WSI Challenges in Offshore Wind

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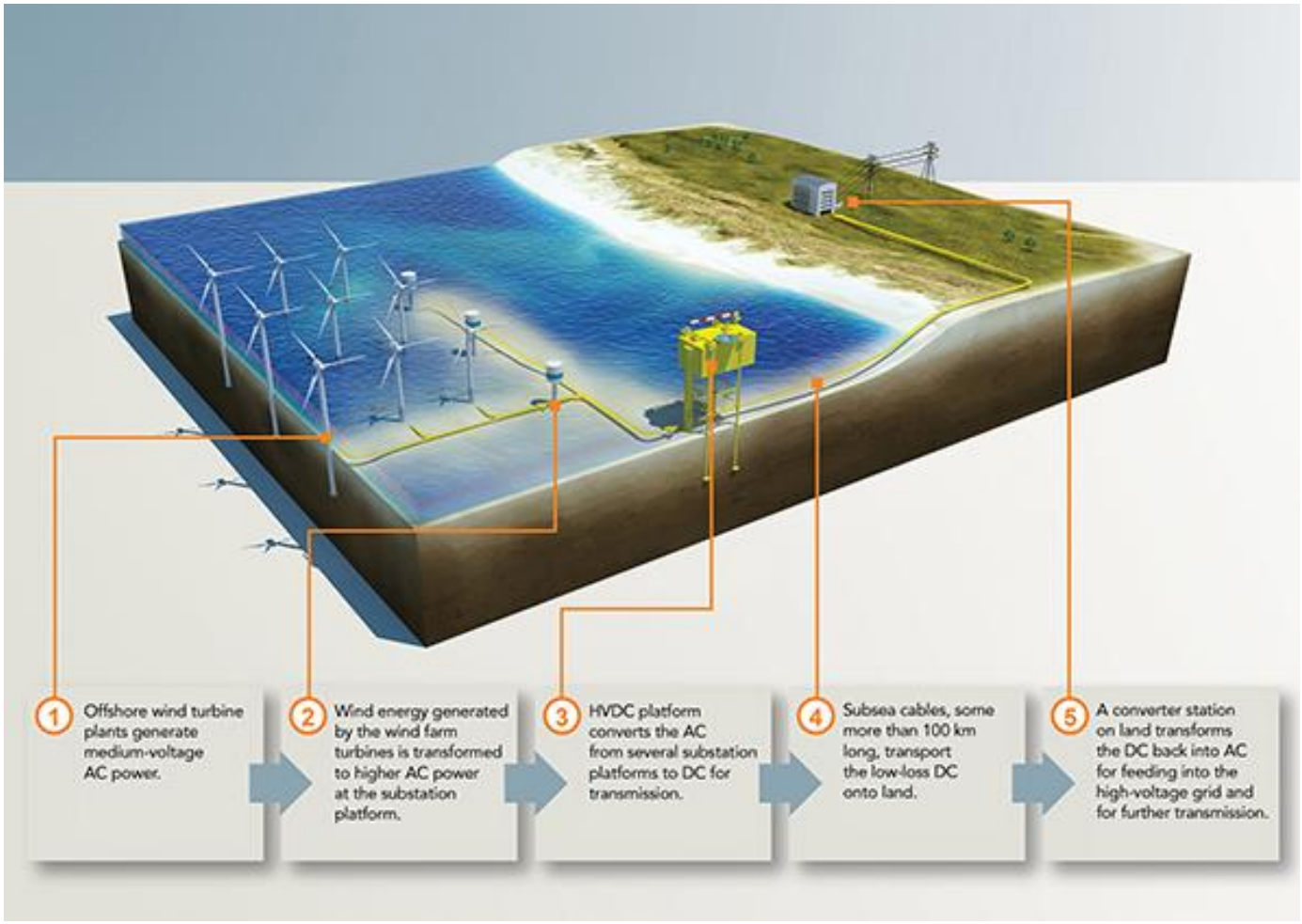
Environmental conditions

- Bathymetry highly variable
  - Sandbanks influence local wave/tidal conditions but probably stable over asset lifetime
  - Sandwaves have less influence but mobile over asset lifetime
  - Conditions can vary widely over the project area

