Foundation Design of Wind Turbines - Onshore

- Dynamic Analysis (Frequency and fatigue Checking)
- Seismic Analysis
- Soil-Foundation-Turbine Interaction Analysis
- Foundation Design (ULS, SLS, FLS)
- Selection of Foundation Type? (e.g. Gravity, Raft, Piled)
Foundation Design of Wind Turbines - Offshore

- Dynamic Analysis (Frequency and fatigue Checking)
- Complicated Installation and Maintenance
- Access Platform/Boat Landing (Secondary Structures)
- Transition Piece (Grout/Flange Connection)
- Corrosion/Marine Growth
- Foundation Design (ULS, SLS, FLS)
- Offshore Geotechnics (Specific GI planning)
- Seismic Analysis
- Wave Fatigue Analysis
- Hydrodynamic Analysis
- Current/Wave Loadings (Breaking Wave?)
- Scour (Scour protection?)
- Soil-Foundation-Turbine Interaction Analysis
- Selection of Foundation Type? (e.g. Gravity, Monopile, Tripod, etc.)
Offshore Foundation Types

Drag anchors  Suction anchors  Torpedo anchors

Source: B. Byrne Geotechnique Lecture
Concept Development – Finding the Best Solution

• Consideration of technical, financial, business planning and project management to realize viable offshore wind development solutions.

• Use of efficient Offshore Wind Foundation screening tools to identify the most promising foundation solutions
Monopiles

• Current industry preference is for monopiles in up to 30m water depth

• Typically up to 6m diameter but up to 11m diameter monopiles commercially available

• Relatively simple design

• Overall vibration and deflection are subject to large cyclic lateral loading and moments due to current and wave loads.

• Need for transition piece to level the mast above
Monopiles – XL – Going Bigger and Deeper

• Wind farm installations are moving further offshore and bigger turbines are being developed
  ➢ Deeper water
  ➢ Deeper penetration
  ➢ Larger diameter
  ➢ Heavier
  ➢ Increased waves

• Advanced geotechnical and hydrodynamic engineering

• Future wind farms will demand innovation to reduce costs while managing the overall risk new concepts
Pre or Post Pile Jackets

- Suitable for deeper water in excess of 20m to 50m and rough sea conditions but can also work in shallow water
- Lower wave loads compared to monopiles
- Challenges to ensure pile location is accurate and well connected
- Fabrication expertise widely available
- Higher construction costs and potentially higher maintenance costs

courtesy of Alamy
Suction Buckets

- Used in O&G for many years with high capacities

- Key advantages for offshore wind turbines
  - suitable for weaker soils
  - no pre-drilled piles
  - faster and easier installation and removal
  - shallower penetration necessary

- Can lead to significant LCOE savings

- Efficient use requires key expertise in geotechnical engineering and soil structure interaction.
WindACE – Self Installing Mast

Suction bucket foundations installed by upending complete turbine and foundation assembly
Concrete Gravitas Foundation

A simple solution for offshore wind turbine foundation funded by UK Department of Energy & Climate Change:

- No heavy lifting
- No special vessels
- Minimized seabed preparation

Typical Principal Data:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tr>
<td>Turbine</td>
<td>6 MW</td>
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<tr>
<td>Water depth</td>
<td>35 m</td>
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<tr>
<td>Hub height</td>
<td>90 m</td>
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<td>Outer diameter, caisson</td>
<td>31 m</td>
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<tr>
<td>Concrete volume</td>
<td>2,800m³</td>
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<tr>
<td>Steel reinforcement</td>
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An innovative foundation design can also be found for Japan...
Floating Concepts

• Many different solutions being developed

• Largely supported by national or international research and development through demonstration funding programmes

• Poised to move to true commercialization very soon

• Generally more expensive than other systems due to the deep water conditions and high technology but costs are coming down as technology improves
Cost Challenge in Deep Water

Manufacturing cost models for 5 MW turbine foundations (various sources)
LCOE Floating and Fixed vs Water Depth

Turbine Foundation Design Approach

- 20 year design life

- Detailed load combinations to consist of both ultimate and fatigue load conditions

- Control natural frequency of entire turbine and substructure to be within specified ranges provided by turbine supplier

- Control deflection and rotation at interface level to be within acceptable limit specified by turbine supplier (0.5 degrees)

<table>
<thead>
<tr>
<th>Frequencies 频率</th>
<th>1 p (Hz)</th>
<th>3 p (Hz)</th>
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<tr>
<td></td>
<td>0.17 – 0.27</td>
<td>0.51 – 0.81</td>
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Advanced Analysis and Parametric Studies

• More powerful computing power and interactive programming tools enable:

➢ Advanced analysis be adopted and completed in a reasonable time scale

➢ Optimisation through parametric study

➢ Automotive design of repetitive tasks

➢ Better visualisation and 3D simulation
Soil Model Development

Material models used in-house:

- Simple model
  - [Linear elastic]
  - Mohr Coulomb
  - Brick Model
  - MAT-hysteretic
  - Nor-Sand

- Advanced model
  - Sanisand LSDyna 3D

Model calibration:
- Drained/undrained monotonic triax tests
- Undrained cyc triaxial test

Graph showing shear stress vs. shear strain for different models:
- **Loose Model (Dr = 35%)**
- **Medium Dense Model (Dr = 63.5%)**
Effects of Wave Ringing

- “Pure” ringing is a result of wave scattering from the surface of the structure, resulting in a resonant excitation of the first bending mode.
- In practice, impulsive loads from wave slamming may act in combination to amplify the effect.
- A failure to consider dynamic structural response can result in significant under-prediction of extreme wave loads.
- Scale tests or computational fluid dynamics offers a solution.
Why are Wind Turbine Monopiles Becoming Vulnerable?

* Parameters from UK HSE, Research Report 468, Non-linear potential flow forcing: the ringing of concrete gravity based structures, Tromans, P., Swan, C., Masterson, S.
Thank You