DANGEROUS PHENOMENA IN ADVERSE WEATHER AND SEA CONDITIONS: When Stability Criteria Need to be Supplemented by Recommendations to the Master

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Summary

The weather routing is not only a problem of comfort and energy saving. It is also (principally?) a problem of safety.

The state of the art in the development of IMO instruments for ship stability and their foreseeable future.

Res. A.167(ES.IV)
1968

Res. A.562(14)
1985

Other IMO
instruments

Different types
of ships

GZ properties for pass. & cargo ships + crowding&heel in turning for pass. ships

Weather
Criterion

Code creation by collation
(1988-1993)

Res. A.749(18)
1993 (later amended in 1998 by MSC.75(69))

Recommendation

This was the situation until 2001…

WARNINGS IN A.749 (1995)

"Throughout the development of the Code it was recognized that, in view of a wide variety of types, sizes of ships and their operating and environmental conditions, problems of safety against accidents related to stability have generally not yet been solved...

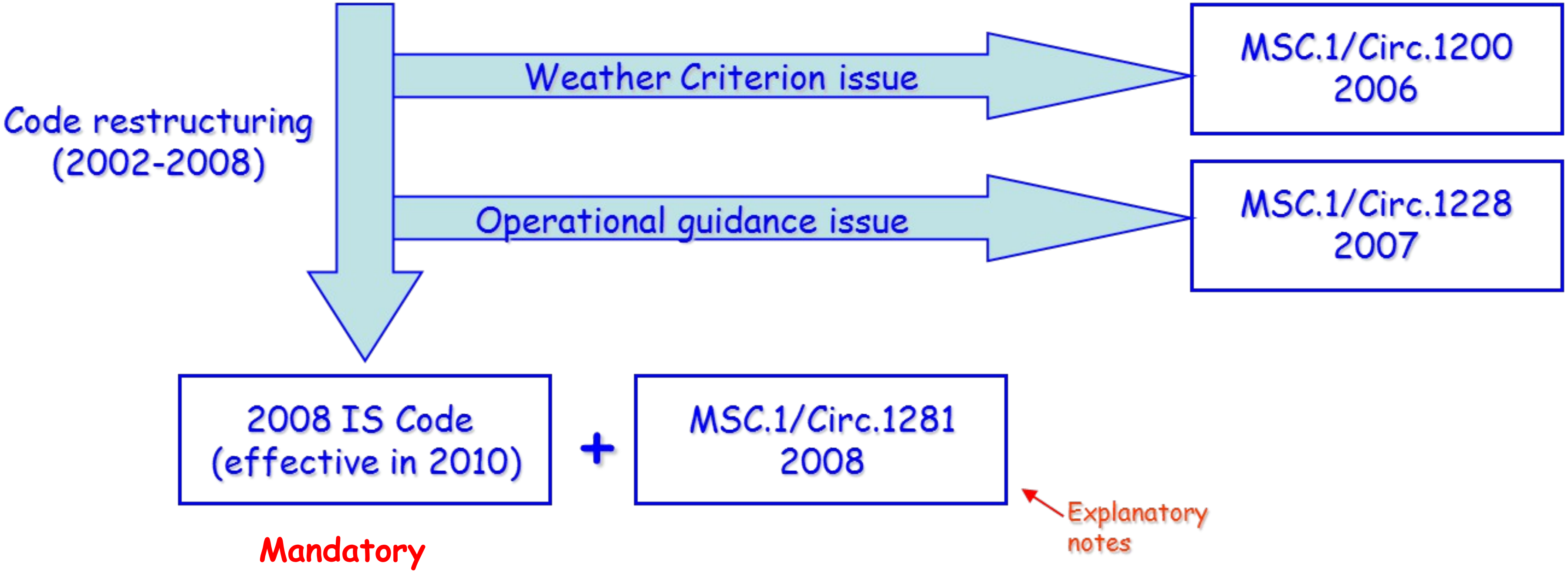
… It is recognized that development of stability criteria, based on hydrodynamic aspects and stability analysis of a ship in a seaway, poses, at present, complex problems which require further research."

