Offshore Wind Structures: Gambling With Grout – Worth The Risk?
The Engineering Integrity Society - 4th Durability & Fatigue Advances in Wind, Wave and Tidal Energy BAWA, Filton, 28th January 2016

Dr. Chris Golightly GO-ELS Ltd.
Geotechnical & Engineering Geology Consultant
Presentation Contents

Differences; Oil & Gas Platforms – Wind Turbines
Foundation Concepts 2012 – 2020 [Berger 2013]
Types of Turbine Foundation for OWT
History of Monopile [MP] Connections
Advantages and Disadvantages
Applications & Factors Affecting Ultimate Strength (Refs. 1 & 2)
DNV OS J101 Design Code & Shear Keys (Refs. 5 to 7)
Offshore Wind - Brittle High Strength Grouts
Monopile Vs Tripod/Jacket Loading
RWE Gwent Y Mor Grouting Study (Ref. 8)
JIP Conical Connections
Trelleborg Elastomeric Spring Bearings (Refs. 3, 4 & 11)
Pile Swaging & Slip Joints (Ref. 19)
Integral and External Mating
Quick Coupling; Integral MP & TP
Fatigue Life; OWI-LAB BELWIND (Refs. 3 & 4)
Conclusions, References, Contact Details

Differences; Oil & Gas Platforms – Wind Turbines

Oil & Gas Platforms

- Relatively stiff structures, usually founded on long driven piles and mudmats
- Axial loads dominate due to high structure weights
- Structural dynamics are not critical with weight >>> bending moments
- Wave loads tend to dominate design in high energy areas such as North Sea
- Straightforward Force – Response relationship
- Each design is one-off “Prototype” at a single location

Offshore Wind Turbines

- Relatively flexible towers on variety of foundation types, monopiles 4 to 9 m diameter, tripods/4 leg jackets, GBS.
- Structural dynamics always critical. 3P Eigenvalue resonance
- Bending moment and lateral response more important than axial load
- Wind and wave loads both very important
- Complex uncorrelated/uncoupled loading
- Large Nos. of OWT in arrays (80 [German AV Tripods] to 2000 [FOREWIND Statoil UK])

## Offshore Wind Foundation – Definition. The “Sub-Structure”

<table>
<thead>
<tr>
<th>FOUNDATION</th>
<th>DEPTH [m]</th>
<th>CUM 2012</th>
<th>TREND 2020</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity-based foundations</td>
<td>20</td>
<td>21%</td>
<td></td>
<td>Currently only used in shallow water; however, new GBF concepts could have potential for renewed future application up to 40 meters</td>
</tr>
<tr>
<td>Monopile</td>
<td>10-30</td>
<td>75%</td>
<td></td>
<td>Remains most widespread foundation type. Limitations in water depth and weight are increasingly being overcome with new concepts</td>
</tr>
<tr>
<td>Tripod/pile</td>
<td>25-50</td>
<td>2%</td>
<td></td>
<td>High production costs due to complex structure and great weight are likely to limit use of both concepts</td>
</tr>
<tr>
<td>Jacket</td>
<td>20-60</td>
<td>2%</td>
<td></td>
<td>Jackets will increase their share due their flexibility and low weight (40-50% less steel than monopiles), commercially worthwhile &gt;35 m</td>
</tr>
<tr>
<td>Floating</td>
<td>&gt; 50</td>
<td>&lt;1%</td>
<td></td>
<td>Currently at R&amp;D stage, but could become relevant for countries with steep shores. No commercial use expected before 2020</td>
</tr>
</tbody>
</table>

1) Up to 40 m with new concept

Source: EWEA, 4offshore, Ramhold, Roland Berger

Types of Foundation for Offshore Wind Turbines [OWT]

Choice of foundation solution influenced by:

- Water depth and seabed conditions, especially depth to rockhead.
- Environmental loading (wind, wave, tidal).
- Onshore fabrication, storage and transportation requirements.
- Offshore vessel & equipment spread costs & availability.
- Installation & Construction methodology available.
- Developer CAPEX investment appetite and OPEX (Repair & Maintenance) predictions.

Smarter solutions available (suction caissons, GBS, lighter jackets/trusses, hybrids, seabed anchored templates).

