Report of the

Committee on Stability in Waves

27th ITTC • Copenhagen

Committee on Stability in Waves

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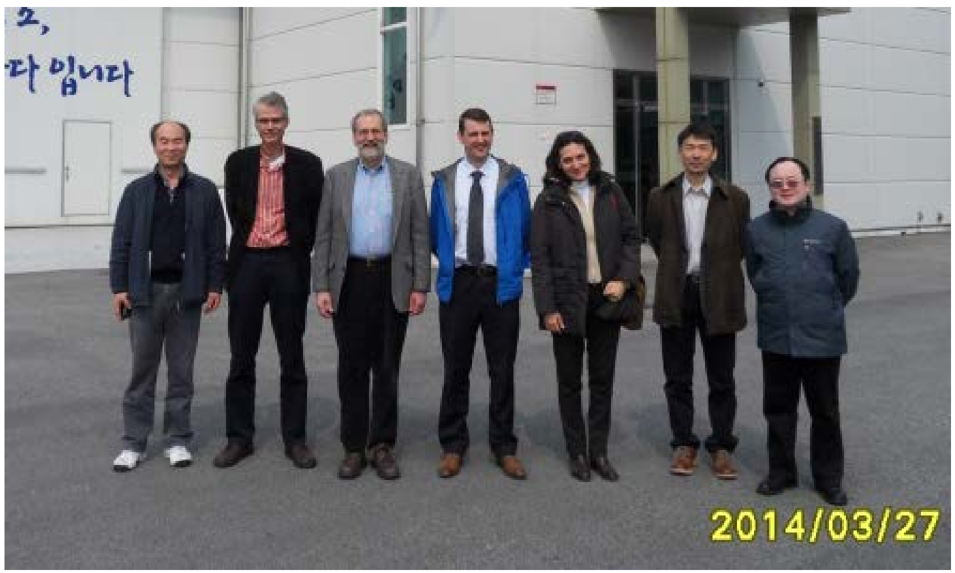
Committee on Stability in Waves

Meetings:

Osaka, Japan	February 2012
Athens, Greece	September 2012
Washington, DC, USA	June 2013
Daejeon, Korea	March 2014



Committee on Stability in Waves

Tasks:

1. State-of-the-Art review
2. Procedures for prediction of capsizing of damaged ship
3. Investigate uncertainty analysis for intact and damaged model tests
4. Investigate the criteria for modelling wave spectra
5. Develop understanding of uncertainty form experiments and simulation of extreme motions
6. Review vulnerability criteria for intact and damaged ships (IMO)
7. Investigate validation of roll damping for large amplitude roll motions in irregular seas
8. Cooperate with IMO SLF

Acknowledgments

Dr. Janou Hennig
Dr. Joel Park
Ms. Suzanne Reed

1. State-of-the-Art Review

Internal Geometric Modelling

- FLOODSTAND — a European research project which derived data on flooding mechanisms to validate numerical simulation tools
- Routes floodwater takes as it progresses inside a ship and the order in which compartments fill can have a significant effect.
- Complex internal structure makes it challenging to model damage stability of a passenger vessel both numerically and physically.
- Distribution of floodwater affects sinkage, heel and trim of a ship, and consequently the stability — Survivability of a vessel
- Complex subdivisions and multiple damage openings = small changes in floodwater = various possibilities for flooding
- Not straightforward to predict with certainty what final flooded state of a vessel will be.

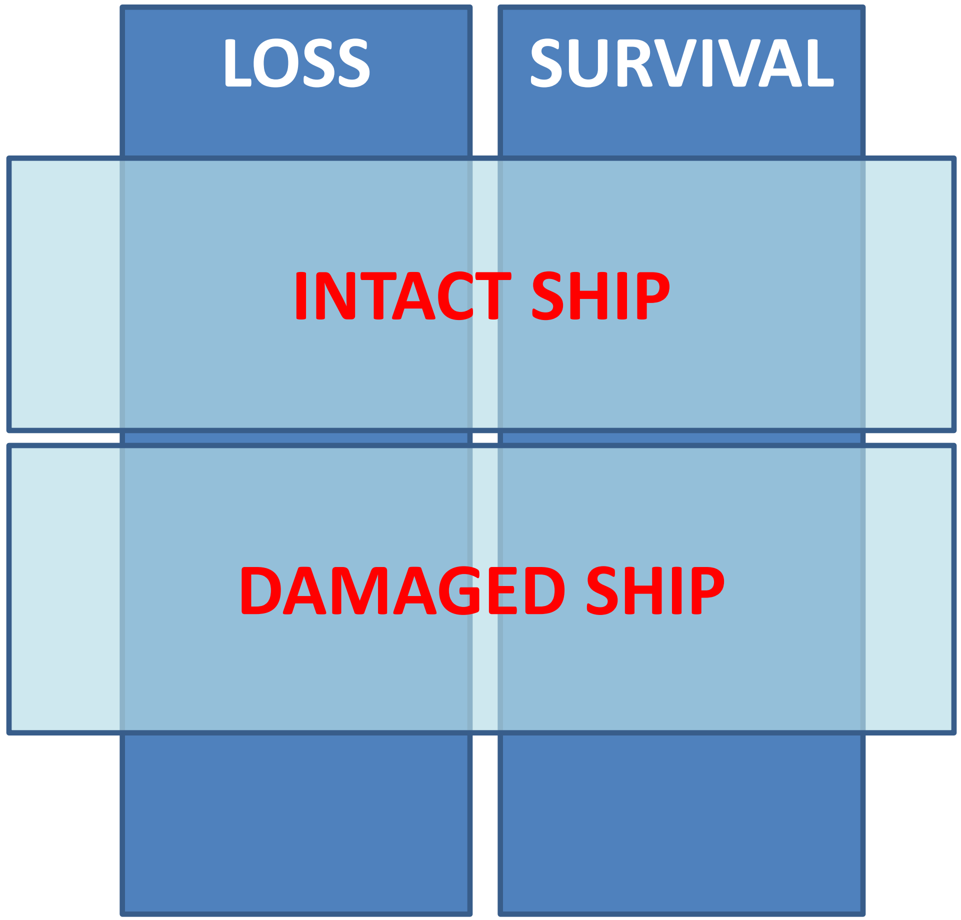
Internal Geometric Modelling

- Leakage and collapsing of --watertight structures, can have a very remarkable effect on time-to-flood calculations
- Experimental and numerical studies to develop guidelines on modelling leaking and collapsing structures in flooding simulation
- Results indicate that the effect of these flow coefficients and collapse pressures on transient heeling in the beginning of flooding is minimal
  - Parameters were found to have a notable effect on the time-to-flood
- Leakage area ratio also was found to have a significant effect on the time-to-flood, especially in a flooding case where closed doors do not reach collapse

Leak and Collapse Pressures of Water-Tight Doors and Bulkheads

- FLOODSTAND Project investigated flooding through watertight doors and hatches
- For many doors, the leakage-area ratio increased almost linearly as a function of the pressure head
- Assumption that leakage area is evenly distributed vertically is not valid — often a gap between the bottom of door and sill
- Different categories of doors behave very differently under flooding conditions
- Same door within the same category can behave very differently as the gap between the sill and the door can vary considerably
- Sensitivity analysis recommended
- Significant further work is needed

Definition of Loss and Survival

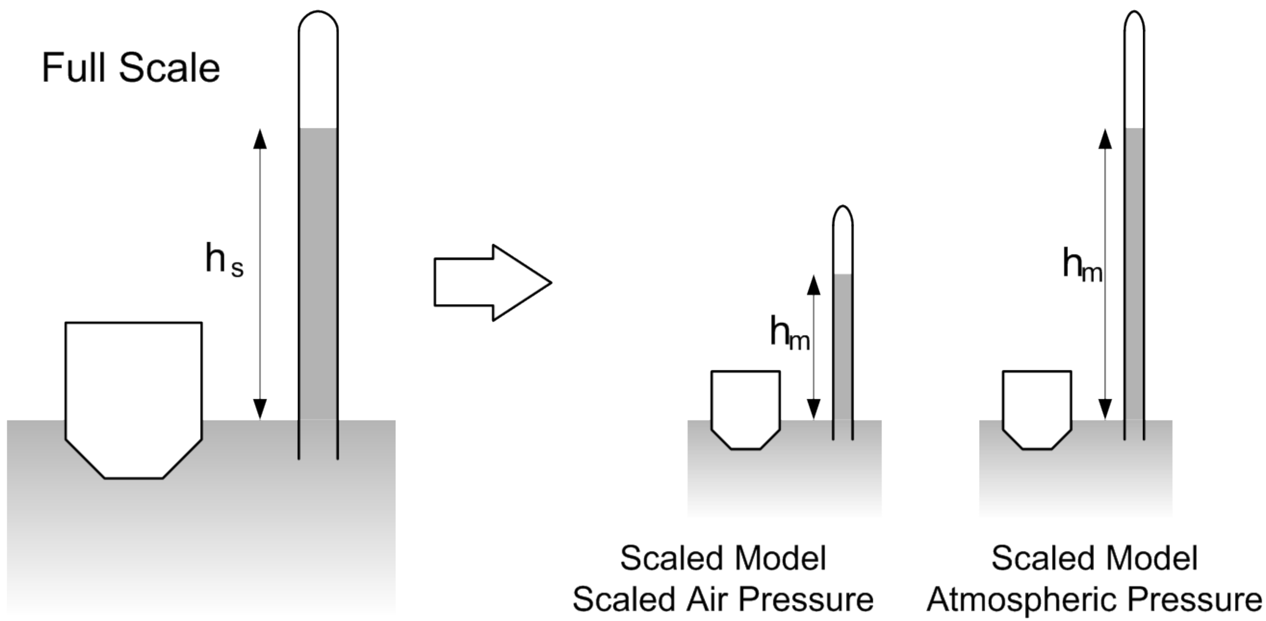


Discussed under Vulnerability Criteria

2. Procedures for Prediction of Capsizing of Damaged Ship

Model Tests on Damage Stability

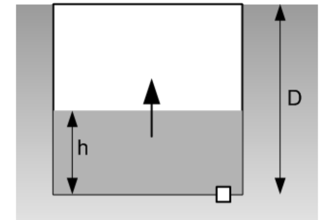
- Scale effects in air pressure on flooding-model tests under atmospheric conditions

