Classification: Statoil internal Status: Draft

REASONS FOR FOCUSING ON THE PREDICTION OF THE VERY EXTREME SEA STATES

Requirements from a design point of view (Norwegian Continental Shelf Practise)

Bad behaving response problems

Prediction of events corresponding to prescribed annual exceedance probabilities

Environmental contour lines

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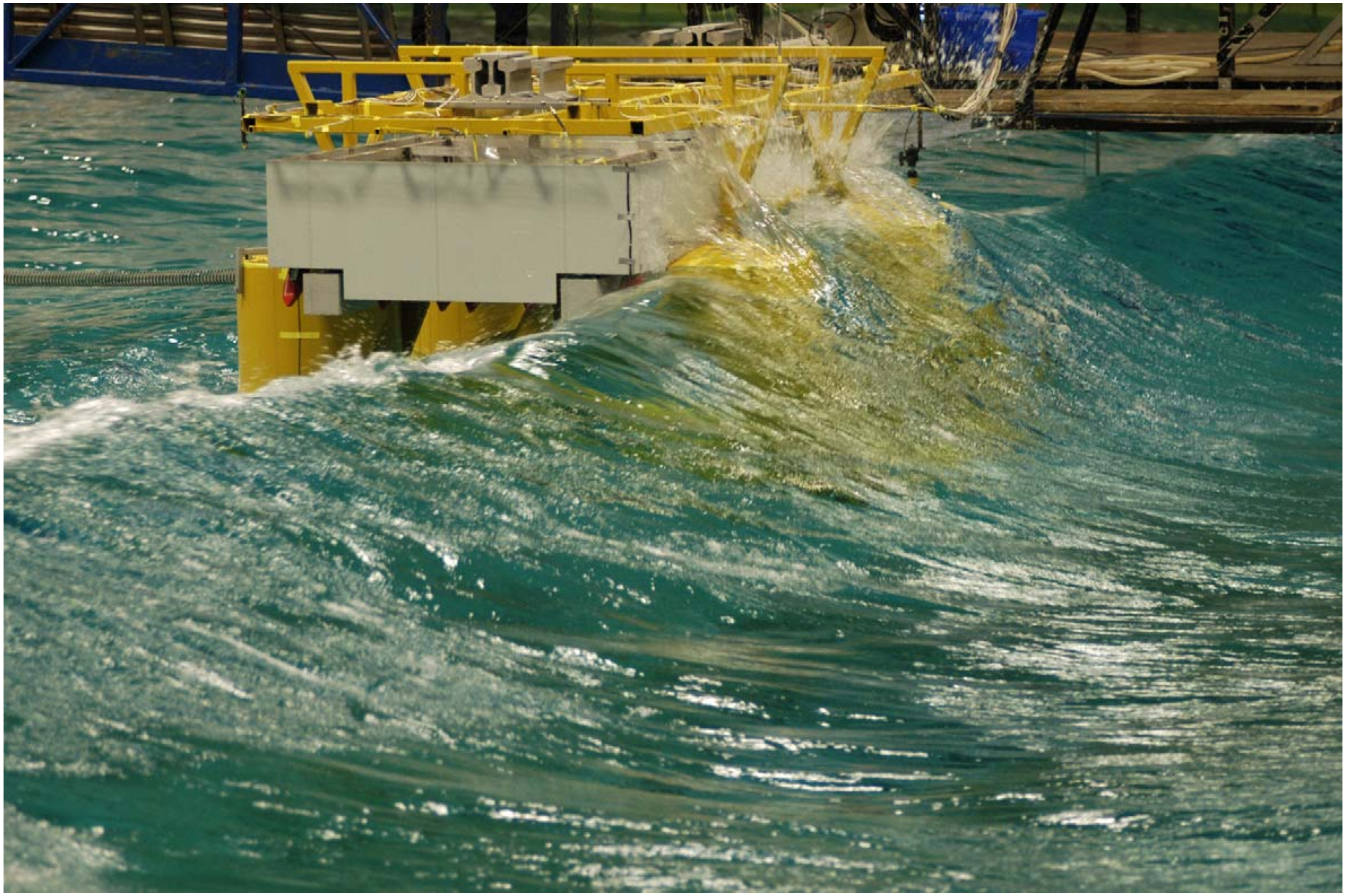
Åsgard C January 2006: H_s = 12-15m

