Specialist Committee on Stability in Waves

Membership:

M Renilson (Chairman),	AMC, Australia
A Peters (Secretary),	QinetiQ, UK
W Y Duan,	Harbin Engineering University, China
P Gualeni,	University of Genoa, Italy
T Katayama,	Osaka Prefecture University, Japan
G J Lee,	MOERI, Korea
J Falzarano,	Texas A & M University, USA
A M Reed,	David Taylor Model Basin, USA
F van Walree,	MARIN, Netherlands

Specialist Committee on Stability in Waves

Meetings:

College Station, TX, USA	February 2009
Genoa, Italy	November 2009
Wageningen, Netherlands	June 2010
Gosport, UK	February 2011

Specialist Committee on Stability in Waves

Tasks:

1. State of the art review
2. Numerical prediction of capsizing
3. Procedures for prediction of capsizing of damaged ship
4. Benchmark test study for predicting parametric rolling
5. Numerical techniques for assessing survival time of passenger ships
6. Procedure for numerical estimation of roll damping
7. Cooperate with IMO SLF

State of the art review

- Major efforts in ship stability research
  - Significant amount of work in this subject area
  - Multiple International Ship Stability Conferences and Workshops
  - Dynamic Stability Task Group
- IMO
- CRNavies

State of the art review

- Potential impact of new technology developments on ITTC procedures
- Improvements in computational predictions
  - Hydrodynamic
  - Probabilistic
- Investigations into system sensitivity
- Strong nonlinear behaviour of large amplitude rolling = understanding nonlinear dynamical systems analysis techniques

State of the art review

- New experimental and extrapolation methods and the practical applications of computational methods to stability predictions and scaling
- Roll damping is a significant aspect of model testing and computations for prediction of capsize
- New methods of analysing experimental roll decay data are needed
- In addition numerical methods for correctly predicting roll damping are key

State of the art review

- Development of vulnerability criteria and assessment methods for intact ships considered by the IMO and navies
  - These bridge the gap between pure prescriptive criteria and time consuming and expensive numerical simulation which require validation by model testing.
- The validation of a numerical tool dealing with ship motions in extreme wind and waves is still really a great challenge

Numerical prediction of capsize

- When a ship capsizes it is the result of the simultaneous influence of :
  - Ship dynamics,
  - Environmental circumstances,
  - Operational profile,
  - and human behaviour
- Investigation of ship performance in terms of capsizing implies a definition of a comprehensive methodology where the numerical simulation of the motions is only one of the required components