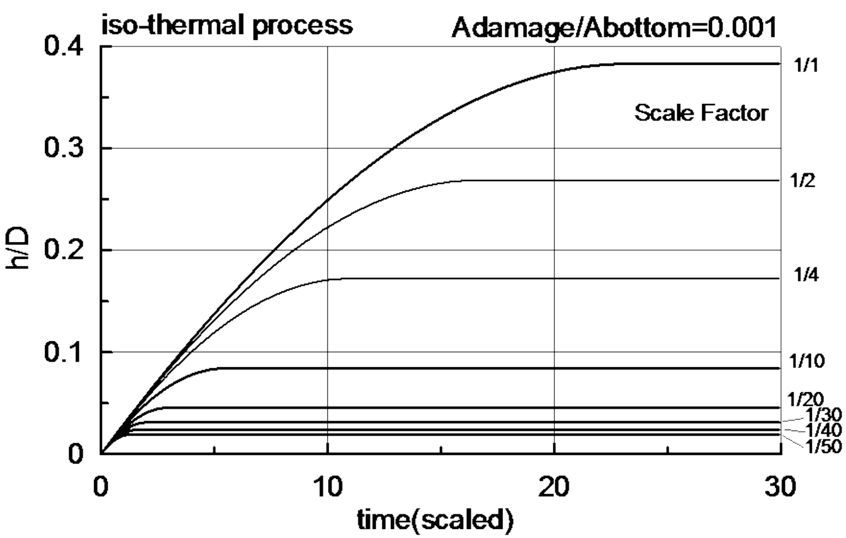


Concept of a scaled-model test

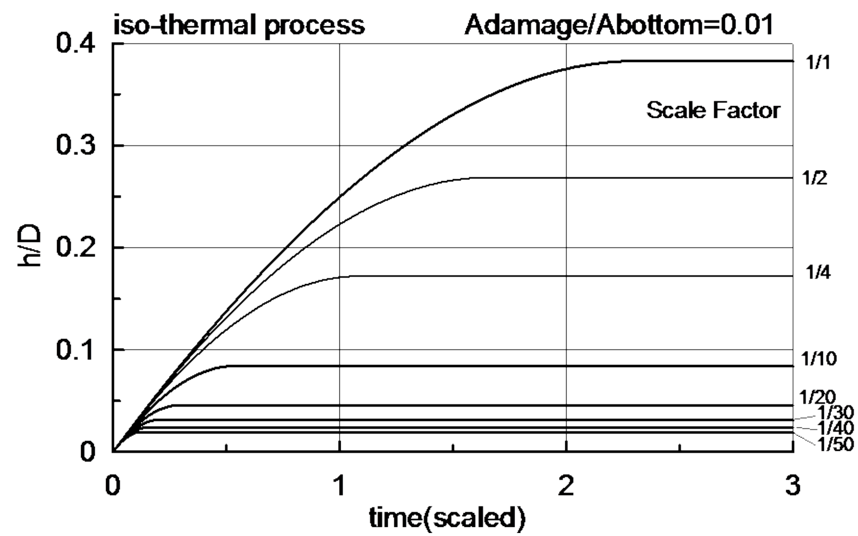
Model Tests on Damage Stability

- Trapped (Non-vented) Cases
  - Scale Effect is Significant



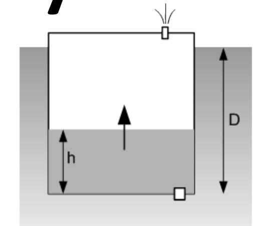


For Small Opening

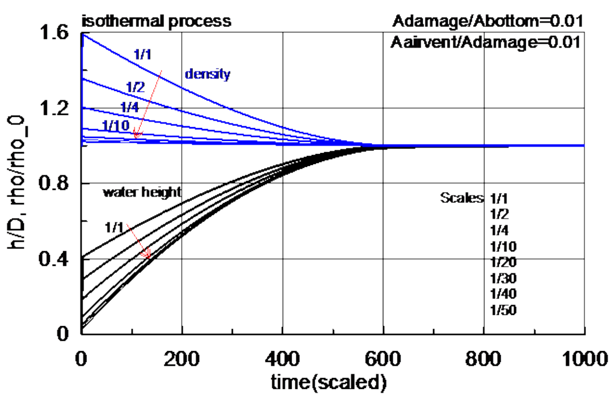


For Large Opening

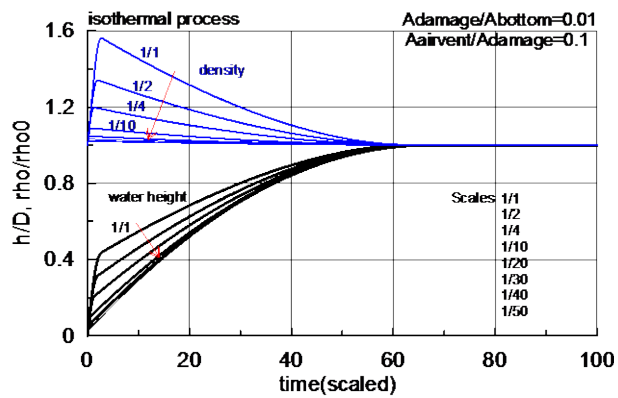
Model Tests on Damage Stability



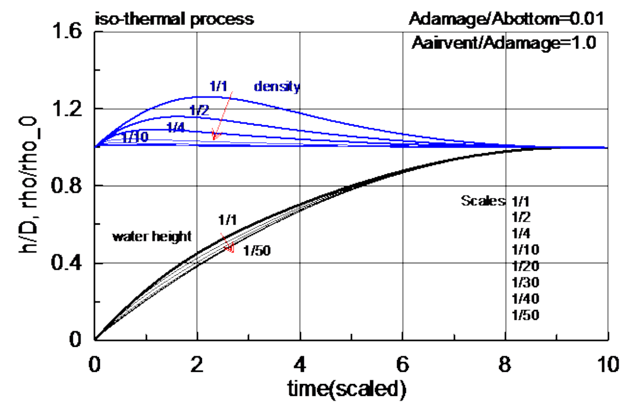
- Vented Case
  - Ratio vent area/damage area plays a crucial role.
  - Calculation for abrupt damage



Small area ratio
Large scale effect



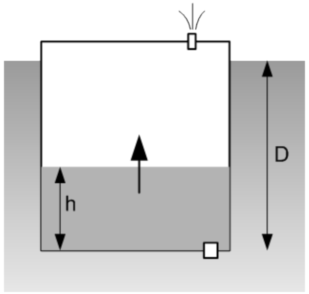
Medium area ratio
Non-negligible effect

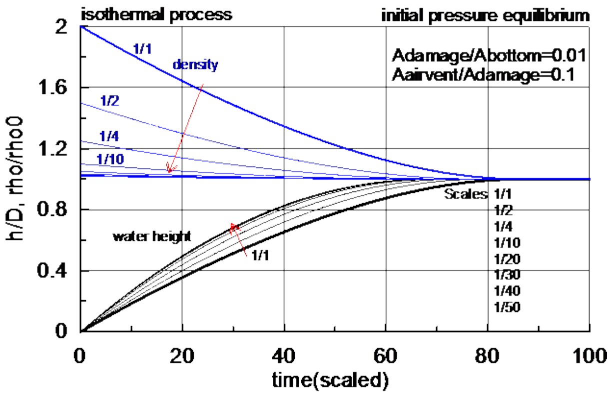


Large area ratio
Small scale effect

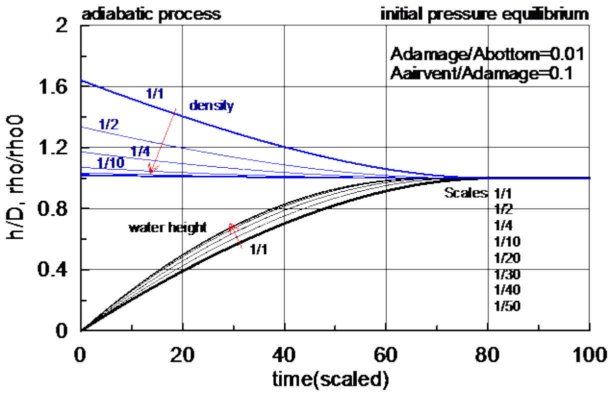
Model Tests on Damage Stability

- Vented Case (medium area ratio)
  - For the initially pressure balanced case (reflecting a model test in waves)
  - Scale effect is not large.





Iso-thermal



adiabatic

Computations of Damage Stability

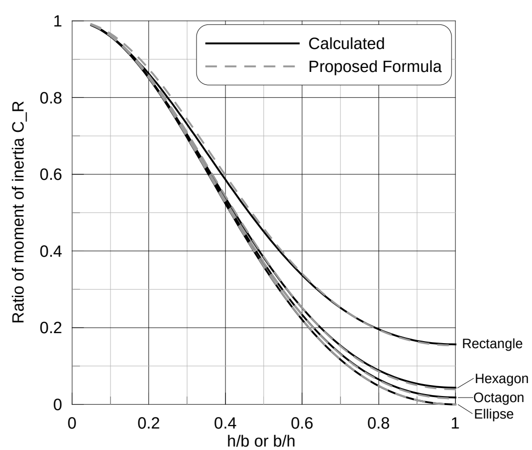
- Inertia due to floodwater mass (Floodwater Domain)
  - Criteria to determine how the floodwater should be treated
    - What is the amount of water and is it or is it not moving with the ship?
    - What, if any, is the significant pressure jump across the compartment boundary?
    - Can the dynamics of the water be solved separately or not?
  - Above criteria provide clues as to what to consider as floodwater when examining damaged ships

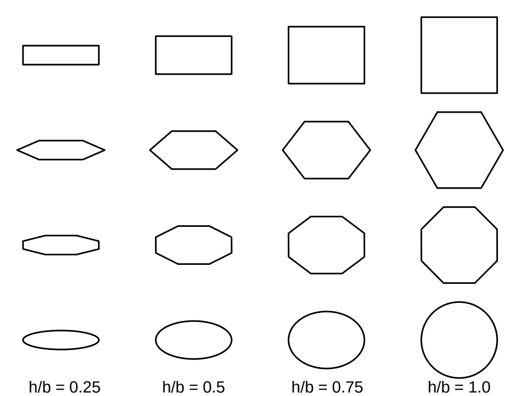
Computations of Damage Stability

- Inertia due to floodwater mass (Partially Flooded Compartment)
  - Analysis focused on the Center of Gravity:
    - Quasi-Static Analysis, Resonant-mode Analysis
    - Floodwater mass must be included in the ship's mass
  - Fully Dynamic Analysis:
    - Potential-flow theory, computational fluid dynamics (CFD)
    - Floodwater mass need not be included in the ship's mass