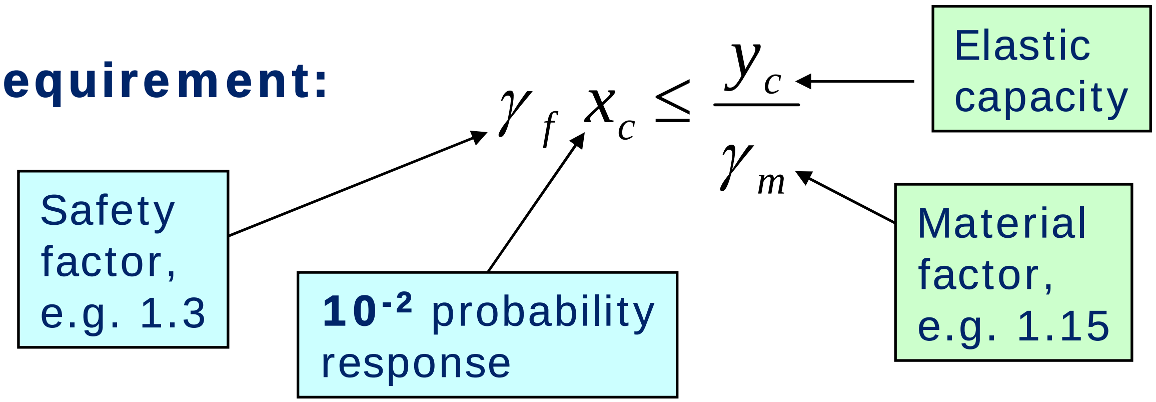
Sea state severity approaching a level where structural integrity can be at risk



Requirements from a design point of view

(Norwegian Continental Shelf Practise)

- **Norwegian Rules and Regulations** require that offshore structures are controlled at two levels regarding overload – ULS and ALS.
- **Ultimate limit state (ULS) requirement:**



