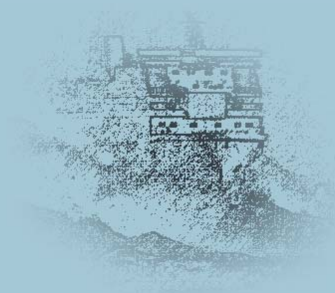


# **Structural Reliability Analysis for Intact and Damaged Ships by Rolf Skjong, DNV**

**Open Workshop on Risk-Based  
Approaches in the Maritime Industry**

**22nd and 23rd May 2007, National  
Maritime Research Institute (NMRI),  
Tokyo, Japan**



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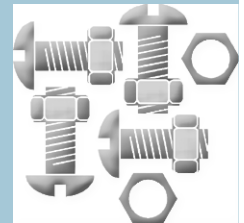
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# Introduction-Background

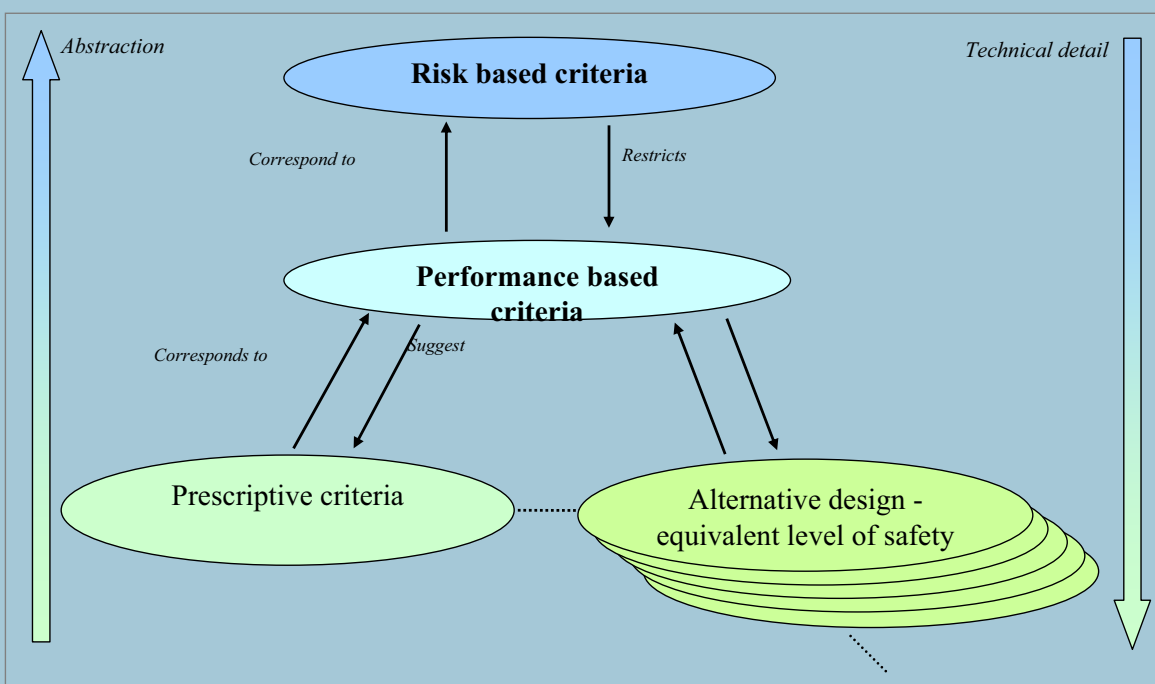


Innovative and Risk Based Design will normally mean

- Some functions, systems, sub-systems are innovative
- Some prescriptive rules are violated (prescriptive for previous technology)
- For other functions, systems, sub-systems standard solutions are used, and Rules are applicable
- Note also that some Rules are just industry standards
- Also for risk based optimization it is unlikely that all rules are challenged



# Approach: Equivalency



# Introduction

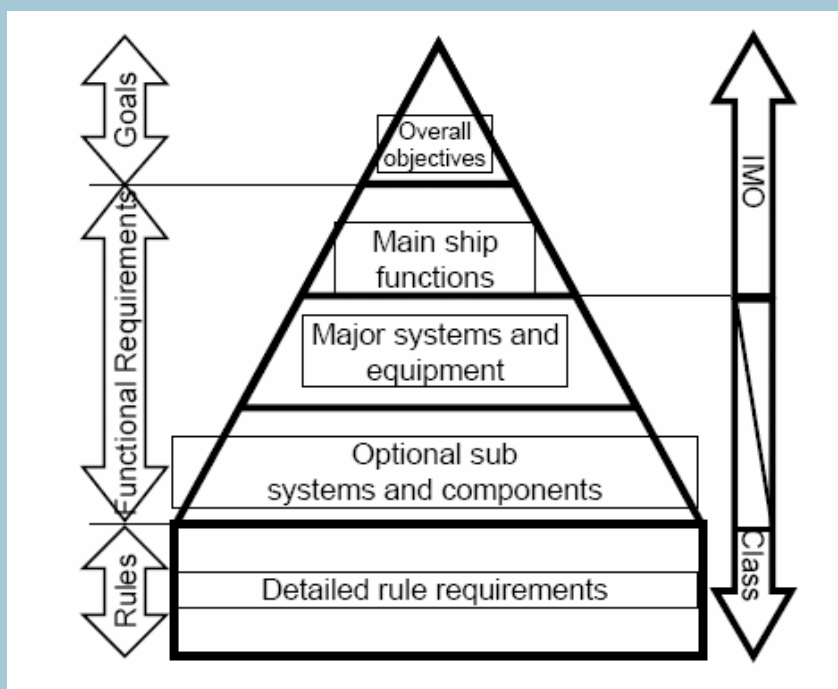


The trend from prescriptive to functional or performance based is a continuous process

**Bulk carrier: constructed generally with single deck top-side tank and hopper side tanks in cargo spaces and intended primarily to carry dry cargo in bulk, and includes such as ore carriers and combination carriers**

