SUPERGEN Wind

Wind Energy Technology

Wave Loading on Wind Turbine Sub-Structures

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SUPERGEN Wind Energy Technologies Consortium Phase 2

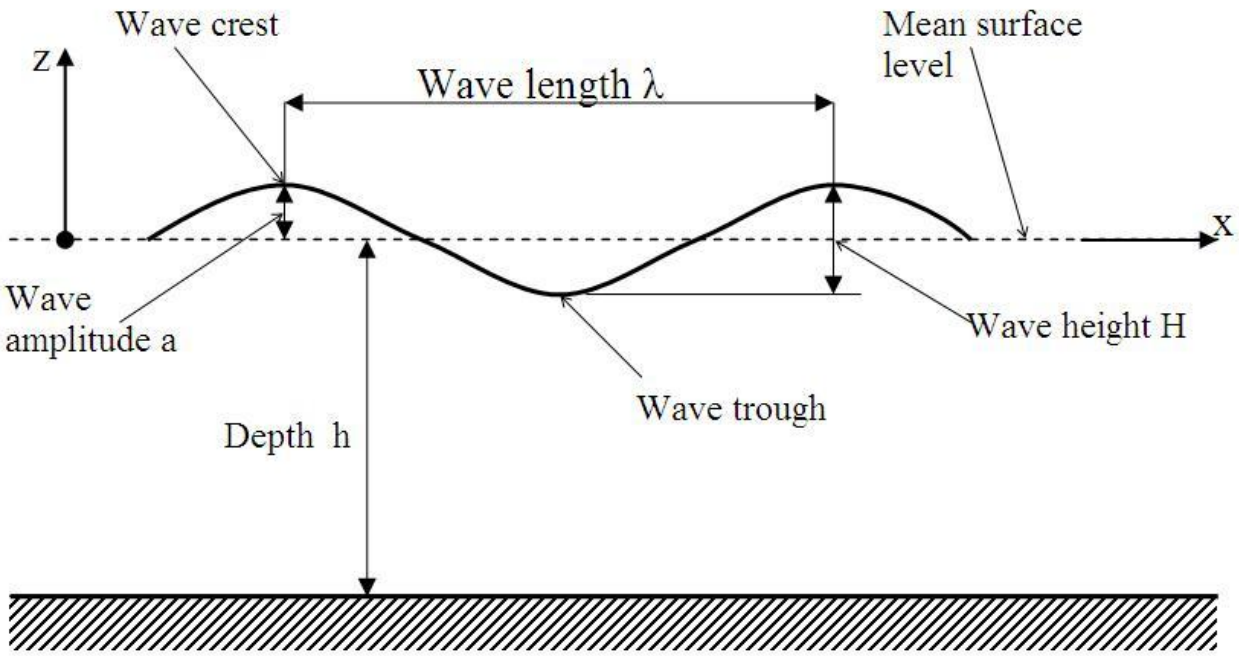
3rd Training Seminar, Loughborough University

12th -13th September 2011

Contents

- Waves
- Wave climate
- Wind turbine support structures
- Wave loading on wind turbine support structures
- Summary