Computations of Damage Stability

- Inertia due to floodwater mass
  (Fully Flooded Compartment)
  - In Rectilinear acc., floodwater mass acts like a solid
  - In Rotational acc., moment of inertia of floodwater will be small compared with a solid
    (account for the aspect ratio of the compartment)





Computations of Damage Stability

- Inertia due to floodwater mass (Floodwater entering a ship)
  - Force Due to the Momentum Change accounts for the intake and/or discharge of floodwater

$$\vec{F} + \vec{v}\,'\frac{dm}{dt} = m(t)\frac{d\vec{v}}{dt},$$

$$\vec{M} + \vec{\omega}\,'\frac{dI}{dt} = I(t)\frac{d\vec{\omega}}{dt}$$

3. Investigate Uncertainty Analysis for Intact and Damaged Model Tests

Uncertainty Analysis for Models
(Used In Seakeeping and Extreme Motion Tests)

- Results of seakeeping & extreme motions testing are the characteristics of stochastic processes in random seas
  - No uncertainty to be reported in the results, but rather
  - Confidence bands on statistics characterizing results of the experiment
  - Statistical uncertainty of seakeeping and extreme motions in a seaway will be discussed later
- In seakeeping and extreme-motions experiments, area where traditional deterministic uncertainty analysis applies is in determining the mass properties of the models being tested

Uncertainty Analysis for Models

- Given uncertainty range on mass properties of a motions test, the ideal approach would be to repeat experiment with model ballasted to extremes of uncertainty of mass properties to determine impact of this uncertainty on experimental results
- Technically this is impossible as there would again be uncertainties associated with the mass properties for these new tests
- To say nothing of cost in terms of:
  - Time
  - Money
  - Resources

Uncertainty Analysis for Models

- Only feasible approach to determining impact of uncertainties in mass properties on the uncertainties of experimental results appears to be computational
  - There is no established procedure.
- From a practical perspective, the use of a validated linear seakeeping code is the most realistic approach to solving the uncertainty problem
  - Will allow rapid assessment of the impact of mass-properties uncertainties on the measured motions
  - Linear code will have its own accuracy issues
  - Will provide a consistent metric against which the impact of mass-properties uncertainties can be judged

Uncertainty Analysis for Models

- Uncertainty analysis provided for:
  - Model Weight and Mass
  - Longitudinal Centre of Gravity
    - Levelling Method
    - Two-point Suspension Method
  - Vertical Centre of Gravity
  - Moment of Inertia
    - Composite Roll MOI
    - Composite Pitch MOI
  - Transverse Metacentric Height

Uncertainty Analysis for Models

- Uncertainty analysis for model weight and mass

$$W = \rho g \nabla$$

$$W_{\mathrm{m}} = m_{\mathrm{s}} \rho_{\mathrm{m}} g_{\mathrm{m}} \nabla_{\mathrm{m}} / (\rho_{\mathrm{s}} \nabla_{\mathrm{s}}) = m_{\mathrm{s}} \rho_{m} g_{\mathrm{m}} / (\rho_{\mathrm{s}} \lambda^{3})$$

$$m_{\mathrm{m}} = m_{\mathrm{s}} \rho_{m} / (\rho_{\mathrm{s}} \lambda^{3})$$

$$U_{m\mathrm{m}} / m_{\mathrm{m}} = \sqrt{(U_{\rho\mathrm{m}} / \rho_{\mathrm{m}})^{2} + (3U_{L\mathrm{m}} / L_{\mathrm{m}})^{2}}$$

$$U_{\mathrm{c}} = \sqrt{U_{\mathrm{meas}}^{2} + U_{m\mathrm{m}}^{2}}$$

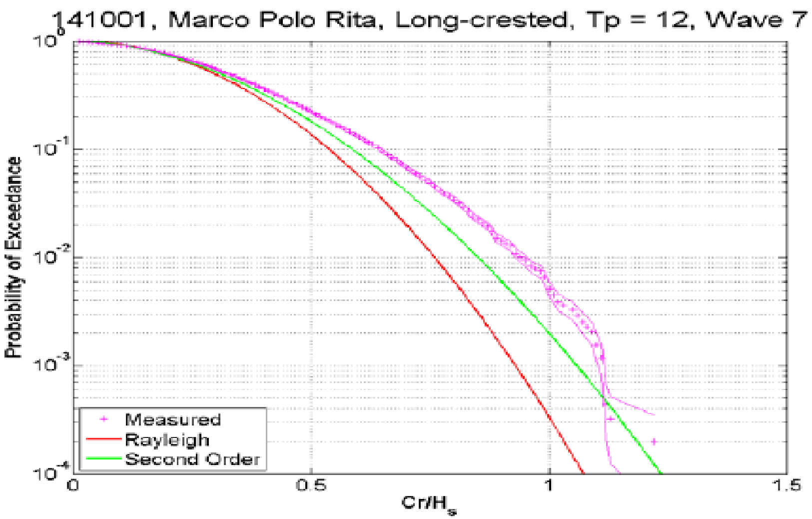
4. Investigate the Criteria for Modelling Wave Spectra

Extreme Wave Modelling

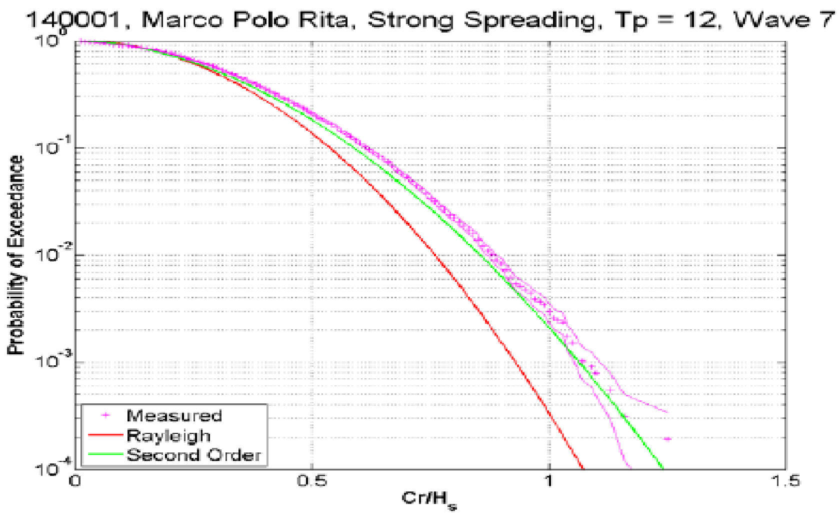
- Questions relevant to stability research are:
  - How often do extreme waves occur and how relevant are they,
  - What are their typical shapes and kinematics,
  - How can we model extreme waves.
- CresT project has investigated some of these questions
  - E.g. effect of wave directional spreading on exceedance probability of wave crests

Extreme Wave Modelling

Wave-crest exceedance probability depending on spreading



Long-crested



Strong-spreading (s=4)

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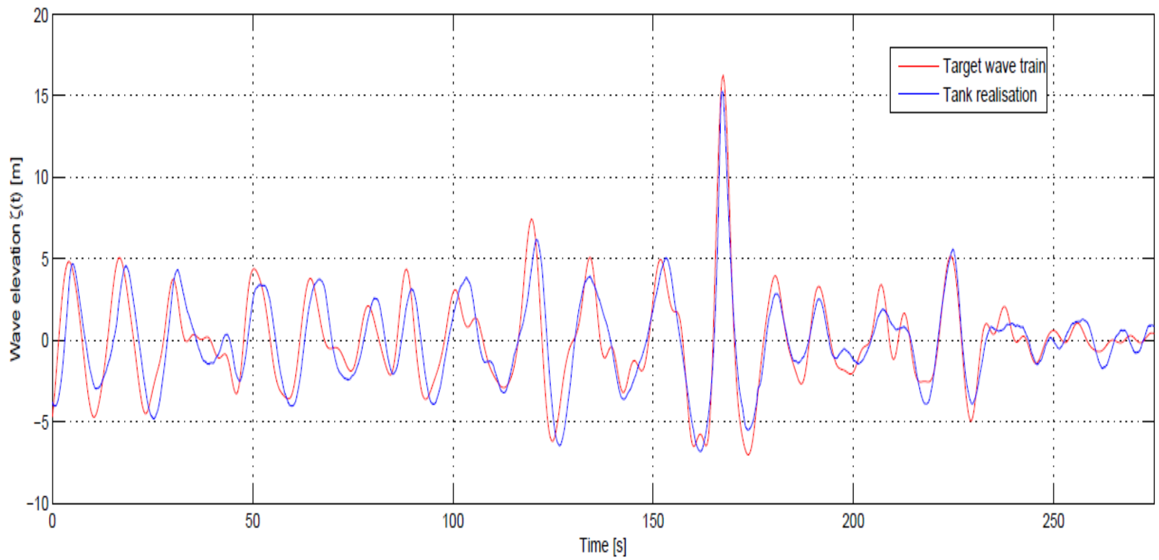
Extreme Wave Modelling

- Other items related to wave generation in a model basin include:
  - Effect of wave steepness on wave crest exceedance probability,
  - Effect of distance from wave maker on wave crest exceedance probability
  - Calibration of directional waves
  - Modeling of extreme waves with optimization of wave realisations

Extreme Wave Modelling

Example of extreme wave modeling in basin



Draupner New Year wave

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5. Develop Understanding of Uncertainty From Experiments and Simulation of Extreme Motions

