This presentation is an update of the preliminary one presented at
7th International Workshop on
Stability and Operational Safety of Ships
Shanghai, China, November 2-3, 2004
and includes the final results of the benchmark study

24th ITTC Benchmark Study on Numerical Prediction of Damage Ship Stability in Waves Analysis of Final Results

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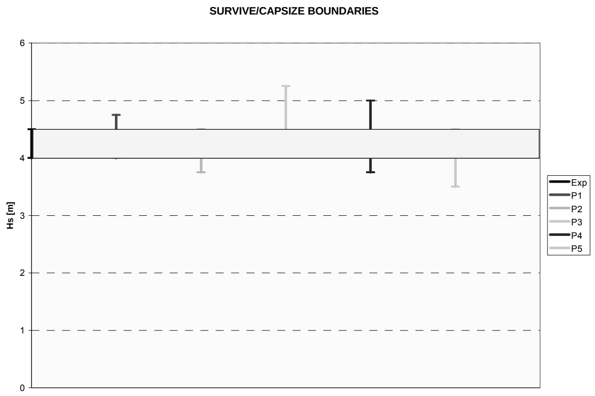
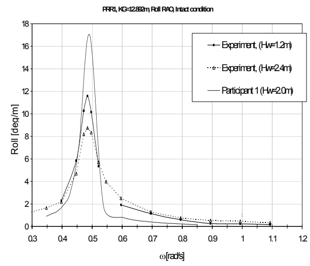
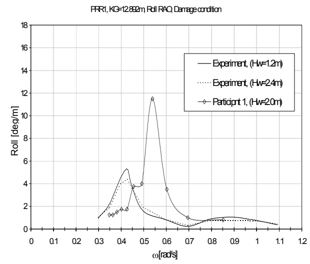
Review of 23rd ITTC Benchmark Study

- In **December 2001** the first international benchmark study on numerical methods for the prediction of capsize of damaged ships in sea waves was completed, it was coordinated by **the 23rd ITTC Specialist Committee on the Prediction of Extreme Motions & Capsizing**.
- There were five (5) independent participants in this study each employing different and independently developed computer simulation code. The five participants were:
  - Marine Research Institute (**MARIN**)
  - Ship Design Laboratory of National Technical University of Athens (**NTUA-SDL**)
  - **Osaka** University
  - Flensburger Schiffbau Gesellschaft (**FSG**)
  - The Ship Stability Research Center of Universities of Glasgow and Strathclyde (**SSRC**)
- This benchmark study is believed to have represented at the time of its conduct the state of the art in the field.

23rd ITTC Benchmark Study
Results







23rd ITTC Benchmark Study
Performance of numerical methods – key results

- Free roll decay
  - Intact ship: satisfactory
  - Damaged ship: non-satisfactory
- Regular (large) waves excitation
  - Intact ship motions: mixed quality
  - Damaged ship motions: non-satisfactory
- Irregular Waves excitation
  - Dynamics: mixed quality
  - Critical seastates/ capsizal boundaries: satisfactory

24^{th} ITTC Benchmark Study (in progress)

- The 24^{th} ITTC Specialists Committee on Stability in Waves has initiated an extension of the benchmark study in early 2004 and the study is expected to be completed at the end of year 2004.
- With the aim to attract more benchmark study participants and to resolve to the extent feasible several open questions identified in the study, this work will update the state of the art in the field.
- The study activities and results can be found on the ITTC damage stability benchmark website:

www.naval.ntua.gr/~sdl/ITTC/ittc.htm

24^{th} ITTC Benchmark Study Participants

Institute	Acronym	Country
National Technical University of Athens, Ship Design Laboratory	NTUA-SDL	Greece
Ship Stability Research Center, Universities of Glasgow and Strathclyde	SSRC	United Kingdom
Marine Research Institute	MARIN	The Netherlands
Instituto Superior Tecnico, Lisbon	IST	Portugal
Korea Research Institute of Ships and Ocean Engineering	KRISO	Korea