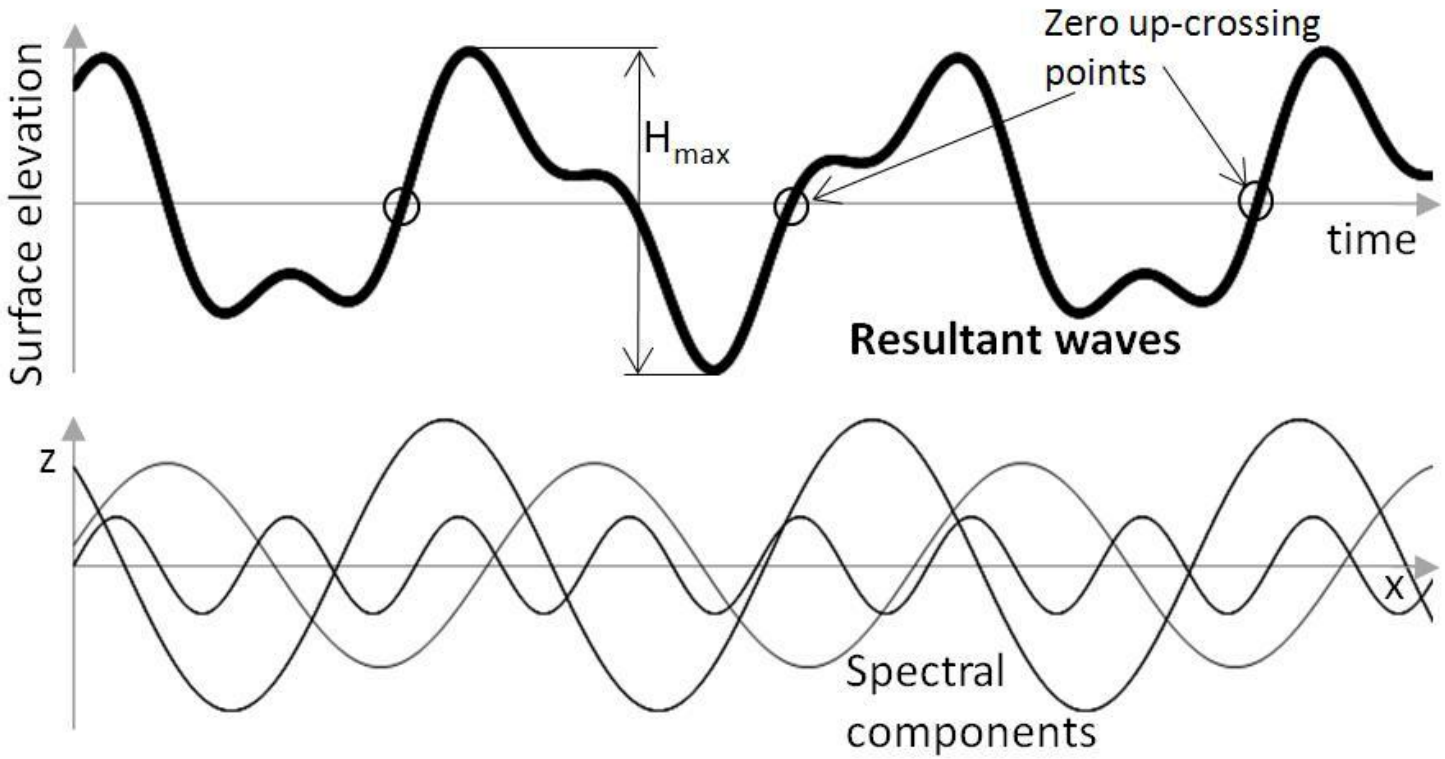
Waves



Sinusoidal progressive linear wave train

- This type of wave is very rare in the real ocean

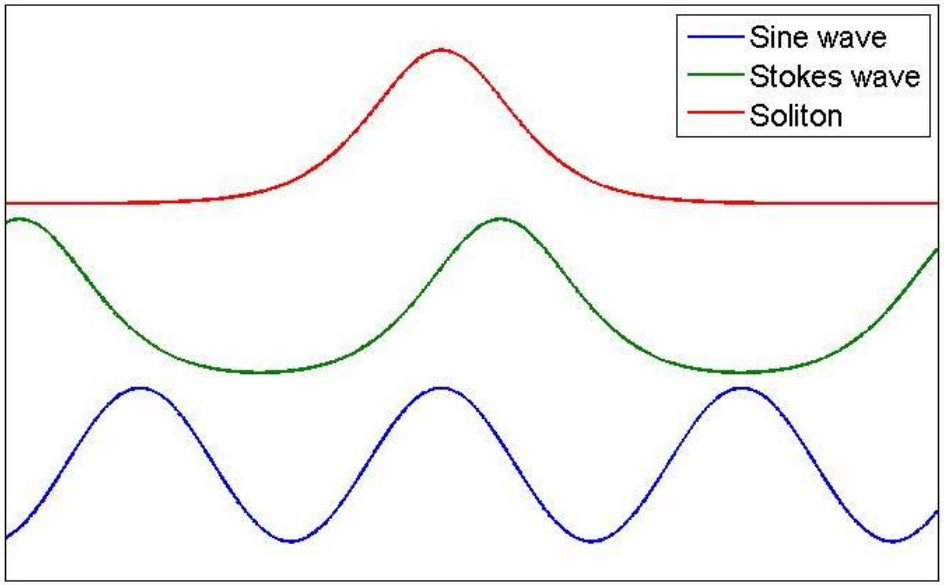
Waves



– Slightly more realistic, but still uni-directional and linear

Waves

- Jacobian elliptic functions provide an alternative to sinusoids, called cnoidal waves



Source: Osbourne (2011)

Waves

In general waves are non-linear and quasi-random

Photo: Margrith Ettlin, Alfred Wegener Institute

Waves

- Wave generation
  - Lee-side sheltering
  - Lee-side turbulent boundary layer thickening
  - Wave induced air pressure fluctuations
- Wave transformation
  - Refraction
  - Diffraction
  - Interaction
  - Shoaling

Waves

- Wave energy dissipation
  - White capping
  - Wave-wave interaction
  - Breaking
  - Wave induced motion of movable bed
  - Turbulent shear stress in bottom boundary layer

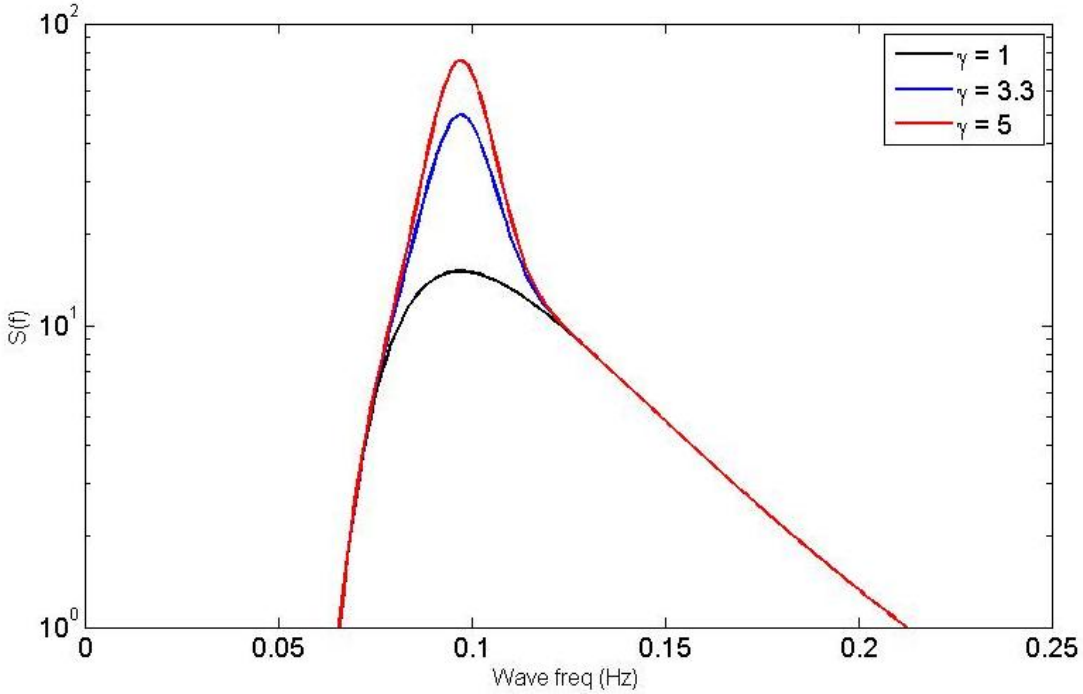
Source: http://fartheroutnearerto.wordpress.com/2010/08/17/

