Freak Waves:

A Suggested Definition and Possible Consequences for Marine Structures

1. What is the target safety level of offshore structures?
2. Are rogue waves a problem?
   - A) What is a rogues wave?
   - B) Given freak waves exist, do they represent a problem?
3. What is the basic question related to freak waves?
4. Concluding remarks

Sverre Haver, Statoil,
Stavanger, Norway

STATOIL

Target Safety Level of Offshore Structures

By designing according to Norwegian Rules and Regulations, it is tacitly assumed that the nominal annual probability of structural failure is 10^{-4} – 10^{-5} or lower.

➔ A structure should resist all wave events or wave induced load events corresponding to an annual exceedance probability of 10^{-4} with a proper margin (i.e. in worst case some local damage damage may be experienced).

➔ Quantity of concern regarding ultimate safety is therefore the very, very upper tail of the annual distribution function of wave events and loads.

STATOIL

Target Safety Level of Offshore Structures

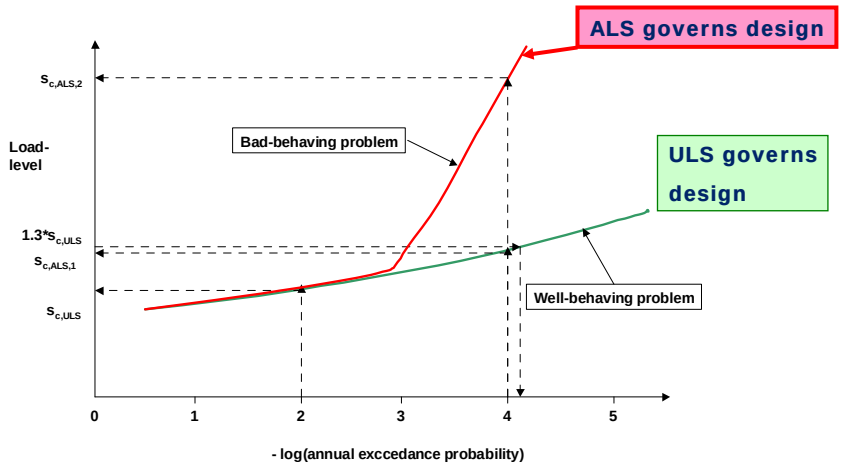
Regarding overload failures, industry aims to fulfill target by the following design controls:

i) Ultimate Limit State (ULS)
Component based control ensuring that the 10^{-2} – annual probability loads multiplied by a load factor are lower than a low percentile of the elastic component capacity divided by a material factor.

ii) Accidental Limit State (ALS)
System based control ensuring that the 10^{-4} annual probability load is smaller than the the system capacity.

STATOIL

Governing limit state (introducing the ugliness property)



STATOIL

Are rogue waves a problem for structural design?

Could be – but that depends very much what is meant by rogues waves.

At least two options:

a) "Classical" extreme waves
i.e. rare members of a population of waves defined by modelling the surface process as a piecewise stationary and homogenous slightly non-Gaussian process.

This type of extreme waves are presently accounted properly for by the offshore industry provided some accidental wave load scenario is implemented. Traditional shipping may have some room for improvements.

However, waves that are likely to cause structural failure do exist within this population, but their annual probability of occurrence should be lower than say 10^{-5}.

STATOIL

Are rogue waves a problem for structural design?

b) Freak (extreme) waves;
defined as typical members of a population being in agreement with physical mechanisms well beyond those under a).

This type of extreme waves are outside our design events. If such a population exists, it may challenge present design recipes if it effects the 10^{-3} – 10^{-5} annual probability of exceedance level at a given site.

STATOIL

Suggested definition of freak waves

A freak wave event is an event that is governed by mechanisms and/or phenomena well beyond those underlying the piecewise stationary and homogenous second order model of the sea surface.