Probability of Capsizing

Probability of Capsizing

Intact

Damage

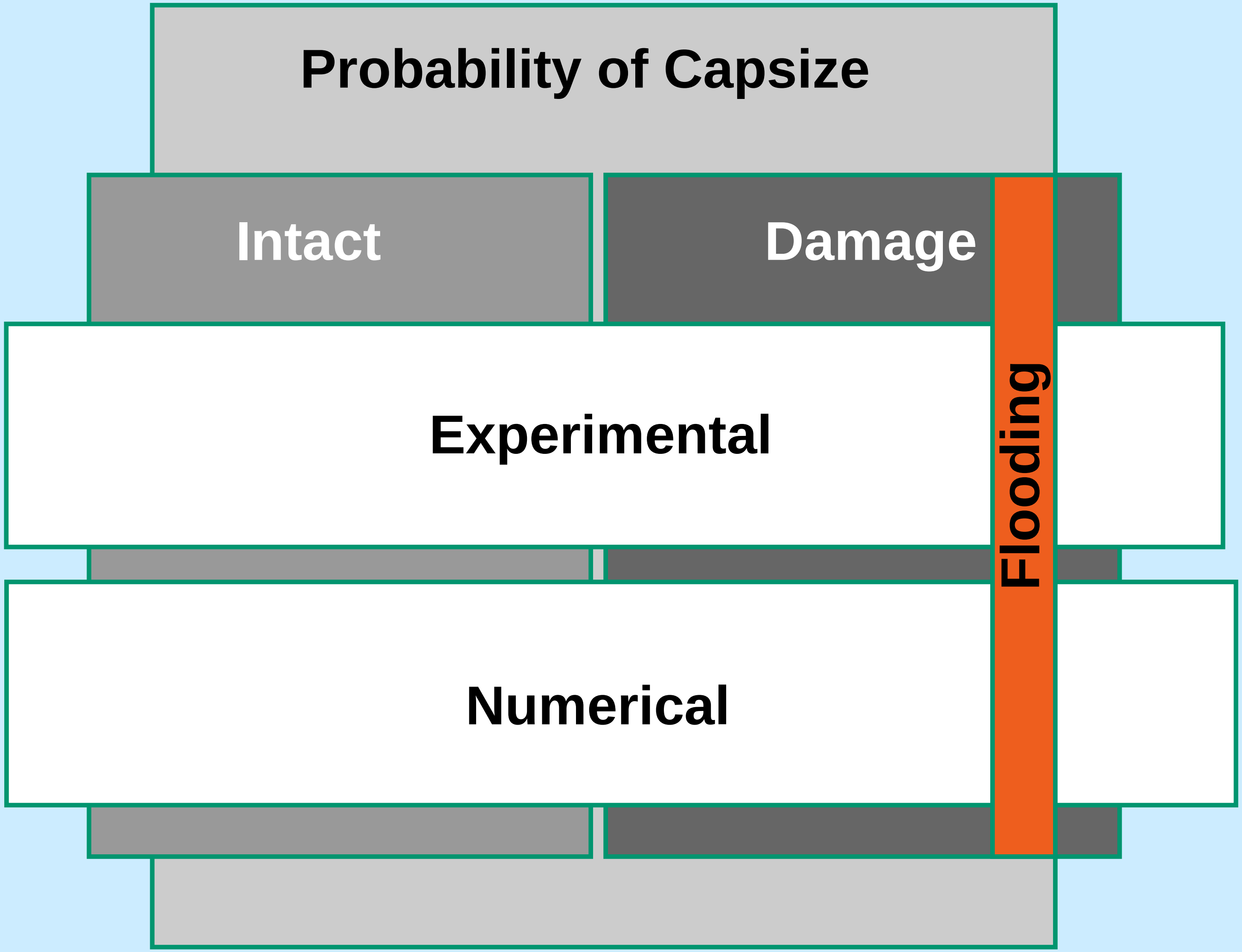
Probability of Capsizing

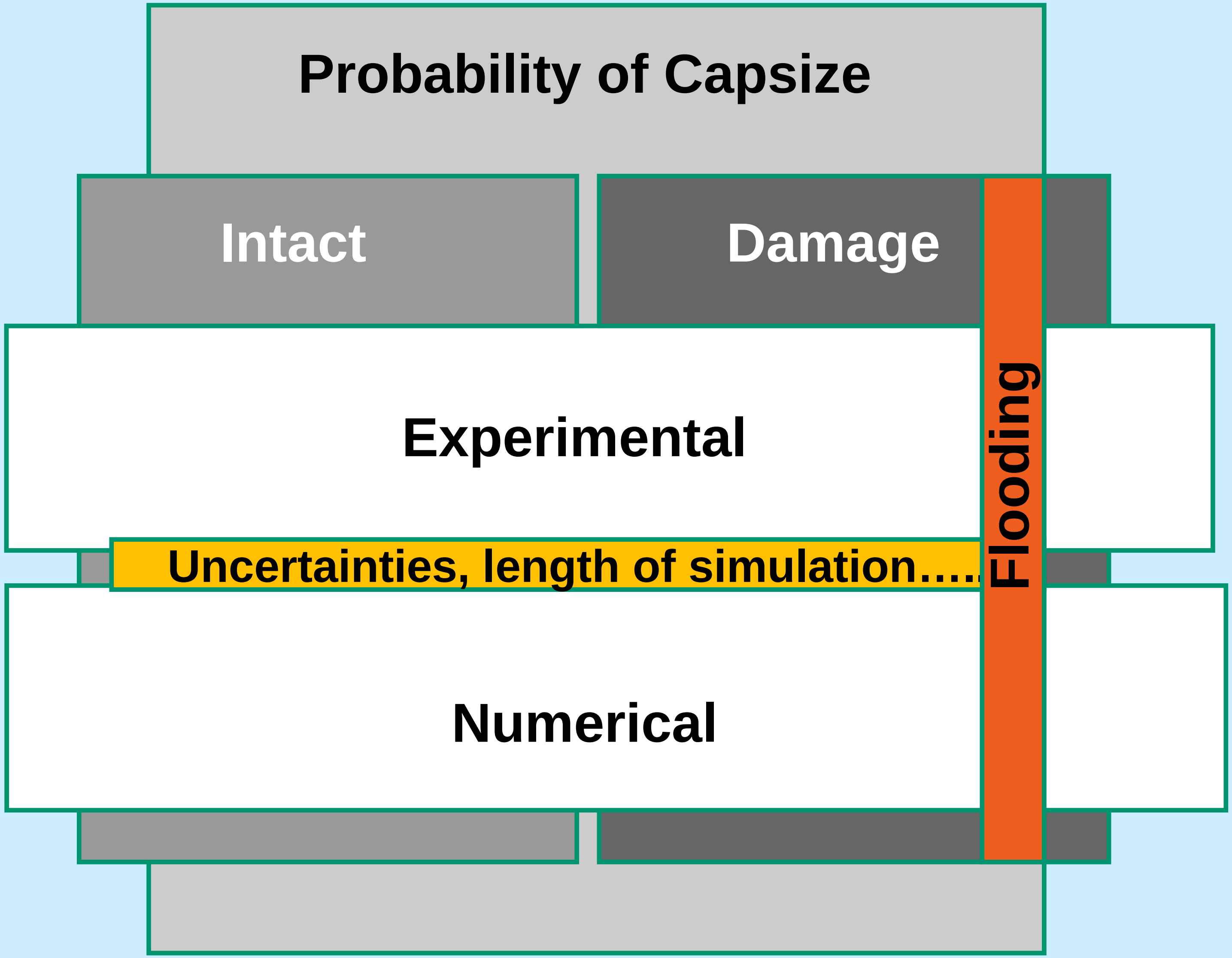
Intact

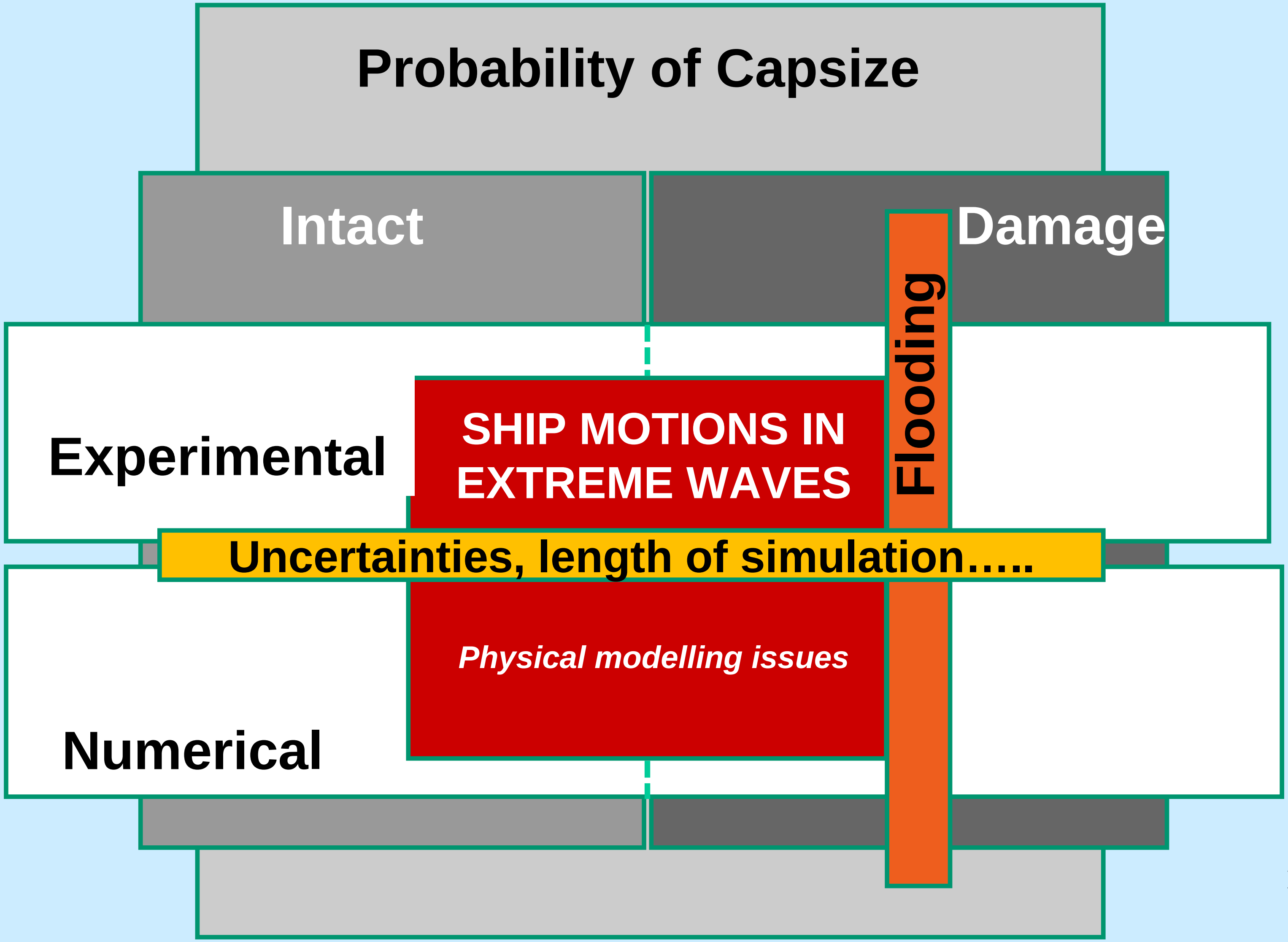
Damage

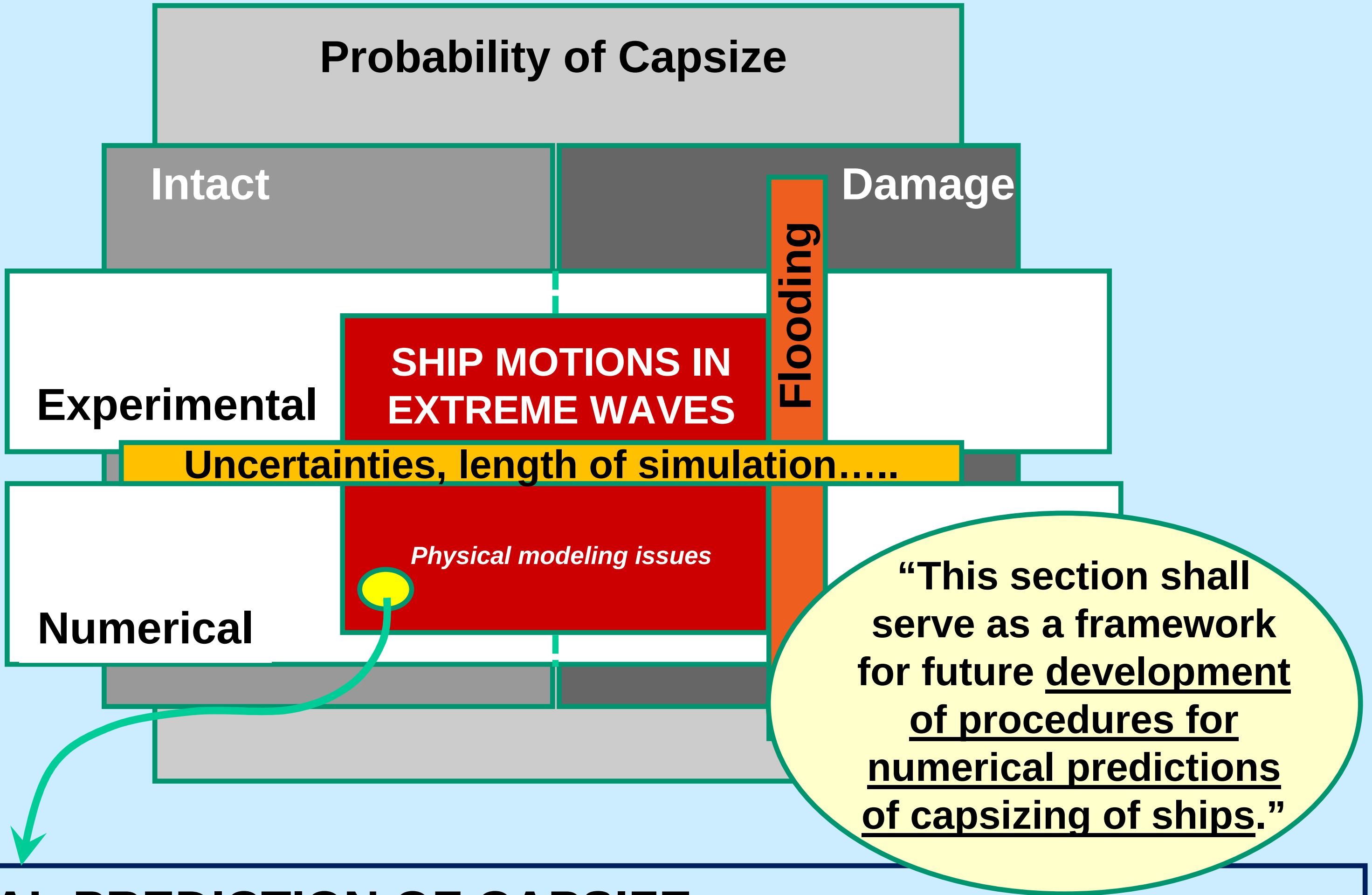
Experimental

Numerical


Probability of Capsize
Intact
Damage
Experimental
Numerical
Flooding


Probability of Capsize
Intact
Damage
Experimental
Uncertainties, length of simulation….
Numerical
Flooding


Probability of Capsize
Intact
Damage
Flooding
Experimental
SHIP MOTIONS IN EXTREME WAVES
Uncertainties, length of simulation…..
Physical modelling issues
Numerical



NUMERICAL PREDICTION OF CAPSIZE:
"various cases and methods for numerical prediction of capsizing"

“procedure for numerical predictions of capsizing of ships”

PROBABILITY OF CAPSIZE

ASSESMENT

TIME DOMAIN SIMULATION

Analysis of the problem in terms of different cases for capsizing (1/3)

In ITTC Stability Workshop (1996), great trust in large computational power is given and a possible holistic comprehensive synthesis approach is foreseen. Nevertheless, as soon as discussion moves onto practical and technical aspects, the reference to specific capsizing modes becomes necessary and a long detailed list is given.

Table 1: Capsize modes predicted by simulations and model tests

- pure loss of transverse stability in wave crest
- parametric rolling (low cycle resonance)
- broaching (low speed) in successive overtaking waves
- broaching (high speed) due to bow submergence and wave-induced yaw excitation
- surf-riding and broaching
- surf-riding and loss of stability in wave crest
- surging, yawing, and rolling with dynamic loss of stability
- resonant beam waves
- excessive wave-induced roll moment in beam seas

ITTC Trondheim 1996 Workshop on Stability

Analysis of the problem in terms of different cases for capsizing (2/3)

ITTC
22 Seoul/Shanghai 1999
Report of Specialist Committee on Stability

Static loss of stability
Dynamic loss of stability
- dynamic rolling
- parametric excitation
- resonant excitation
- impact excitation
- bifurcation

Broaching (variety of modes)
Other factors

In line with this trend, at ITTC (1999) it is clearly stated that, given the level of complexity of an hypothetical comprehensive tool, it is necessary to develop prediction tools focused on specific modes of capsizing rather than address the problem holistically.

Analysis of the problem in terms of different cases for capsizing (3/3)

DRAFT TERMINOLOGY FOR THE NEW GENERATION INTACT STABILITY CRITERIA

Parametric rolling	is an effect of amplification of roll motion of a ship due to periodic changes of restoring moment causing parametric resonance. Periodic changes of restoring moment may be caused by wave pass effect and or coupling with other degrees of freedom (e.g., MSC.1/Circ.1228 for phenomena explanation).