Source: Wikimedia commons

Waves

- Statistical analysis is required to describe real seas
- JONSWAP spectrum designed for the North Sea

$$S(f) = 0.0749\ H_s^2\ T_z\ (T_z f)^{-5}\ \gamma^q\ exp[-0.4567\ (T_z f)^{-4}]$$



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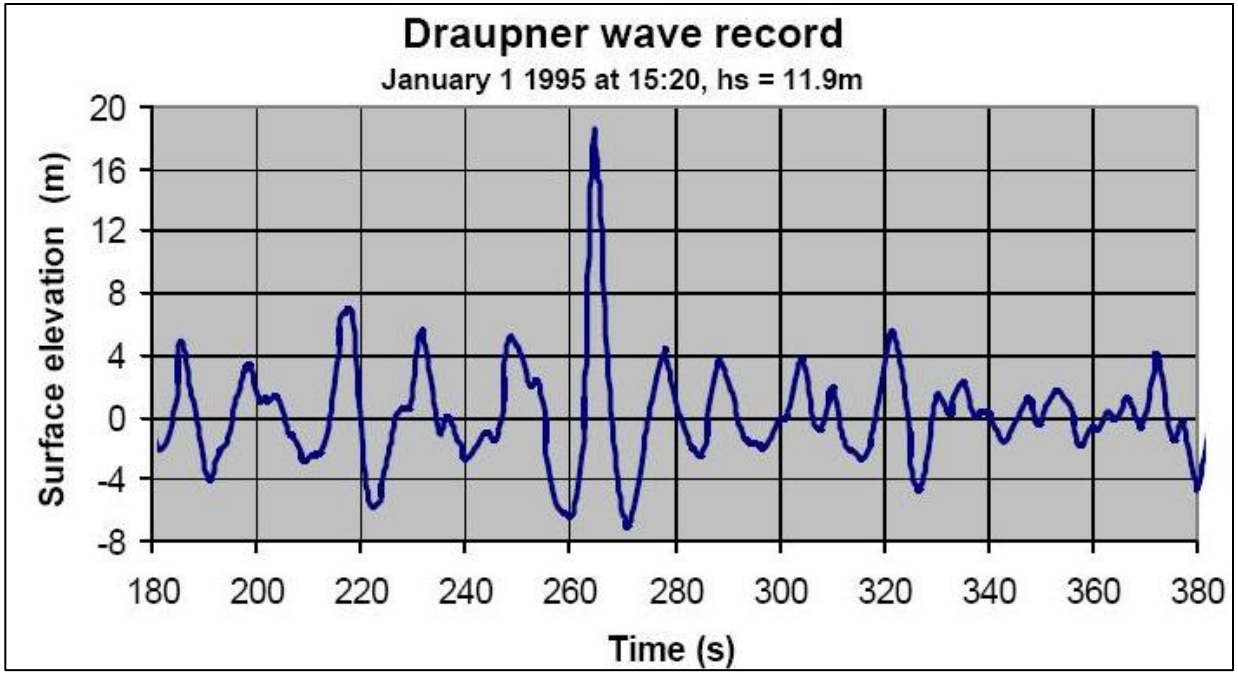
Waves