The problem

The prediction of extreme motions of the damaged ship in high waves

- The main contributing factors to this problem are:
  - Mass inertia and hydrodynamic mass effects
  - Restoring effects
  - Potential and viscous damping
  - Wave induced forces
  - The flooding process
  - The floodwater effects on the ship motions

- The various benchmark methods are characterized by the specific modeling applied to the basic components of the problem

Numerical Methods

Numerical Method	**P1**	**P2**	**P3**	**P4**	**P5**
Ship motion degrees of freedom	6	6	4	6	6
hydrostatic forces by direct integration	x	x	x	x	x
strip theory		x	x	x	x
3D panel method	x				
incident wave forces by direct integration	x	x	x	x	x
Memory effects	x	x	x	x	x
semi-empirical roll viscous	x	x	x		x
roll viscous analysis in components				x	
floodwater with horizontal free surface			x	x	x
floodwater with moving free surface	x	x			
Internal motion by shallow water equations			x		
flooding by simple hydraulic model	x	x	x	x	x

Benchmark Study Setup

- Objectives:
  - To provide a thorough insight into the fundamental properties of the benchmark numerical methods
  - To assess the performance of each numerical method with respect to the available experimental data and the other methods
  - To assess the overall efficiency of the investigated methods

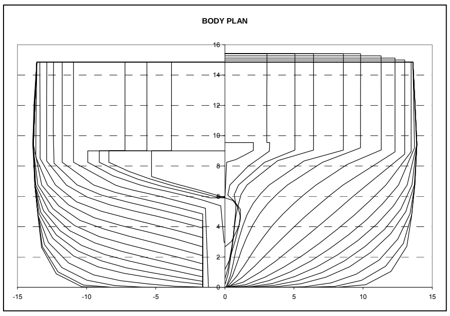
- Method:

  The numerical methods are assessed by a series of tests of various complexity. The tests are selected in such a way to enable to the extent feasible the isolation of the basic component of the problem. The sensitivity of the numerical methods as well as their absolute efficiency are assessed.

Benchmark Study Setup

PHASE A Testing in Calm Water (free roll decay)						**PHASE B** Testing in Waves
A	PRR01	intact	A1	KG = 12.200 m	The flooding process and floodwater effects are canceled. The change in restoring is considered.	(planned for the 25th ITTC Committee)
			A2	KG = 13.456 m		
B	PRR01	damaged	B1	KG = 12.200 m	The flooding process and floodwater effects are present. The change in restoring is considered. Test B with respect to Test A provides a change to hull integrity	
			B2	KG = 13.456 m		
C	TNK	partially filled	C1	d = 0.00 m	The flooding process is canceled. The change in floodwater is considered.	
			C2	d = 1.00 m		
			C3	d = 4.00 m		
			C4	d = 16.00 m		
D	PRR02	transient flooding	D1	1-frame cross duct area	The flooding process is dominant. The progressive flooding is considered.	
			D2	2-frame cross duct area		
			D3	3-frame cross duct area		

Passenger/Ro-Ro Ferry (PRR01)