MSC Circular 707

Following this indication, IMO developed the required "Guidance to the master for avoiding dangerous situations in following and quartering seas" as MSC/Circ.707 in 1995.

This Guidance was developed as ship-independent and of a qualitative type. It contained indications intended to avoid dangerous phenomena in following and quartering waves, i.e.: surf-riding & broaching, reduction of stability on the wave crest, synchronous rolling, parametric rolling, successive high wave attack.

Later on…


Code restructuring
(2002-2008)
Weather Criterion issue
MSC.1/Circ.1200
2006
Operational guidance issue
MSC.1/Circ.1228
2007
2008 IS Code
(effective in 2010)
+
MSC.1/Circ.1281
2008
Mandatory
Explanatory
notes

MSC.1/Circ.1228

The casualty to APL China in October 1998 evidenced that parametric rolling can happen with catastrophic amplitudes in head sea conditions too. This made necessary a revision of MSC/Circ.707 to accommodate the phenomenon not only in following sea, but also in head waves.

The circular was revised in 2007 producing the new MSC.1/Circ.1228.

In view of the short time available, MSC.1/Circ.1228 was again a ship-independent instrument, leaving however the task of developing ship-dependent guidelines for the (close) future.

THE 2nd GENERATION INTACT STABILITY CRITERIA

After completing the revision of the Intact Stability Code, attention was devoted to the dangerous phenomena not explicitly or not properly covered by the 2008 IS Code. A series of failure modes were firstly identified:

a) - pure loss of stability in longitudinal waves;

b) - parametric resonance in head and/or following seas;

c) - dead ship condition;

d) - manoeuvring related problems. In particular broaching and its typical precursor, i.e. surf-riding;

e) - large accelerations and loads on cargo, and persons on board;

THE 2nd GENERATION INTACT STABILITY CRITERIA

With the aim of producing specific stability criteria for each of the mentioned failure modes the "Second Generation Intact Stability Criteria" were envisioned, as a multi-tiered structure based on different levels of assessment:

- Level 1 Vulnerability Assessment;
- Level 2 Vulnerability Assessment;
- Direct Stability Assessment.

THE 2nd GENERATION INTACT STABILITY CRITERIA

The idea is that for each failure mode, at least one level of assessment should be passed to claim that the ship, in the considered loading condition, can be regarded as "safe".

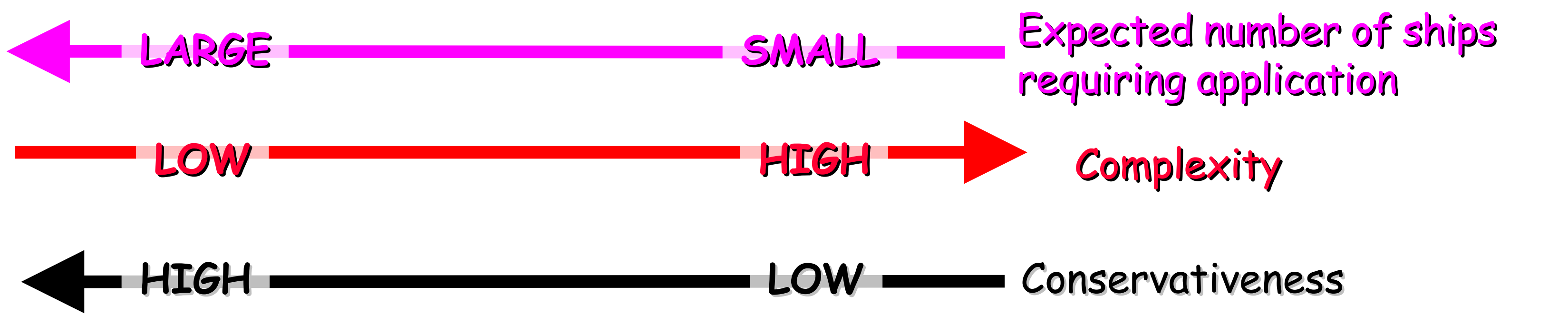
As an equivalent alternative, appropriate ship-specific operational guidance should be developed, to the satisfaction of the Administration.