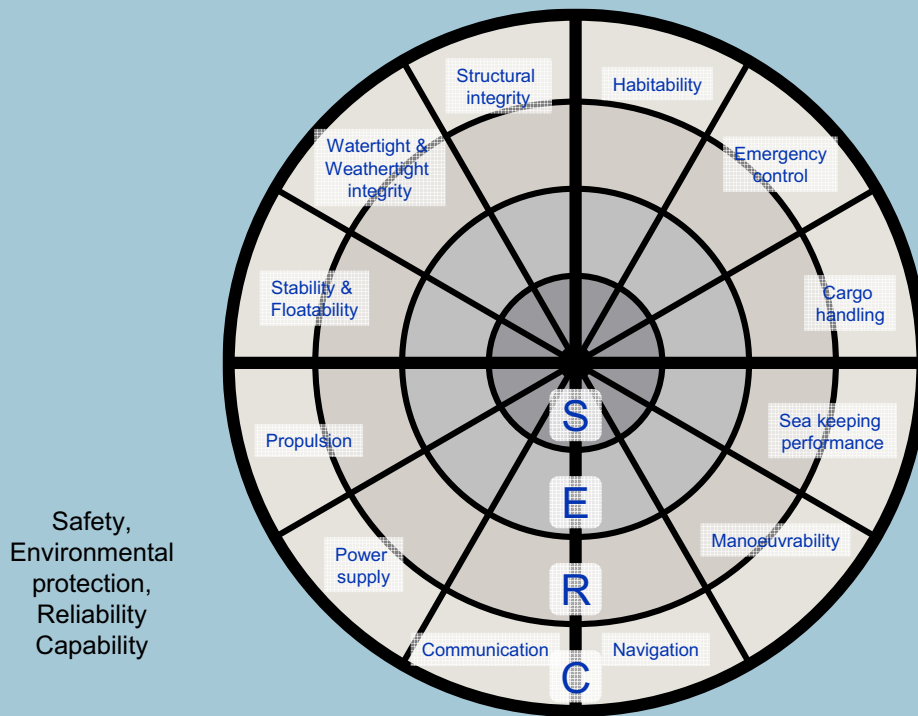
**Bulk carrier: intended primarily to carry dry cargo in bulk, including such as ore carriers and combination carriers**

# Goal Based Standards



**Goal Based Standard is an attempt to structure the rules according to safety objectives and functions**

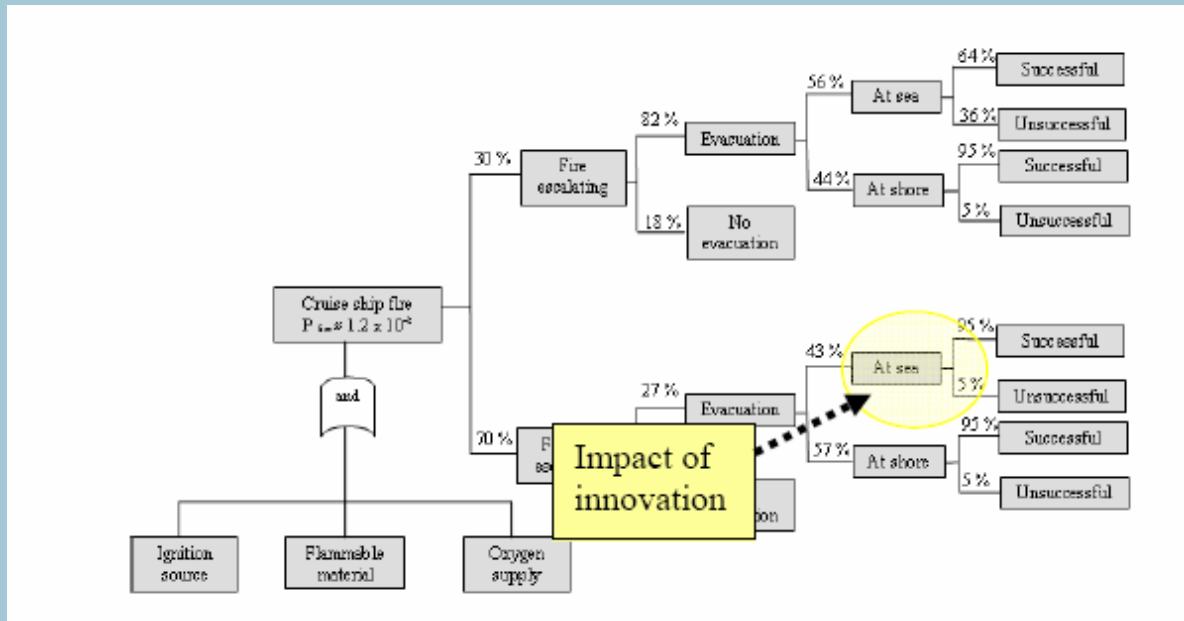
# Functional Breakdown -Example



## Methodology. Reference to FSA

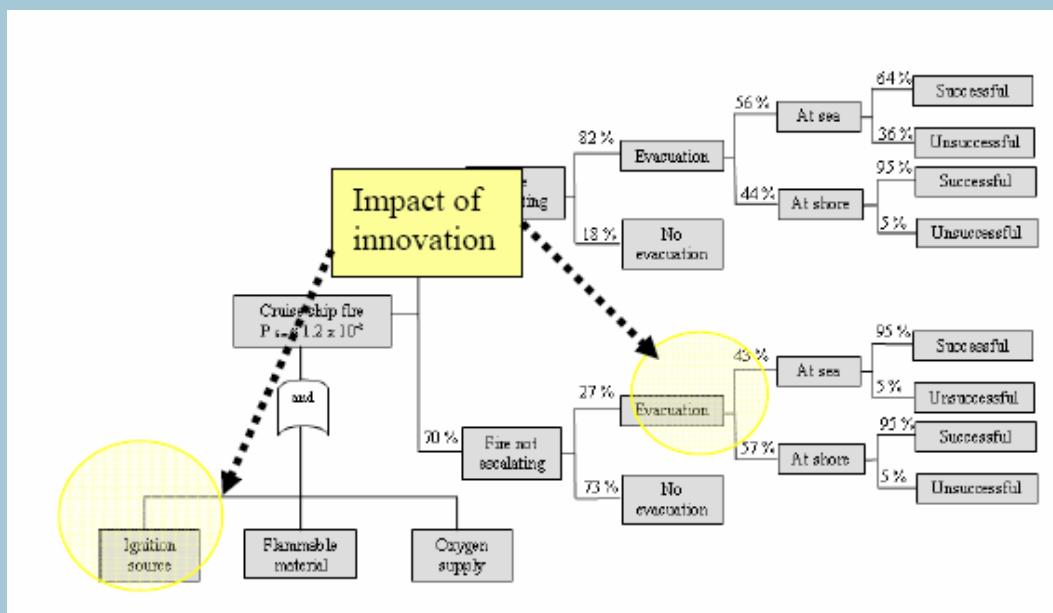
- An FSA usually will contain a breakdown to functions and systems, and contains the accepted reliability
- For FSAs to be used they should have been used by IMO for decision making
- Note that e.g. a target reliability may be defined from safety, environmental protection or economic considerations or a combination
- We use the term 'dimensioning' to express which considerations are driving the design

