EXTREME WIND & WAVE LOADS

SITE-SPECIFIC COMBINATION OF DESIGN RULES

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Outline

- Introduction
- Methodology
- Results
- Conclusions

Introduction

- **Background**
  - Existing design practice for <u>individual</u> storm loads
    - » Onshore wind: 10 min, 50 year return period, γ_f = …
    - » Offshore wave: 3 hr, 100 year return period, γ_f = …
  - May these be combined to be applied to an OWT?
    - » Both wind and wave loads are dominant
    - » The same load safety factor
    - » Same level of reliability

- **Motivation**
  - Site-specific conditions
  - Refined compared to present standards

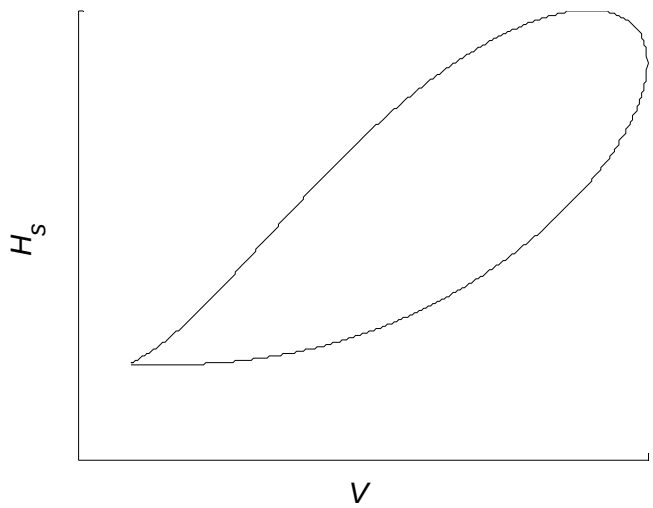
Former Results

- **Based on assumptions**
  - ISO 19002 uncertainty model, NE Regional Annex
    - » drag-dominated loads
    - » North sea environment
  - IEC 64100-1 uncertainty model
  - Reliability in agreement up to 0.25 difference in β
  - Simplified response models
    - » Minor dynamical amplification of wave loads

- **It was not rejected that one can use**
  - 50-yr return period environment for wind and waves
  - 10-min wind max combined with 3-hr wave max.
  - Same safety factor: 1.35

Methodology

- **IFORM**
  - Construct 50-yr return period environmental contour
  - This is structure independent
  - Search for max response along the contour
  - The point of max response gives the load combination



Stochastic Model

- **Distributions for wind, waves, uncertainties, etc.**

Name	Description	Type	Bias	CoV	Char. Value
$\tilde{H}^2_{\max}$	Annual maximum hydrodynamic load effect, pure drag, normalised by characteristic value	$\mathrm{Min}_3(k=1)$	1.00	31%	98%/ 99%
		Gumbel	1.00	*20%/ 30%*	
X_{Eh}	Model uncertainty, hydrodynamic loads	Gaussian, truncated at $\pm 1.5\sigma$	1.09/ *1.00*	10%	Mean
		Lognormal	*1.00*	*10%/ 15%*	
$\tilde{P}$	Annual maximum 10-minute mean wind load effect normalised by charac. value	Gumbel	1.00	32%	98%
X_{Ea}	Model uncertainty, aerodynamic loads	Lognormal	1.00	10%	Mean
$\tilde{T}$	Normalised extreme turbulent response	Gumbel	1.00	10%	Mean
X_{dyn}	Model uncertainty	Lognormal	1.00	5%	Mean
$\tilde{F}_{\mathrm{y}}$	Normalised yield strength	Lognormal	1.13	5%	5%
X_m	Model uncertainty	Lognormal	1.11	8.5%	Mean

- **Nataf's distribution**
  - Useful for e.g. mildly site-specific conditions

Response Model

- **Simplified response combination**

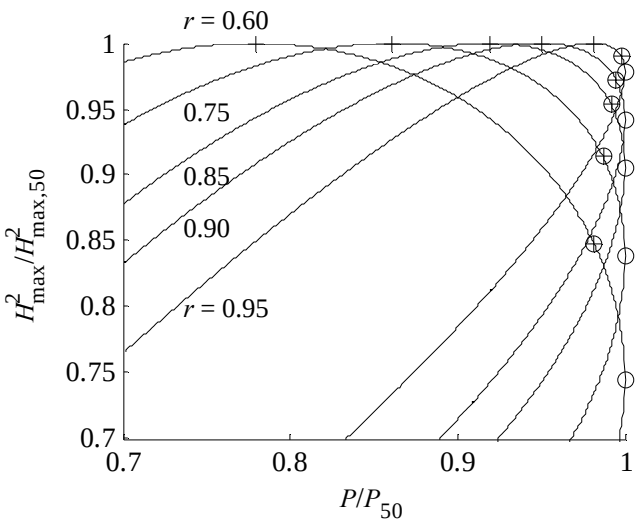
$$E_{\max} = \mu_{E_{\text{aero}}} + \sqrt{(E_{\max,\text{aero}} - \mu_{E_{\text{aero}}})^2 + E_{\max,\text{hydro}}^2}$$