$$\gamma_f \, x_c \le \frac{y_c}{\gamma_m}$$

Safety factor, e.g. 1.3

10^{-2} probability response

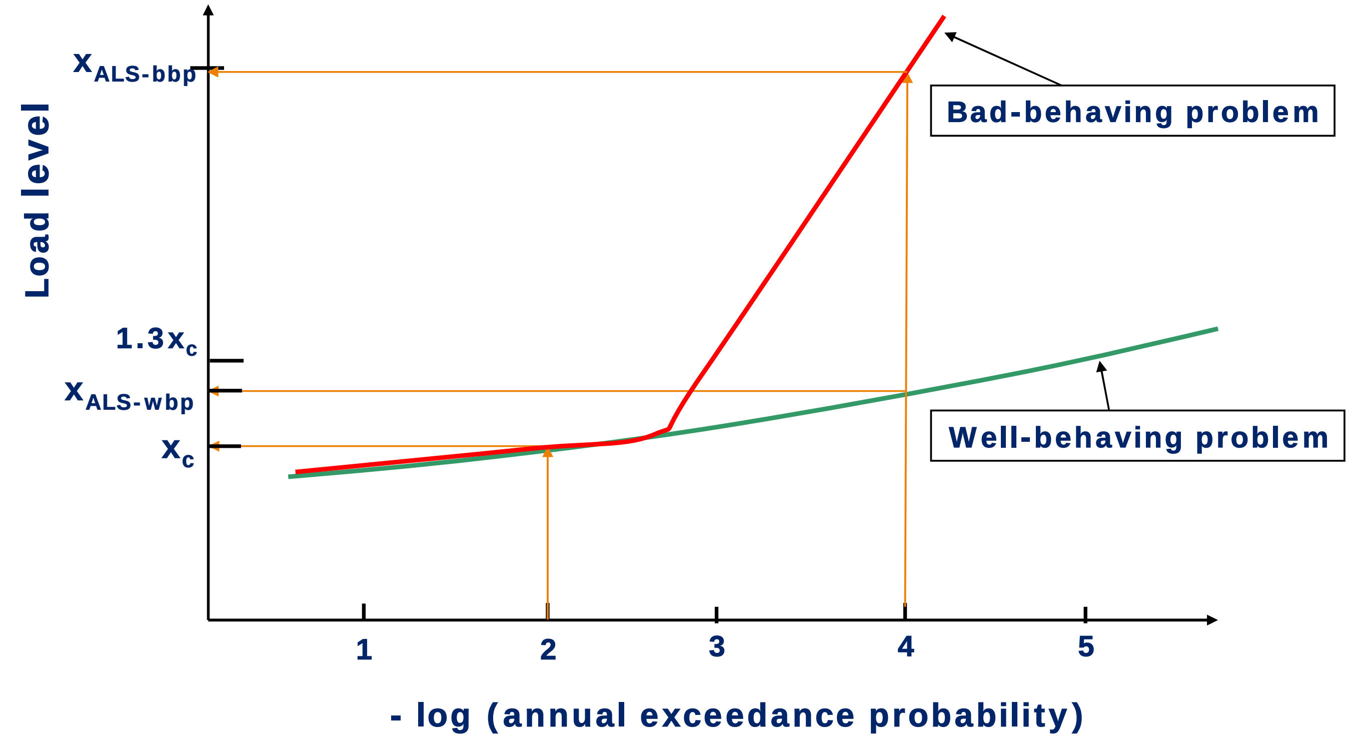
Elastic capacity

Material factor, e.g. 1.15

Accidental limit state (ALS) requirement:
As above with $\gamma_f = \gamma_m = 1.0$, $x_c = 10^{-4}$ annual probability load, and y_c = plastic system capacity

➔ we should be concerned with response corresponding to very low annual exceedance probabilities.

Why be concerned with 10^{-4} environmental load - Bad behaving problems



➔ If the response – annual exceedance probability relation changes abrubtly in a worsening direction ULS requirement will not ensure a sufficiently low annual failure probability

Consistent prediction of q-probability loads

