MINISTÈRE DES ARMÉES
Liberté
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DGA
DIRECTION GÉNÉRALE DE L'ARMEMENT
Techniques hydrodynamiques

Friday May the 16th - 2025

ATMA 2025

Probability of capsizing of naval ships

SGISC, application to naval ships

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Questions

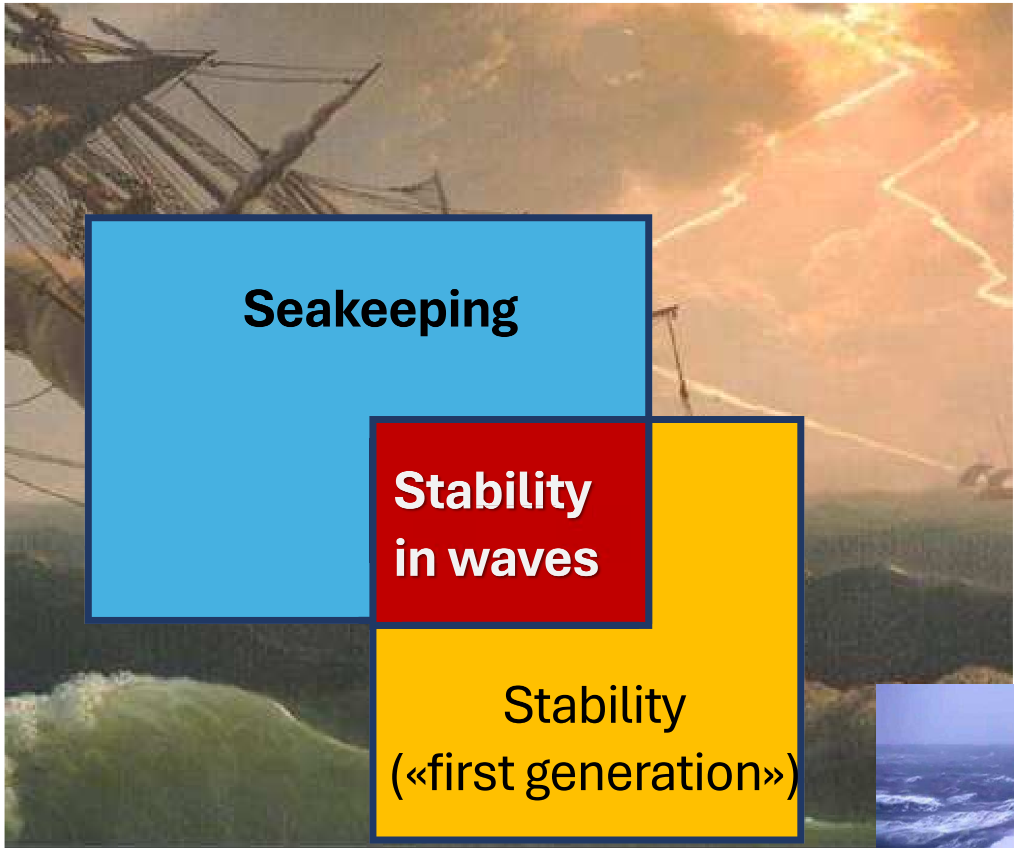
- ❑ **Why they are named «Second Generation»?**
- ❑ **Developed at IMO, which is the possible relation with naval ships? In which way their application in this context can be beneficial?**
- ❑ **Are naval ships complying with SGICS?**

The context


A Shipwreck in Stormy Seas
Claude-Joseph Vernet


OPERATIONAL PERFORMANCE
Seakeeping
Stability in waves
Stability («first generation»)
SAFETY

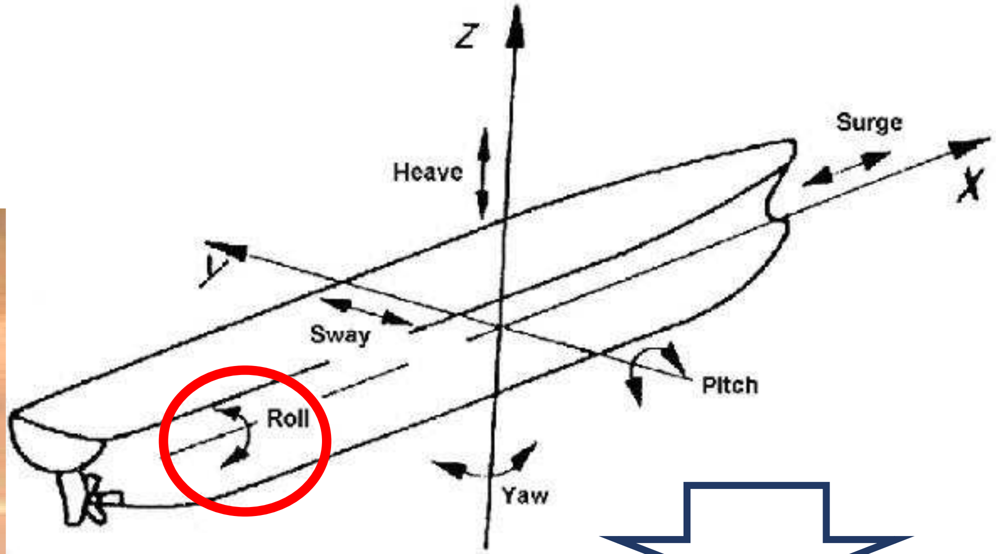
The context



Seakeeping

Stability in waves

Stability («first generation»)