# Methodology. Reference to FSA



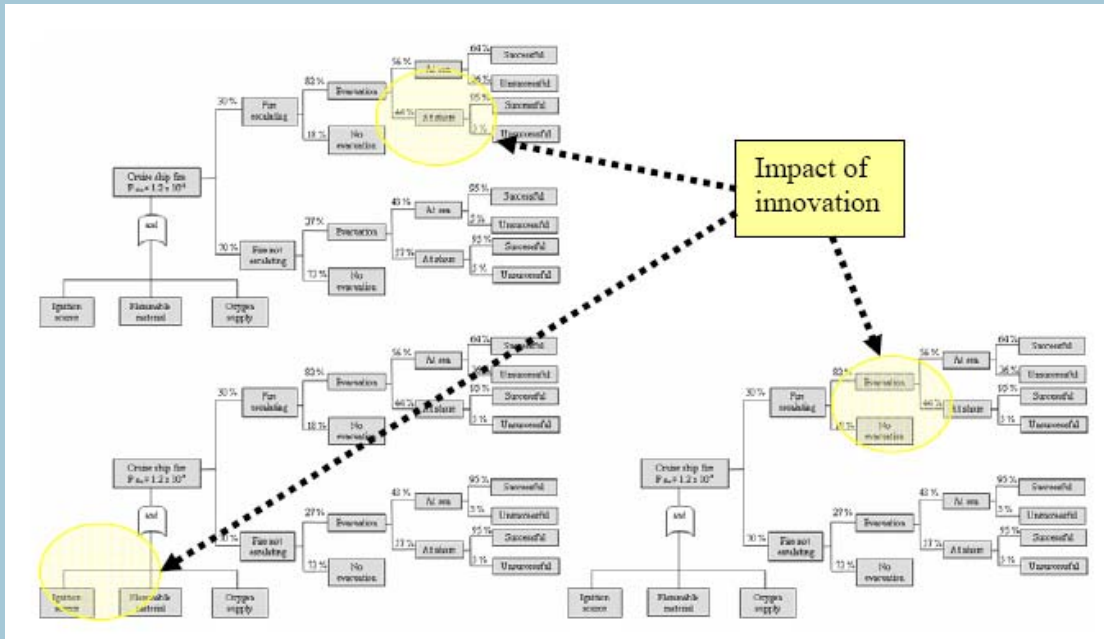
Simple case

# Methodology. Reference to FSA



Not quite Simple case

# Methodology. Reference to FSA

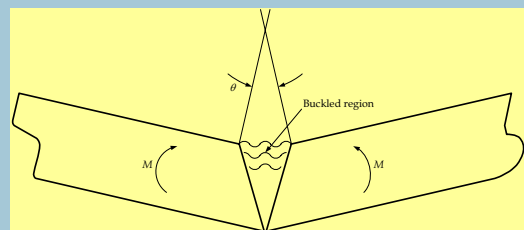


Multiple Scenario impact

# Example: Risk-based Structural Design

## Example:

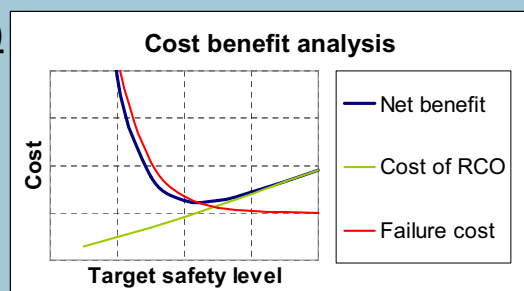
- Hull Girder Ultimate Strength Vertical Sagging Bending Moment Loaded condition, heavy weather
- Double Hull Tankers
- 5 test ships: Product, Aframax, Suezmax, 2 VLCCs



## Use: Formal Safety Assessment (FSA)

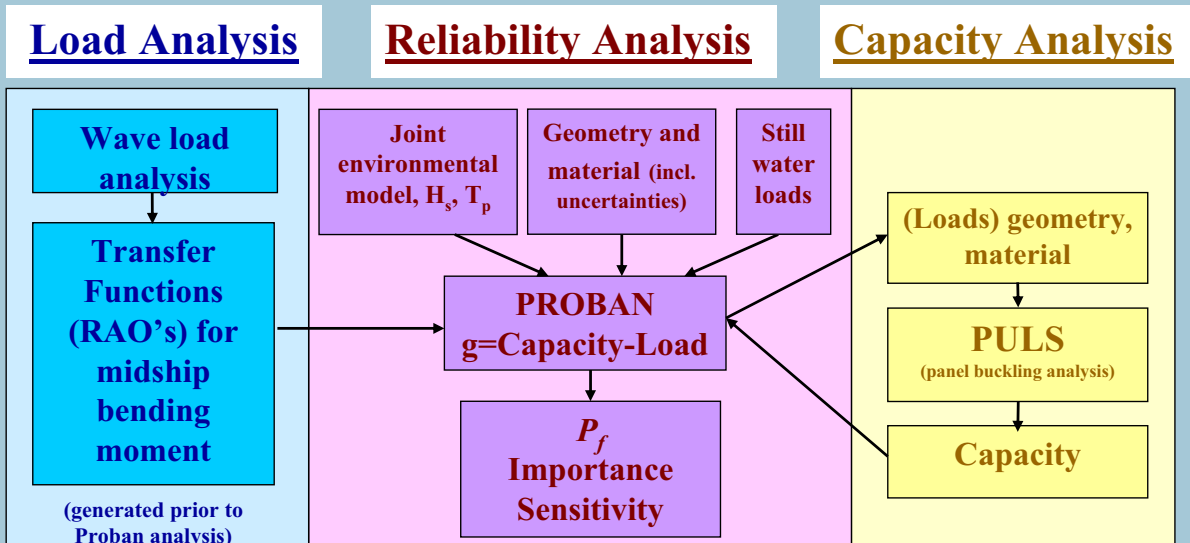
- Structural Reliability Analysis (SRA)
- Cost Effectiveness Assessment (CEA)
- Rule as a function of safety level

SRA, ref. JTP background, section 9 (currently being revised).  
<http://www.jtprules.com/background/>