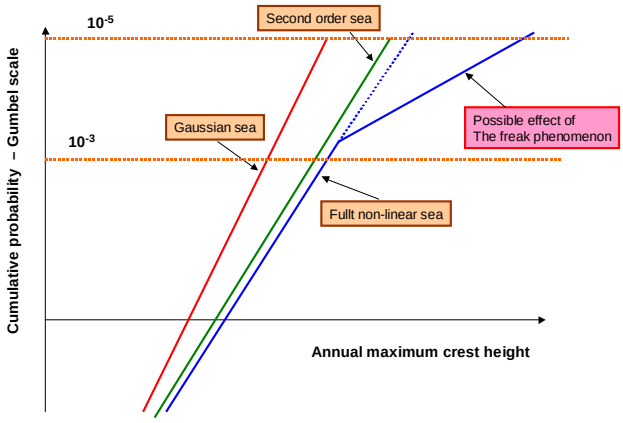
A second order model is selected as a reference population for non-freak events because that is the most sophisticated model available for routine design.

A factor definition is not very useful since it may – with low probability – be exceeded even under Gaussian assumption for the sea surface elevation.

STATOIL

Can freak waves represent ”an ugly” mechanism?

YES – IF THEY MAKE THE UPPER TAIL (10^{-3} – 10^{-5}) FOR THE ANNUAL EXSTREME VALUE DISTRIBUTION AT A GIVEN SITE SIGNIFICANTLY FATTER

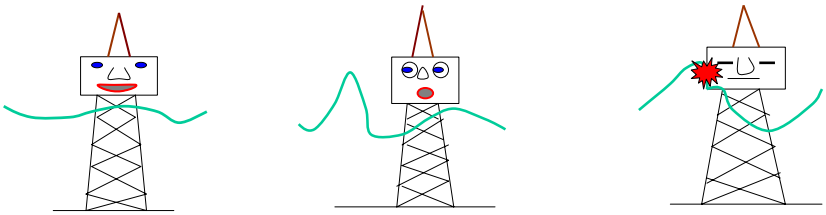


STATOIL

If freak wave exist – what is the problem?

For ship og platforms, freak waves will mainly represent a problem if their crest hits a structural element which is not designed for wave loads.

Examples: Wave deck impact of fixed platforms and green water impact on superstructure of ships.



STATOIL

The Challenge!

KNOWN THREAT

"Classical" extreme waves: Major sources regarding environmental loading on marine structures, but their annual occurrence probability can be predicted with a reasonable accuracy.

UNKNOWN THREAT

Freak extreme waves: Their existence as a separate population is not known. Their annual occurrence probabiliity and and corresponding characteristics (height, crest height, steepness and kinematics) is neither known. At presnt it is not possible to account for freak waves in design in a rational way.

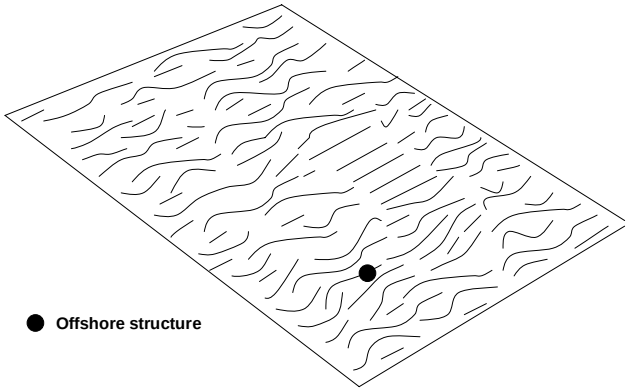
THE FUTURE CHALLENGE:

Does a separate freak wave population exist? If so how can we determine their annual occurrence probabilities at a given site? How to determine their corresponding wave characteristics?

Most promising way ahead: Further developments of mathematical tools accounting for all important non-linearities. Extensive data collection will probably not be that useful.