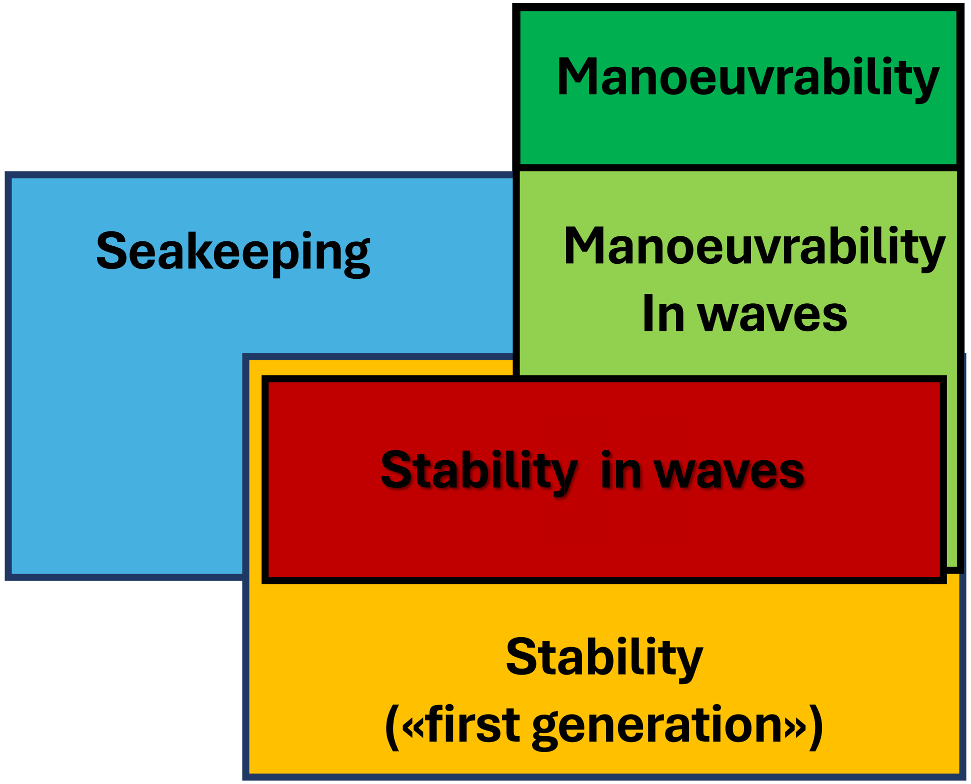


LARGE roll angles

and/or

EXCESSIVE accelerations

The context

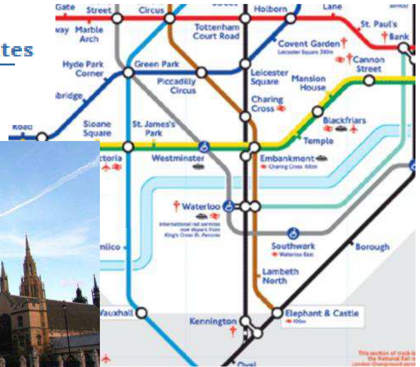

Manoeuvrability
Seakeeping
Manoeuvrability
In waves
Stability in waves
Stability
(«first generation»)

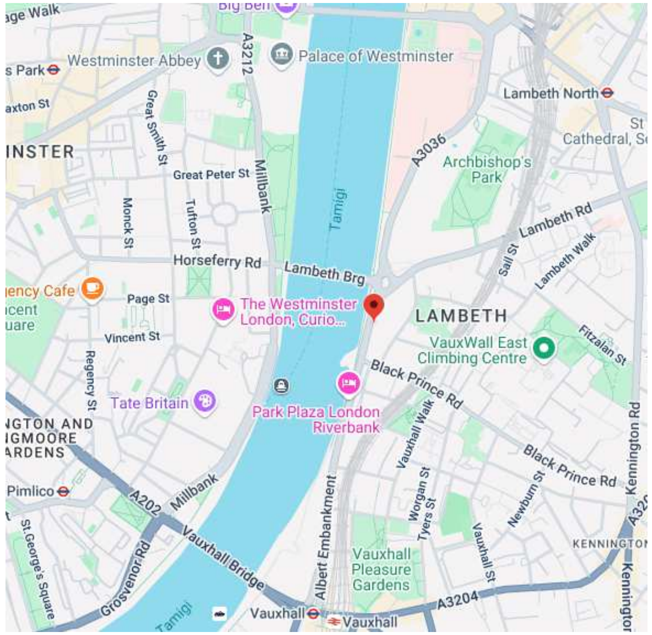
About IMO

https://www.imo.org/

IMO – the International Maritime Organization – is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. IMO's work supports the UN SDGs.

176 // Member States





INTERNATIONAL MARITIME ORGANIZATION

IMO

Why Second Generation Intact Stability criteria ?

Back to IS code 2008

" PREAMBLE

4. ***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. In particular,* ***the safety of a ship in a seaway involves complex hydrodynamic phenomena which up to now have not been fully investigated and understood.***

[…]

Based on hydrodynamic aspects and stability analysis of a ship in a seaway, **stability criteria development poses complex problems that require further research.** "

Credits: Resolution MSC.267(85) - Adoption of the international code on Intact Stability. IMO, 2008

SGISc - *Physically-based criteria*

...applicable to all ships in principle!

The criteria have been developed taking into account the actual physics beyond the addressed phenomenon.

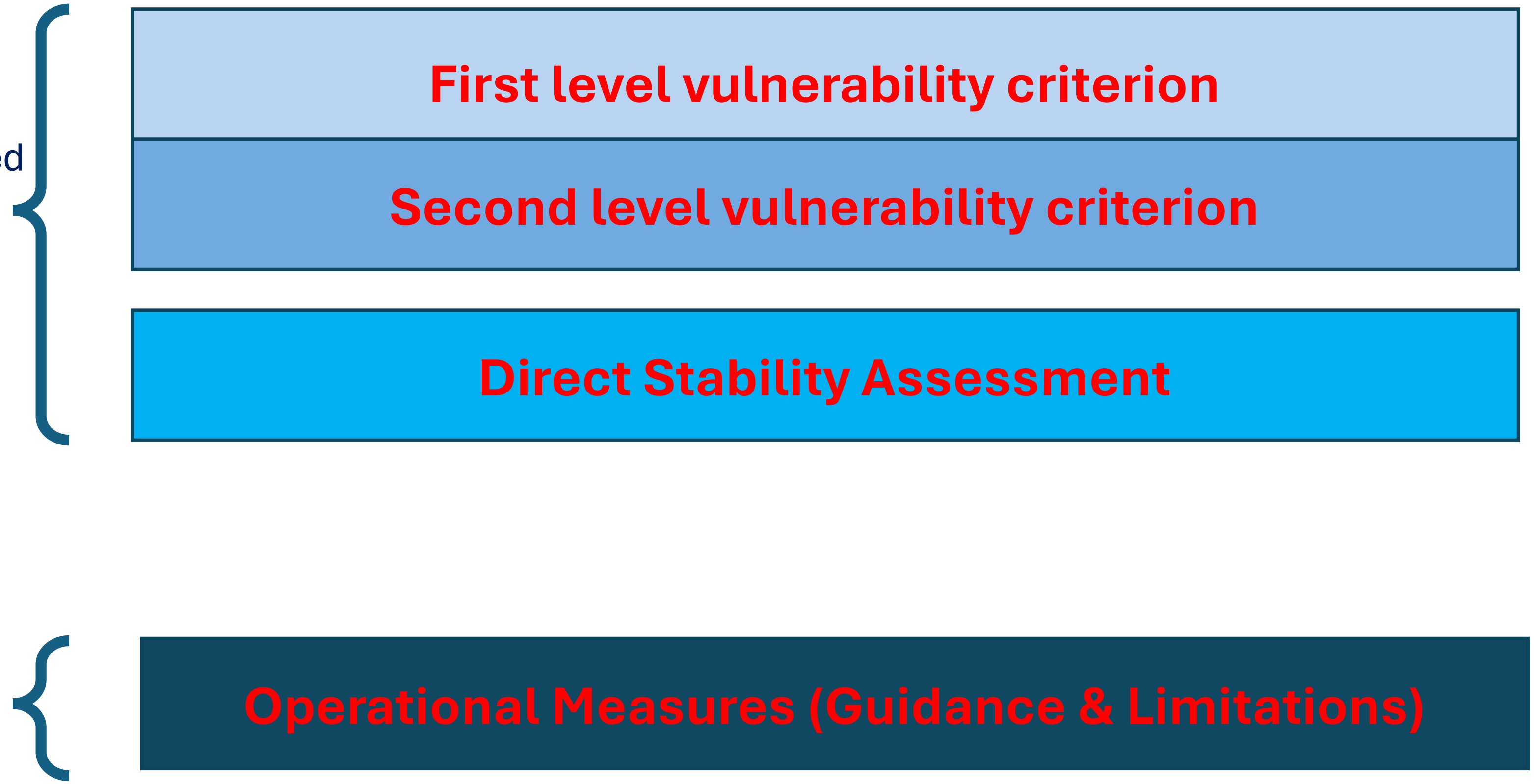
In principle, this means that Second Generation Intact Stability criteria are generally applicable to all vessels subject of IMO regulations.