Synchronous rolling	roll motion induced by an external excitation force having its frequency equal to the natural roll frequency.
Broaching-to	a phenomenon where a ship cannot keep constant course despite maximum steering efforts and experiences a significant yaw motion in an uncontrolled manner.
Surf-riding	a phenomenon where mean speed of a floating body is shifted from the original one to wave celerity because of wave actions (e.g., MSC.1/Circ.1228 for phenomena explanation).
Dead-ship condition	Condition under which the main propulsion plant, boilers and auxiliaries are not in operation due to the absence of power (SOLAS regulation II-1/3.8).
Pure loss of stability	Condition under which static balance in heel is lost due to reduction of righting lever curve or increase of heeling moment.

IMO
SLF 51/4/1
10 April 2008

SHIP RELATED ISSUES			
MODE OF FAILURE			
PARAMETRIC ROLL (in head/following sea)			
SURF-RIDING / BROACHING			
DEAD SHIP CONDITION			
PURE LOSS OF STABILITY			

For the purpose of the report a selection is considered

ITTC

23 Venice 2002 The Specialist Committee on Prediction of Extreme Ship Motions and Capsizing

Table 2.6 Comparison of numerical prediction methods for Ship A-1.

Organisations	DOF		Radiation	Manoeuvring Damping	Roll Restoring
A	6		strip theory	exp. (non-linear)	hydrostatics in waves
B	6	(linear in sway, heave, pitch, yaw)	strip theory	ignored	hydrostatics in waves
C	6	(coupled with fluid motion)	CFD (non-linear)	ignored	CFD (non-linear)
D	6	(two stage model)	strip theory	exp. (linear)	hydrostatics in waves
E	6		strip theory	empirical	hydrostatics in wave
F	6		empirical	empirical	hydrostatics in waves
G	6		strip theory	exp. (non-linear)	hydrostatics in waves

ITTC

23 Venice 2002 The Specialist **Committee** on Prediction of Extreme Ship Motions and Capsizing

Table 2.7 Comparison of numerical prediction methods for Ship A-2.

Organisations	DOF	Radiation	Manoeuvring Damping	Roll Damping	Roll Restoring	Froude-Krylov	Diffraction
A	4 static heave & pitch	slender body theory at ω=0	experimental (linear)	exp.+ empirical forward speed effect	hydrostatics in calm water	linear	slender body theory at ω=0
B	6	3D theory (Green function at Fr=0)	ignored	empirical + tuned	hydrostatics in waves	non-linear	3D theory (Green function at Fr=0)
C	4 static heave & pitch	strip theory	experimental (non-linear)	exp.+ empirical forward speed effect	hydrostatics in calm water	non-linear	slender body theory at ω=0
D	6 two stage model	strip theory	experimental (linear)	empirical	hydrostatics in waves	non-linear	strip theory

Organisations	Hydro-dynamic Lift due to Waves	Hull Resistance	Propeller Thrust	Rudder Force	Incident Wave	Hydro-dynamic Memory Effect	Specified Initial Con-dition
A	end term	exp.	exp.	exp.	linear	ignored	yes
B	ignored	empirical	tuned	empirical	non-linear	included	no
C	ignored	exp.	exp.	exp.	linear	ignored	yes
D	ignored	exp.	exp.	empirical	linear	included	no