- **Assumes**
  - Limited interaction, e.g. damping
  - Approximately the same zero-crossing frequency of wind and wave load response
  - Not too different distribution of response

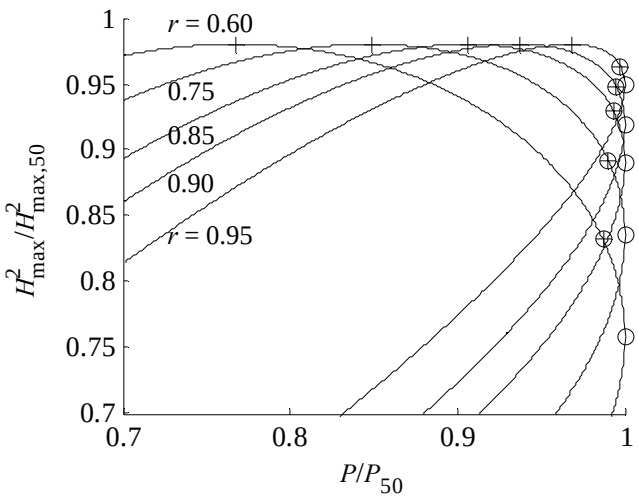
Results, no Time Delay, I

- **Environmental contours**

○ Pure wind load + Pure wave load ⊕ Fifty-fifty



P and $H_{max}{}^2$ Gumbel and shifted exponentially distributed



P and $H_{max}{}^2$ are both Gumbel distributed.

Results, no Time Delay, II

- **Return periods**

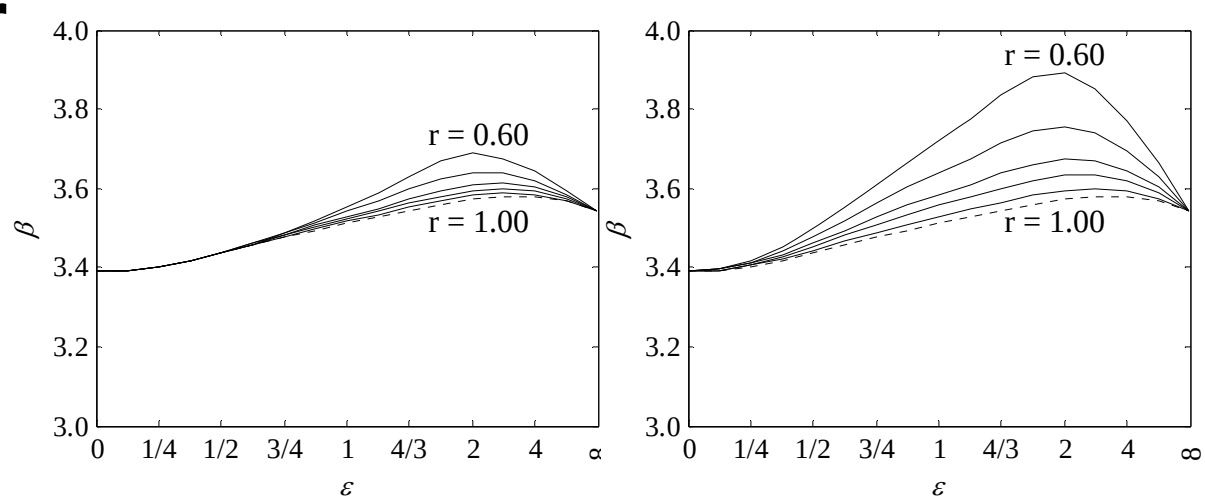
r	Wind		Fifty-fifty		Wave	
	P	H_{max}^2	P	H_{max}^2	P	H_{max}^2
0.60	50	10	45	20	10	50
0.75	50	18	46	25	18	50
0.85	50	26	50	35	26	50
0.90	50	34	50	40	34	50
0.95	50	42	50	45	42	50
1.00	50	50	50	50	50	50