SGISc - Multi-layered approach

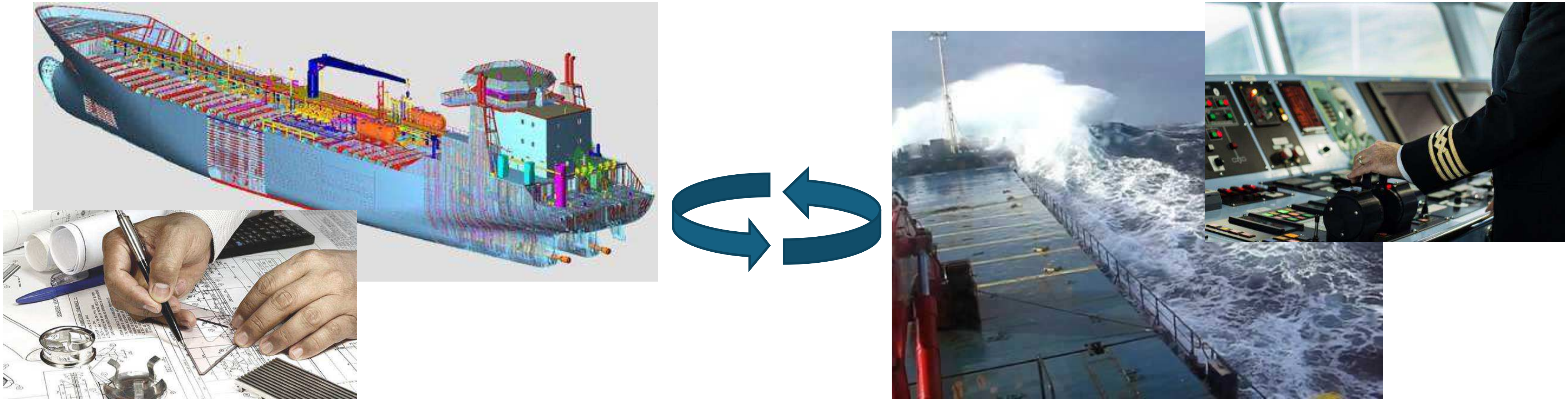
During the development process of the SGISc it has been introduced the so called «Multilayered approach».

The first three levels are called “Design Assessments”

Ship operational aspects are addressed by “Operational Measures”.



Design aspects VS Operational aspects



Second Generation Intact Stability criteria introduce a strong link between Design and Operational aspects in ship stability evaluation.

SGISc - Multi-layered approach

During the development process of the SGISc it has been introduced the so called «Multilayered approach».

The first three levels are called "Design Assessments"

First level vulnerability criterion

Second level vulnerability criterion

Direct Stability Assessment

Ship performance prediction

Design aspects VS Operational aspects

Ship operational aspects are addressed by "Operational Measures".

Operational Measures (Guidance & Limitations)