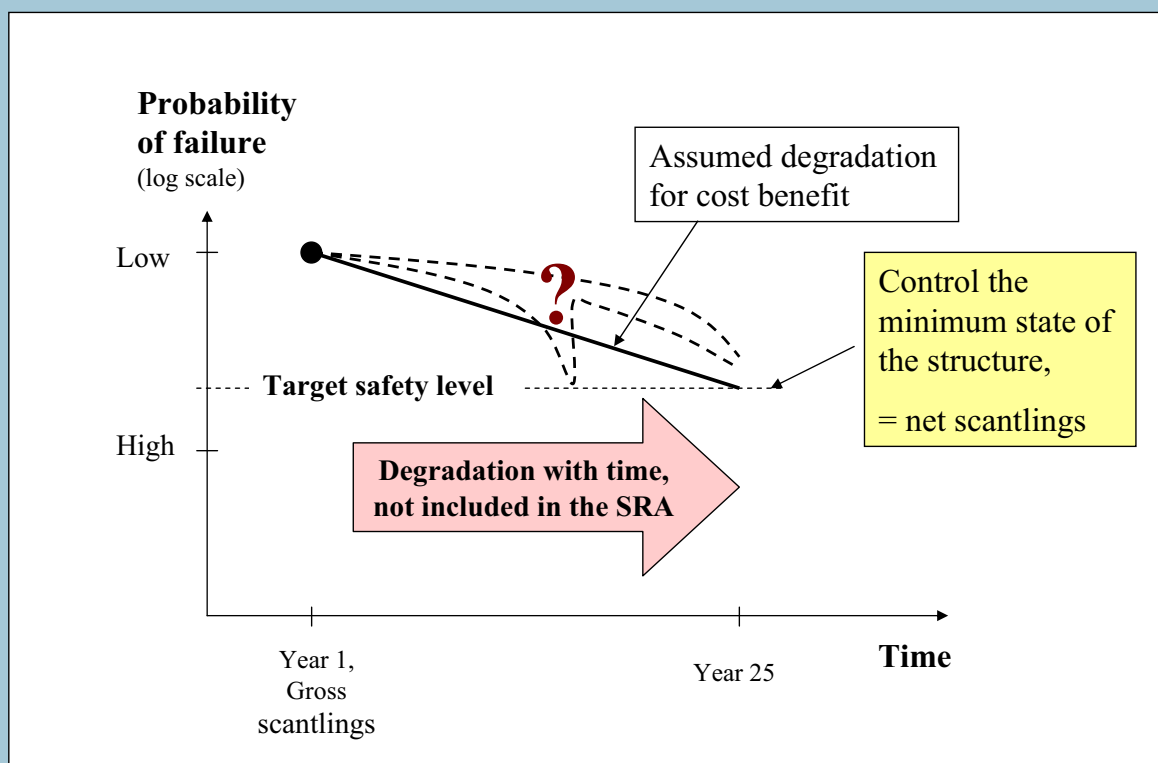


# Structural Reliability Analysis

Application overview:

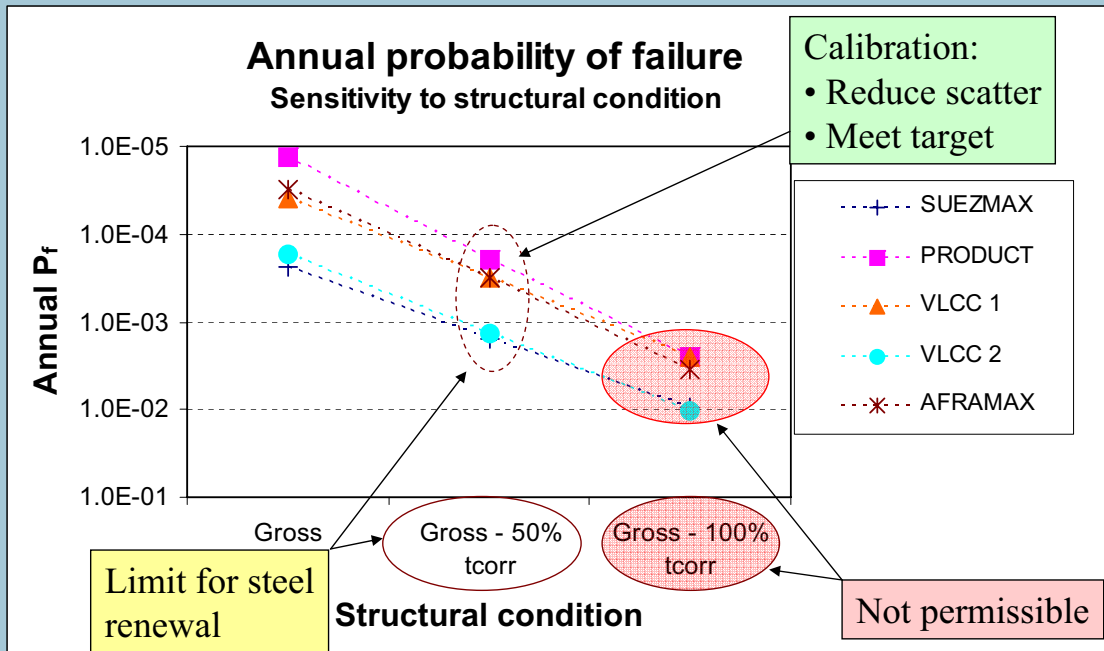


# Degradation, Net Thickness Approach



# Annual Probability of Failure

SRA result for initial design, various states of corrosion

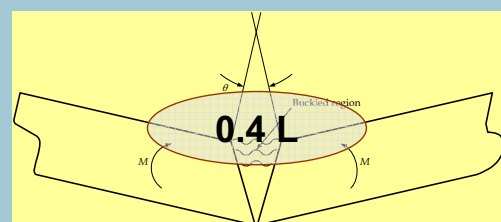
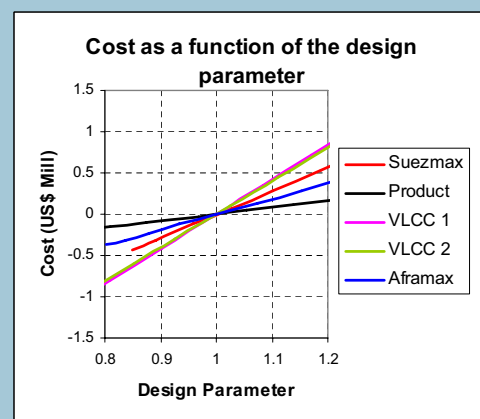


# Risk Control Option, Costs Parametric model

Design parameter = "deck weight scaling factor, with a defined steel distribution for plates and stiffeners"

## Cost of deck strengthening:

- Cost in terms of difference compared to the initial design
- Steelwork price: \$2.5/kg (Values between \$1/kg (China) and \$4/kg (EuroMed) are listed by Drewry (2004))
- Extension of 0.4 L amidships
- Impact on cargo capacity, fuel consumption, loads etc. are ignored