Rogue waves

– More than twice the significant wave height



Source: http://griger.blog.sme.sk/c/102744/Extremne-vlny.html
Accessed 2/09/11

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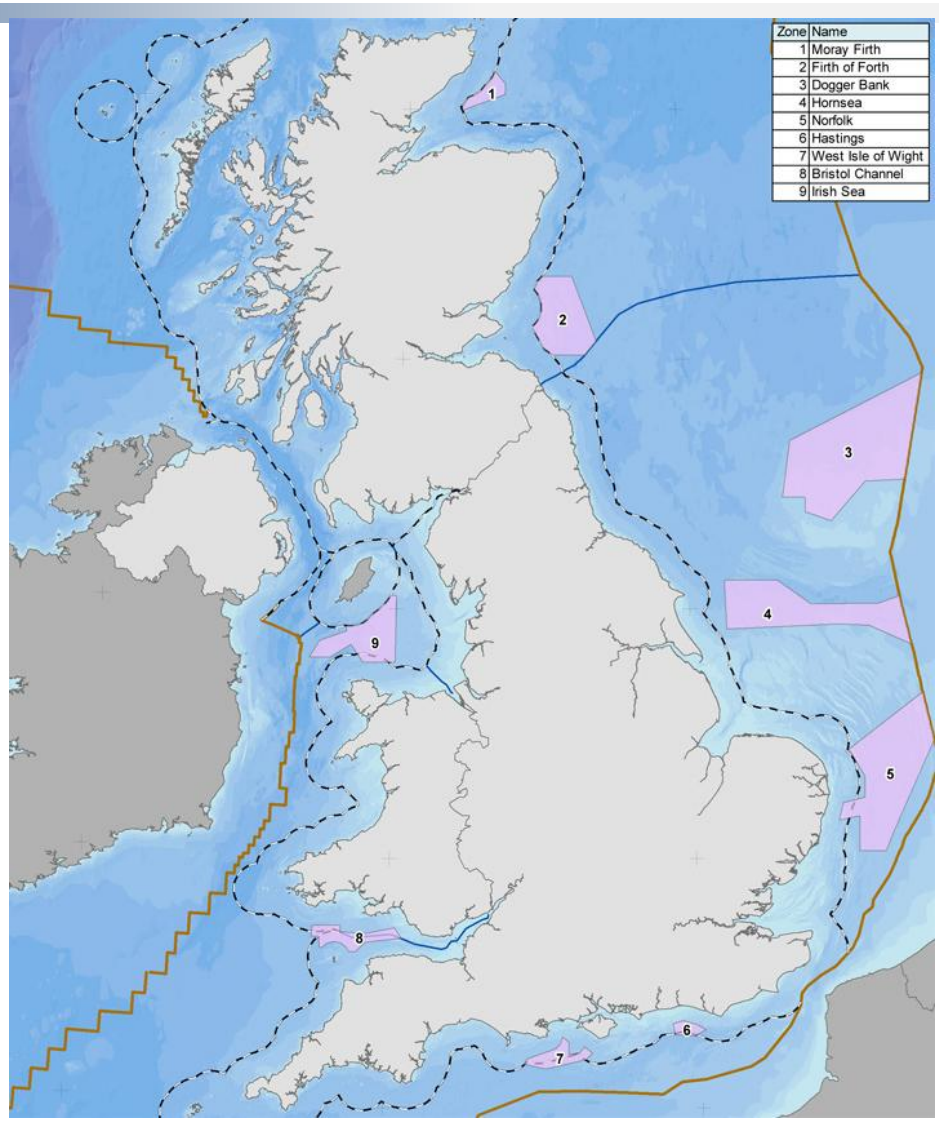
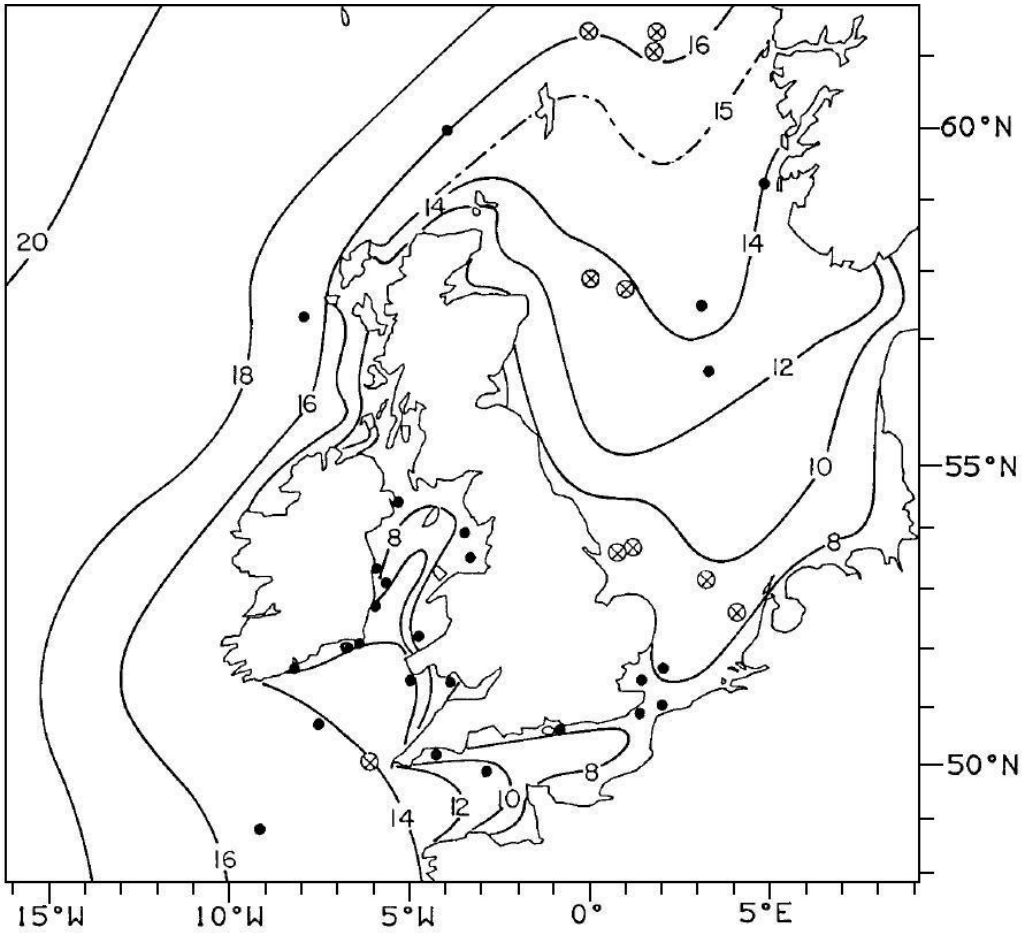
Wave climate



Source: Crown Estate (2010)