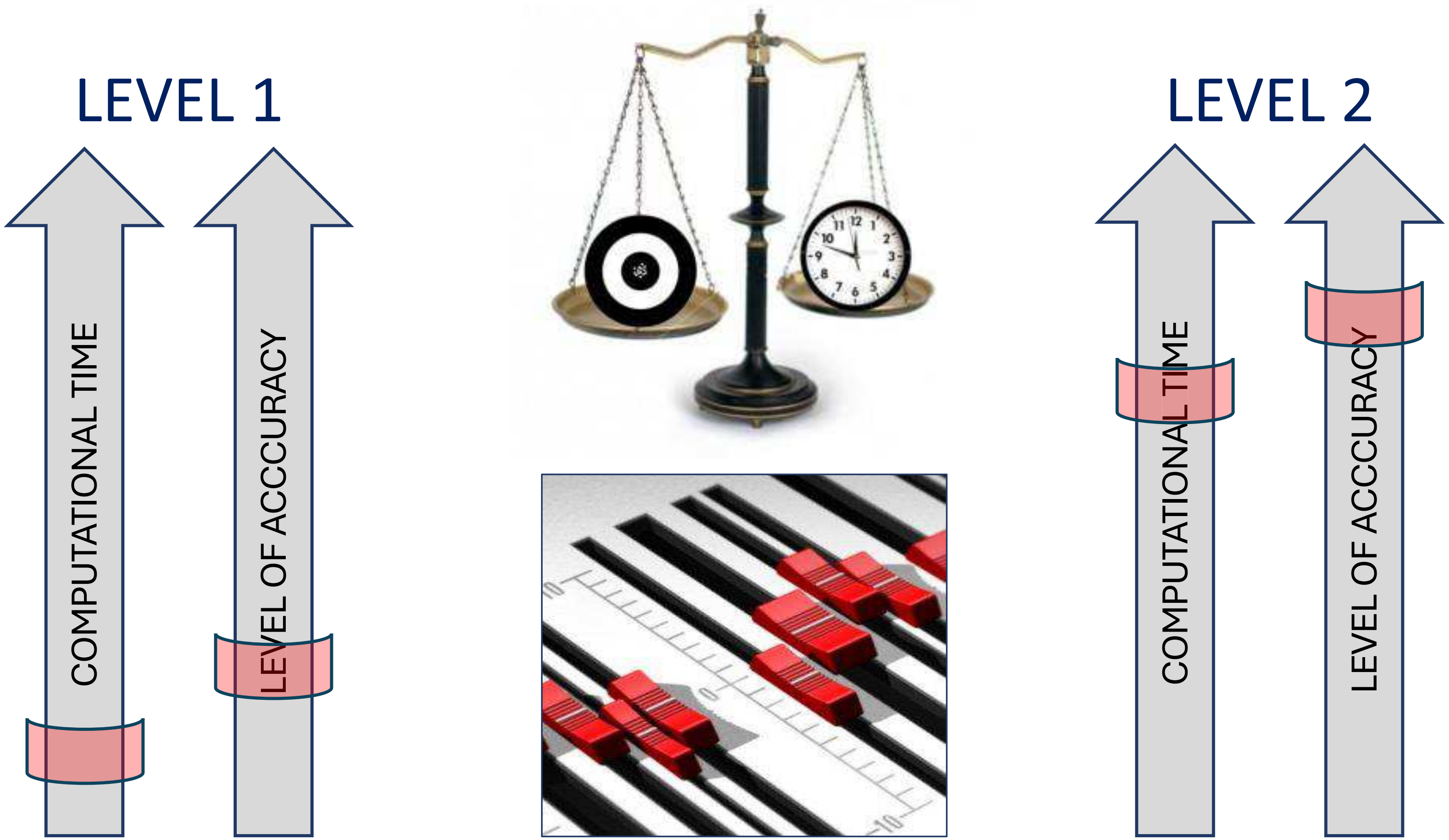
Ship performance prediction

Detailed ship motion prediction requires powerful tools which are highly time and cost consuming.

- ❑ Numerical Simulation code
- ❑ Towing tank reproducing irregular waves

*****The big challenge of Extreme roll prediction*****

SGISc - Relationship between levels



DESIGN ASSESSMENTS

- Vulnerability Level 1

- Very simple structure
- Based on simplifying assumption from 2nd level
- Very conservative results

- Vulnerability Level 2

- More information required and calculation effort
- Long term analysis considering many environmental condition
- More accurate results

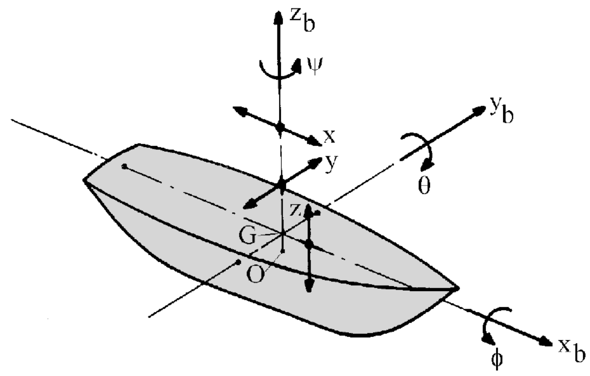
Direct Stability Assessment

- A non-linear time domain computational tool or model test are required
- At least 4 coupled DOF should be considered
- After many simulations, the estimated stability failure rate should be evaluated
- The most accurate but also the most time-consuming

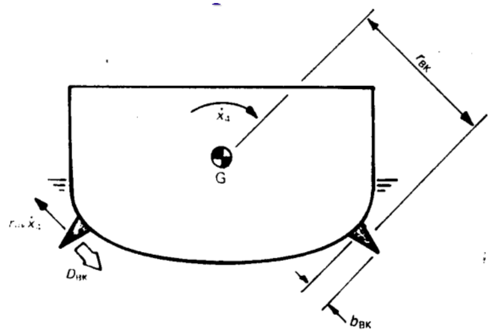
Extreme roll prediction

Prediction of roll motion at large heel angle is a hard challenge due to non-linearities problems:

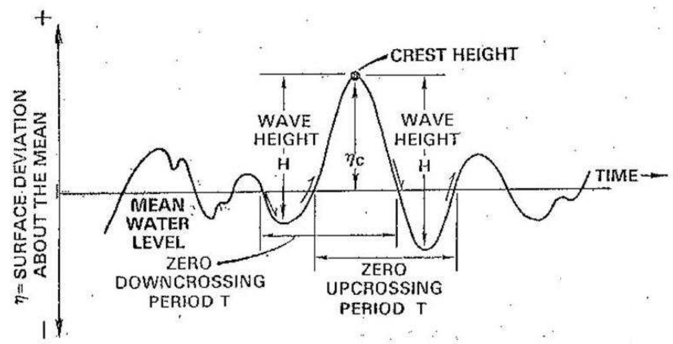
- ❑ Coupling terms among 6 degrees of freedom



- ❑ Damping effects



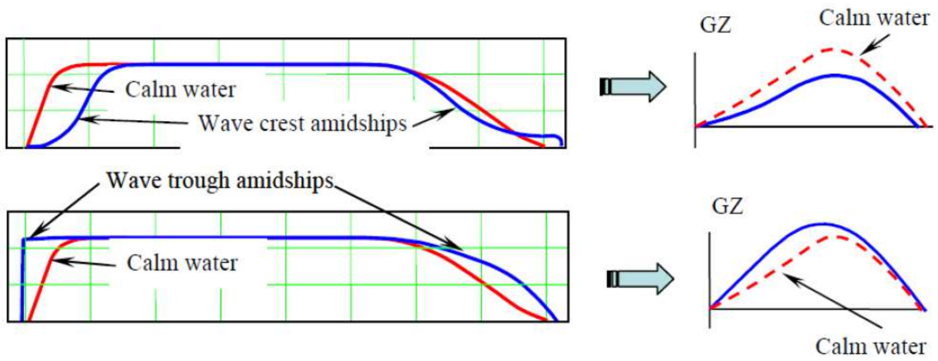
- ❑ Interaction between Ship and Environment (Wind and Wave)