ITTC

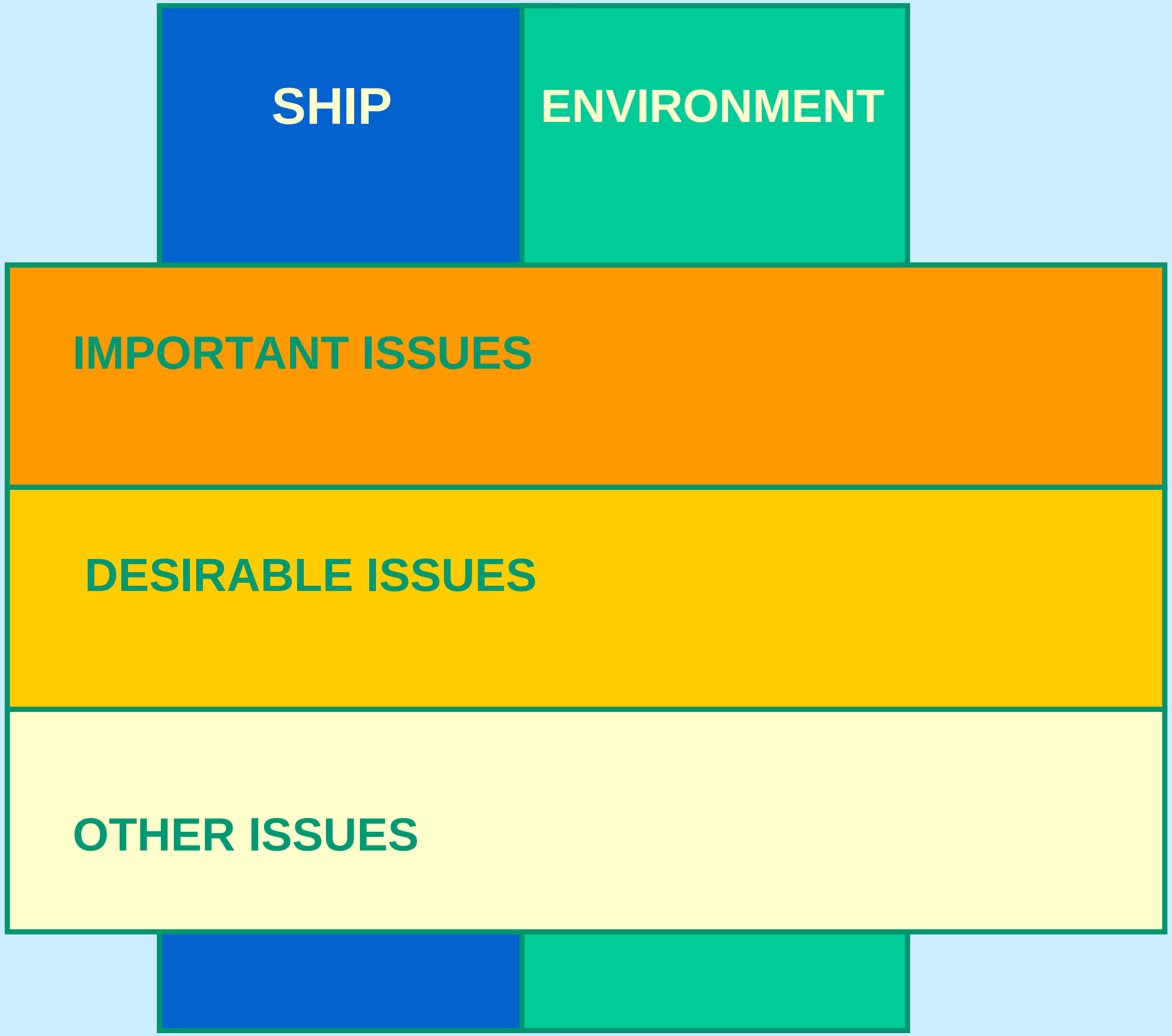
22 Seoul/Shanghai 1999
Report of Specialist Committee on Stability

Table 3: Key Factors in the Modelling of Intact Ship Capsize

Modes / Factors	Static loss of stab.	Dyn. rolling	Param. excitat.	Reson. excitat.	Impact excitat.	Bifur-cation	Broach.
Above water hull shape	✓	✓	✓		✓		
GZ curve (including large angles)	✓	✓	✓	✓	✓	✓	✓
GZ variation in waves	✓	✓	✓				✓
KM variation with speed (if appropriate)	✓	✓	✓				✓
Pitch quasi-static	✓						✓
All 6 d.o.f.		✓					✓
Heel/yaw coupling		✓					✓
Surge response	✓						✓
Roll Damping		✓	✓	✓	✓	✓	
Integration of wave up to free surface		✓	✓				✓
Resistance and propul-sion characteristics		✓					✓
Bilge keels, anti-roll fins, skegs, etc.		✓	✓	✓	✓	✓	✓
Rudder and auto-pilot		✓					✓
Roll and sway				✓	✓	✓	

SHIP RELATED ISSUES			
MODE OF FAILURE			
PARAMETRIC ROLL (in head/following sea)			
SURF-RIDING / BROACHING			
DEAD SHIP CONDITION			
PURE LOSS OF STABILITY			

For the purpose of the report a selection is considered


SHIP
ENVIRONMENT
IMPORTANT ISSUES
DESIRABLE ISSUES
OTHER ISSUES

SHIP RELATED ISSUES

MODE OF FAILURE	IMPORTANT ISSUES	DESIRABLE ISSUES	OTHER ISSUES
PARAMETRIC ROLL (in head/following sea)	Time varying in roll restoring term; Time varying Froude-Krilov forces Roll damping; Natural frequency in roll;	Variation of speed in the wave;	Variation of heading; Roll wave excitation; Water on deck;
SURF-RIDING/BROACHING	Longitudinal forces; Wave yawing moment; Rudder yawing moment;	Roll/yaw coupling; Auto-pilot; Manoeuvring model; Roll restoring term;	Roll wave excitation; Water on deck;
DEAD SHIP CONDITION	Roll wave excitation; Roll wind excitation; Roll damping; Roll restoring moment; Roll natural period; Water on deck;	Heading; Wave drift force; Wind drift force;	Manoeuvring model;
PURE LOSS OF STABILITY	Varying in roll restoring term;	Longitudinal forces;	Roll damping; Natural frequency in roll;

ENVIRONMENT RELATED ISSUES

MODE OF FAILURE	IMPORTANT ISSUES	DESIRABLE ISSUES	OTHER ISSUES
PARAMETRIC ROLL (in head and following sea)	Wave length; Wave steepness; Encounter frequency; Wave groupiness; Wave spreading;	Non-linearities in the ship-wave interface;	
SURF-RIDING/BROACHING	Wave length; Wave steepness;	Non-linearities in the ship-wave interface;	Wave spreading;
DEAD SHIP CONDITION	Modal period and groupiness of waves; Wave steepness; Non-linearities in wave breaking; Wind and gustiness effects;	Wave spreading;	
PURE LOSS OF STABILITY	Wave length; Wave steepness; Encounter frequency;	Non-linearities in the ship-wave interface;	

Procedure for prediction of capsizing of a damaged ship in irregular beam seas

1. Refinement of model test procedure

2. Numerical test procedure

Procedure for prediction of capsizing of a damaged ship in irregular beam seas

1. Refinement of model test procedure

Model test procedure has been refined, however:

- Uncertainty assessment of the experimental results is vital
- Further investigation of effect of atmospheric pressure on flooding
- Further investigation into use of ventilation openings at model scale required to prevent air trapping

Procedure for prediction of capsizing of a damaged ship in irregular beam seas

2. Numerical test procedure

Procedure addresses:

- Demands set for numerical methods to deal with the non-linearities involved and the flooding process
- Discretisation of ship geometry
- Wind and wave conditions
- Simulation preparation, initial conditions, duration of simulations
- Determination of probability of capsize
- Documentation of simulations

Procedure for prediction of capsizing of a damaged ship in irregular beam seas

2. Numerical test procedure

Procedure does not address:

- Amount of detail required for modelling internal geometry
- How to deal with inertia due to flood water mass
- Lack of data on leak and collapse pressures for wt doors etc
- Effect of forward speed on initial flooding

It is recommended that these aspects are addressed by the next committee.