Wave climate



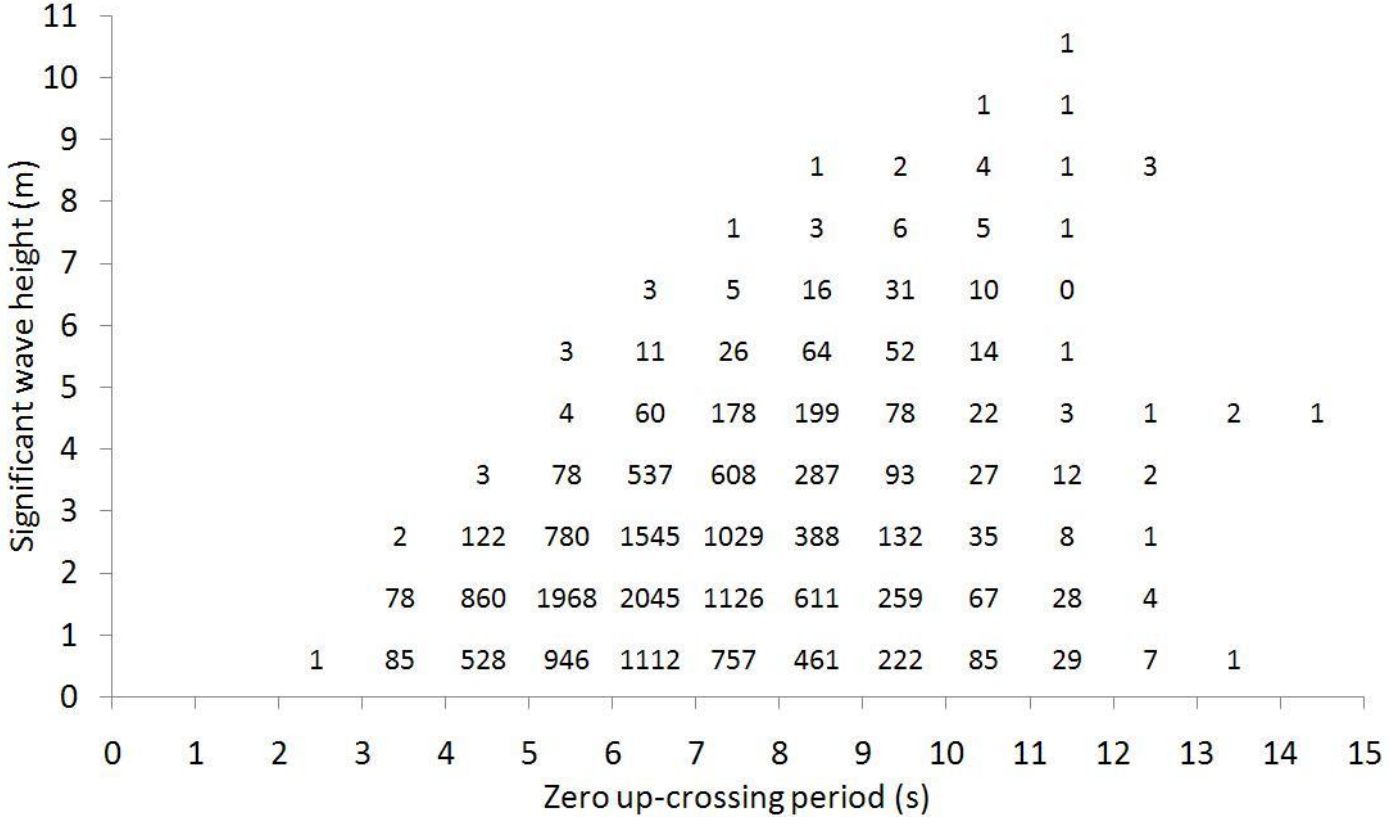
$$H_{50} \approx 1.86 H_{S_{50}}$$

$H_{S_{50}}$ (m)	H_{50} (m)
8	14.9
12	22.3

Source: HSE (2002)

Wave climate

Wave climate at St Gowan light vessel for around 7 years between 1970 and 1985



Data source: (BODC, 2011)

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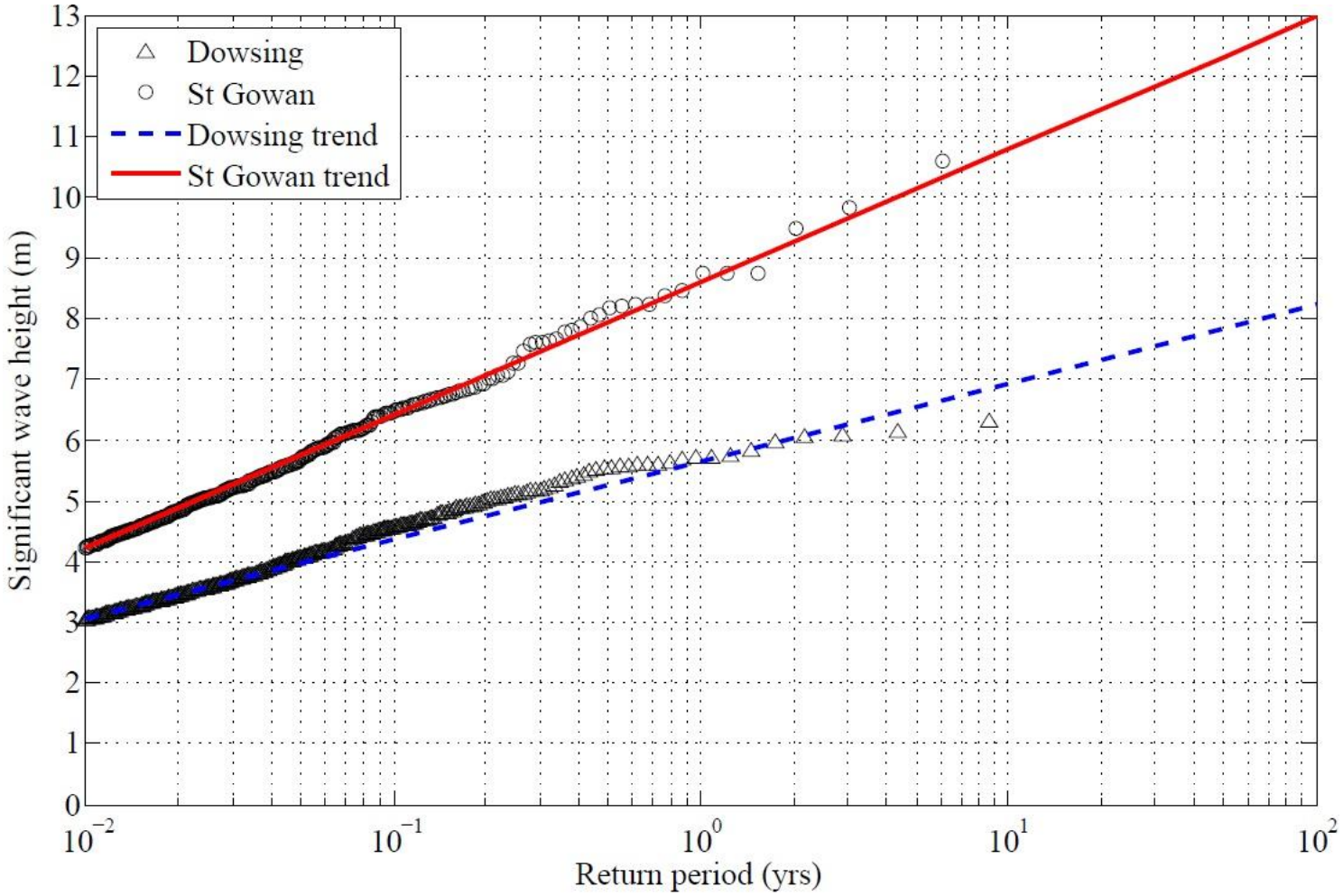
Wave climate