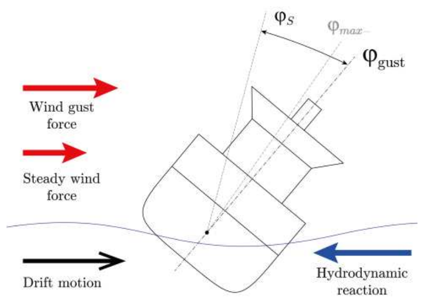


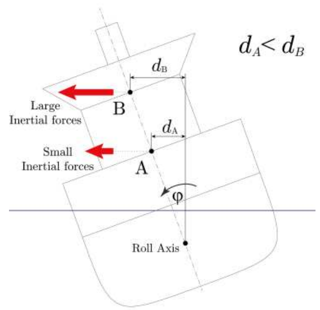
SECOND GENERATION INTACT STABILITY CRITERIA

ship stability in a seaway condition by five stability failure mode:

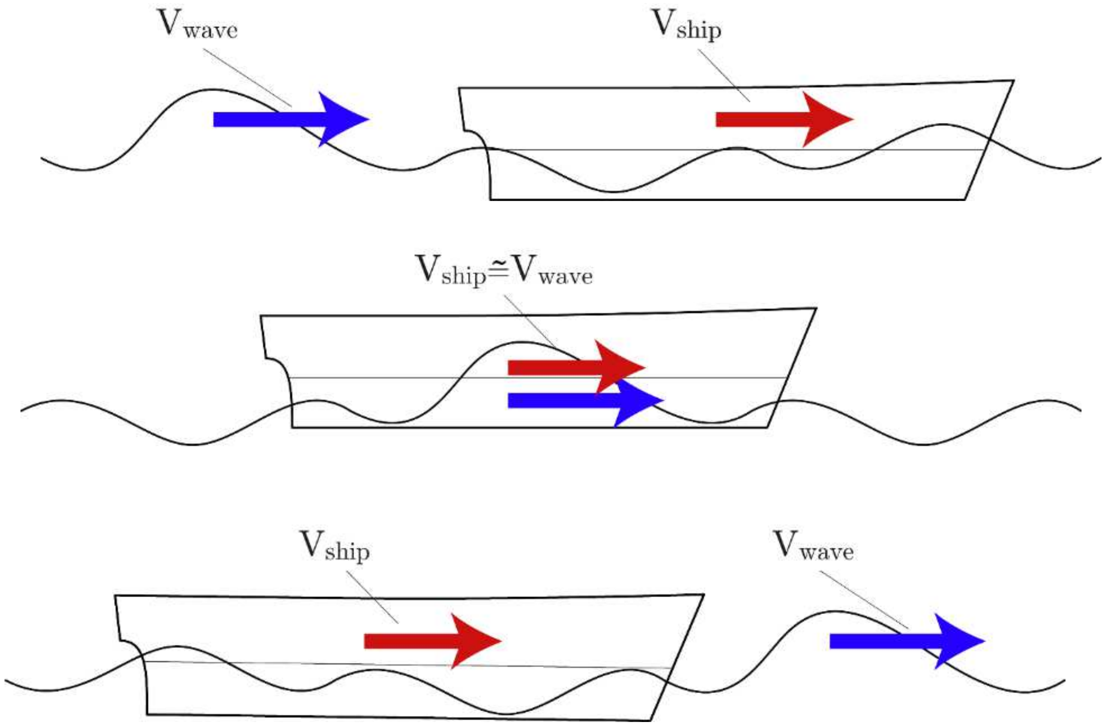
- Parametric Rolling
- Pure Loss of Stability
- Surf-Riding
- Dead ship condition
- Excessive Acceleration