Assuming that the sea state is characterized by H_s and T_p and denoting a 3-hour maximum response quantity by X_{3h}, the long term distribution for X_{3h} is given by:

$$F_{X_{3h}}(x) = \int_h \int_t F_{X_{3h}\,|\,H_s,T_p}(x|h,t)\, f_{H_s T_p}(h,t)\, dt\, dh$$

As the long term distribution is known, the q-probability value is found by solving:

$$1 - F_{X_{3h}}(x_{3h,q}) = q / m_{3h}$$

Expected number of 3-hour events above threshold per year

➔ We need to account for both the long term weather variability and the short term response variability for obtaing consistent q-probability values.

Approximate method for consistent long term extremes

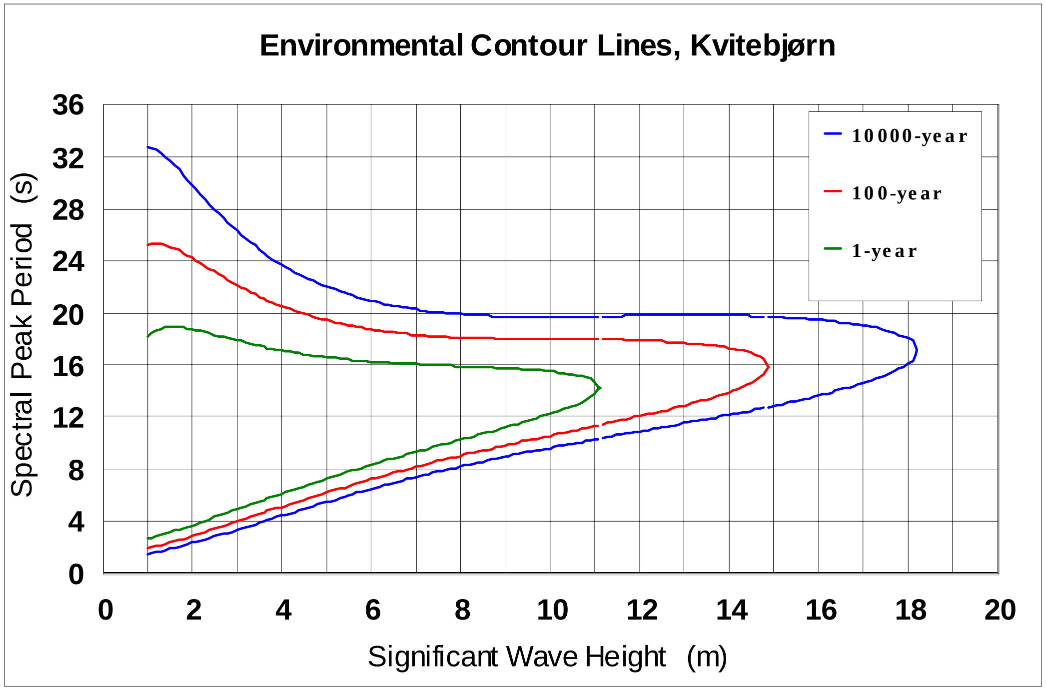
i) Determine the q-probability contour of H_s and T_p