Statistical Uncertainties

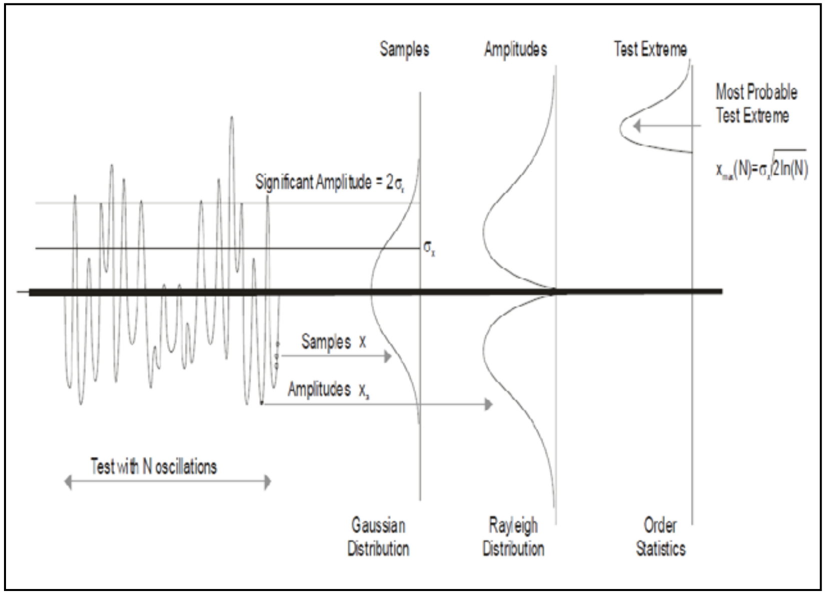
- In seaway, loads on and responses of a ship are random processes
- Results of model tests and numerical simulations of ships in waves depend on duration of the tests or numerical simulations
  - Key factor in determining number of test runs for model experiments and numerical simulations
- Furthermore, in analysing test or simulation data, it is important to assess statistical reliability of motions and events

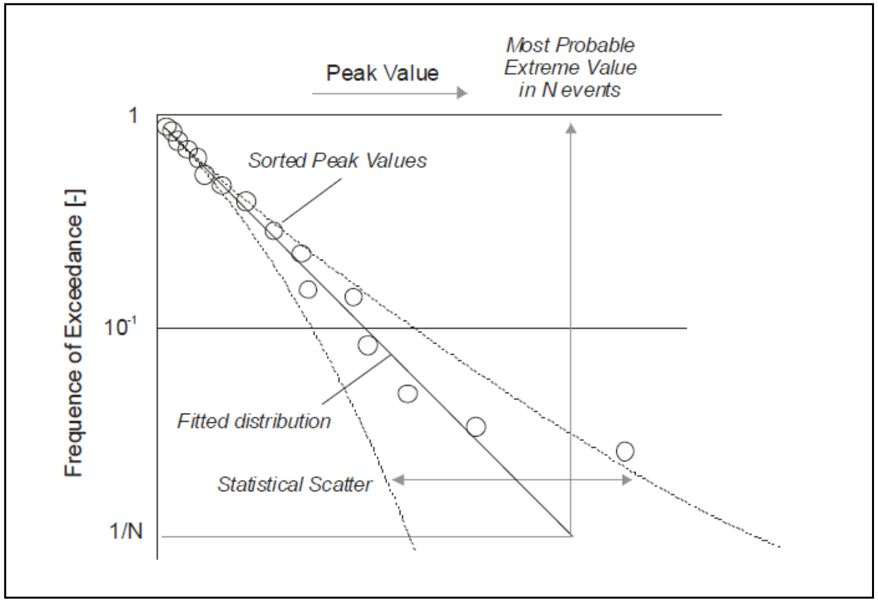
Statistical Uncertainties

- Low and moderate incident waves and resulting ship motions can be regarded as linear signals
- Straightforward formulations available for probability distribution functions based on standard deviation of signal
- Local extremes satisfy distribution functions which depend on bandwidth of frequency spectrum
  - Most probable extreme value is then characterised by number of oscillations and standard deviation

Statistical Uncertainties

Schematic view of distribution functions





Linear Signals

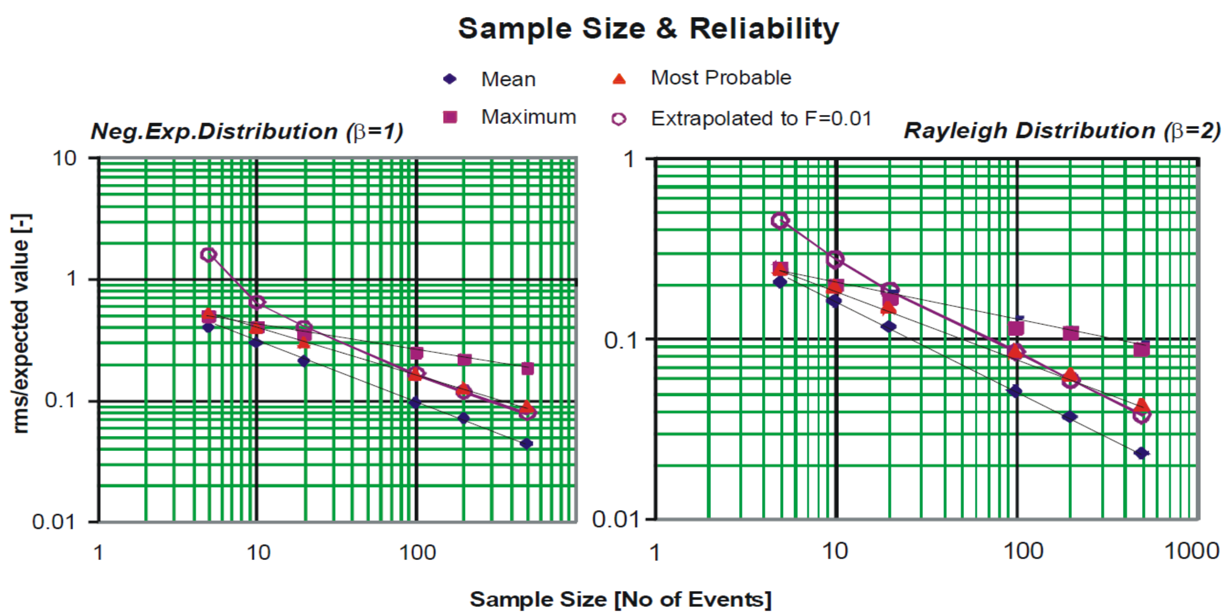
Nonlinear Signals

Statistical Uncertainties

- Events such as wave impact pressures, parametric roll, water ingress and broaching can be regarded as ‘nonlinear’ signals
- Extreme values can be expressed as function of frequency of exceedance
  - Most probable value can be obtained by extrapolation towards required number of events
- Reliability of this procedure depends on number of events
- Methods are described to assess the statistical uncertainty of nonlinear events

Statistical Uncertainties

Statistical reliability versus sample size

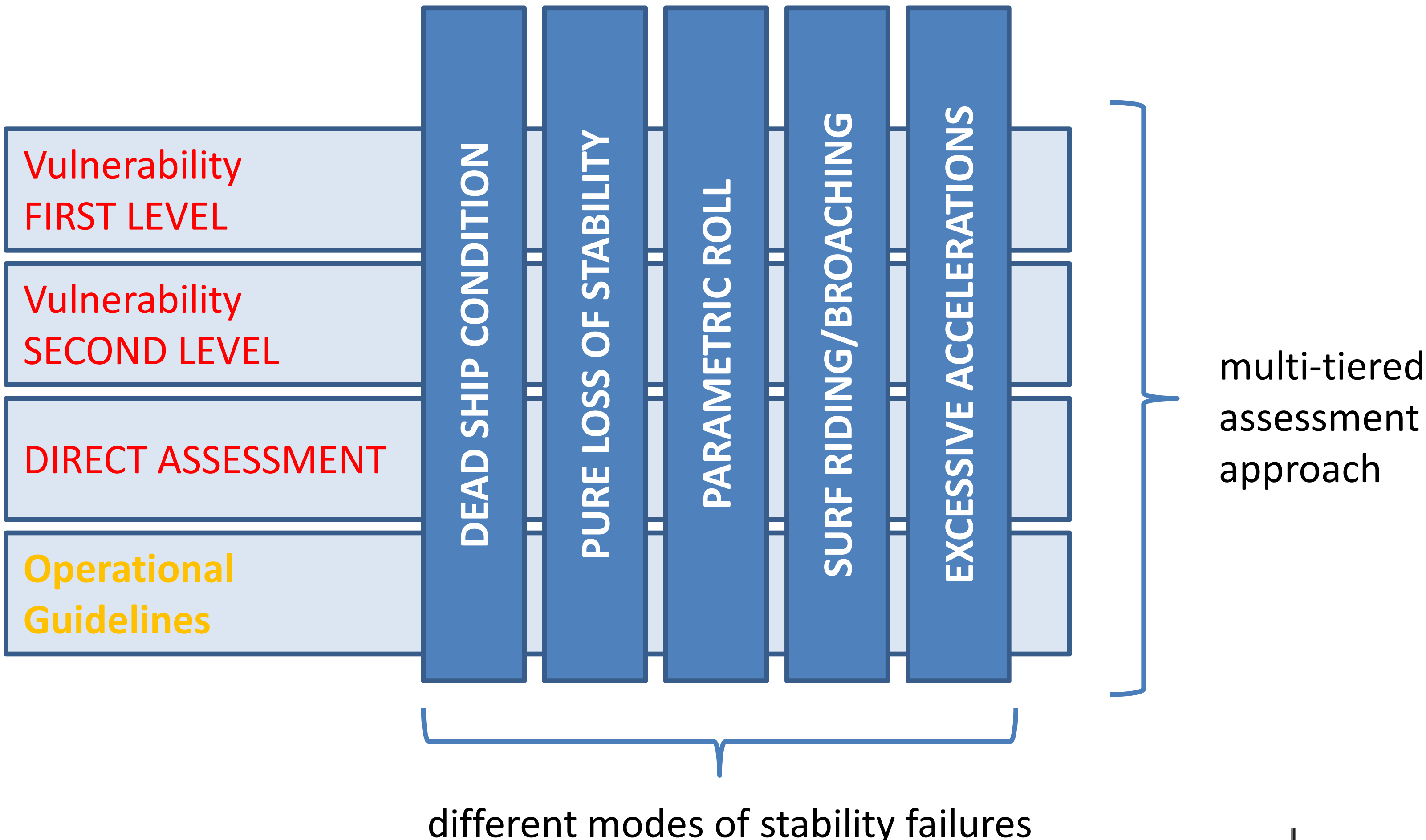


6. Review vulnerability criteria for intact and damaged ships (IMO)

Review of vulnerability criteria

- The concept of a vulnerability criterion has a very clear definition when dealing with an ***INTACT SHIP***
- In ***IMO documents***, vulnerability criteria are intended as tools to assess whether a ship is susceptible to different modes of stability failure
- IMO “Second-generation Intact-stability Criteria,” are developed in sub-domains
  - Approached in terms of tools and in terms of stability failures