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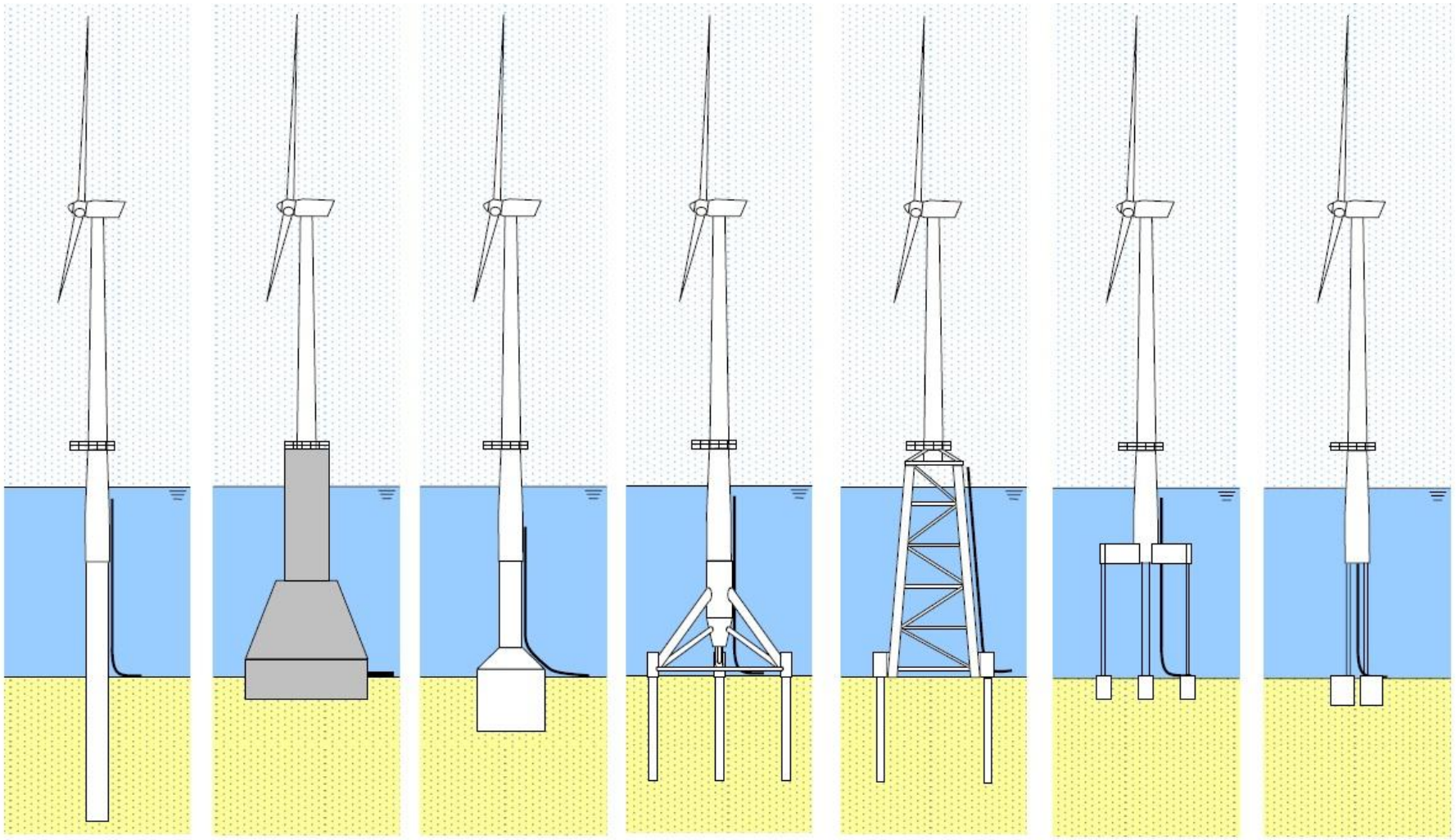
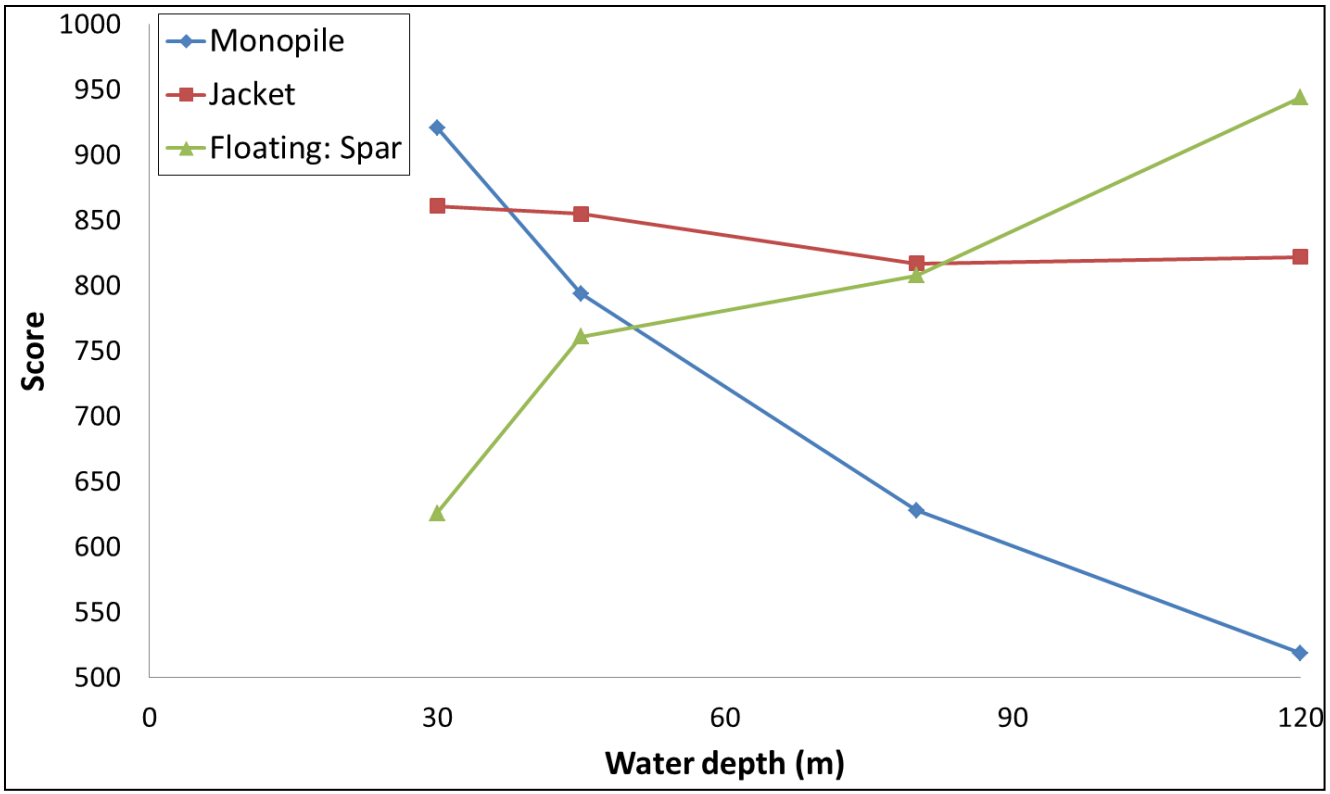
Wind turbine sub-structures