Parametric roll benchmark

Aim: to evaluate numerical simulation methods currently employed for the prediction of the parametric rolling of ships in head seas

Parametric roll benchmark

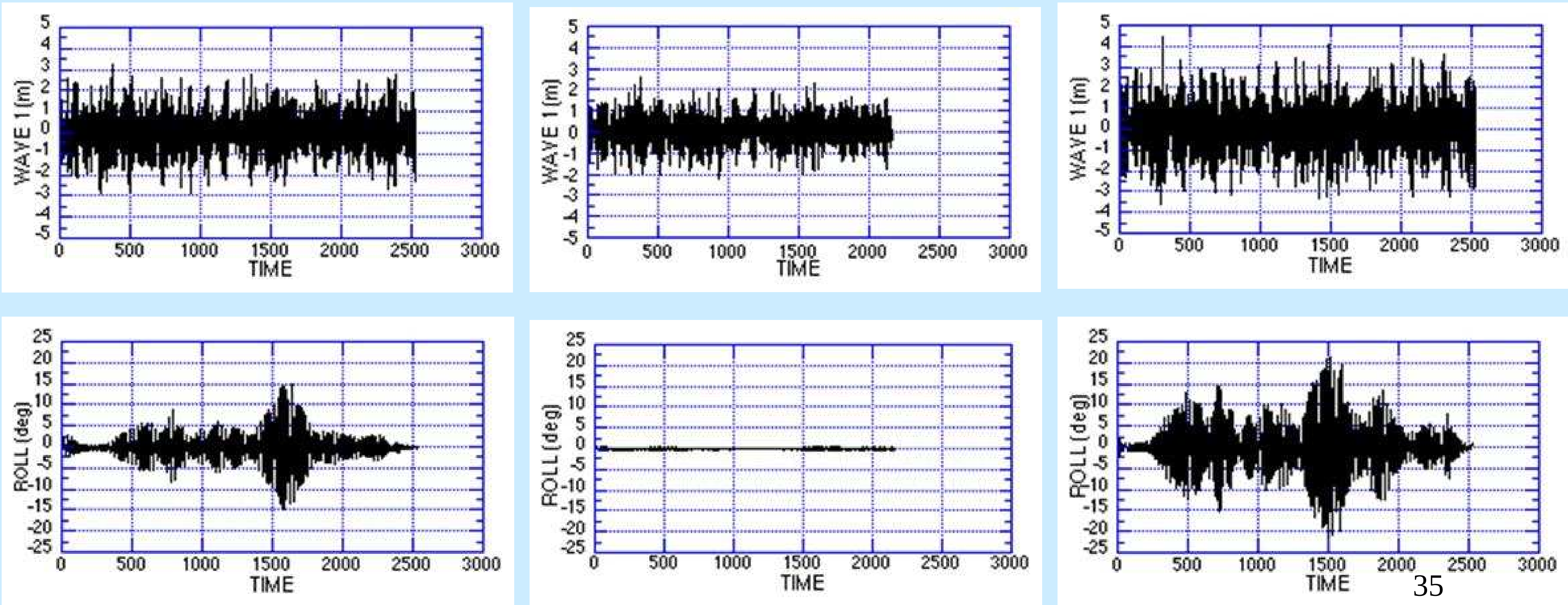
Simulation of behaviour of C11 containership:

- Irregular longitudinal head waves
- 3 wave steepnesses
- 1 speed
- 1 ship loading condition


C11-Class
Container Ship
Longcrested
Seas

Parametric roll benchmark

Model test results



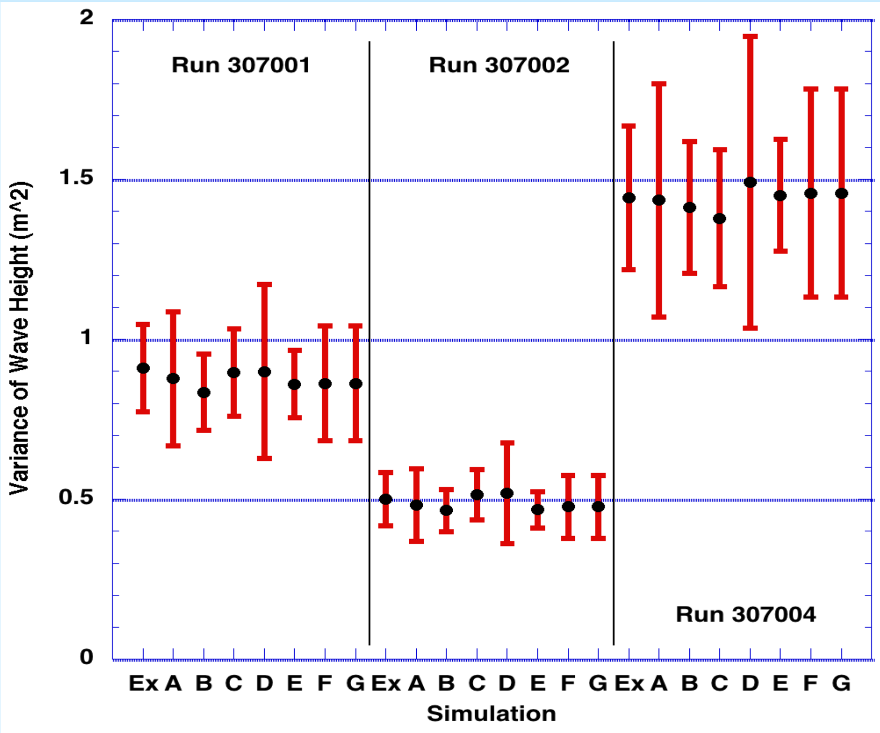
Parametric roll benchmark

Participants

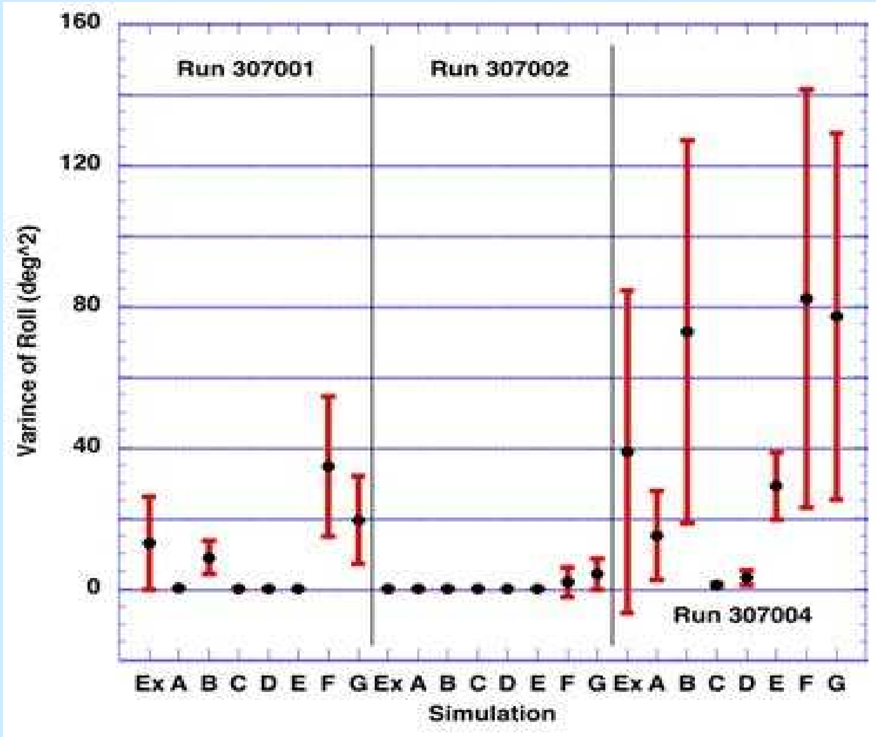
Organisation	Code(s)
David Taylor Model Basin (NSWC/CD)	FREDYN, v9.8
HSVA	ROLLSS
MARIN	FREDYN, v10.1
Osaka University	OU-PR
Science Applications International Corporation	LAMP 3
Seoul National University	SNU-PARAROLL, WISH