Review of Vulnerability Criteria



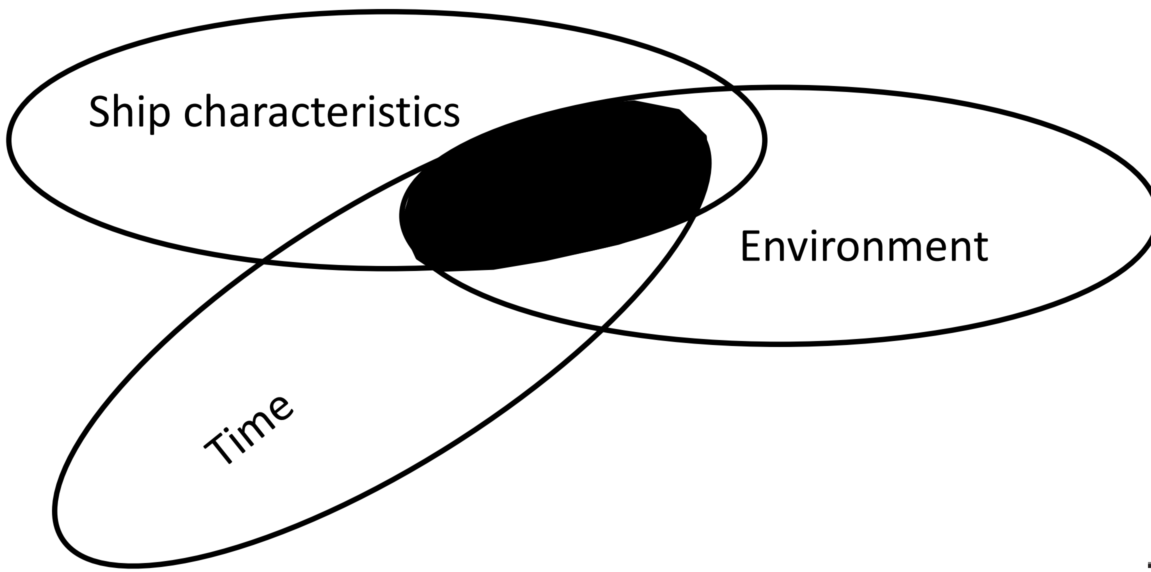
Review of Vulnerability Criteria

- In recent years the activity at the IMO has focused on the development of first- and second-level criteria
- **The first level criteria** is designed to be a simple procedure based on geometry/hydrostatics, load conditions, and basic operational parameters.
- **The second level criteria** relies on simplified physics-based calculations with reasonable computational efforts and straight-forward applications following suitable guidelines.
- **Direct assessment procedures** for stability failure intended to employ most advanced technology available, yet be sufficiently practical so as to be uniformly applied, verified, validated, and approved using currently available infrastructure
  - Ship motions in waves, used for assessment of stability performance, can be reproduced by means of numerical simulations *or* model tests

Review of Vulnerability Criteria

Important issues for IMO first- and second-level criteria:

- Loading conditions under investigation
- Stability parameters to be observed (GMt, GZ, Roll Angle,…)
- Environmental conditions to be assumed (wave height, wave length, wave period, specific sea state and and/or average of sea conditions,…)
- Consistency between the two levels in terms of sensitivity and standards (r.h.s terms)



Review of Vulnerability Criteria

Important issues for Direct Assessment:

- Identification of a tool/methodology that adequately predicts ship motions in waves
- Development of a procedure that determines ship safety based on the likelihood or risk of stability failure
- IMO (2013) provides description of capabilities of a methodology which is used for direct assessment
  - Presented by stability-failure mode
  - Measurement of likelihood of stability-failure is described as a probabilistic performance-based criteria.

Review of Vulnerability Criteria

Important issues for Direct Assessment (Cont'd) :

- Beside adequate numerical tools, from literature, attention should be paid to:
  - ✓ Time of exposure
  - ✓ Problem of rarity
  - ✓ Statistical uncertainty
  - ✓ Proper selection of reasonable environmental and operational conditions
  - ✓ Short term, long term, reasonably "representative" term,...

Review of Vulnerability Criteria

- For the ***DAMAGED SHIP*** it is uncommon to find explicit reference to the term "vulnerability criteria" in literature
  - Currently appears to be no structured reference frame-work for damaged ships as there is for intact ships with functions and purposes
- A definition of vulnerability is given as "the probability that a ship may capsize within a certain time when subjected to any feasible flooding case"
- In some occasions, expressions like "vulnerability to flooding" and "vulnerability to open watertight doors" are used in relation to a rapid capsize

Review of Vulnerability Criteria

- For ***DAMAGED SHIP,*** term SURVIVABILITY is used much more; and word vulnerability may be defined as an antonym of the term survivability since vulnerability is the conditional probability of being 'lost' given a certain scenario
  - In a situation where susceptibility (probability of being damaged) is equal to 1, survivability and vulnerability can be considered mathematical "opposites" for the purpose of this review

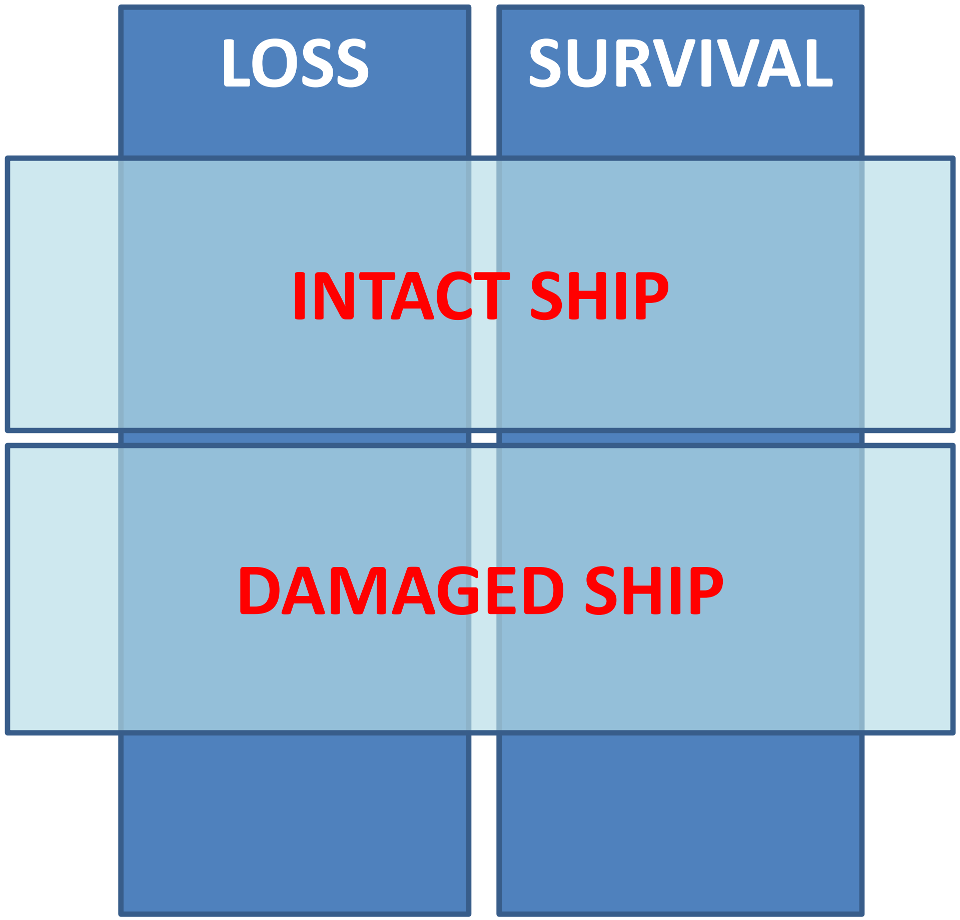
Review of Vulnerability Criteria

- In damaged-ship scenarios, time is a central issue in vulnerability investigations and often represents the most important factor in many situations:
  - ✓ Time-to-flood
  - ✓ Time-to-capsize
  - ✓ Time-to-sink
  - ✓ Survival time