Source: de Vries et al. (2007)

Wind turbine sub-structures

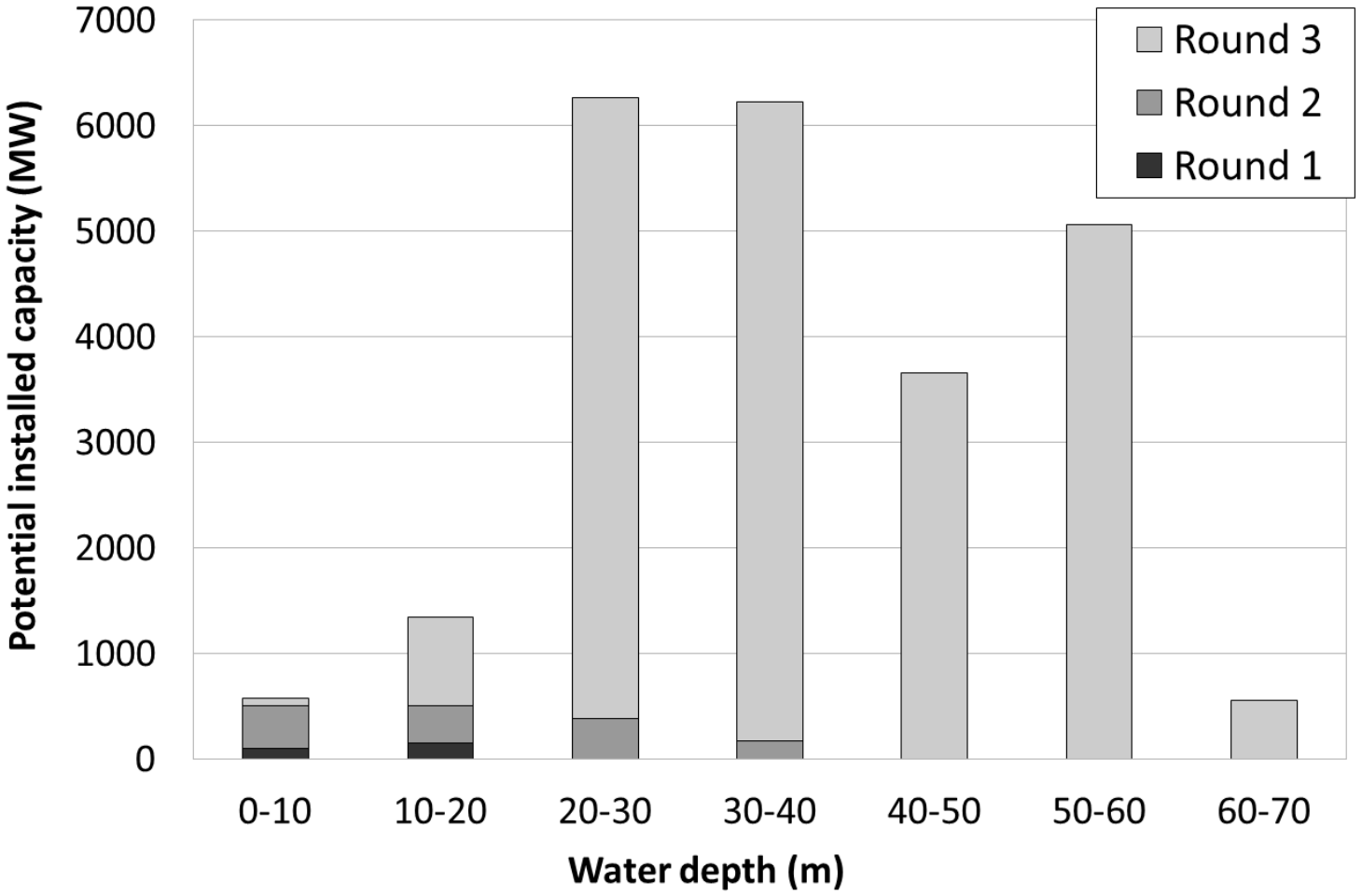


Suitability of different structures with water depth.

Assessment based on site conditions, design factors, fabrication, installation, maintenance and decommissioning.