Parametric roll benchmark

Wave Height



Roll Angle



Variance with 95% confidence bands as predicted from the experiments (Ex) and computations (A – G)

Parametric roll benchmark

Explanation of Results

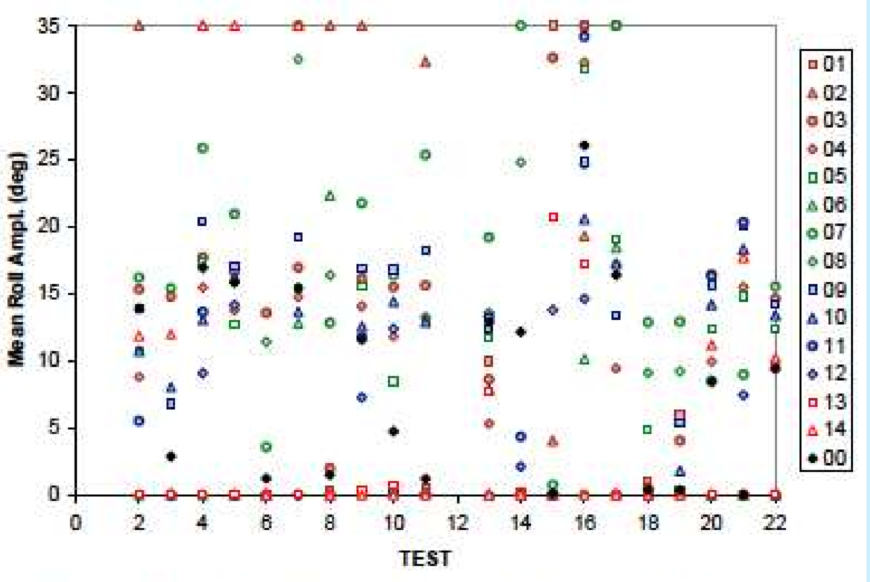
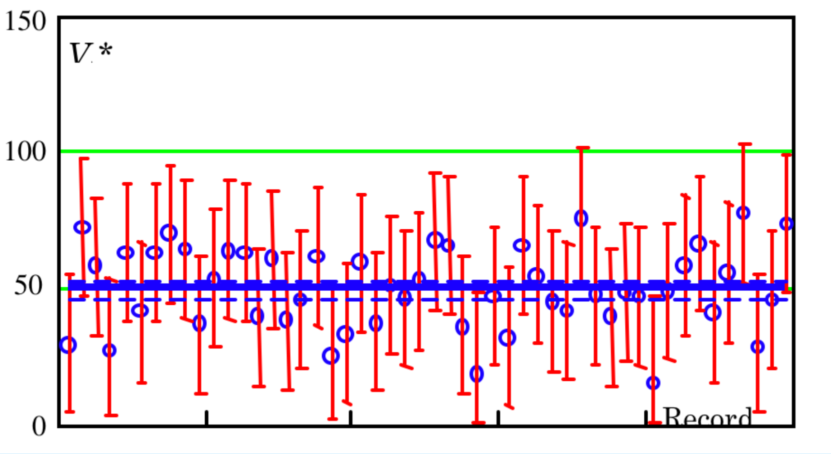
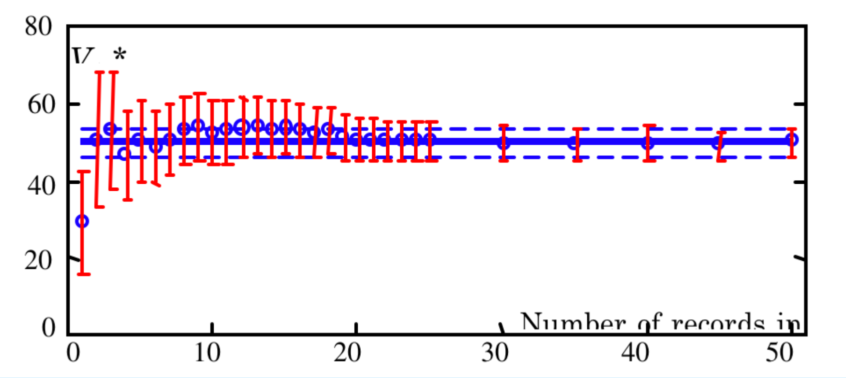


Figure 9 *Simulations:* Estimated Mean roll amplitude (01-14: Methods, 00: Experimental)

From: Spanos & Papanikolaou (2009)





From: Belenky & Weems (2011)

Parametric roll benchmark

Conclusions

1. Confidence bands are required to enable comparisons to be made;
2. The results show significant scatter in the predicted roll variance;
3. The vast majority of the predictions are within the 95% confidence band of the experimental results; and
4. Insufficient data is being accumulated by such benchmark studies, either experimentally or computationally, to produce reasonable confidence bands.

Review of numerical techniques for assessing survival time for damaged passenger ships

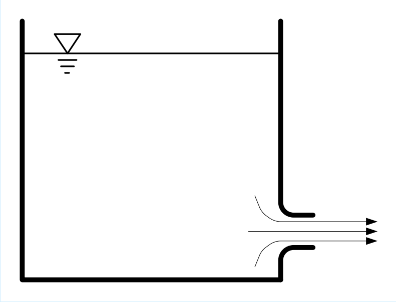
Behaviour is affected by three main mechanisms

1. Flooding process and floodwater dynamics;
2. Ship motions in waves; and
3. Interaction between floodwater and ship motion.

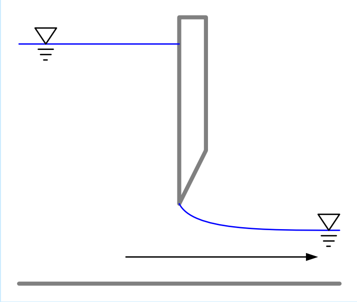
Review of numerical techniques for assessing survival time for damaged passenger ships