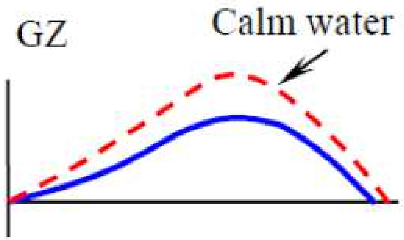






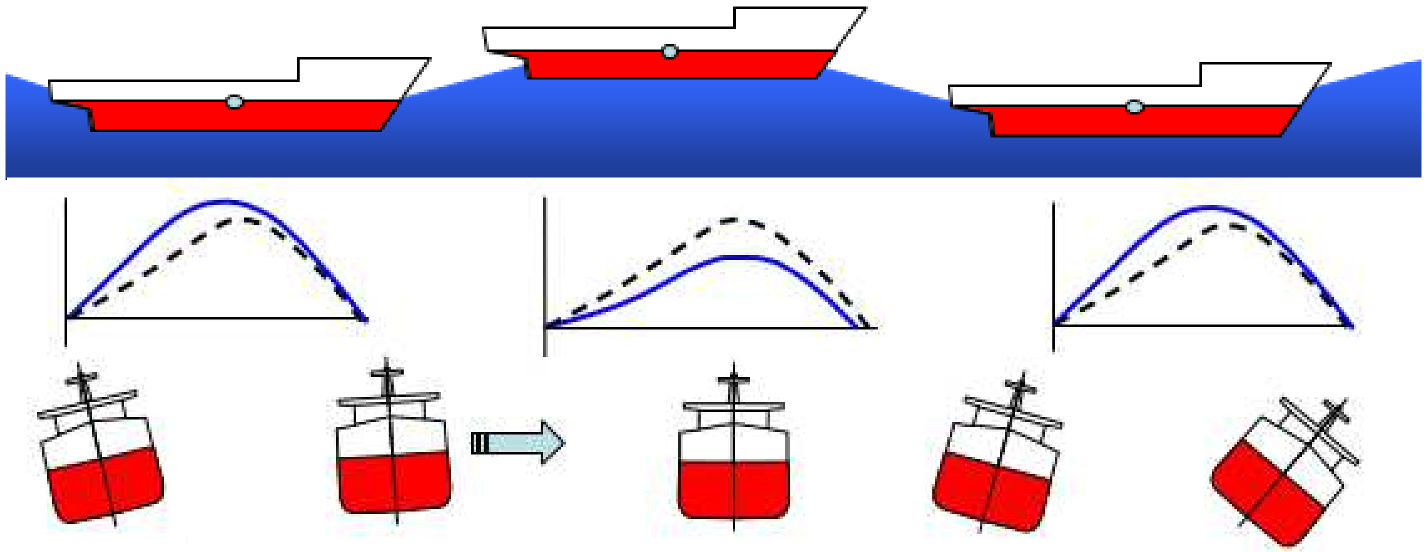
• PURE LOSS OF STABILITY





Righting arm curve is reduced for a long-time period

- PARAMETRIC ROLL

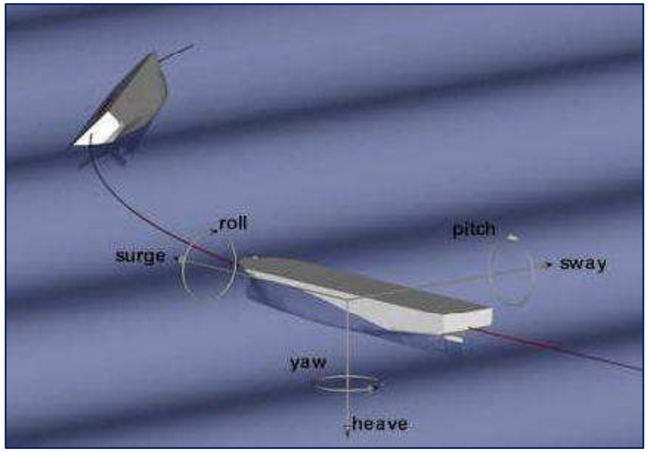


Credits: V. Belenky, et al. Development of second generation intact stability criteria. Hydromechanics Department Report, Carderock, USA, 2011

Ship length comparable to wave length and specific encounter period:

$$\mathbf{T_{nat} = 2 \cdot T_{enc}}$$

- BROACHING-TO / SURF-RIDING



Credits: http://www.phisicalpsience.com/public/Tumblehome_Hull_DDG-1000/Tumblehome_Hull_DDG-1000.html

Broaching is defined as a sudden and uncontrollable turn despite a steering effort to counteract it

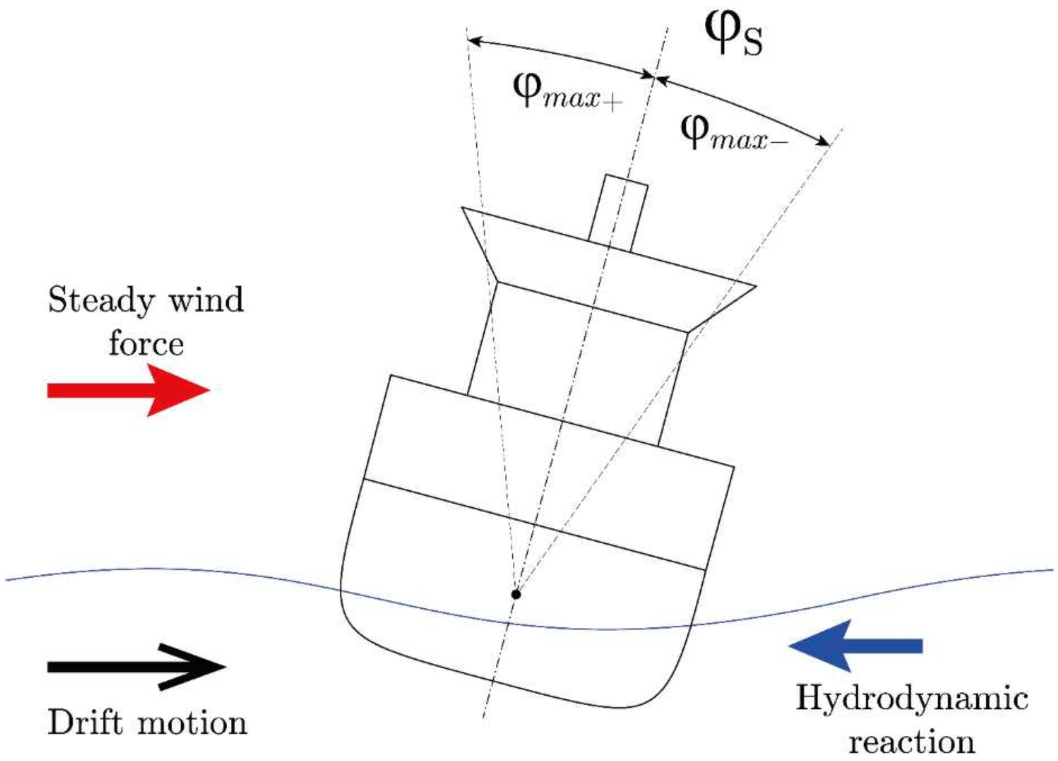
Credits: Osaka University – http://nrife.fra.affrc.go.jp/plant/kaiyou/capsizing-e.html

Surf-riding phenomenon: a ship is accelerated at wave celerity by a following wave.

It may be considered as a non-linear dynamic system with one degree of freedom:

$$R_{\text{hull}} - F_{\text{prop}} = f_x \cdot \sin(-k\, x_G)$$

DEADSHIP CONDITION

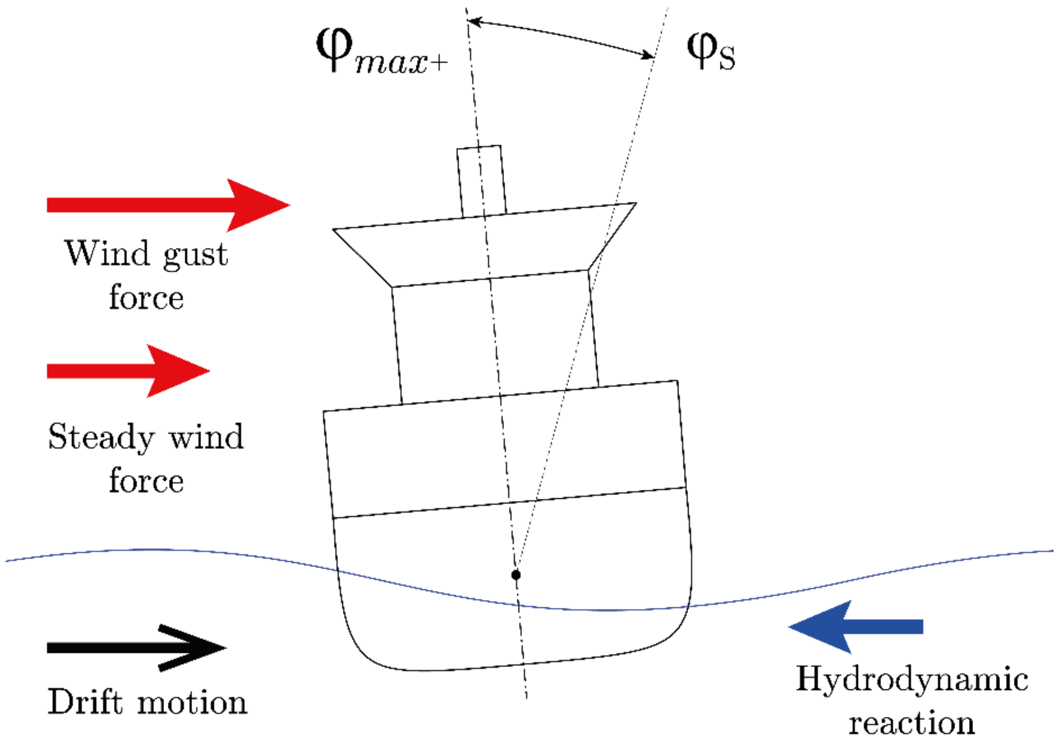


1) A vessel has lost its power and has turned in beam seas. The vessel is rolling around a static heel angle under the action of waves and steady wind.

2) A sudden wind gust hit the ship when she is at her maximum windward heel angle.

3) The wind gust is assumed to last enough time to push the vessel toward the leeward roll angle.

DEADSHIP CONDITION



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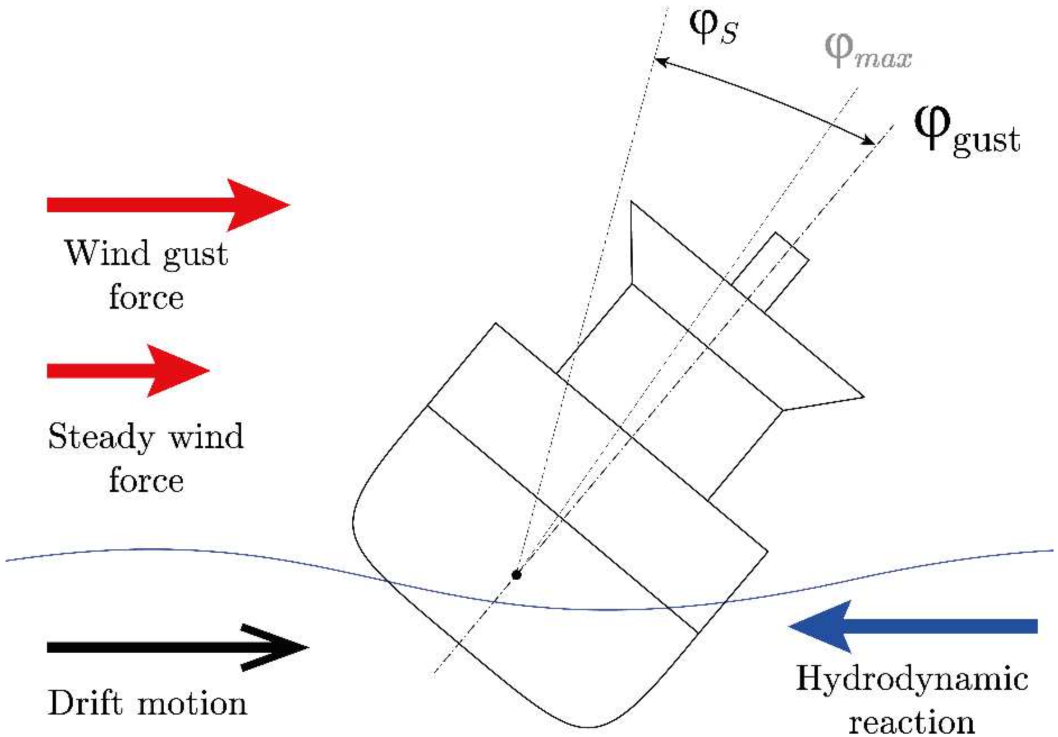

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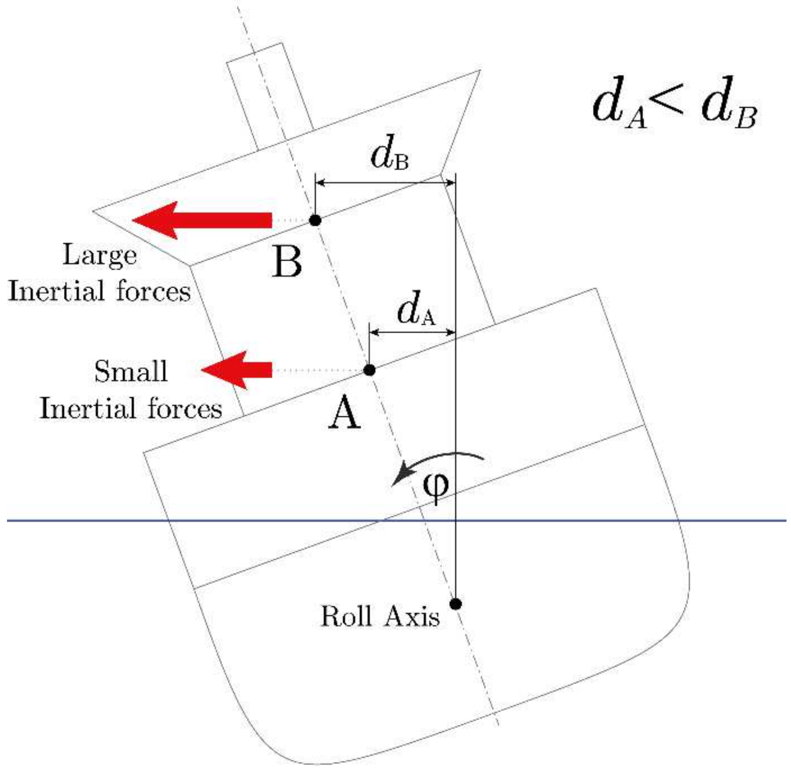
EXCESSIVE ACCELERATIONS



The roll rate is constant along the ship:
Point B has to cover in the same time a longer distance than Point A, therefore the highest point has a large lateral linear velocity.

Higher lateral velocities cause large lateral accelerations, that means large inertial forces.