ii) Determine the worst sea state along contour for selected response.

iii) Estimate the distribution of 3-hour maximum response for this sea state.

iv) The α-percentile of this distribution is a good estimate for the q-probability response, α is typically around 90.

Example contour – all sea states



➔ A good estimate is a percentile well above the most probable value

Predicting q-probability response in a storm climate

- **Full long term analysis:**

  * Joint distribution of H_s and T_p for all 3-hour events exceeding storm threshold.

  * Conditional distribution of 3-hour maximum response given H_s and T_p.

➔ This estimate will be considered as the ”true” value.

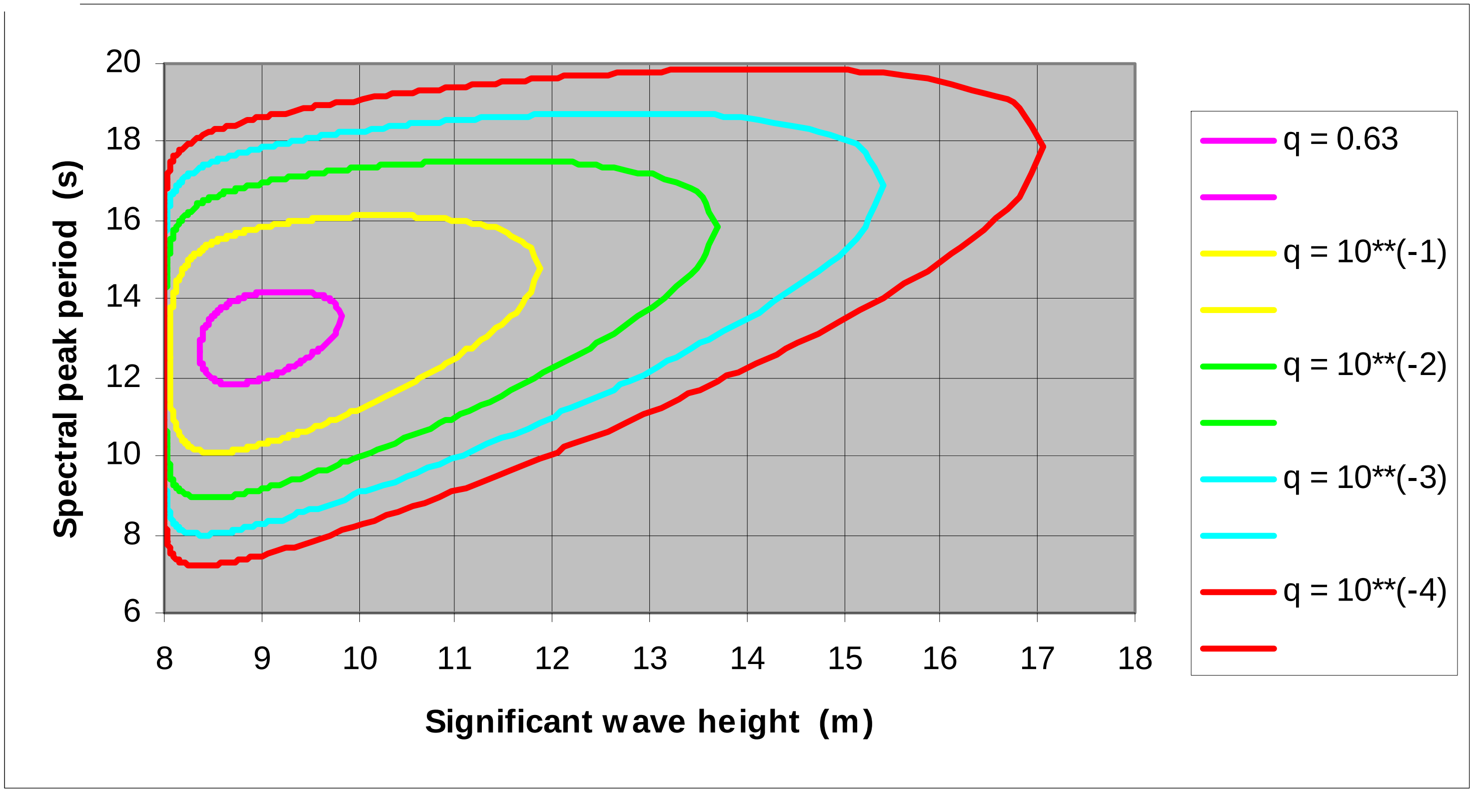
- **Environmental contour method:**

  * q-probability contour for storm peak characteristics.

  * Conditional distribution for the most unfavourable sea states along the contour line.

➔ This is an approximate estimate, it will be demonstrated how good it is.

Storm peak contour lines



Response example

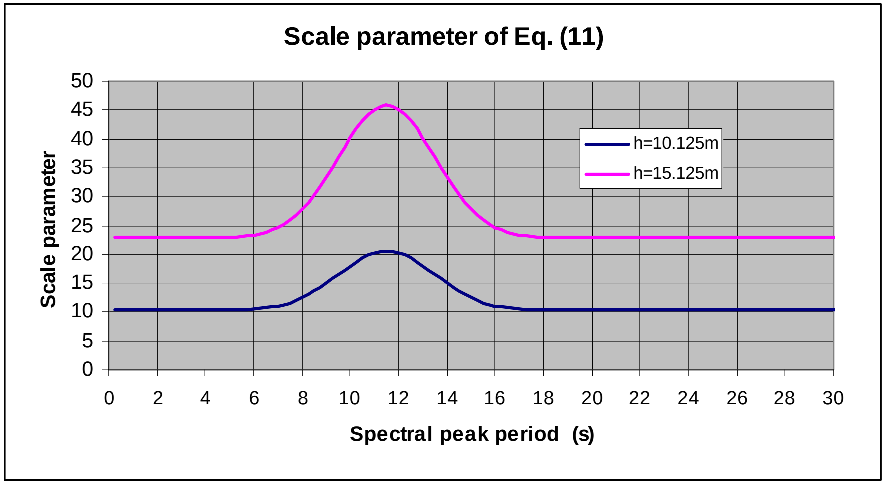
The conditional distribution of 3-hour maximum response given the sea state is modelled by a Gumbel model:

$$F_{X_{3h}|H_{sp}T_{pp}}(x|h,t) = \exp\left\{-\exp\left[-\left(\frac{x-\alpha(h,t)}{\beta(h,t)}\right)\right]\right\}$$

Distribution parameters:

$$\beta(h,t) = 0.1h^2\left[1+\cos^{40}\left(\frac{2\pi(t-11.5)}{80}\right)\right]$$