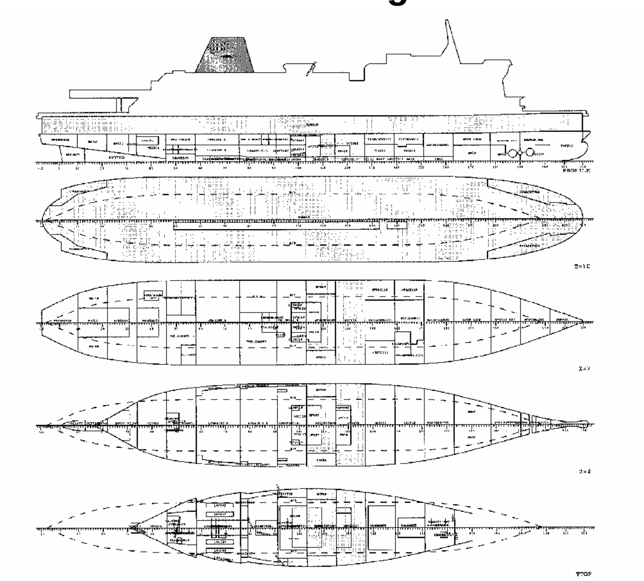


Main Particulars

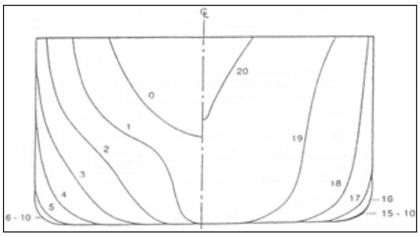
Length Lpp (m)	170.00
Beam, B (m)	27.80
Draft, T (m)	6.25
Displacement (tons)	17269
Car deck (m)	9.00
Model scale	1:40

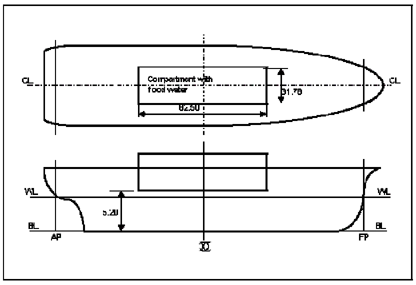
- PRR01 model also investigated in the previous ITTC benchmark study in 2001
- Experimental Data: NEREUS E.C. project, (2000). First Principles Design for Damage Resistance against Capsize. DG XII-BRITE, 2000-2003, data provided by DMI, April 2004.

PRR01: Damage Case



Tanker (TNK)



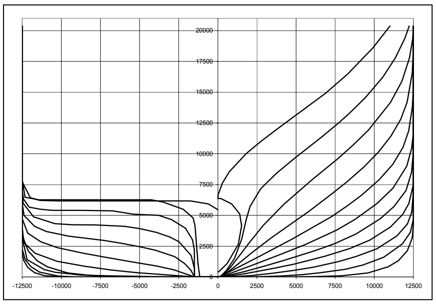


Main Particulars

Length Lpp (m)	310.20
Beam, B (m)	47.20
Draft, T (m)	16.00
Displacement (tons)	202600
Depth, D (m)	26.07
Model scale	1:82.5
Length of compartment, Lc (m)	82.50
Width of compartment, Bc (m)	31.76
Compartment's height above baseline	5.20

- Experimental data: “De Kat J., (2000). Dynamics of a Ship with Partially Flooded Compartment. Contemporary Ideas on Ship Stability, Elsevier, pp 249-263.”

Passenger/Ro-Ro Ferry (PRR02)

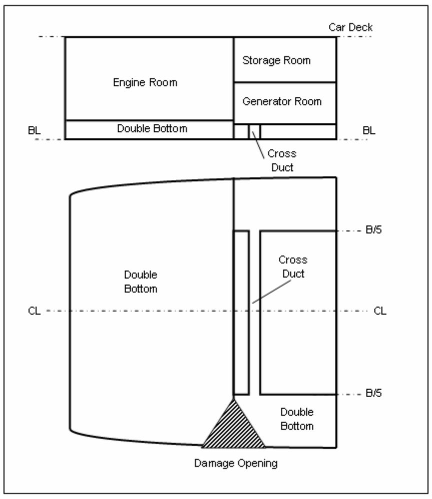


Main Particulars

Length Lpp (m)	174.800
Beam, B (m)	25.000
Draft, T (m)	6.40
Car deck (m)	9.10
Center of gravity above baseline, KG (m)	12.300
Model scale	1:38.25

- Experimental Data: HARDER E.C. project, (2000). “Harmonization of Rules and Design Rational”. DG XII-BRITE, 2000-2003. Data provided by MARIN, July 2004.