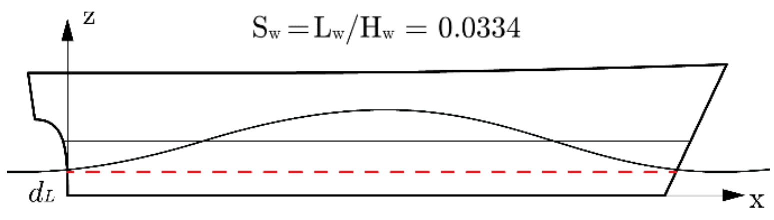
Increasing the GM, the roll period gets shorter so the rate of velocity change is higher, hence, large lateral accelerations occur.

- PURE LOSS OF STABILITY
  - 1st vulnerability level

Only ships having Fn > 0.24 should need to apply the vulnerability assessments.

A ship is not considered vulnerable if :

$$GM_{min} > 0.05 \ (\mathrm{m})$$



Simplified procedure

- PURE LOSS OF STABILITY
  - 2^{nd} vulnerability level

A ship is not considered vulnerable if :

$$max\left(CR_1; CR_2\right) < \quad 0.06 \ (\text{-})$$

First check

$$CR_1 = \sum_{i=1}^{N} W_i \cdot C1$$

$$C1_i = \begin{cases} 1 & \phi_V < \ 30 \text{ deg} \\ 0 & otherwise \end{cases}$$

Second check

$$CR_2 = \sum_{i=1}^{N} W_i \cdot C2$$

$$C2_i = \begin{cases} 1 & \phi_s > \ 15 \text{ or } 25 \text{ deg} \\ 0 & otherwise \end{cases}$$

$$\mathrm{R_{PL3}} = 8(\mathrm{H_{wave}}/\lambda\lambda) \ \mathrm{d} \ \mathrm{Fn}^2$$

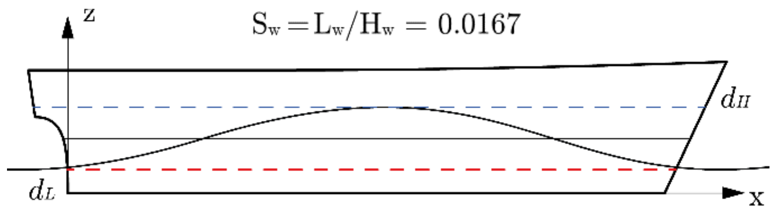
- PARAMETRIC ROLL

    - 1st vulnerability level

A ship is not considered vulnerable if :

$$\frac{\Delta GM_1}{GM_c} \leq R_{PR}$$

$$R_{PR} = f(Cm;\ Ak;\ L;\ B)$$



Simplified procedure

- PARAMETRIC ROLL

  - 2nd vulnerability level

A ship is not considered vulnerable if :

$$C1 \leq 0.06 \; or \; C2 \leq 0.025$$

First check – Evaluation of the occurrence of parametric rolling

$$C1 = \sum_{i=1}^{N} W_i \cdot C_i \quad \begin{cases} Ci = 0 \quad \text{if} \begin{cases} GM(H_i,\lambda_i) > 0 \\ \dfrac{\Delta GM(H_i,\lambda_i)}{GM(H_i,\lambda_i)} < R_{PR} \end{cases} \\ Ci = 1 \qquad otherwise \end{cases}$$

Wave case number	Weight W_i	Wave length λ_i (m)	Wave height H_i (m)
1	0.000013	22.574	0.350
2	0.001654	37.316	0.495
3	0.020912	55.743	0.857
4	0.092799	77.857	1.295
5	0.199218	103.655	1.732
6	0.248788	133.139	2.205
7	0.208699	166.309	2.697
8	0.128984	203.164	3.176
9	0.062446	243.705	3.625
10	0.024790	287.931	4.040
11	0.008367	335.843	4.421
12	0.002473	387.440	4.769
13	0.000658	442.723	5.097
14	0.000158	501.691	5.370
15	0.000034	564.345	5.621
16	0.000007	630.684	5.950

- PARAMETRIC ROLL
  - 2^{nd} vulnerability level

A ship is not considered vulnerable if :

$$C1 \leq 0.06 \; or \; C2 \leq 0.025$$

Second check – Evaluation of the magnitude of roll angle

$$C2 = \left[\sum_{i=1}^{12} C2_h(Fn_i) + \frac{\left(C2_h(0) + C2_f(0)\right)}{2} + \sum_{i=1}^{12} C2_f(Fn_i) \right] /25$$

$$C2_h(Fn) = \sum_{i=1}^{N} W_i \cdot C_i$$

$$C2_f(Fn) = \sum_{i=1}^{N} W_i \cdot C_i$$

$$\begin{cases} \mathrm{C}i = 1 & \text{if} \quad \phi_{\max} > 25 \text{ deg} \\ \mathrm{C}i = 0 & otherwise \end{cases}$$

- BROACHING-TO / SURF-RIDING
  - 1st vulnerability level

A ship is not considered vulnerable if :

$$\mathrm{Fn} < 0.3 \ (\text{-}) \qquad \text{or} \qquad \mathrm{L} > 200 \ (\mathrm{m})$$

A very easy check based on the following assumptions:

- Slow ships require too much energy to be accelerated at wave celerity
- Long ships hardly achieve a speed comparable to the celerity of long waves

- BROACHING-TO / SURF-RIDING
  - 2^{nd} vulnerability level

A ship is not considered vulnerable if :

$$C = \sum_{H_S} \sum_{T_Z} \left(W(H_S; T_Z) \cdot \sum_{i=1}^{N_\lambda} \sum_{j=1}^{N_a} (W2_{ij} \cdot C2_{ij}) \right) < \ 0.005 \ (\text{-})$$

Where the criterion is defined as

$$\mathrm{C2} = \begin{cases} 1 & \text{if} \quad Fn > Fn_{\text{crit}} \\ 0 & otherwise \end{cases} \longrightarrow \quad T_e(u_{cr}; n_{cr}) - R(u_{cr}) = 0$$

While the statistical weight is formulated as

$$\mathrm{W2}_{ij} = \frac{4\sqrt{g}}{\pi\nu} \frac{L^{5/2} T_{01}}{(H_s)^3} s_j^2 r_i^{3/2} \left(\frac{\sqrt{1+\nu^2}}{1+\sqrt{1+\nu^2}} \right) \Delta r \Delta s \cdot \exp\left[-2 \left(\frac{L \cdot r_i \cdot s_j}{H_s} \right)^2 \left\{ 1 + \frac{1}{\nu^2} \left(1 - \sqrt{\frac{g T_{01}^{\ 2}}{2\pi r_i \ L}} \right)^2 \right\} \right]$$