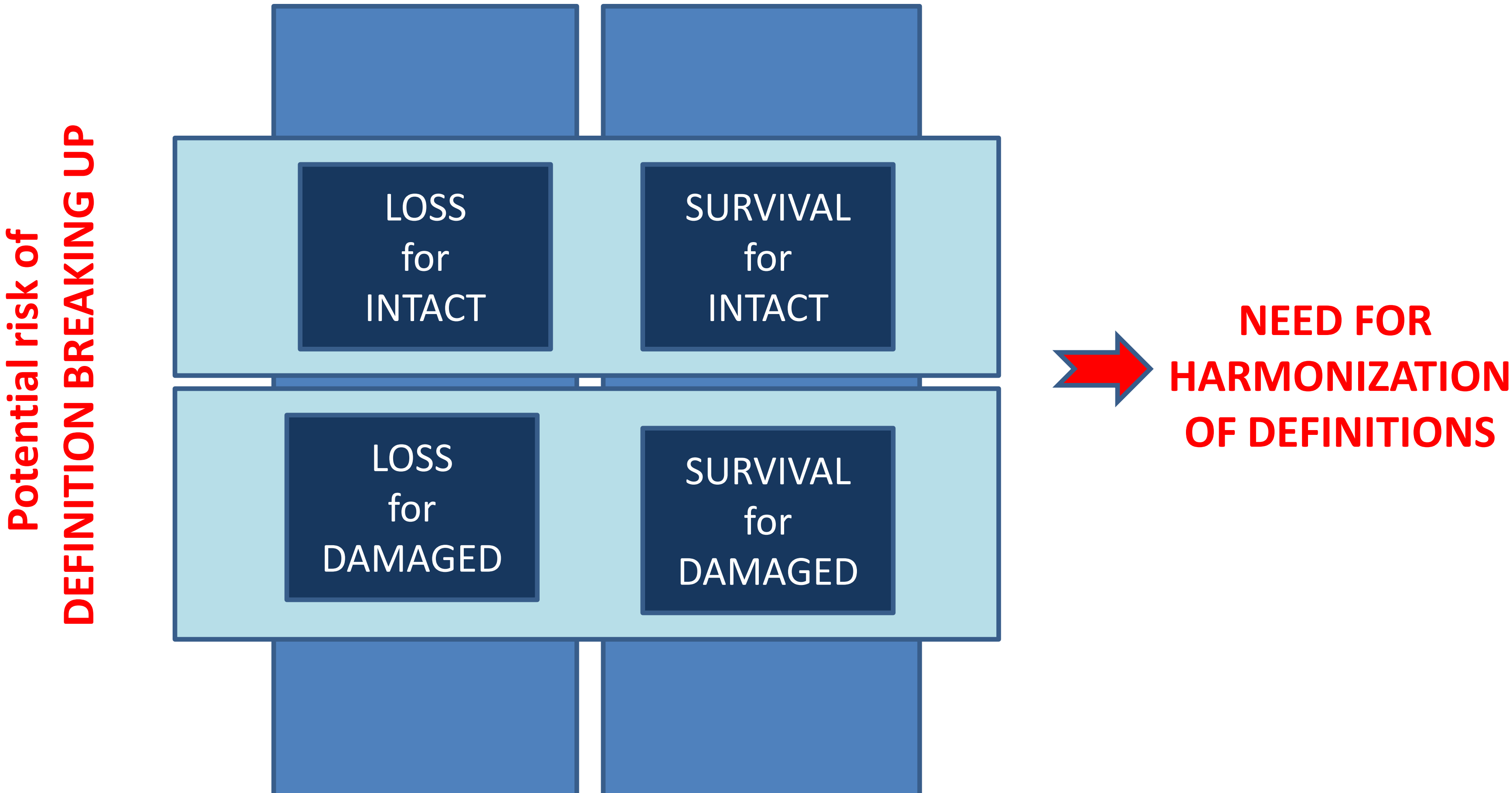
Review of Vulnerability Criteria

- In investigations where “time” is a fixed parameter (30 minutes, one hour, etc.), the out-come of the assessment process is given in terms of:
  - ✓ Capsize probability
  - ✓ Probability of survival
  - ✓ Capsizing risk
  - ✓ Capsizing index
  - ✓ Capsizing band
- In these investigations with “time” a fixed parameter, attention is paid to critical environmental conditions, in particular to significant wave height

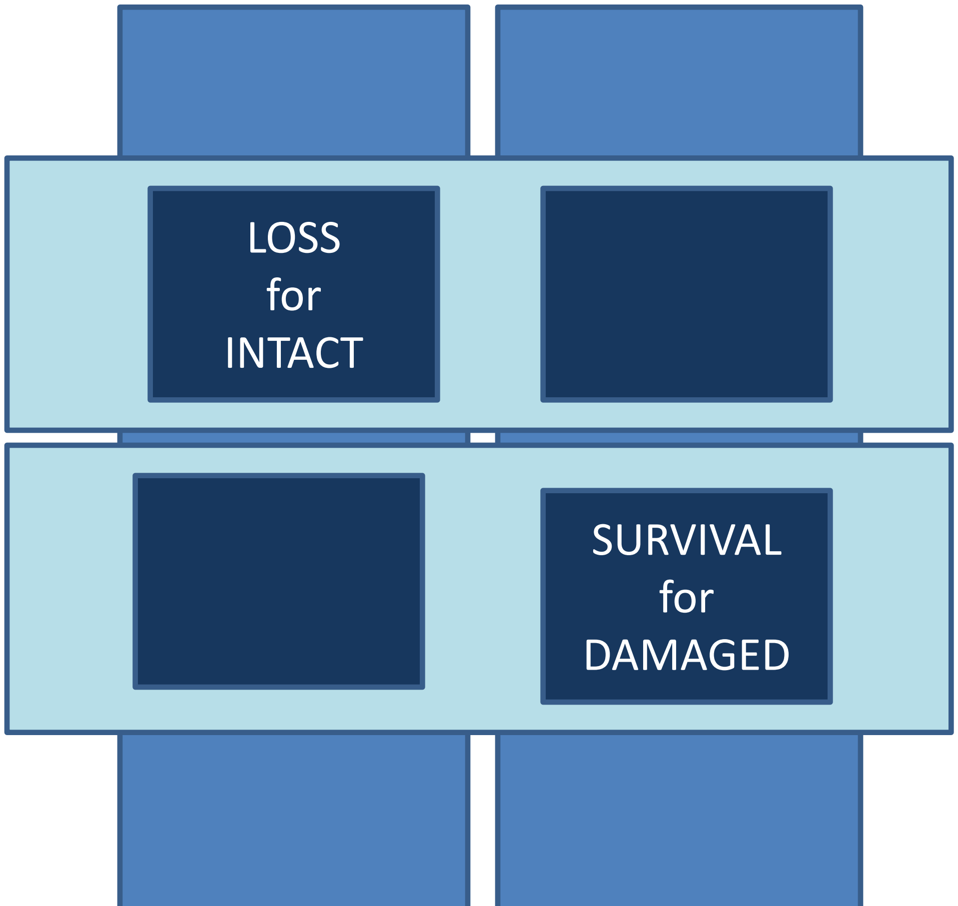
Definition of Loss and Survival



Definition of Loss and Survival



Definition of Loss and Survival



In current literature, a trend has been to discuss the concept of **“ship loss”** when dealing with an **intact ship,** while **“ship survival”** is more likely to be used when dealing with the safety of a **damaged ship**

Review of Vulnerability Criteria

- As much as possible, development of vulnerability criteria should remain consistent between intact and the damaged ship cases
- Many common points can be identified:
  1. Loss mode
  2. Loss threshold
  3. Ship operational conditions
  4. Environmental conditions
  5. Time of exposure
  6. Methodology for short-term prediction
  7. Methodology for long-term prediction

Review of vulnerability criteria

- Additional issues for a damaged ship include:
  - ✓ Damage scenario
  - ✓ Flooding process
  - ✓ Presence of water on-board after damage
- Moreover for the intact ship
  - – Non-ergodic nature of capsizing is incompatible with the linear hypothesis of the traditional statistical procedures used to assess the risk of capsizing for an intact ship

7. Investigate Validation of Roll Damping for Large Amplitude Roll Motions in Irregular Seas

Predicting Roll Motion and Damping

- Validation of Predictions of Roll Damping
  - Damping Coefficients from Forced-roll Tests
  - Free-decay Test Data
  - Roll damping in time-domain simulations of large-amplitude motions

Validation of Predictions of Roll Damping

Damping Coefficients from Forced-roll Tests

- Purpose: To calculate roll amplitude in regular waves
- Character
  - Frequency-domain coefficient
  - Equivalent linear coefficient for one cycle
  - Including nonlinearly on the roll amplitude

Note: Measurement should be carried out after a few oscillations from rest in order to remove transient effects

Validation of Predictions of Roll Damping

Free-decay Test Data

- Purpose: To estimate onset of large-amplitude roll motions at roll natural frequency
- Character
  - Coefficient for natural roll period
  - Equivalent linear coefficient for half cycle
  - Including nonlinearly on the roll angular velocity (roll amplitude at roll natural period)

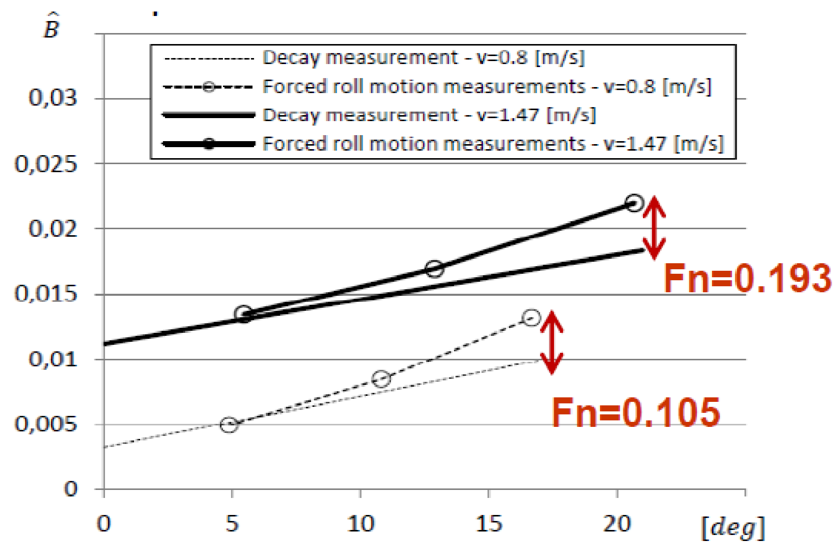
Validation of Predictions of Roll Damping

Free-decay Test Data

Note

Results may not be the same as forced-roll test results, even if it is for roll natural period.

Difference between them occurs particularly during the first few oscilla-tions because roll-decay motion is a transient motion.



Comparison of measured results by free-decay tests and forced-roll tests by sinusoidal harmonic-roll excitation (Handschel, *et al.*, 2012).