Source: de Vries, W. et al. (2007)

Wind turbine sub-structures



Source: Carbon Trust OWA (2009)

Wind turbine sub-structures

Source: Wikimedia commons

Source: Talisman Energy

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Wave loading on wind turbine support structures

- Morrison equation

$$F = \frac{1}{2} C_D \rho A u |u| + \rho C_M V \frac{\mathrm{d}u}{\mathrm{d}t}$$

Morison et al. (1950)

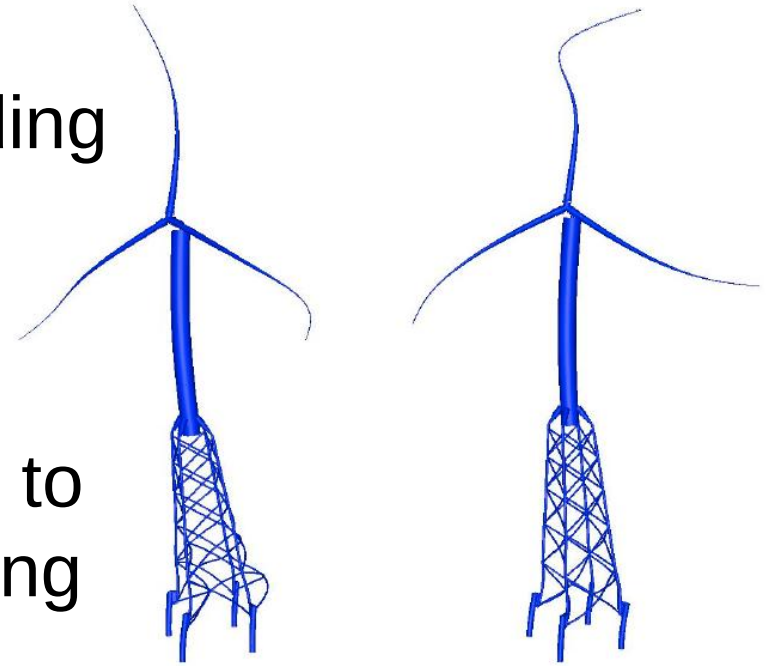
  - C_D and C_M determined empirically

- Slamming force $F_s = \frac{1}{2} \rho C_s D \lambda U^2$ Prasad (1994)

- Buoyancy force $F_b = \rho g V_s$ Sarpkaya and Isaacson (1981)

Wave loading on wind turbine support structures

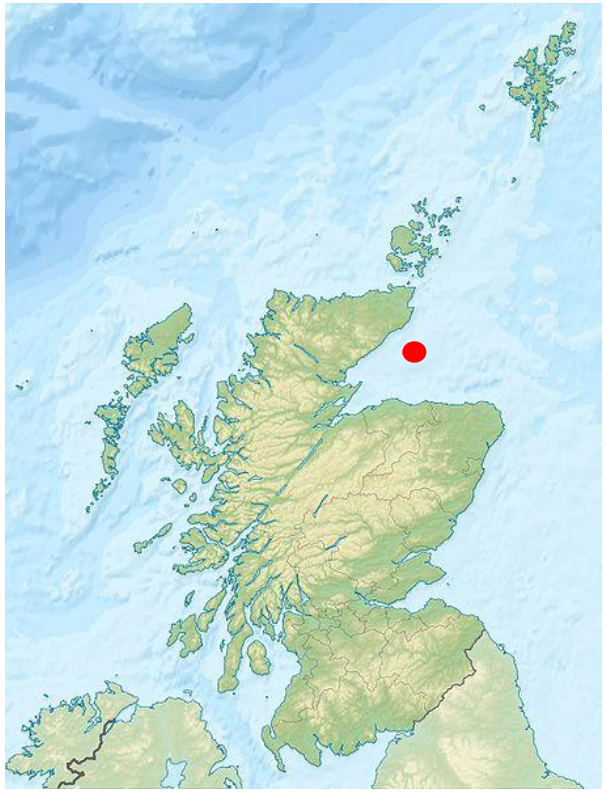
- Wave loading frequencies may approach global bending frequencies
- Local high frequency resonances may build due to vortex shedding or slamming loads
- Wind – wave – structure interaction



Source: Seidel and Ostermann (2009)

Wave loading on wind turbine support structures

Beatrice project case study



Source: Wikimedia commons

Source: offshorewind.net

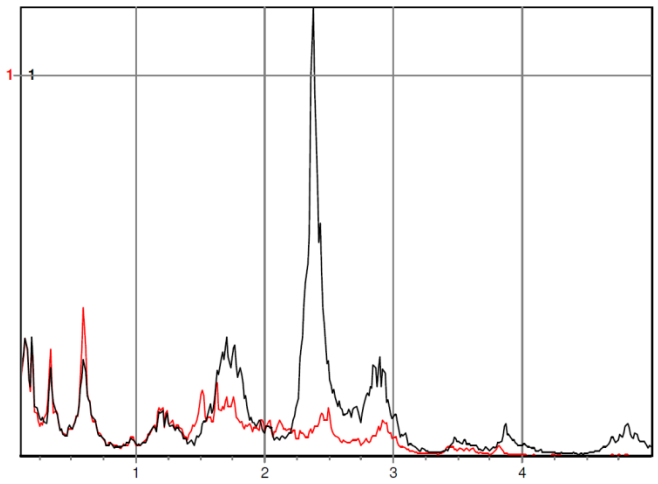
Wave loading on wind turbine support structures

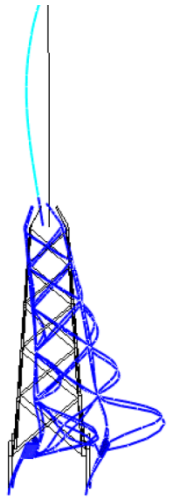
Beatrice project case study (Seidel and Foss 2006)

Turbine start-up frequency increased to 8.5 rpm

- First global mode at ~0.33 Hz
- Rotor speed 6.9 to 12 rpm => 0.115 to 0.200 Hz

  Blade frequency => 0.345 to 0.600 Hz





Source: Seidel and Ostermann (2009)

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Summary

- Waves are complex and some processes are still poorly understood
- Statistical analysis allows a local wave climate to be established
- Sub-structure choice is location dependant
- Wave loading analysis must consider the whole structure and interactions with wind and currents

References and sources

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