$$\alpha(h,t) = \beta(h,t)\ln\left(\frac{10800}{0.75t}\right)$$



Results using contour line method

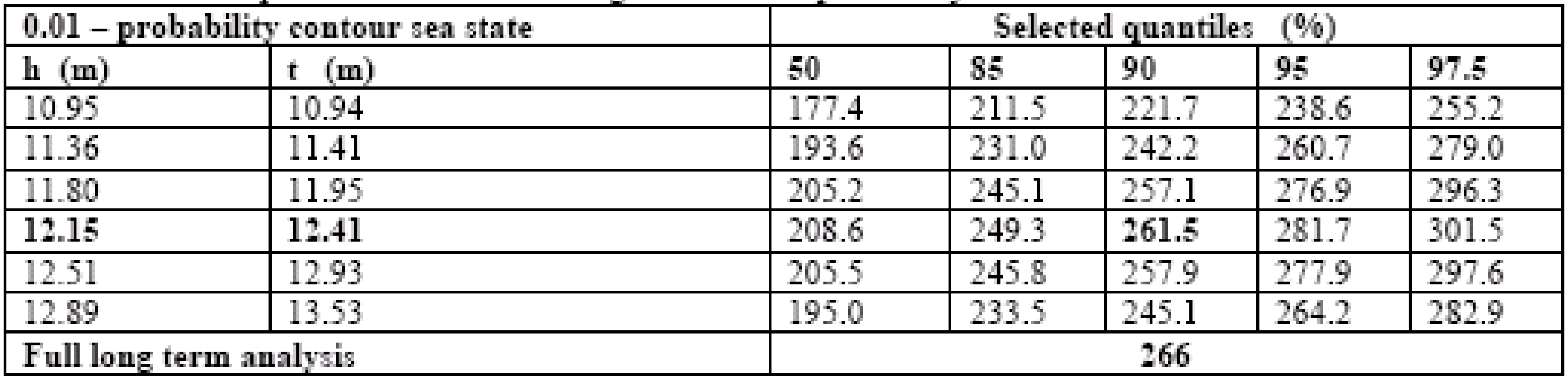


Table 3 Various quantiles for the worst range of the 0.01- probability contour line

0.01 – probability contour sea state		Selected quantiles (%)				
h (m)	**t (m)**	**50**	**85**	**90**	**95**	**97.5**
10.95	10.94	177.4	211.5	221.7	238.6	255.2
11.36	11.41	193.6	231.0	242.2	260.7	279.0
11.80	11.95	205.2	245.1	257.1	276.9	296.3
12.15	**12.41**	208.6	249.3	**261.5**	281.7	301.5
12.51	12.93	205.5	245.8	257.9	277.9	297.6
12.89	13.53	195.0	233.5	245.1	264.2	282.9
Full long term analysis		**266**				

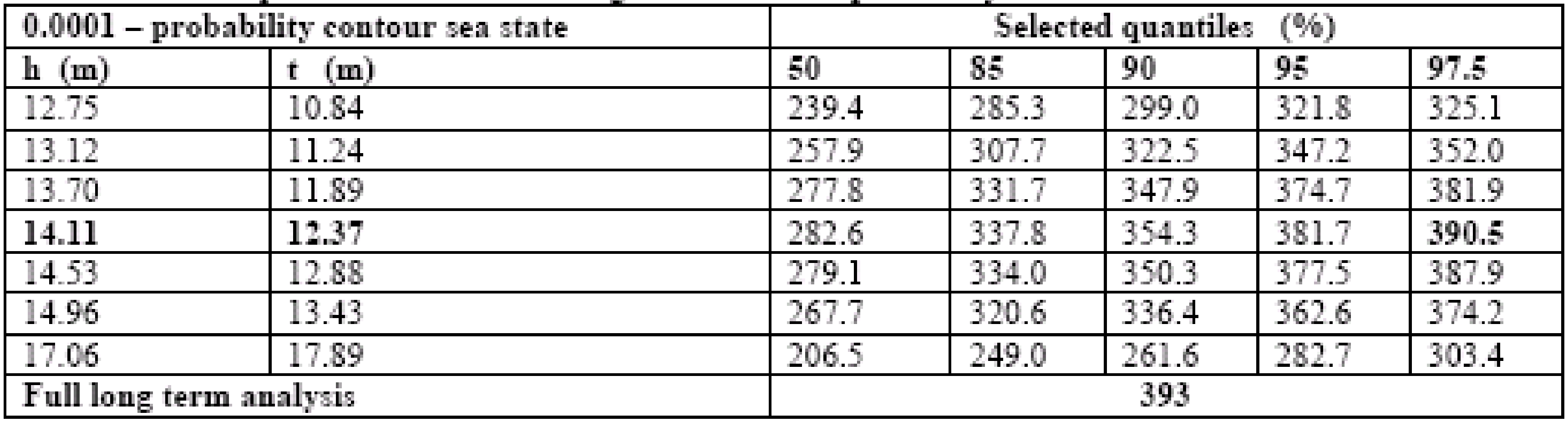


Table 5 Various quantiles for the worst range of the 0.0001- probability contour line