- Waves in intermediate/shallow water depths
  - Irregular wave kinematics less well understood
  - Possible wave breaking
  - Refraction/shoaling over sandbanks

Anatomy of an offshore wind farm



(Image from Transmission & Distribution World article: Germany Increases Role of Offshore Wind, Dec 2014)

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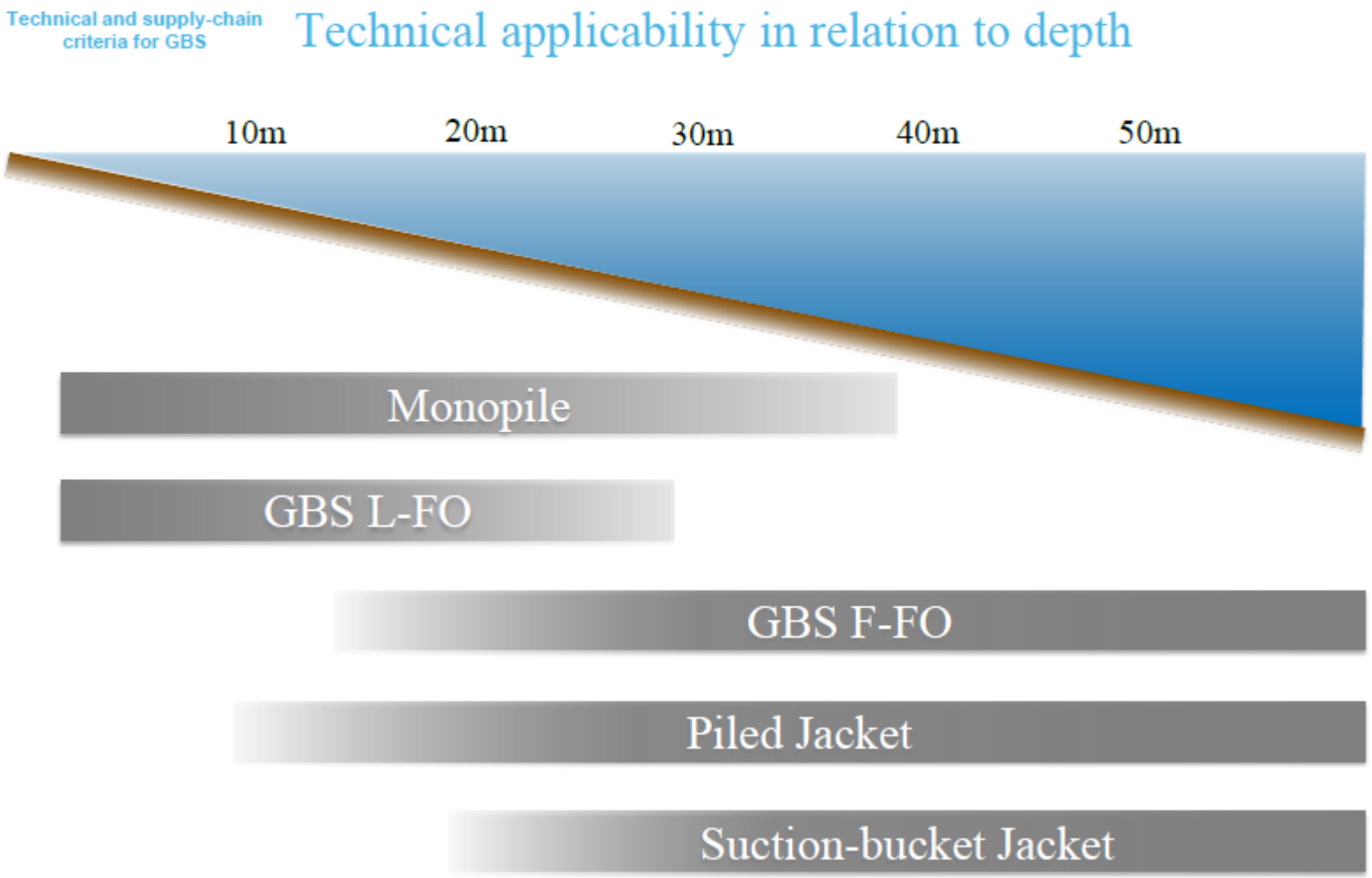
Turbine/substation foundation technologies