Validation of Predictions of Roll Damping

Roll damping in time-domain simulations of large-amplitude motions

- Purpose: To simulate time-domain large amplitude irregular motion
- Important Character
  - Flow-memory effects
  - Interaction between the waves and hull &bilge keels
  - The Interaction may cause reduction of eddy-damping component of bilge-keel by deformation of the water surface

Validation of Predictions of Roll Damping

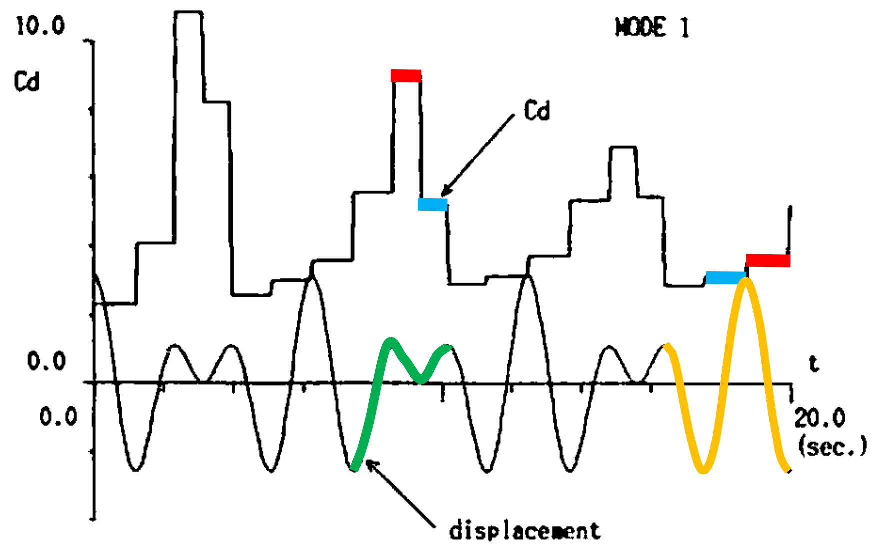
Roll damping in time-domain simulations of large-amplitude motions

- Flow-memory effects

When previous oscillation is larger amplitude than present oscillation, the drag coefficient is large

When previous oscillation is smaller amplitude than present oscillation, the drag coefficient is small

(Ikeda, et al. 1988)

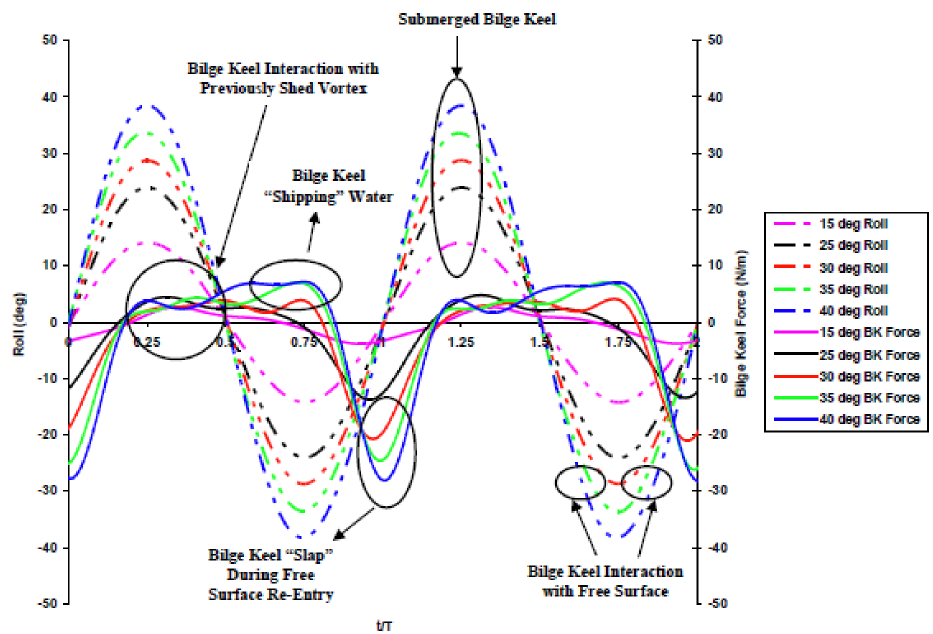


Validation of Predictions of Roll Damping

Roll damping in time-domain simulations of large-amplitude motions

- Interaction between waves by the hull and bilge keels

  Effects of hull geometry, bilge-keel geometry, deck edge, and the free surface all affect the hydrodynamic components during large-amplitude roll motions



(Bassler, 2013)

Validation of Predictions of Roll Damping

Roll damping in time-domain simulations of large-amplitude motions

- Existing data
  - These data indicate some important characteristics
  - It may not include all important characteristics and may not enough to validate simulations
- More data is required for validation
  - Irregular- and large-amplitude forced-roll test data
  - Irregular- and large-amplitude roll mo-tion data in extreme irregular waves

8. Cooperate with IMO SLF

IMO Liaison

- SiW Committee reviewed and commented on draft reports of Intercessional Correspondence Group (ISCG) as well as IMO documents including SLF54, SLF55 and SDC1 sub-committee reports
- The reports discuss methodologies for vulnerability criteria and direct stability assessment for the following stability failures:
  - Quasi-steady stability variation in waves in following/stern quartering seas
  - Parametric resonance due to stability variation in waves;
  - Dead-ship conditions
  - Broaching, manoeuvrability and course keeping ability

IMO Liaison

- SiW Committee reiterated the availability of technical specifications for numerical tools for direct assessment of vulnerability criteria that were contained in the Committee’s report to the 26th ITTC

Technical Conclusions

Technical Conclusions

1. State-of-the-Art review

Focused on modelling the internal geometry of a damaged ship and definition of loss and survival of a ship

- Methodologies used to model damage must reflect the mechanisms involved with the physics of damaged-ship motions leading to loss of a vessel
  - Sensitivity to scaling in model tests, nonlinear effects of progressive flooding, and floodwater effects on damping of roll on other degrees of freedom
- Leak and collapse pressures of watertight doors and bulkheads is another key area that must be covered for damaged-ship modelling

Technical Conclusions

1. State-of-the-Art review (Cont'd)

- Two terms, loss and survival, under specific conditions, express complementary concepts
- Possible to identify many analogies but also differences while investigating the concepts of loss and survival for an intact ship versus a damaged one
- Prevalent trend in defining loss and survival is to focus on the capsizing event, but due to inherent practical difficulties in dealing with this phenomenon, attention is often shifted to focus on the definitive representative roll-angle value
  - Critical roll-angle value is a particular characteristic of a specific ship under investigation
- From a performance- based assessment perspective, it is recommended that attention also be paid to the loss of functional capabilities
  - In some cases the functional capabilities (e.g., ship power production and delivery) are beyond the specific focus of the ITTC

Technical Conclusions

2. Modelling tests on damage stability in waves

Focused on scale effects on air pressure on flooding-model tests under atmospheric conditions and how to deal with the inertia due to floodwater mass

- The investigation concluded that the scale effects on air pressure are not significant in most cases, except for the case of trapped air and for a large-damage opening with a small-vent area
  - Procedure 7.5-02-07-04.2 has been updated
- The inertia due to floodwater mass was investigated with regard to computational modelling
- Included momentum-change description of the effect of floodwater and development of a description of floodwater dynamic properties
  - Procedure 7.5-02-0704.4 has been revised

Technical Conclusions

3. Uncertainty analysis for use in intact- and damaged-model tests

Focused on the uncertainty involved in making establishing mass properties of models as the experiments are stochastic in nature, not deterministic

- Formulas established for the uncertainty in:
  - Model Weight and Mass
  - Longitudinal Centre of Gravity
    - Levelling Method
    - Two-point Suspension Method
  - Vertical Centre of Gravity
  - Moment of Inertia
    - Composite Roll MOI
    - Composite Pitch MOI
  - Transverse Metacentric Height
- Establishing the impact of these uncertainties on experimental results will require the use of computational tools
  - Experimental determination is impractical if not impossible

Technical Conclusions

4. Investigation on modelling wave spectra

Focused on wave characteristics for determining dynamic instability of intact vessels in extreme seas

- Looked at:
  - Nonlinear wave kinematics
  - Statistical distribution of crest and trough height
  - Nonlinear wave propagation
- A number of modelling methods are presented to achieve realistic environmental conditions.

Technical Conclusions

5. Uncertainties associated with results from experiments and simulations

Focused on better understand the results from experiments and simulations of extreme motions of intact vessels in realistic irregular seaways

- Quantitative techniques which reflect the nature and magnitude of the phenomena of extreme motions have been reviewed
- These techniques address the statistical reliability of both “linear” and “nonlinear” signals and events
- Techniques were reviewed to determine extreme values and confidence intervals for nonlinear signals.

Technical Conclusions

6. Vulnerability criteria for intact and damaged ships

Focused on an harmonized approach for intact and damaged ships, highlighting the different priorities that can be identified in the two states in the context of current IMO stability criteria

- Common approaches are recommended to identify and discuss the relevance and treatment of the environmental context, ship loading conditions, and time of exposure
- Coupled with the current developments of simulation tools for the prediction of nonlinear dynamic ship behaviour
- Looking specifically at case of damaged ship, stochastic nature of flooding, especially in the transient progressive process, should be addressed in conjunction with proper stochastic treatment of entire damage scenario

Technical Conclusions

6. Vulnerability criteria for intact and damaged ships (Cont'd)

- Significant difference between an intact- and a damaged-ship situation with respect to safety assessments, is the issue of time-to-loss
  - intact ship the time-to-loss interval is so long that the estimation of the rare-event occurrence implies the need to further develop methodologies for statistical extrapolation
  - Damaged ship, the critical point to determine is if the time-to-loss is sufficient to perform emergency procedures or to evacuate the ship
- Outcome from these investigations is extremely diverse which suggests a review is required for the identification of an efficient, final assessment index.

Technical Conclusions

7. Validation of roll damping for large-amplitude motions in irregular seas

Focused on validation data for predictions of roll damping for large amplitude roll in irregular seas

- State-of-the-art review was conducted
- Validation data focused not only on large- amplitude irregular motion but also on small- amplitude regular motion
- Existing and useful model-scale experimental data has been identified for validation
- Data are presented separately as total hydrodynamic moment, and roll damping with its components
- Characteristics required of future experiments are described