Vulnerability criteria

Stability failure mode	Level 1	Level 2	Direct stability assessment	Operational guidance
Pure loss of stability				
Parametric roll				
Surf-riding/ Broaching				
Dead ship condition				
Excessive accelerations				

Majority of work and discussion so far

Presently gaining more attention (particularly, for the moment, DSA)



WEAK POINTS…

Particular concerns were raised by the fact that, when dynamical criteria are introduced together with statical stability criteria, the usual concept of "minimum stability" is partially lost.

Indeed, the introduction of criteria based on ship dynamics can introduce limitations on loading conditions also in terms of maximum GM.

Even the possibility of ending up with "intervals of acceptable stability" cannot be ruled out. Presently, maximum GM indications are typically associated with guidelines in the Cargo Securing Manual…

THE NEW SCENARIO

Although still in a quite simplified way, the complexity of the ship dynamics at sea, calls for a comprehensive approach based on:

1. Criteria, to be applied at the design stage;

AND

2. Ship-Specific Operational Guidance (Limitations?), to be applied in operation.

DESIGN VERSUS OPERATIONAL LIMITATIONS

It is recognised that for some types of ships and/or for certain loading conditions it is not possible to completely avoid some dangerous phenomena only at design stage, unless the ship design is modified to an unacceptable extent.

In such cases it is expected that risk can be controlled by a judicious combination of design countermeasures and ship-specific operational guidance/limitations.

In the SGISC framework "direct stability assessment" and "issuing of ship-specific operational guidance" are linked.

FUNDAMENTAL INGREDIENTS FOR EFFECTIVE SHIP-SPECIFIC OPERATIONAL GUIDANCE

-A simulation tool embedding a proper mathematical model able to address nonlinear ship motions and manoeuvring in wind and waves;

-A proper realistic representation of the environmental conditions (wind & waves)

Note: in some cases danger warnings could be issued on the basis of simplified tools tailored for specific failure modes (e.g. parametric roll, pure loss of stability).

POTENTIAL SUITABILITY OF DIFFERENT TYPES OF TOOLS FOR APPLICATION AT DIRECT ASSESSMENT / OPERATIONAL GUIDANCE LEVELS

	CFD	Hybrid (blended) codes	Simple models (e.g. n-DOF system based models)
Computational time	HIGH (typically very high)	MEDIUM	LOW
Accuracy	HIGH	SUFFICIENT	LOW/MEDIUM
Self adaptability to "unforeseen" phenomena	HIGH	SUFFICIENT	LOW (typically)
Overall appropriateness for DSA/OG	LOW (only for providing some parameters, e.g. roll damping)	**HIGH**	LOW/MEDIUM

Some accidents where ship-specific information to the master regarding nonlinear ship motions in waves could have made the difference:

APL China, 1998, Container

Parametric roll

Estimated overall loss: $100 million

Some accidents where ship-specific information to the master regarding nonlinear ship motions in waves could have made the difference:

Aratere, 2006, Ro-Pax

Large heel in following waves

Cargo shift & damage to cargo

Some accidents where ship-specific information to the master regarding nonlinear ship motions in waves could have made the difference:

CCNI GUAYAS, 2009, Container

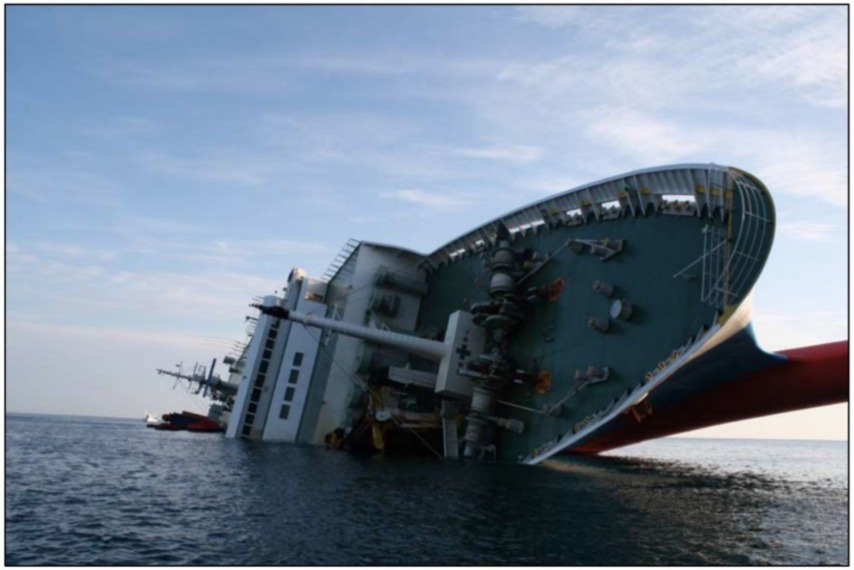
Large accelerations on bridge

Fatal accident

Some accidents where ship-specific information to the master regarding nonlinear ship motions in waves could have made the difference:

Ariake, 2009, Ro-Cargo

Large heel in following waves -> -> cargo shift -> permanent list



CONCLUSIONS

- Second Generation Intact stability Criteria: efforts are being spent at IMO level in order to try embedding ships dynamics in waves within intact stability regulations
- In certain cases, when risk control options at design level are not enough, risk can be controlled by issuing ship-specific operational guidance based on appropriate simulation tools
- For a proper risk assessment, particularly when this is done during ship in operation, a correct representation of the actual environment conditions (wind & waves) is fundamental

WEATHER Criterion
versus
WHETHER Criterion?

Level	Description	Complexity	Safety Margin	Objective
Direct stability assessment	These criteria should be based on the best "state-of-the-art" concepts available. The following is envisioned as minimum requirements to direct stability assessment methods to ensure physical robustness. Time-domain numerical simulation with "hybrid" method and probability theory, as appropriate, should be used for the failure mode considered. The "hybrid" method includes potential flow + empirical viscous models. Specifically, rigid body-nonlinear dynamics model with undisturbed wave pressure (Froude-Krylov assumption). Specified formulation for added mass/wave damping/diffraction, externally specified coefficients for viscous/hydrodynamic lift components of roll damping and manoeuvring, and propulsion force, external environmental actions should be included, as appropriate. Suitable guidelines and procedures (e.g., wave scatter diagram, ship operation conditions, etc.) should be clearly stated. Assessment is expected to be made using a probabilistic measure to evaluate safety level.	High	Lower standards can be applied	To evaluate safety level and prepare information for the development of ship-specific operational guidance
Operational Guidance	Ship-specific operational guidance, if applicable, should be based on the output of the direct stability assessment procedure and on the analysis of stability failures.	N/A	N/A	To assist with safe operation of a vulnerable ship

Main characteristics of the simulation tools which are expected to be used for DSA/OG (*SLF52/WP.1 – Annex 2, 2010*)

SHIXDOF ("nonlinear SHIp motion simulation program with siX Degrees Of Freedom")

$$
\begin{cases}
m \cdot \left[\dot{\mathbf{u}}_{O} + \boldsymbol{\omega} \times \mathbf{u}_{O} + \dots \right] = \mathbf{f}_{ext} \left(\quad \right) \\
\mathbf{I}_{O} \dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times \mathbf{I}_{O} \boldsymbol{\omega} + \dots = \mathbf{m}_{O,ext} \left(\quad \right) \quad mmO \left(\quad \right) \left(\quad \right) \\
\frac{d}{dt} \left(\xi_{O}, \eta_{O}, \zeta_{O} \right)^{T} = \mathbf{R}_{S \to \Sigma} \left(\quad \right) \quad \frac{d}{dt} \left(\phi, \vartheta, \psi \right)^{T} = \mathbf{T}_{\omega_S}^{-1} \left(\quad \right) \boldsymbol{\omega} \left(\quad \right)
\end{cases}
$$