PRR02: Damage Case



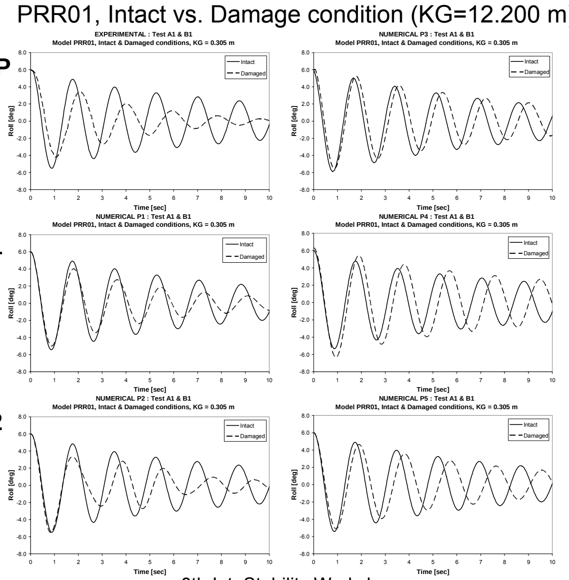
Test A1 vs. B1 : Roll Results

PRR01, Intact vs. Damage condition (KG=12.200 m)

EXP P3

P1 P4

P2 P5



Solid: Intact

Dashed: Damage

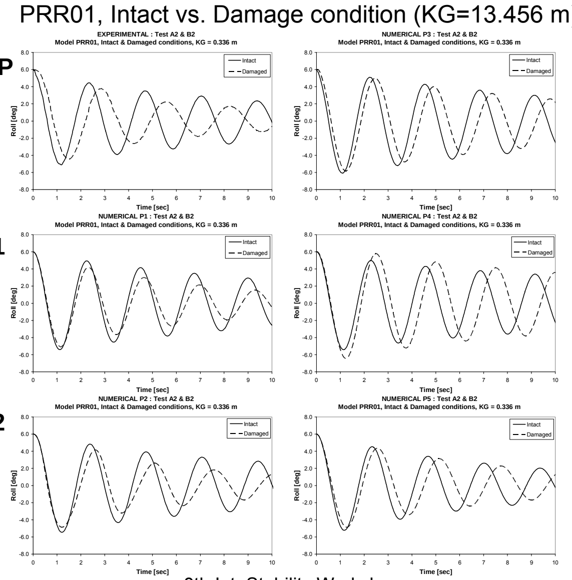
Test A2 vs. B2 : Roll Results

PRR01, Intact vs. Damage condition (KG=13.456 m)

EXP P3

P1 P4

P2 P5



Solid: Intact

Dashed: Damage

8th Int. Stability Workshop,
Istanbul, October 6-7, 2005

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Test A & B : Roll Time Series

A1
intact

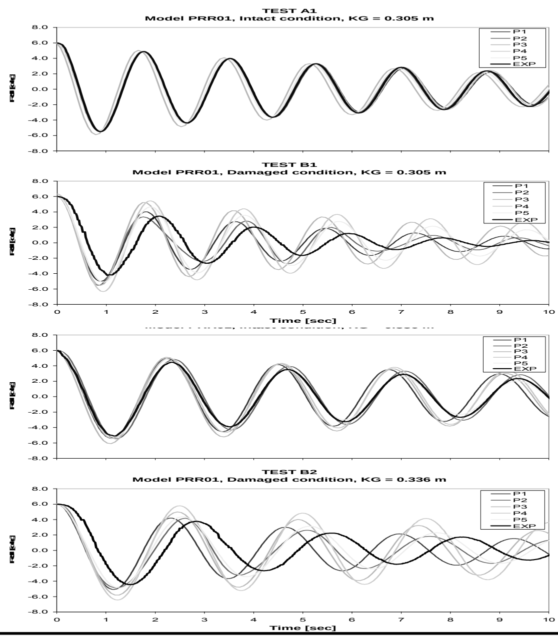
B1
damage

KG=12.200

A2
intact

B2
damage

KG=13.456



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Measured - Assessed Quantities