Recommendations to Conference

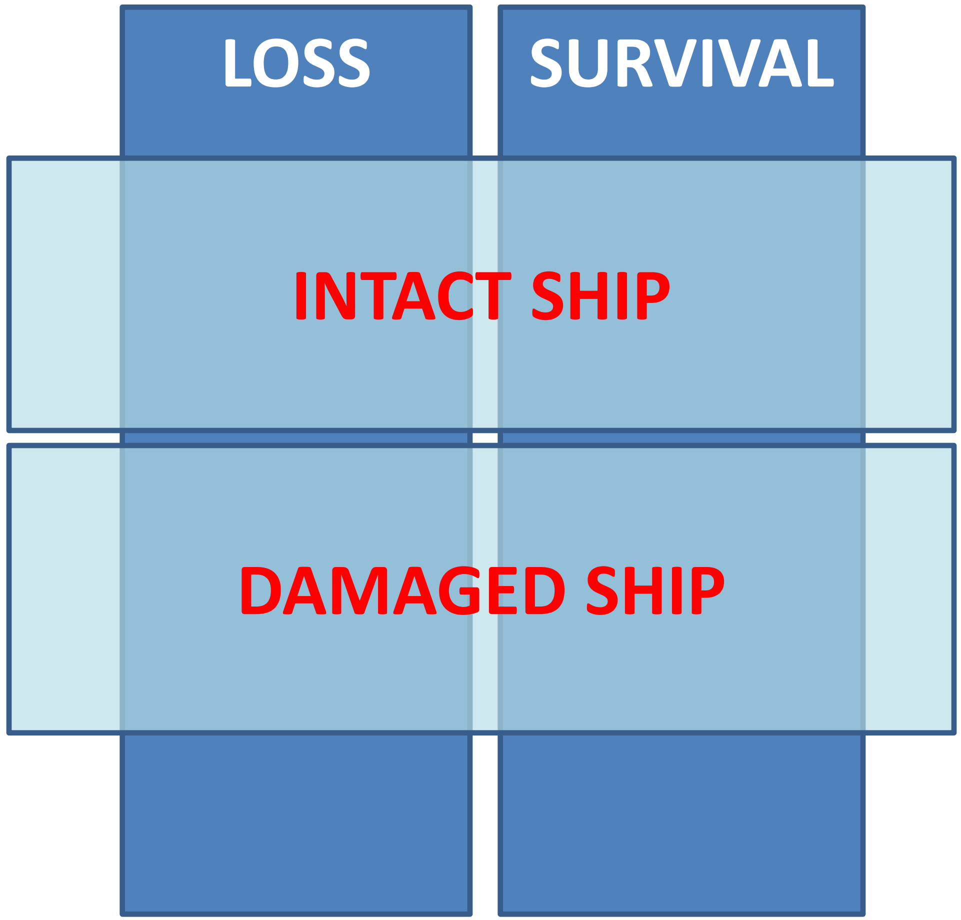
Recommendations to Conference

- Adopt the following revised procedures:
  - 7.5-02-07- 04.2, Model Tests on Damage Stability in Waves
  - 7.5-02-07- 04.4, Numerical Simulation of Capsize Behaviour of Damaged Ships in Irregular Beam Seas

Thank you

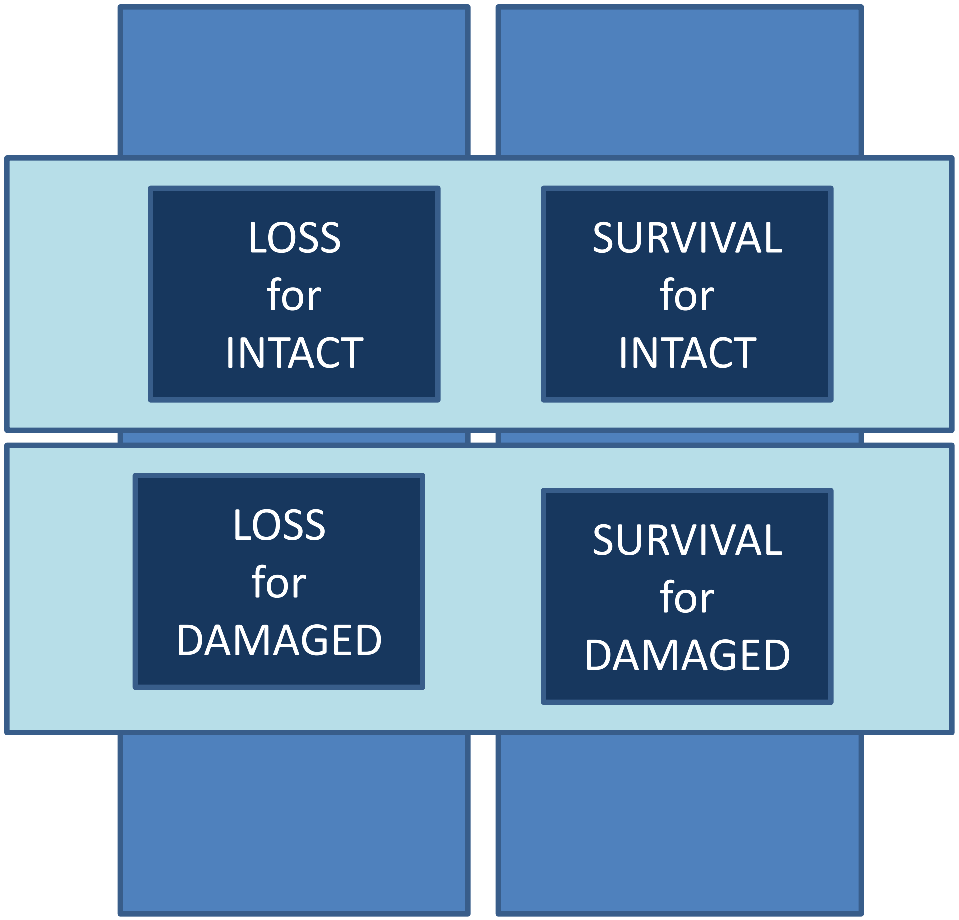
Questions?

Definition of Loss and Survival



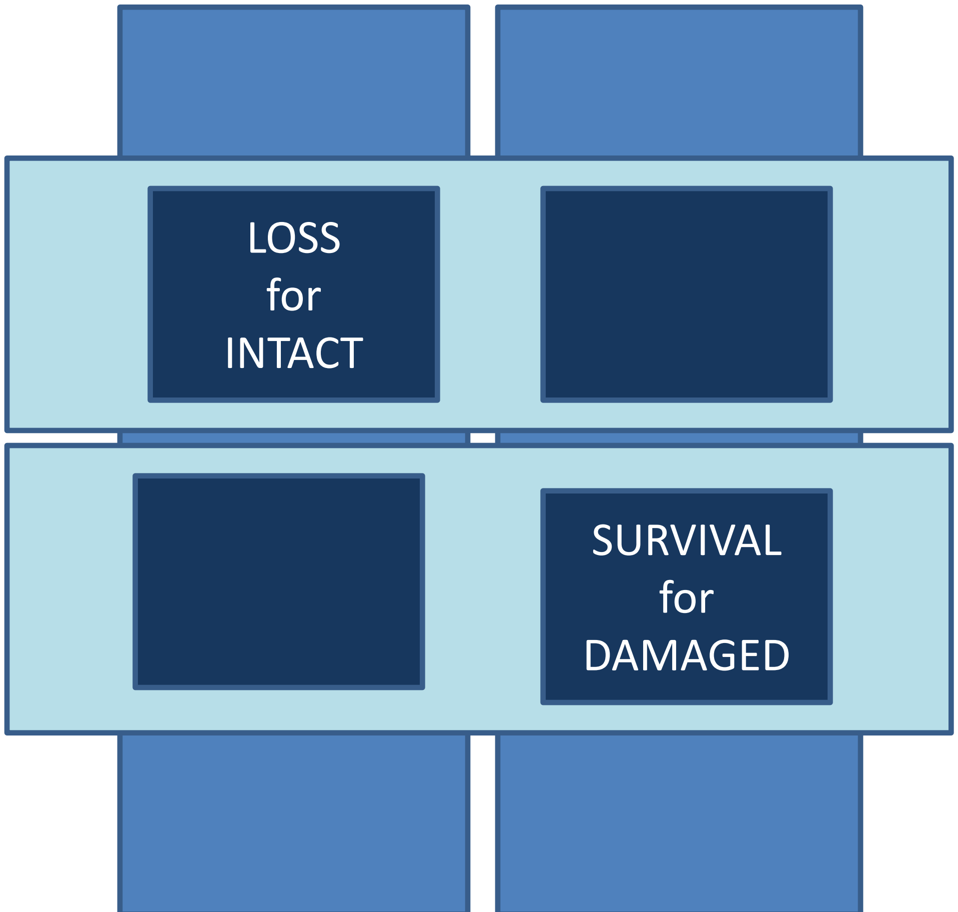
Definition of Loss and Survival

Potential risk of DEFINITION BREAKING UP



NEED FOR HARMONIZATION OF DEFINITIONS

Definition of Loss and Survival



In current literature, a trend has been to discuss the concept of **“ship loss”** when dealing with an **intact ship,** while **“ship survival”** is more likely to be used when dealing with the safety of a **damaged ship**

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Definition of Loss and Survival

Looking for a conceptual relation between Loss & Survival

$$P_S = 1 - P_H \cdot P_{K/H}.$$

In terms of probabilistic definition, survivability P_S, is the combination of:

- SUSCEPTIBILITY P_H (the inability to avoid an undesired event or a related initiating event)

and

- VULNERABILITY $P_{K/H}$, (the inability to withstand the effect of an undesired event)

(Ball & Calvano, 1994).

Definition of Loss and Survival

Looking for a conceptual relation between Loss & Survival

$$P_S = 1 - P_H \cdot P_{K/H} \cdot$$

Vulnerability represents the probability of <u>severe consequences or even total loss</u> of a vessel when an undesired initiating event has occurred.

In terms of probabilistic definition, survivability P_S, is the combination of:

- SUSCEPTIBILITY P_H (the inability to avoid an undesired event or a related initiating event)

and

- VULNERABILITY $P_{K/H}$, (the inability to withstand the effect of an undesired event)

Definition of Loss and Survival

$$P_S = 1 - P_H \cdot P_{K/H}$$

- We can assume that “LOSS” is an extreme negative consequence GIVEN A CERTAIN UNDESIRED INITIATING EVENT
- From this perspective we can consider “LOSS” as the mathematical complement to “SURVIVAL”

Definition of Loss

- The loss of a ship is an expression that, in addition to an explicit negative connotation, can be used to indicate many different levels of severity of a situation

	INTACT
Total Stability Failure	Capsizing
IMO 2008 / Partial Stability Failure	Accidental Heel, List angle
	Roll angle
	Roll accelerations
	Immersion of critical point

From literature

- The loss of a ship defined as the limit exceedance imposed on one (or more) of the above mentioned parameter

Definition of Loss

- Similar list of “loss of a ship” definitions for the damaged ship

INTACT	DAMAGED
-	Sinking
Capsizing	Capsizing
Accidental Heel, List angle	Equilibrium angle after damage
Roll angle	Roll angle
Roll accelerations	Roll accelerations
Immersion of critical point	Progressive flooding

From literature

COMMENTS:

•A “discretization” in partial loss and total loss is advisable also for damaged ship

•Sinking due to accidental flooding from unprotected openings should be considered for a perfect parallelism

Definition of Loss

- A definition of "loss of the ship" expressed in terms of failures of ship operational capabilities, as seems to be suggested in some literature:

INTACT & DAMAGED SHIP
BUOYANCY
STABILITY
STRUCTURAL INTEGRITY
NAVIGATION
….
Some specific operational and systems activity