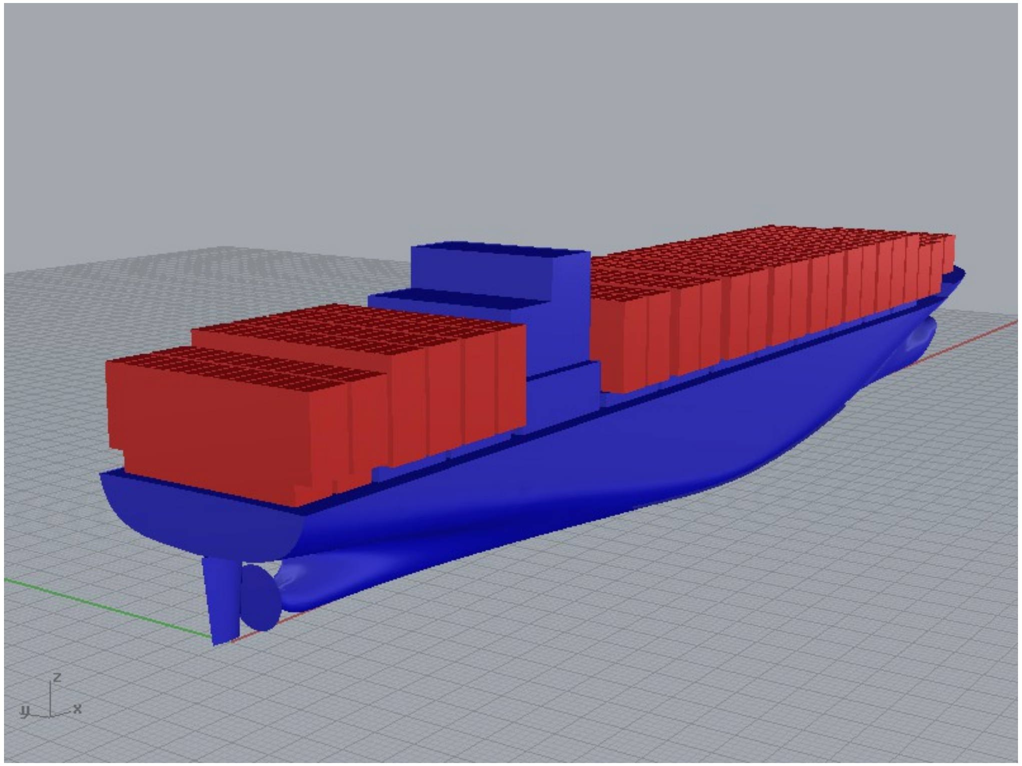
- 6-DOF time domain hybrid code;

-Exact nonlinear rigid body dynamics;

-Manoeuvring in wind and waves;

-In line with IMO SGISC requirements for tools to be employed at DSA/OG level.

Conceptual example case on the importance of correct spectral characterization: applying a directional perturbation to long-crested irregular head waves



Ship ID:	BreCONT (2700TEU)
LBP:	217 m
Breadth:	32.25 m
Depth:	18.8 m
Max draught:	12.2 m
Max speed:	22 knots

Loading condition:

Representative of full load

GM=2m ; T=12.2m ; Trim=0m

Speed in c.w.: 22knots

Simulations with constant RPM and proportional autopilot.

Note: vessel not very prone to PR in the considered loading condition.

Spreading-like effect - Procedure:

-Start from a specific realization of long crested irregular waves with N_h=100 harmonic components;

-Consider a set of standard deviations for the perturbation to the direction: $\sigma_{dir,i}$