- Natural period

The converging value of mean roll period

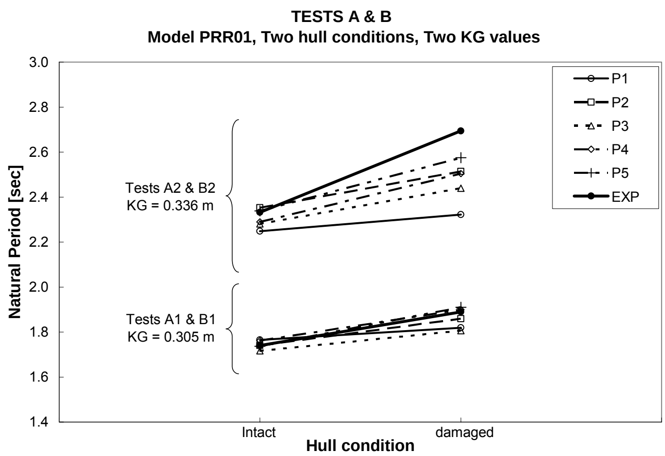
Depends (mainly) on the modeling of inertia (mass and hydrodynamic) and restoring factors

- Decay

Logarithmic decrement : $log(A_o / A_i)$ where *Ai* is the i-th roll amplitude and *Ao* the initial

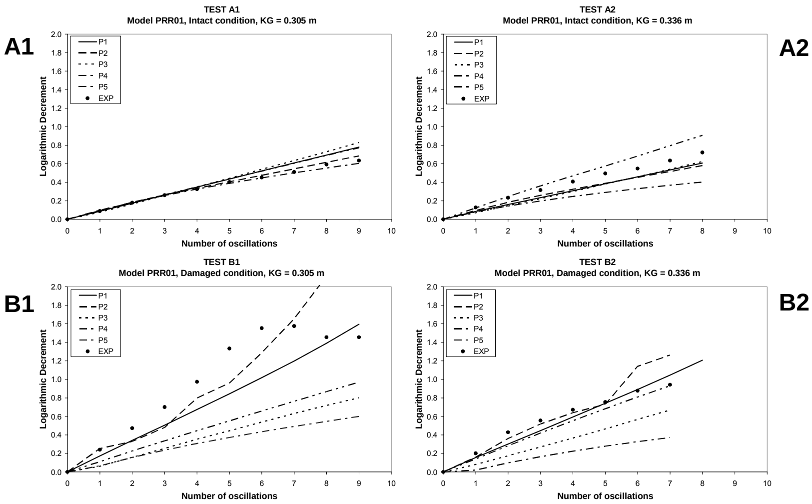
Depends on the modeling of the energy dissipation (damping)