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WSI Challenges for Monopiles

- Industry perception that wave loading on slender structures is well understood.
- This is largely true for quasi-static response
  - Design wave analysis using high order regular waves & Morison's equation
  - Doesn't really deal with higher order harmonics but doesn't matter anyway
- Not the case for dynamic response
  - Ringing & Springing
  - Stochastic analysis using linear/second order wave theory & Morison's equation
  - **Representation of WSI is poor and it matters**

Industry guidance from DNV-OS-J101

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4.5.4.9 For evaluation of load effects from wave loads, possible ringing effects shall be included in the considerations. When a steep, high wave encounters a monopile, high frequency nonlinear wave load components can coincide with natural frequencies of the structure causing resonant transient response in the global bending modes of the pile. Such ringing effects are only of significance in combination with extreme first order wave frequency effects. Ringing should be evaluated in the time domain with due consideration of higher order wave load effects. The magnitude of the first ringing cycles is governed by the magnitude of the wave impact load and its duration is related to the structural resonance period.

Guidance note:

Ringing can occur if the lowest natural frequencies of the structure do not exceed three to four times the typical wave frequency. In case the natural frequency exceeds about five to six times f_p, where f_p denotes the peak frequency, ringing can be ruled out. When a dynamic analysis is carried out, any ringing response will automatically appear as part of the results from the analysis, provided the wave forces are properly modelled and included in the analysis.

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Assessment of Ringing response

- State of the art analytical models
  - FNV model with second order diffraction/radiation solution
  - Computational Fluid Dynamics
- So far none of the “cheap” models have been shown to accurately predict either the magnitude or the phase of the higher order harmonics in the applied loads
  - No point doing rigorous statistics on data from a malfunctioning physics model
  - Can’t even use it for screening as wave kinematics are not compatible with fully non-linear methods
- CFD is a reliable method for calculating the applied loads but need to know what a design event looks like
  - End result is generally wave tank testing if extreme dynamic response is critical

WSI Challenges for Jackets

- Jackets usually stiff enough to avoid dynamic effects
- Wave loading not really an issue
  - Design wave assessment with Morison's equation
  - Analytical methods available for above waterline impulsive loads
  - Possibly some scope to challenge basis for incident wave kinematics due to water depth
- Scour assessment for multi-legged structures is difficult
  - Limited industry guidance other than "it should be assessed"
  - Can be a critical parameter for suction bucket foundations

WSI Challenges for Gravity Bases

- Wave loading on large volume structures typically assessed using linear diffraction/radiation solution
  - Many reasons why this may not be appropriate in intermediate/shallow waters
- CFD overcomes most of these limitations
  - Already in use as a design tool
  - Breaking waves probably the main challenge left to solve
- Scour assessment also difficult
  - Scour protection usually required in sand
  - Probably not needed in clay

WSI Challenges for Substation Platforms

- Subject to all the same issues as turbines for foundation design
- Additional requirement for air gap assessment
  - Need to show 1m air gap for 100 year crest elevation
  - Minimum air gap 20% of 50 year Hs
- If criteria not met platform needs to be assessed for wave in deck loads
  - Some simplified methods available (Kaplan's method) but not clear if these are acceptable basis for design
- Wave tank experiments can often be required to verify air gap and/or assess wave in deck loads

WSI Challenges for Rock Blankets/Berms

- Rock blankets are a popular concept for primary scour protection
- Rock berms frequently required along the transmission cable routes
- Both are technically “structures” and need to be designed against extreme wave loading
  - Designing to withstand extreme sea states leads to large diameter rocks, can be undermined by secondary scour
  - Possible move towards designing “dynamic” structures, which are gradually degraded over the asset lifetime
  - Need better methods to reduce uncertainty over maintenance costs

Summary points

- Dynamic response of Monopile foundations is a significant issue but depends on sensitivity of structure
- Air gap assessment of substations also potentially of interest – this issue is also of relevance to O&G industry
- Assessment of wave slam loads can be of importance for all structural concepts – both quasi-static and dynamic response
- Scour is a **big** issue across the board and predicting impact of extreme storms on rock armour is not a well developed science

Questions?