# Cost of Failure



## Property:

- New-building price of the ship Drewry (2000), adjusted to 2005 prices.
- Linear reduction, scrapping after 25 years (Stopford (1997), US\$200 per lwt.)
- Value of cargo US\$130 pr. ton

## Environment:

- Environmental impact. Loss of 1/5 of the cargo, with 10% chance of polluting the shore. According to Sørgård et. al (1999),
- The Cost of Averting a Ton of oil Spilled (CATS), is taken from Skjong et al (2004), CATS = US\$60,000. (10% → US\$6,000)

## Life:

- Number of crew, 30
- 25% loss of crew
- Cost of Averting a fatality is set to US\$ 3 mill.

|         | Cost of new ship, US\$m | Value at scrapping, US\$ m | Value of cargo US\$m |
|---------|-------------------------|----------------------------|----------------------|
| SUEZMAX | 50                      | 4.5                        | 19.5                 |
| PRODUCT | 30                      | 1.7                        | 4.6                  |
| VLCC 1  | 80                      | 8.4                        | 39.0                 |
| VLCC 2  | 80                      | 8.0                        | 39.0                 |
| AFRAMAX | 40                      | 3.4                        | 13.7                 |

Depreciation of future costs, **5% annually** (Comparable to a risk free rate of return as suggested in MSC 72/16)

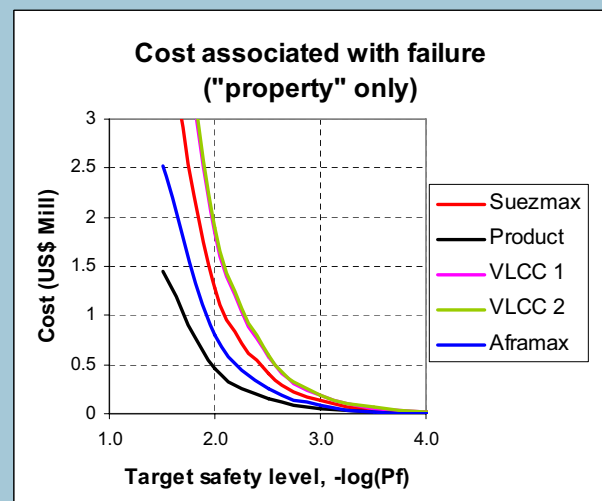
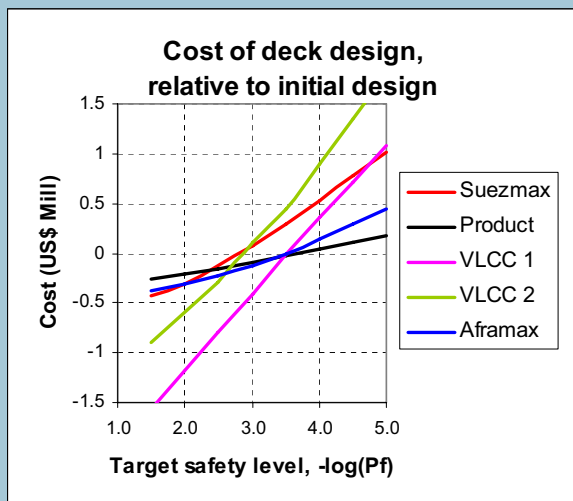
Easy to check the effect of changes in these assumptions