Test A & B : Natural Periods



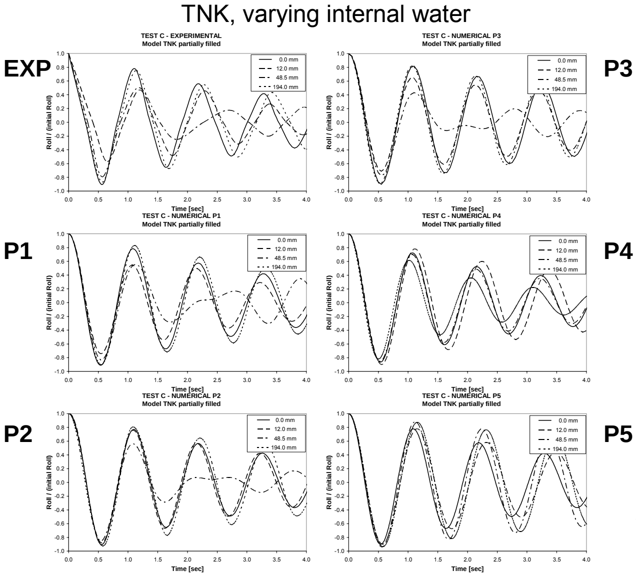
Test A & B : Roll Results

Logarithmic Decrement



Test C : Roll Results

TNK, varying internal water



Solid: Intact

Dashed: Damage

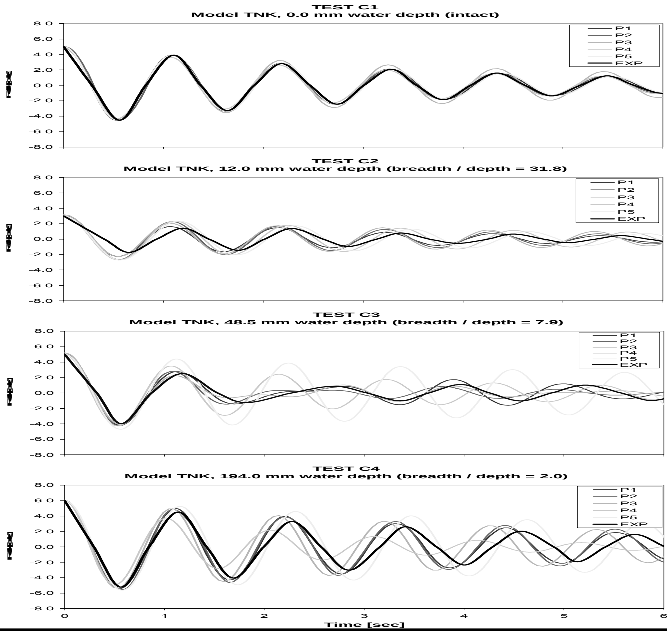
Test C : Roll Time Series

C1
0.0 m

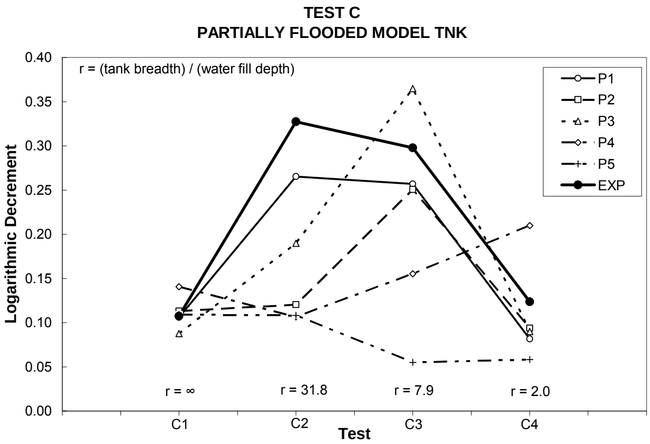
C2
1.0 m

C3
4.0 m

C4
16.0 m

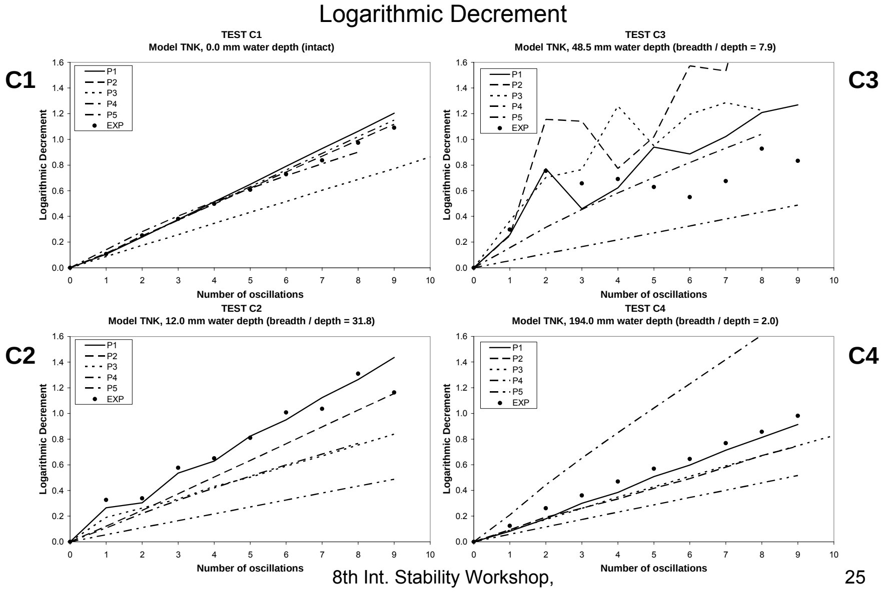


Test C : Natural Periods



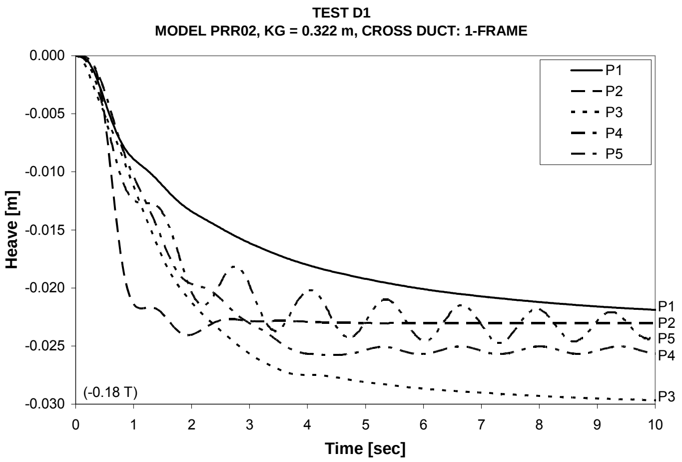
Test C : Roll Results

Logarithmic Decrement



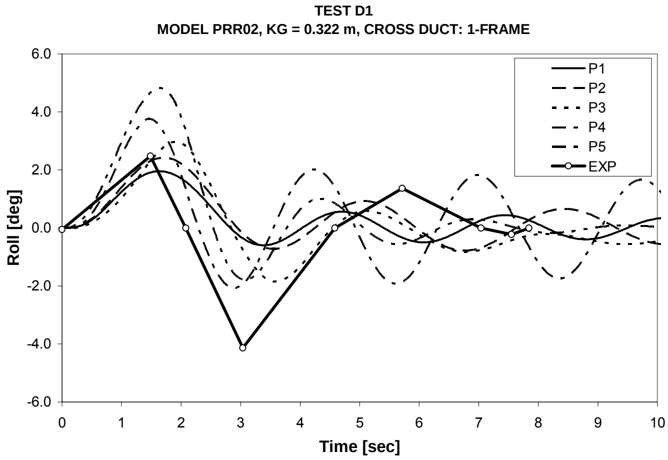
Test D1 : Heave motion

PRR02, cross-duct area 1-frame



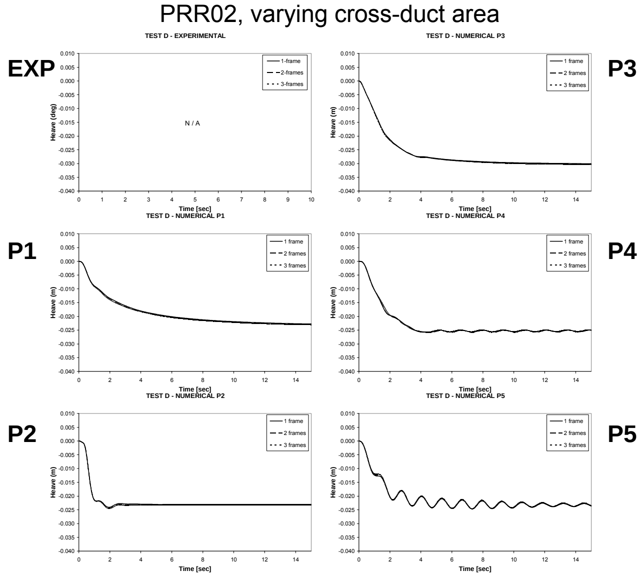
Test D1 : Roll motion

PRR02, cross-duct area 1-frame



Test D : Heave Results

PRR02, varying cross-duct area

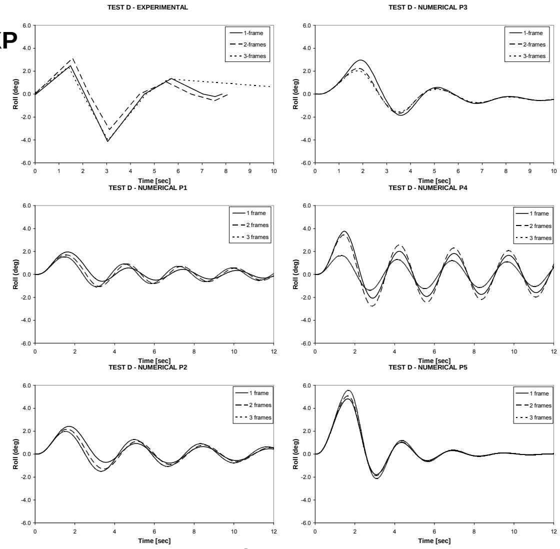


Test D : Roll Results

PRR02, varying cross-duct area

EXP

P3



P1

P4

P2

P5

Test D : Roll Time Series

D1

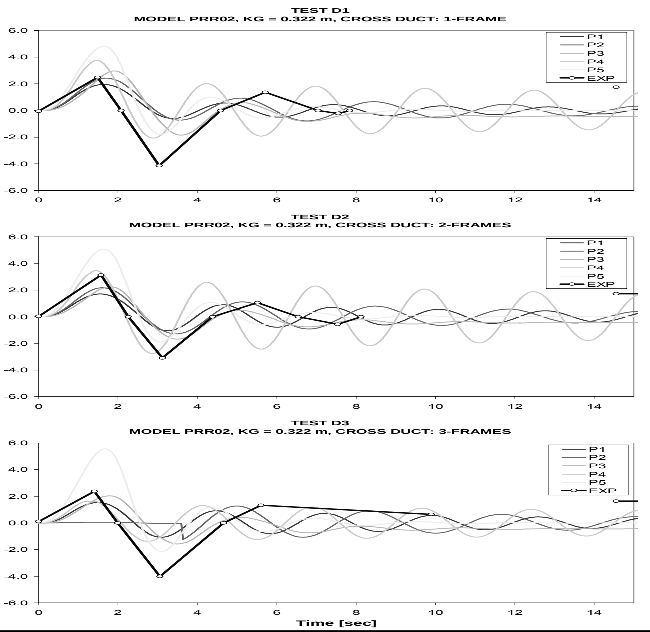
1 frame

D2

2 frames

D3

3 frames



Final Conclusions (1)

- The reviewed results of the first phase of the 24th ITTC damage stability benchmark study provide a thorough insight to the fundamental properties of the benchmark numerical methods for the simulation of motions of damaged ships in waves.
