopt the updated ITTC Procedure 7.5-02-07-04.4, “**Numerical Simulation of Capsize Behaviour of Damaged Ships in Irregular Beam Seas**”;
- Adopt reviewed ITTC Procedure 7.5-03-02-03, “**Practical Guidelines for ship CFD application**”;
- Adopt the new ITTC Recommended Procedure, “**Inclining Tests**”;
- Adopt the new ITTC Recommended procedure **“Extrapolation for direct assessment stability in waves”**;

Recommendations to the Conference

Develop new procedures, update exiting procedures:

- Develop new ITTC Procedure for "**Statistical Validation of Extrapolation Methods for Time Domain Numerical Simulation of Ship Motions and Loads**"
- Develop new ITTC Guidance on "**Avoiding Self- Repetition Effect During Numerical Simulation of Ship Motions**"
- Develop new ITTC Procedure for of "**Estimation of Frequency of Random Events**"
- Develop new ITTC Recommended Procedure for "**Predicting the Instantaneous GZ Curve during Time-Domain Numerical Simulation**"

Submit IMO INF paper on the review of Second Generation Intact Stability Criteria to 8th session of SDC