# Cost Benefit Analysis

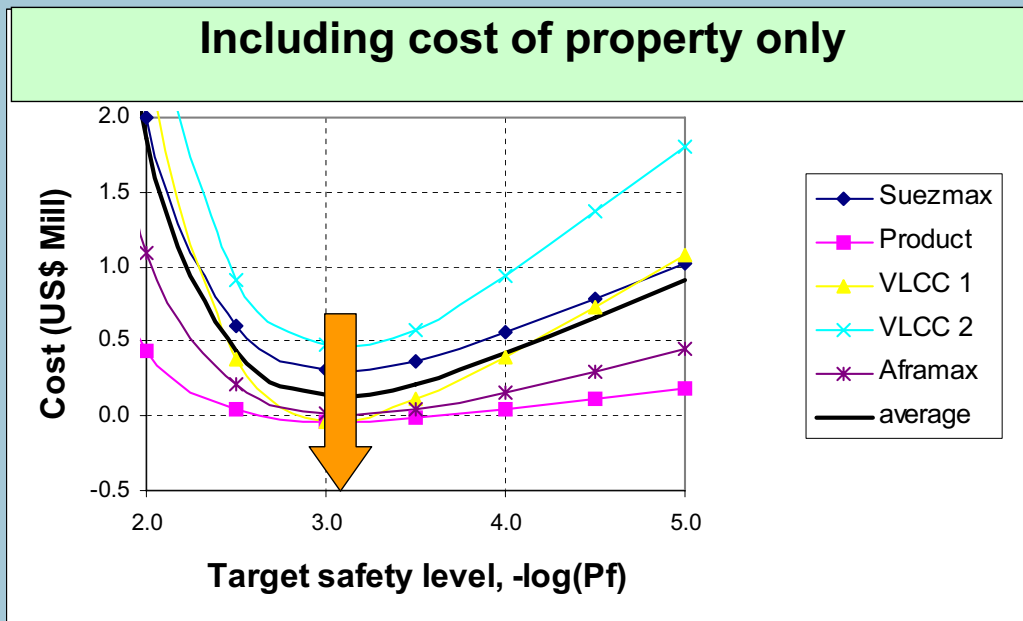


## Cost vs. safety

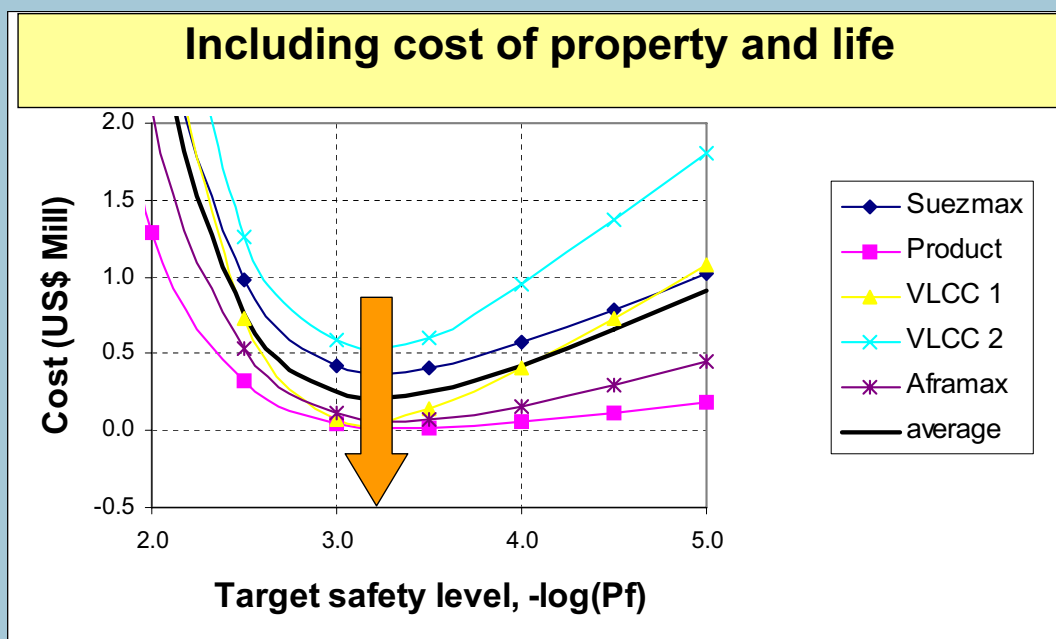
Cost of failure, here loss of ship and cargo (example excl. life and environmental impact)



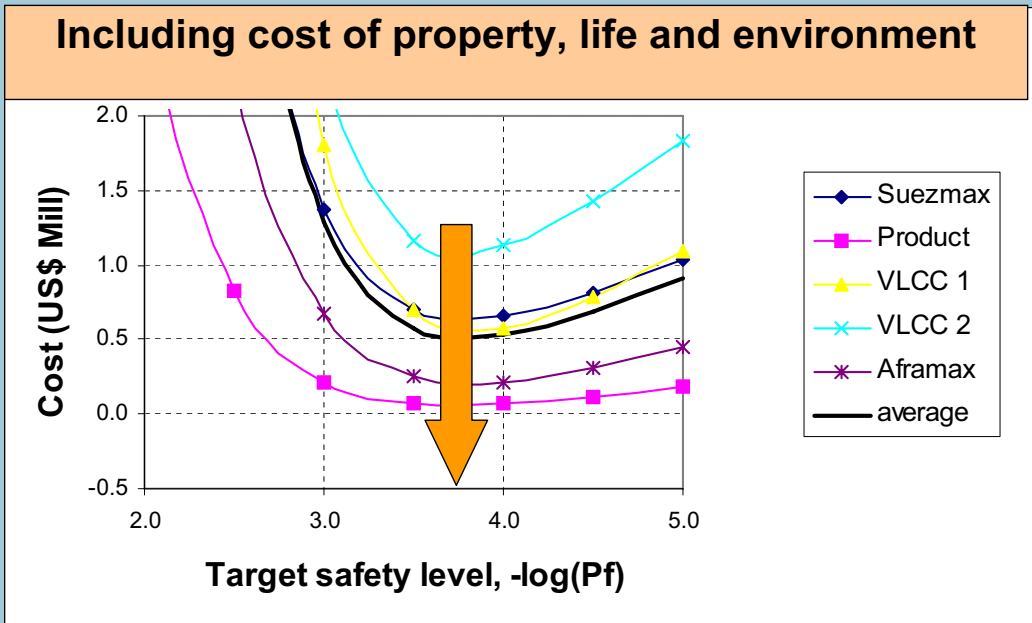
# Cost Benefit Results (1)



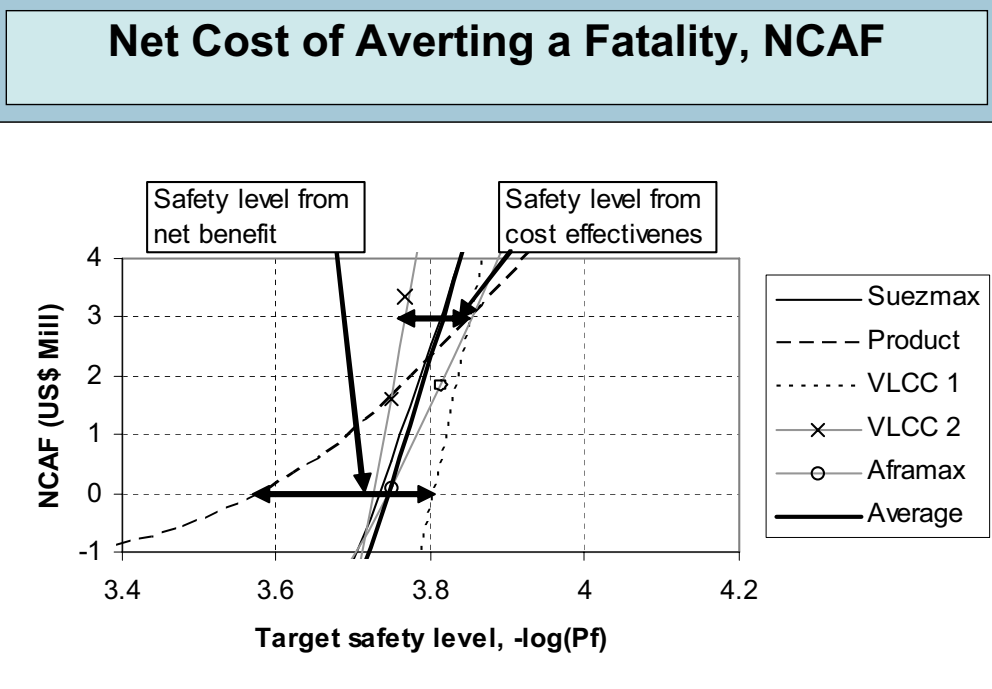
# Cost Benefit Results (2)