STATOIL

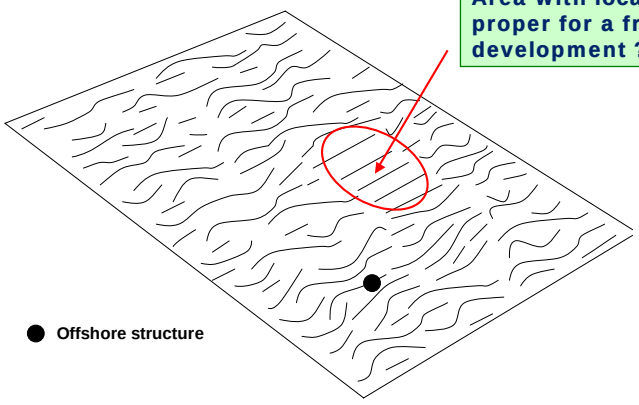
Do freak waves represent a problem for design and survivability of offshore structures?



1: NO!
Provided the surface elevation at all sites and all times are sufficiently accurately modelled by a stationary and homogeneous second order random field.

STATOIL

Area with local conditions proper for a freak wave development ??



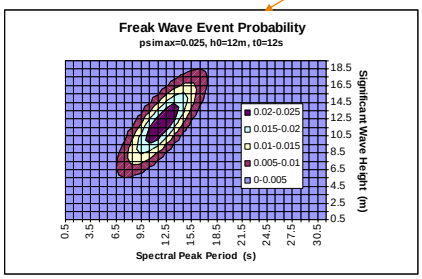
2: YES!
They may if a freak wave development can take place sufficiently frequent and with a sufficient amplification factor to effect 10^{-3} – 10^{-5} annual exceedance probabilities at a given site.

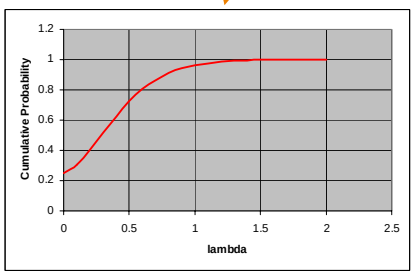
STATOIL

Some basic (from an engineering point view) questions regarding freak waves and their importance

On pure statistical grounds, a 3-hour maximum crest height accounting for a possible freak phenomenon may be expressed as a function of the 3-hour maximum non-freak crest height:

$$C_{3h\text{-}freak} = C_{3h\text{-}non\text{-}freak} + K^{*}\Delta C_{3h\text{-}freak} = C_{3h\text{-}non\text{-}freak}(1 + K^{*}\Lambda)$$

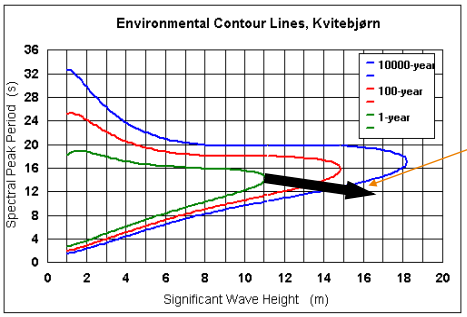




STATOIL

The scenario of concern regarding impact of freak waves

A freak wave mechanism exists and its conditional probability of being realized increases as we enter into the range of non-observed sea states.



P(K=1) increase in the direction of the arrow.

STATOIL

Concluding remarks

- Freak waves (defined as something well beyond a second order model of the surface process) are not expected to represent a significant contribution the annual collapse probability of ships and offshore structures.
- Some concern remains concerning their occurrence probability in sea states outside the range of observed sea states.
- This is the motivation for recommending further research on the existence of freak wave mechanisms and anchoring them to physical sea state parameters. This calls for mathematical models describing the underlying physics and phenomena with a sufficient level of accuracy.

STATOIL

Concluding remarks

- Traditional ships may experience considerable problems if running into very extreme (but still non-freak) wave conditions.
- A major first step in the direction of increasing robustness against unknown wave extremes could be to introduce the accidental wave (10^{-4} annual probability wave) in the design process.

STATOIL