Flooding process and floodwater dynamics

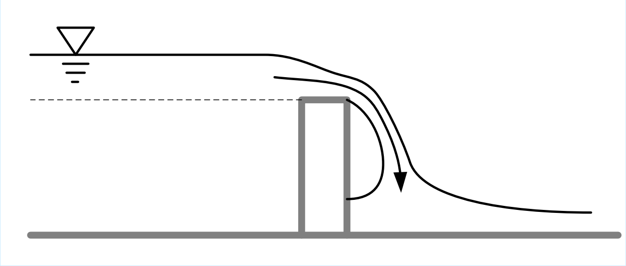
Flow through openings



orifice



sluice gate



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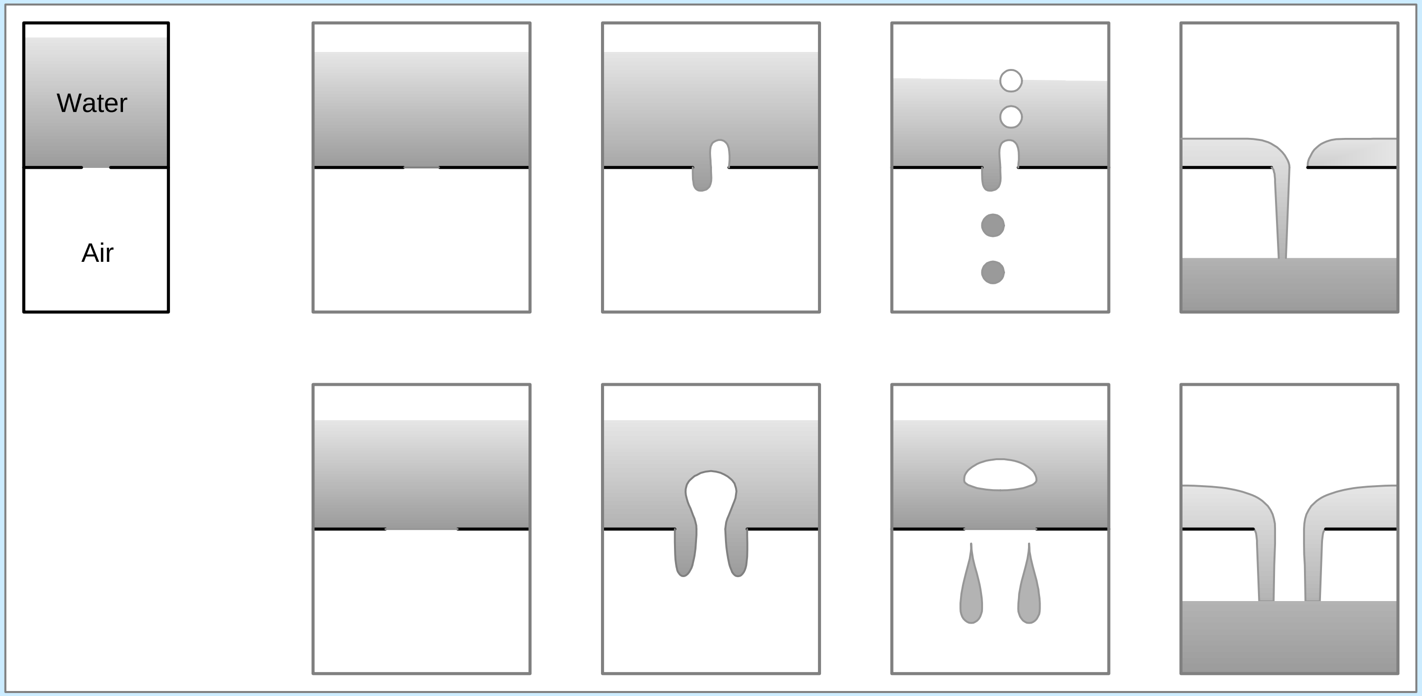
Review of numerical techniques for assessing survival time for damaged passenger ships

Flooding process and floodwater dynamics

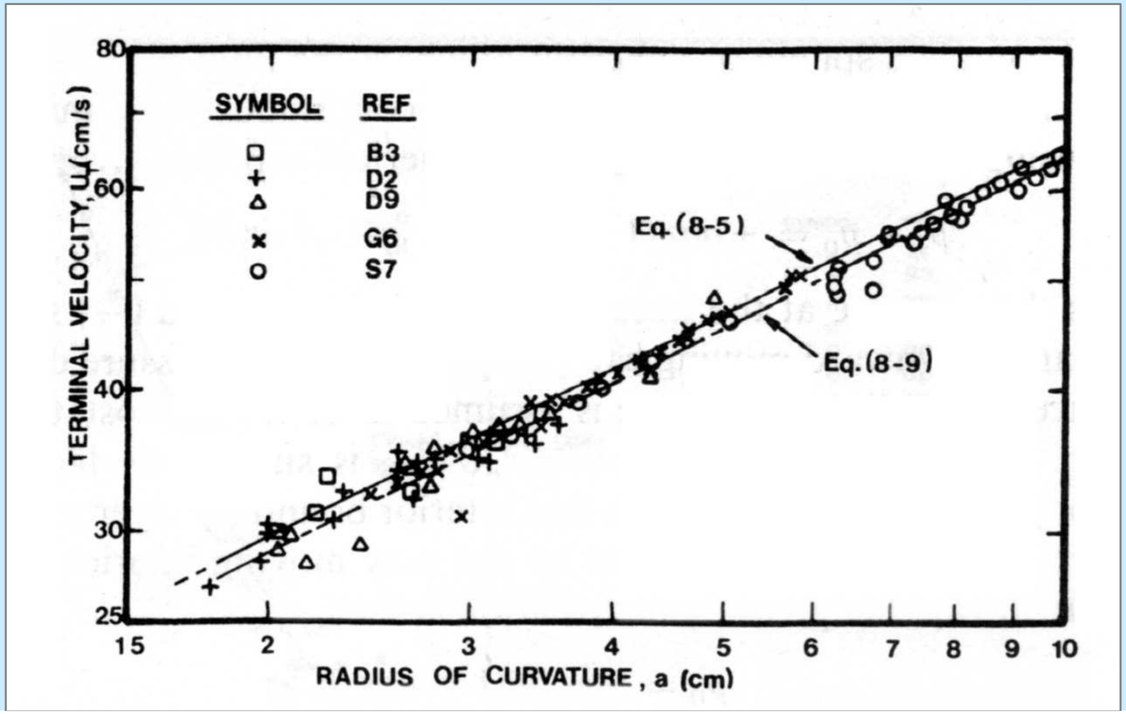
Air compression and flow



Review of numerical techniques for assessing survival time for damaged passenger ships

Flooding process and floodwater dynamics

Bubble dynamics



Review of numerical techniques for assessing survival time for damaged passenger ships

Flooding process and floodwater dynamics

- Semi-empirical formulae
- Assumption of horizontal free surface in compartments
- ‘Lumped mass’ concept
- Volume of Fluid RANSE methods
- Smoothed Particle Hydrodynamics methods

Damaged ship motions

Calculations

- 6-DoF
- 2-D strip method or 3-D panel method
- Empirical roll damping
- CFD for motions in waves – too time consuming for now!

Review of numerical techniques for assessing survival time for damaged passenger ships

Interaction between floodwater dynamics and ship motion

- Added weight concept
- Added force concept

Review of numerical techniques for assessing survival time for damaged passenger ships

Interaction between floodwater dynamics and ship motion

- Interactions

	Floodwater treatment	**Interaction concept**
Quasi-static	Static	added weight
Quasi-dynamic	Dynamic	added weight
Dynamic	Dynamic	added force

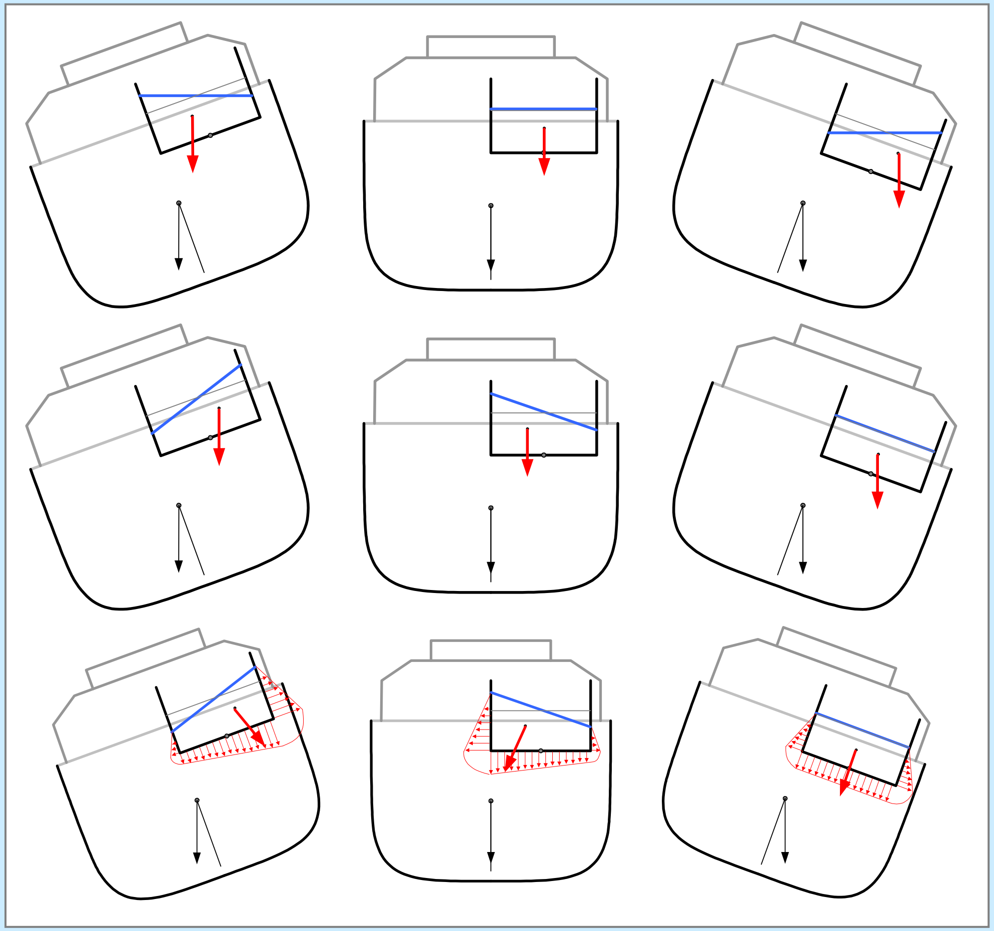
Table 6.1 Three models of interactions

Interaction between floodwater dynamics and ship motion

Quasi-static (free surface horizontal)