0.0001 – probability contour sea state		Selected quantiles (%)				
h (m)	**t (m)**	**50**	**85**	**90**	**95**	**97.5**
12.75	10.84	239.4	285.3	299.0	321.8	325.1
13.12	11.24	257.9	307.7	322.5	347.2	352.0
13.70	11.89	277.8	331.7	347.9	374.7	381.9
14.11	**12.37**	282.6	337.8	354.3	381.7	**390.5**
14.53	12.88	279.1	334.0	350.3	377.5	387.9
14.96	13.43	267.7	320.6	336.4	362.6	374.2
17.06	17.89	206.5	249.0	261.6	282.7	303.4
Full long term analysis		**393**				

Concluding remarks

Why focus on the very extreme weather events?

- Annual probability of structural failure should be smaller than say 10^{-4}

  Loads on this probability level are defined by weather conditions corresponding to annual exceedance probabilities of 10^{-5} – 10^{-3}.

- The adequacy of 10^{-2} - response and safety factor (ULS design control) is affected by whether or not the structural system is well-behaving.

- It is important to account for both the weather randomness and the conditional randomess of the short term response extreme value given the weather.

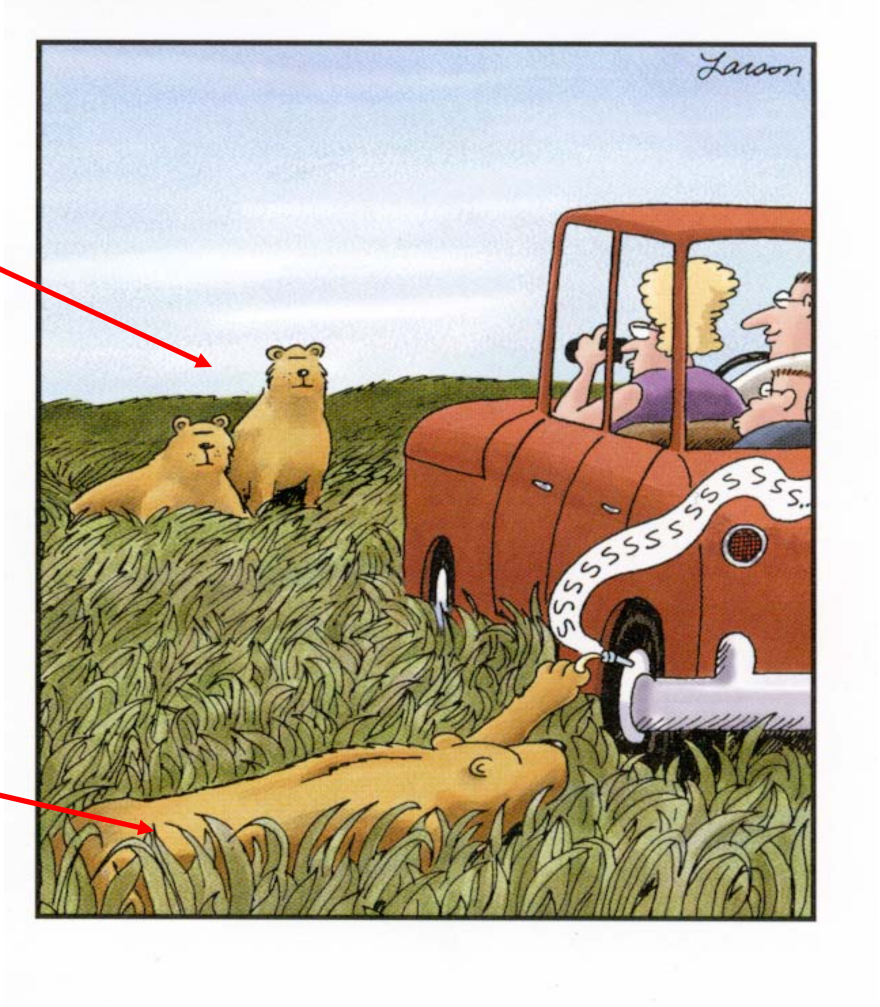
THE CHALLENGE:
ROBUSTNESS AGAINST THE UNEXPECTED

KNOWN THREAT
Dangerous – but can be controlled

Wave-parallel:
10^{-2} – probability sea states

UNKNOWN THREAT
Difficult to control in a rational way.