# Cost Benefit Results (3)



# Cost Effectiveness Results



# Decision making, rule criterion



$$\gamma_S M_{SW} + \gamma_W M_{WV} \leq \frac{M_U}{\gamma_R}$$

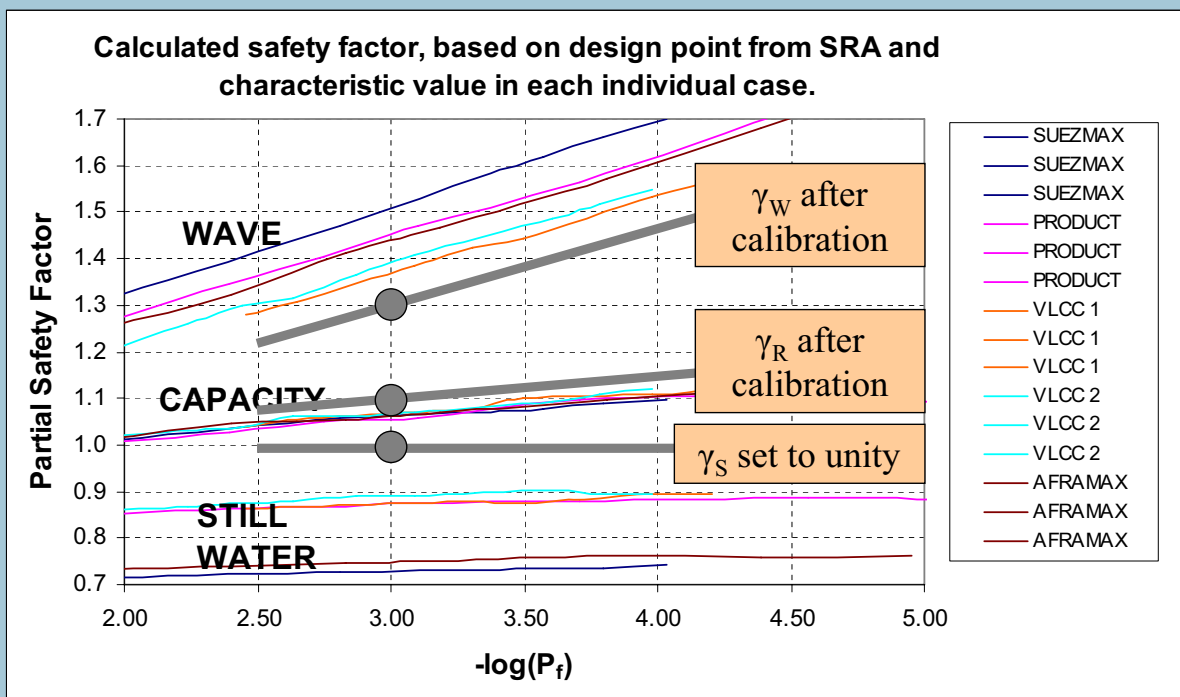
$M_{SW}$  still water bending moment (loading manual)

$M_{WV}$  wave bending moment (IACS formula)

$M_U$  Ultimate bending moment capacity (single step method)

$\gamma_S, \gamma_W, \gamma_R$  partial safety factors for the still water bending moment, the wave bending moment and the ultimate bending capacity respectively

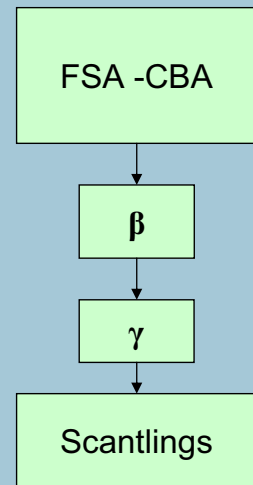
# Partial Safety Factors vs Safety



# Risk-based Structural Design

## Conclusions:

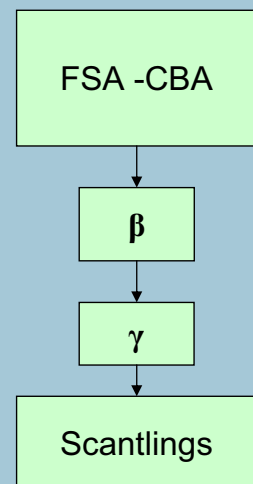
- FSA appropriate for structural rule development
- Structural Reliability Analysis
  - Quantify the probability of failure
  - Quantify effect of risk control option.
- Cost benefit to set target safety level
- Rule formulation. Calibration to SRA  
→ partial safety factors vs. safety level
- Transparent approach, easy to quantify the effect of the various cost assumptions
- Cost of Averting a Ton of oil Spill has a significant impact on the target for tankers



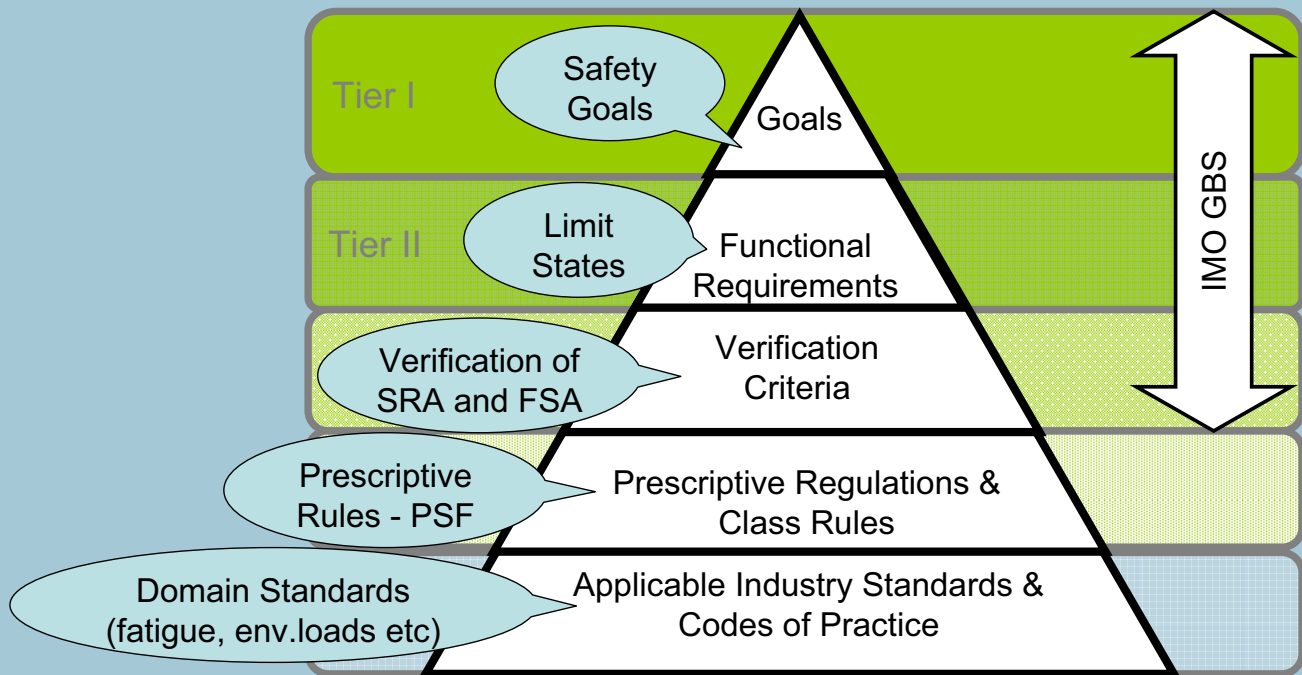
# The model used: 4Δ model

- Check that design is in ALARP area

$$NCAF = \frac{\Delta Cost - \Delta B - \Delta E \cdot CATS}{\Delta PLL}$$



# Significance to GBS



# Conclusions

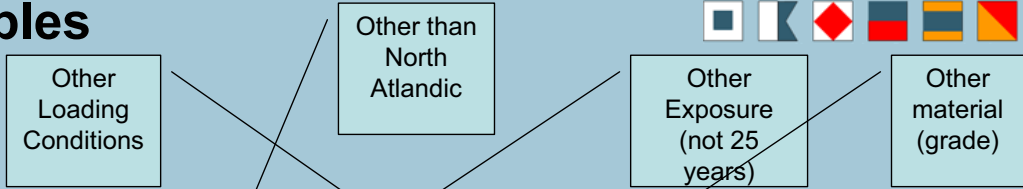
## Risk Model for the relevant scenarios