Reduction of loads:
15 yr: 20%
25 yr: 10%
35 yr: 5%

Note: this is also return periods for V and H_s

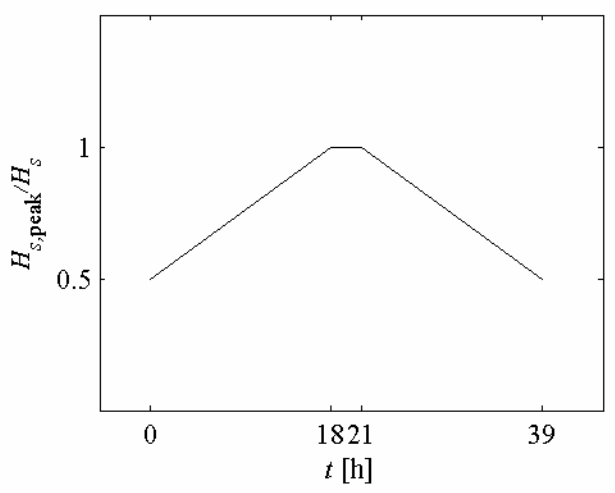
- **Safety factor**

1.35



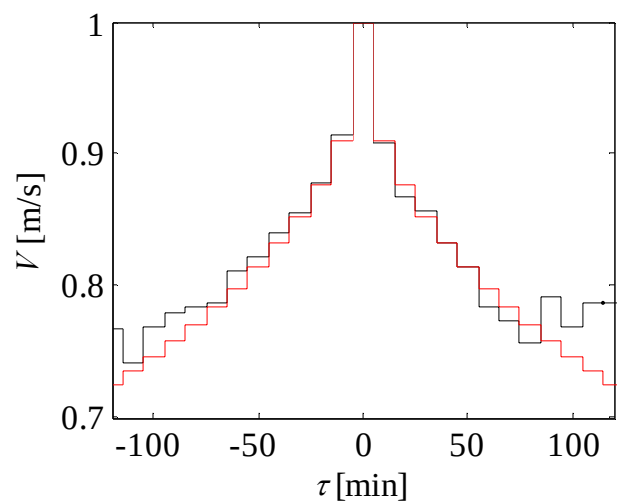
Time Delay

- **Generic storm profiles**



NORSOK wave storm profile

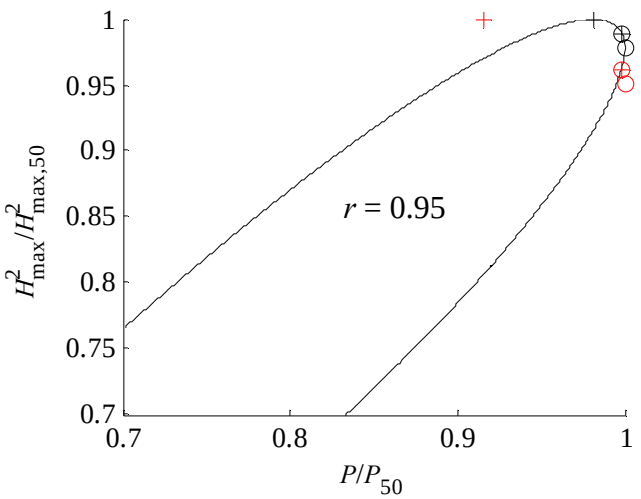
$$s(\tau) = 1 - 0.09\left(\frac{\tau}{10\ \text{min}}\right)^{0.45}$$

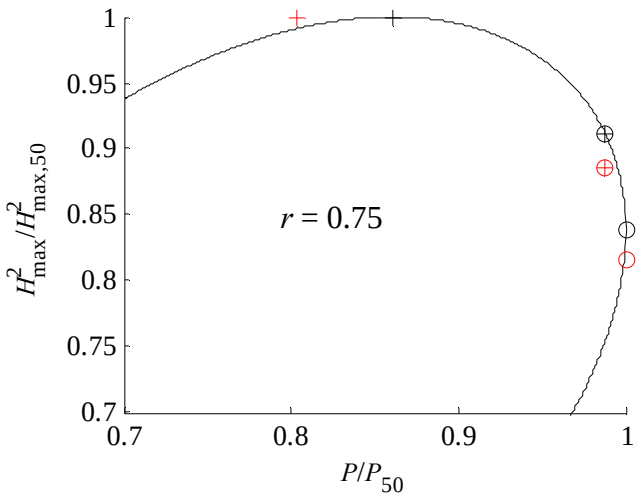


Storm profile from Sprogø

Results, Time Delay

- **2 hr delay**





Conclusions

- **Proposed combination rule for mildly site-specific conditions**
  - Get marginal distributions, correlation and delay
  - Determine reduced return periods
  - Combine 10-min wind max. with 3-hr wave max.
  - Use load safety factor 1.35.

  - Maximal reduction of loads from time delay

- **Future needs**
  - Procedures and distribution models for significantly site-specific environmental conditions