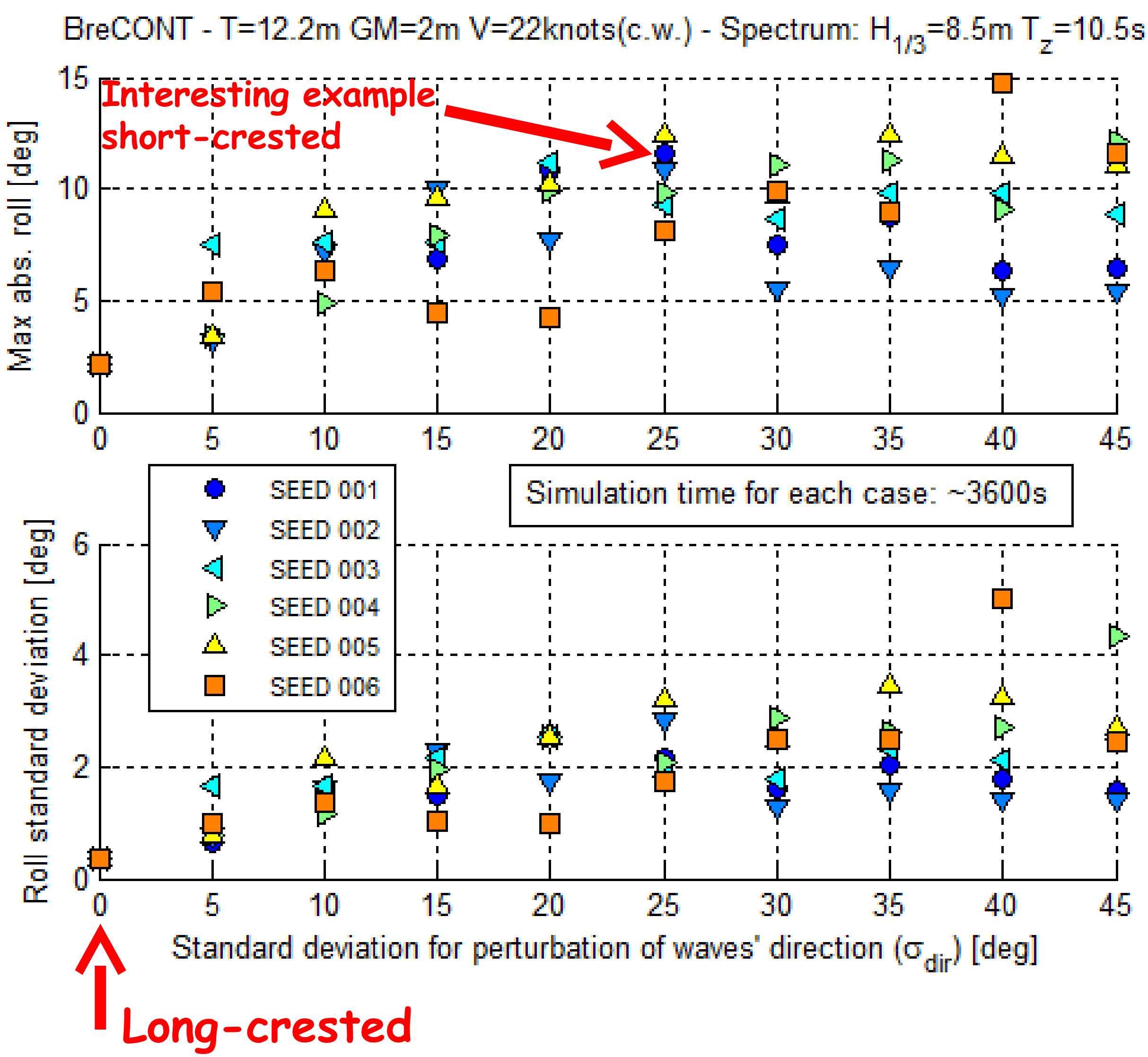
-Generate a series of N_{rnd}=6 (SEED 1 to 6) unitary gaussian N_h-dimensional vectors of perturbation for the direction of each harmonic component – distribution: N(0,1): $\delta_{1,dir,j} \in R^{Nh}$ $j=1,\ldots,N_{rnd}$

-For each standard deviation, simulate motions for each SEED using a perturbation on the direction equal to