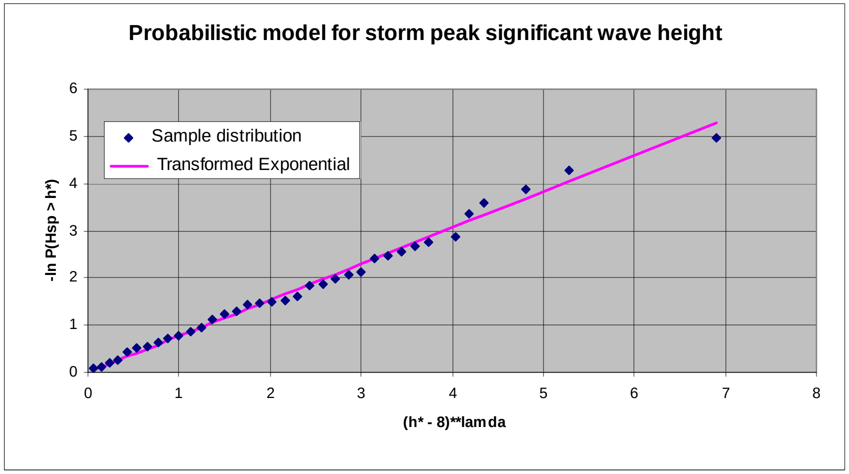
Wave-parallel:
How will 10^{-4} probability sea states look? How bad can it become?



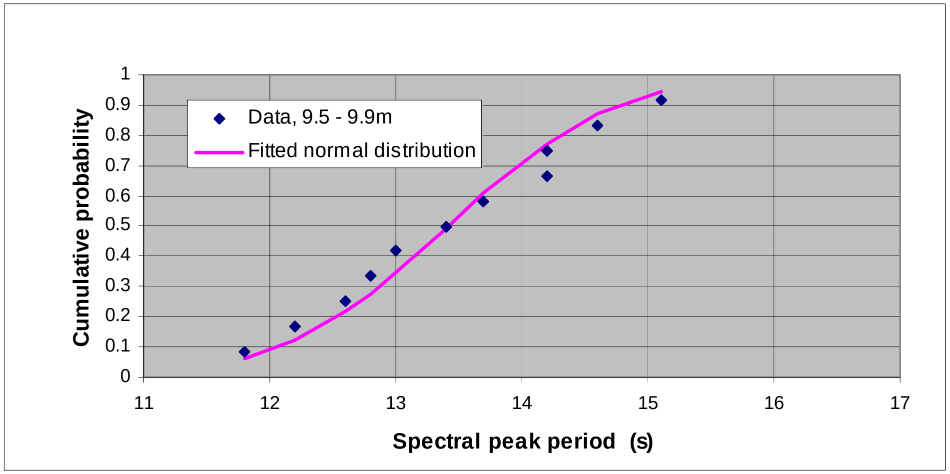
Example wave climate: Storms exceeding 8m significant wave height in the Northern North Sea

- Long term climate model: Truncated version of model proposed by Haver and Nyhus (1986)

- Contour line: Joint model for H_{sp} and T_{pp} fitted to storm peaks exceeding 8m during the period 1973 – 2006 (159 storms).



Marginal for H_{sp}



Conditional for T_{pp} given H_{sp}

Results of full long term analysis

$$F_{X_{3h}}(x)=\int_h\int_t F_{X_{3h}|H_s,T_p}(x|h,t)\,f_{H_sT_p}(h,t)\,dt\,dh$$

$$1-F_{X_{3h}}(x_{3h,q})=q/m_{3h}$$ **, where $m_{3h\_Haver\&Nyhus}(>8m) = 19.56$**

Annual exceedance probability, q	Response, x_q	Ratio: $x_{0.01}/x_q$
0.63 (1-year)	155	1.72
0.10 (10-year)	209	1.27
0.01 (100-year)	*266*	1.00
0.001 (1000-year	327	0.81
0.0001 (10000-year)	*393*	0.68