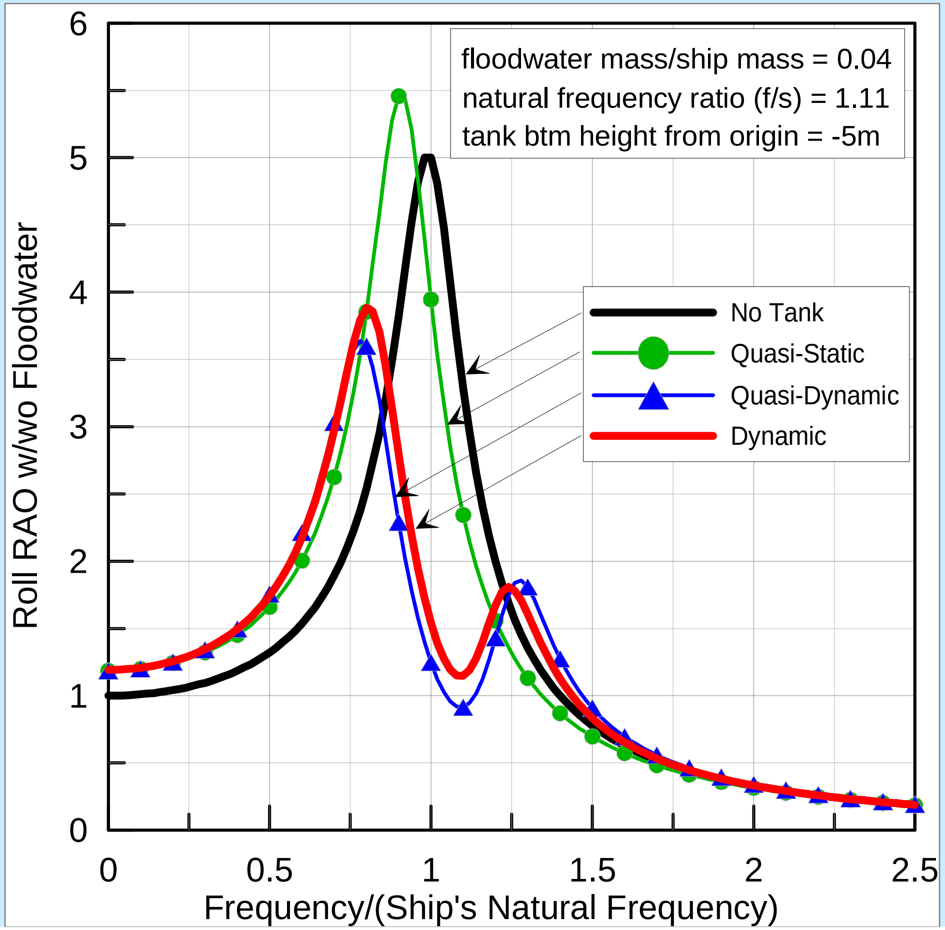
Quasi-dynamic (dynamic free surface)

Dynamic (dynamic free surface, fluid pressure force)



26th International Towing Tank Conference
Rio de Janeiro, Brazil, 28 August - 3 September, 2011

Interaction between floodwater dynamics and ship motion



Typical roll RAO of ship with floodwater tank

Calculation time

T-T ratio	Typical method	Usage
0.01	Potential + calm water	Monte-Carlo or probabilistic study
0.1	Potential + Wave	
1	Real time	Simulator
100	Potential + RANSE Flooding	
1000	Totally RANSE	Analysing of phenomenon

Typical time-time ratio (T-T ratio)

Assessing survival time

Two approaches:

1. Based on SOLAS probabilistic approach
   - Use is made of survival factor: s
   - Quick assessment – but inherent uncertancies

2. Direct numerical simulation
   - Monte Carlo type simulations for matrix of:
     - Loading conditions
     - Damage openings
     - Sea states

Experimental data for validation

- Limited number of model test data sets openly available for vessels with a large number of damage compartments.
- Ruponen performed an experimental study of the progressive flooding of a box-shaped barge.
- Recently Cho *et al*., performed an experimental study on the flooding of a cruise ship.
  - Two damaged compartments: one is the same shape as that used by Helsinki University, except with a double bottom; and the other located at the bow of the ship.
  - Flooding model tests performed with and without waves (regular and irregular waves).

Numerical estimation of roll damping

- Objective

  ***To provide an overview and guidance of current roll damping estimation methods for use in stability calculations, without the need for experimental data*.**
- The guidance has been based on a survey and upon the experiences of domain experts
- Discrete component type method presented
- Reviewed in the reports of the seakeeping committee of the 15th and 16th ITTC Proceedings.
- The final chapter of the guidance provides a literature review

IMO Liaison

The Committee has reviewed draft reports of the ISCG from the following nations

Failure criteria

Stability failure mode	Level 1	Level 2	Level 3	Level 4
Pure loss of stability	Japan, United States	United States Japan	Germany Japan	Germany
Parametric roll	Italy, Japan, United States	United States Japan, ROK	Germany, Japan, ROK	Germany
Surf-riding/ Broaching	Japan, Poland, United States	Japan, United States	Japan	Japan
Dead ship Condition	Italy, Japan	Italy, Japan	Italy, Japan, Germany	

Technical conclusions

1. Development of vulnerability criteria and assessment methods

Methodology must reflect mechanism involved

- Extreme ship motions
- Extreme sensitivity to initial conditions
- Critical behaviour
- Stochastic nature of motions in realistic seaway
- Coupling of roll to other degrees of freedom

Technical conclusions

2. Numerical tools to predict capsize (intact)
    a. Some methods deal with specific modes only
    b. Other methods deal with all modes

3. Investigation of ship capsize performance

    Numerical simulation of motions is only a component of the methodology

Technical conclusions

4. Prediction of motions of damaged ship in waves requires greater understanding of:
   a. Air compressibility
   b. Inertia of flood water mass
   c. Effect of forward speed
   d. Effect of short crested waves
   e. Non-watertight boundaries
   f. Two phase flows
   g. Bubble dynamics

Technical conclusions

5. Need for better understanding of parametric rolling
   a. Uncertainties with results from experiments & simulations
   b. Develop a quantitative technique reflecting nature and magnitude of the phenomenon
6. Parametric roll benchmark
   a. Significant scatter in predicted roll variance
   b. Vast majority of results within 95% confidence band of experimental results
   c. Insufficient data is being accumulated to produce reasonable confidence bands (experimentally or numerically)

Technical conclusions

7. Validation data
   a. Some data exists for validation of flooding mechanisms
   b. No publically available data for survival time for ships with complex interiors

8. Procedures
   a. Numerical estimation of roll damping (7.5-02-07-04.5)
   b. Numerical simulation of capsize behaviour of damaged ships in irregular beam seas (7.5-02-07-04.4)
   c. Experimental prediction of capsizing of damaged ship in irregular beam seas (refinement of existing procedure)

Recommendations to conference

Adopt the following procedures:

a. Numerical estimation of roll damping (7.5-02-07-04.5)

b. Numerical simulation of capsize behaviour of damaged ships in irregular beam seas (7.5-02-07-04.4)

Thank you

Questions?