- The sensitivity of the reviewed methods with respect to the changes of the basic parameters of the problem has been demonstrated. By testing the methods in calm water conditions, the assessment of each method as well as the overall performance without the noise introduced by the waves and particularly the irregular waves was enabled.
- The efficiency of the reviewed methods regarding the specific modeling of the inertia and restoring forces has been found to be satisfactory.
  - The scatter of numerical results for the roll natural period when the KG value is changed indicates the necessity for further investigation on the modeling of this change and subsequent impacts on the natural period. Special attention should be given in the evaluation and sensitivity of the roll radius of gyration both as to the inertia and associated hydrodynamic terms.

Final Conclusions (2)

- The estimation of the viscous roll damping by semi-empirical coefficients, assuming satisfactory relevant experimental data in hand, seems to be well addressed. However, all methods seem to be highly dependent on these data and lack of them might lead to serious differences (both for the intact and particularly the damage condition)
  - A benchmark test that will not provide any information on the roll damping of the ship should demonstrate the actual status of the methods in the prediction of the roll damping effects, that appears at this moment non satisfactory.
- Observed deviations between the benchmark numerical methods are found to be mainly due to the different approaches to the effects of floodwater on ship motions. It was found that numerical methods that consider the floodwater having its free surface continuously horizontal could not capture the floodwater dynamics properly, in contrast to those considering the free surface moving and which demonstrated a satisfactory sensitivity with respect to floodwater effects
  - The significance of the floodwater dynamics on ship motions should be assessed.
- The results of the transient flooding tests showed that employed semi-empirical coefficients greatly affect simulated results
  - Special focus should be given on the semi-empirical weir coefficient as well as the interpretation of the flooding model, as to their impact on the critical stability conditions.
- This benchmark study will be completed with the conduct of its second phase, planned within the 25th ITTC activities, enabling the assessment of the methods in the complicated environment of sea waves.

... end of presentation