Target reliabilities for RBD may be derived using current IMO criteria, or by direct reference to FSA studies performed previously

Important:

**Make sure that model assumptions are the same**

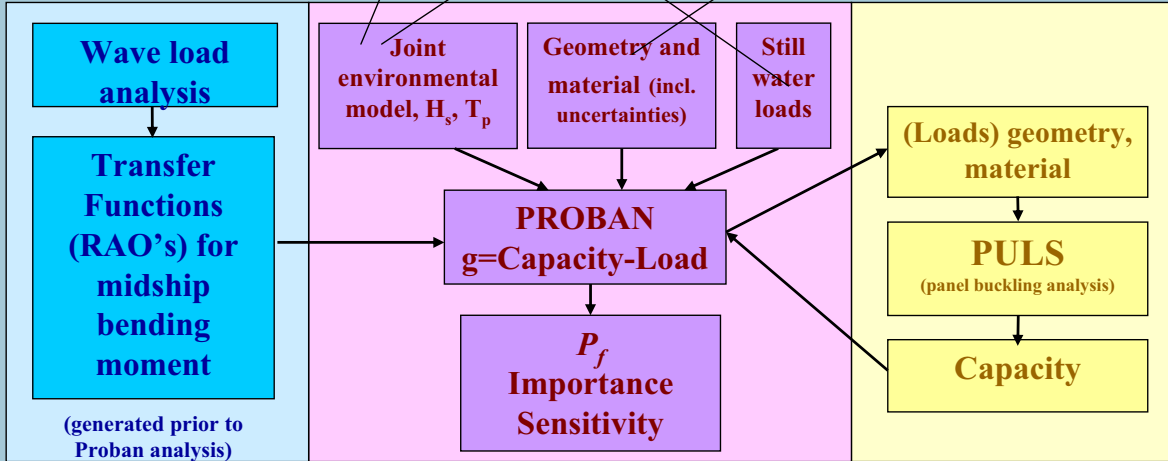
# Examples



## Load Analysis

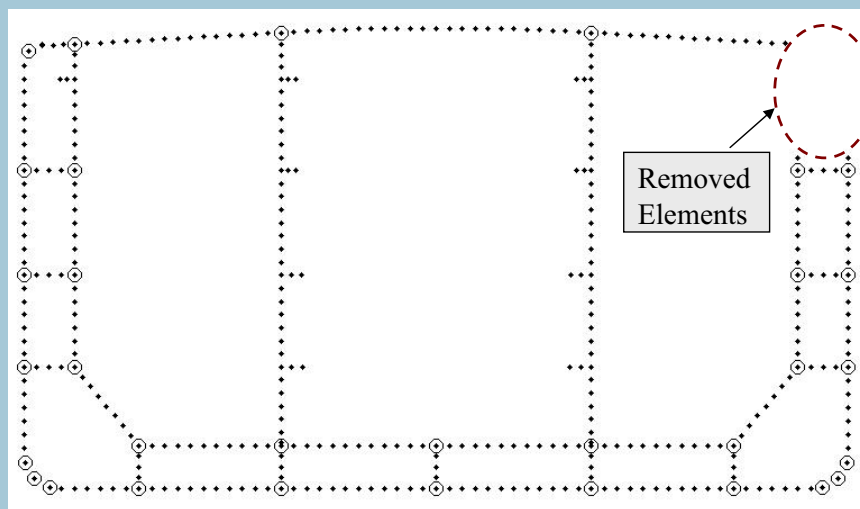
## Reliability Analysis

## Capacity Analysis



# Capacity Calculations

Remove elements in damaged region



# Damaged condition, effect of heading

## Example only

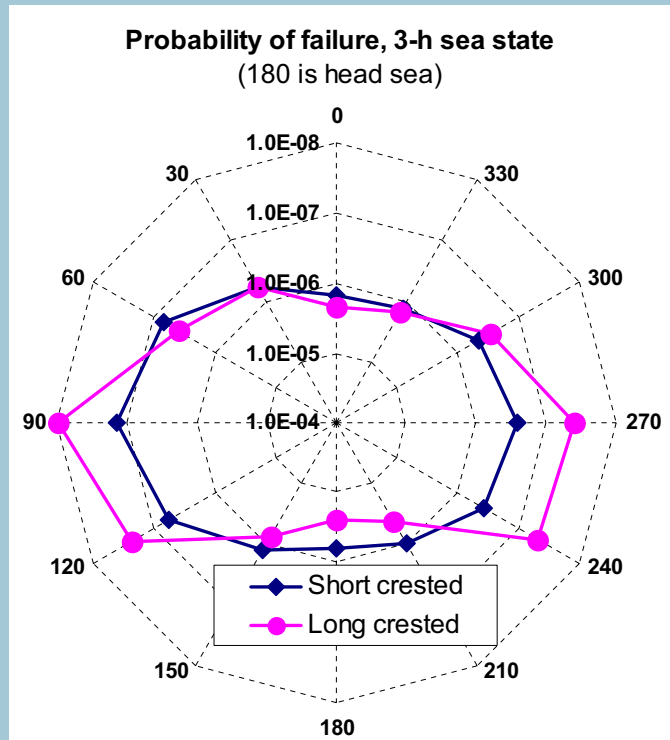
North Atlantic environment, single sea state

Head sea is most critical (following sea, almost as critical)

Long-crested sea is more critical than short crested

Results slightly unsymmetrical;

- waves towards the intact side more critical than waves against the damaged side



# References (Oversimplified)

- Case Study Used is documented in MSC 81/INF.6
- General Structural Reliability Analysis: Textbooks or
- <http://research.dnv.com/skj/OffGuide/SRAatHOME.pdf>