$$\sigma_{dir,i,j} = \sigma_{dir,i} \cdot \delta_{1,dir,j}$$

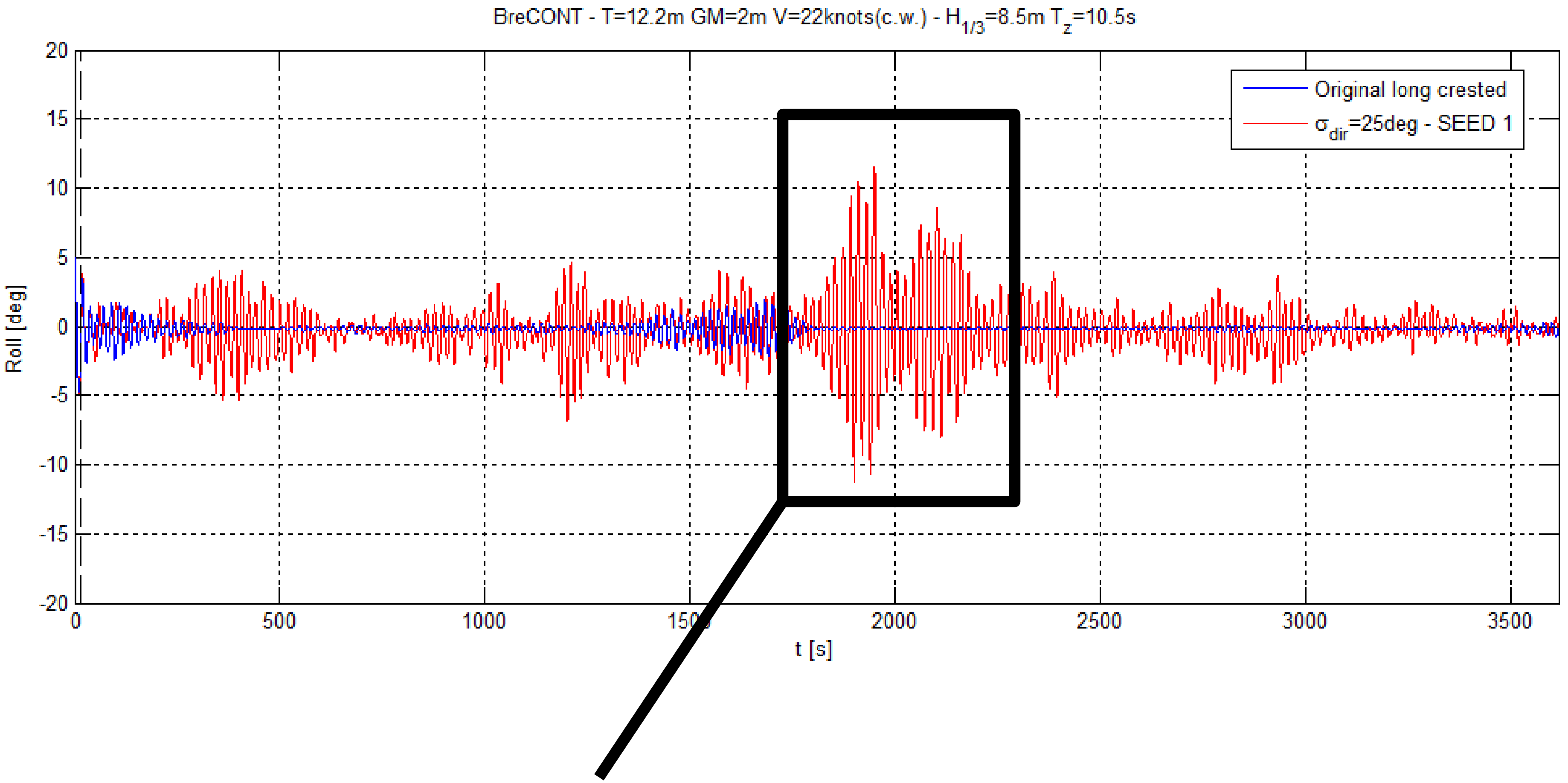
Scope: check the influence of sea directionality on ship motions (parametric roll) with a simple model with reduced random sampling uncertainty.

Results:



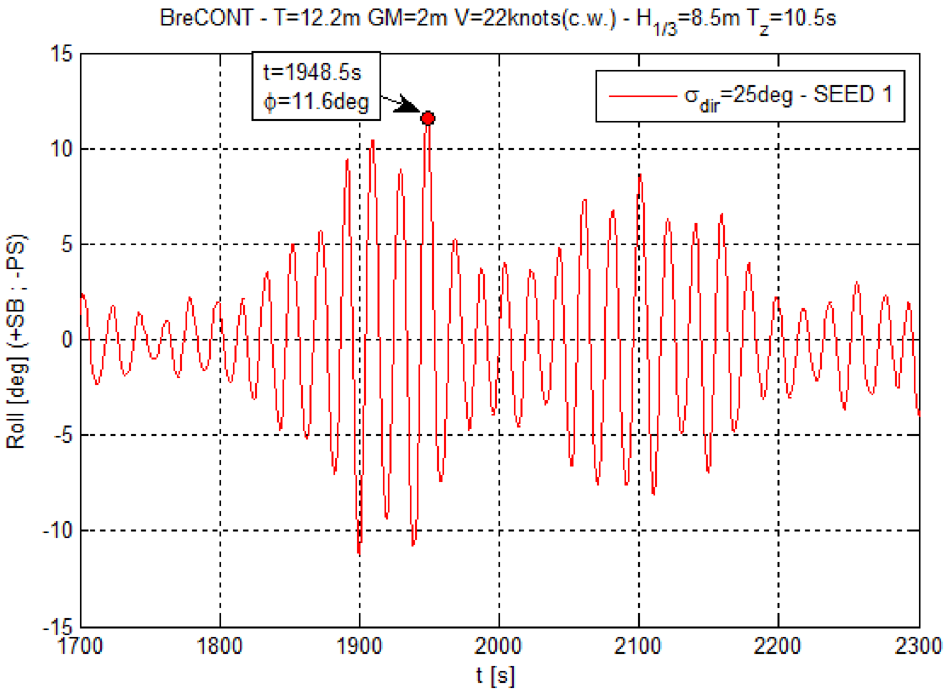
Introduction of **directional spreading** through perturbation of a long-crested sea train, **in the tested conditions**, tends to **promote the inception of larger roll events**.

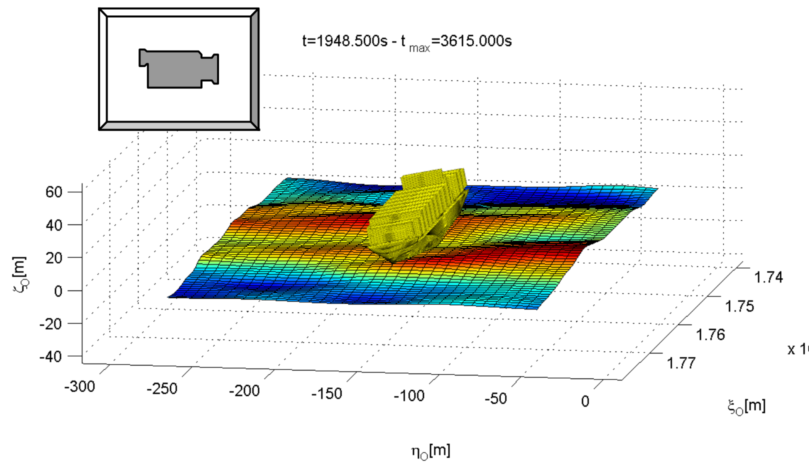
Results:

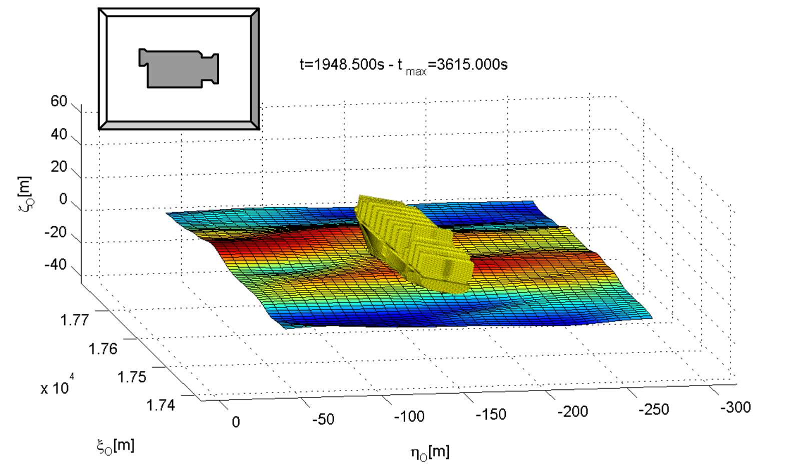


Most significant parametric roll event in this realization

Results:







Maximum roll for this realization:
11.6deg to starboard
at t=1948.5s

Acknowledgements:

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"*Direct intact stability assessment and operational guidance to the master in the framework of International Maritime Organization Second Generation Intact Stability Criteria: development of tools and procedures for safety assessment with particular attention to cargo securing* "

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