“Foundations” (or sub-structure) 30 to 40% of CAPEX & rising. Cost reductions essential. “Smarter” lighter hybrid foundations needed & move away from riskier costly conventional driven tubular steel piling.
Dr. C. R. Golightly GO-ELS Ltd. – Offshore Wind Structures: Gambling With Grout – Worth The Risk?
Transition piece installation
Dr. C. R. Golightly GO-ELS Ltd. – Offshore Wind Structures: Gambling With Grout – Worth The Risk?
Dr. C. R. Golightly GO-ELS Ltd. – Offshore Wind Structures: Gambling With Grout – Worth The Risk?
Dr. C. R. Golightly GO-ELS Ltd. – Offshore Wind Structures: Gambling With Grout – Worth The Risk?
**History of Monopile Connections**

- 1\textsuperscript{st} Offshore Wind UK Round 1 Blyth and Scroby Sands MP projects in 2001 used bolted pre-fitted welded flange connections. This technique was rejected in favour of a cheaper, quicker “more efficient” grouting technique.

- At the end of 2009 grouted connection joints, between large diameter monopiles [MP] and connecting tubular steel transition pieces [TP] at the base of overlying support towers, were found to be failing by cracking and slipping.

- For the majority of 70% of UK offshore MPs which experienced grout cracking, settlements and failures, this was primarily due to widespread absence of shear keys (or weld beads) on the surfaces of straight “plain pipe” MP and transition piece TPs.

- Bending moments as a result of complex wind and wave loading are an important design consideration, which had been underestimated in design.

- Axial connection capacity was found to be very significantly lower than assumed due to MP scale effect, lack of manufacturing and installation tolerances and abrasive wear due to the sliding of contact surfaces subjected to large moments.

- Typical failure modes for the brittle rock-like grout [cement] connections include disbonding, cracking, wear and compressive grout crushing failure.

- These failures resulting from a systemic design fault have necessitated assessment and repairs which have not all been fully reported publically and there have been a number of claims and arbitration cases.
History of Monopile Connections

Advantages and Disadvantages

ADVANTAGES

- Liquid grout displaces sea-water from annulus, allowing for construction imperfections
  - Out of roundness and straightness
  - Tilt and Offset (variable annulus)
  - Surface irregularities (plate rolling imperfections, welds, surface condition etc)
- Easy verticality alignment
- Attachment of secondary steel directly onto TP
- Construction methods well established and fast
- Competitive construction market and costs

DISADVANTAGES

- Relies on durability of the grout seal
- Backing plates – double seals
- Inspection is difficult or indirect
- Certification procedure
- Curing time before installation of tower
- Expensive shear keys
Applications & Factors Affecting Ultimate Strength (Refs. 1 and 2)

APPLICATIONS

- Pile / sleeve or pile / leg connections in multi-legged jacket structures
- Structural connections between sections of deep water jackets
- Sub-sea strengthening & repairs
- Offshore Wind Monopile / TP and Tripod/Truss Tower connections

FACTORS AFFECTING ULTIMATE STRENGTH

- Cross sectional geometry
  \[ K = \left[ \left( \frac{D_p}{t_p} \right) + \left( \frac{D_s}{t_s} \right) \right]^{-1} + \frac{1}{m} \left( \frac{D_g}{t_g} \right)^{-1} \]
- Grout uniaxial compressive strength \( f_{cu} \)
- Shear key height \( h \) & spacing \( s \ (h/s) \)
- Size or scale \( C_p \)
- Length : diameter \( L/D_p \)
- Surface condition
- Manufacturing Imperfections
- Early age cycling
DNV OS J101 Offshore Wind Turbine Design Code and Shear Keys

- The 2 UK offshore wind MP projects with no failures included shear keys, common practice for oil and gas (API RP2A). Designers had Oil & Gas industry experience.

- DNV J101 (2007) offshore wind turbine design code left it open to designers whether to use shear keys/weld beads or not.

- Many designers did not include shear keys as this was perceived to be a cheaper, quicker option and thought shear keys led to “stress concentrations”.

- MP-TP annulus grouting allowed easier, quicker adjustment of the pile out-of-verticallity using jacking to level the turbine tower prior to grouting.

- This was essentially a systemic design error as a result of code phrasing omissions. Many projects are now adopting direct bolted flange connections or unified MP-TP.

- Use of straight “Plain Pipe” non shear keyed connections not recommended and is now discontinued.

- Some MP projects now adopt 1-3 deg. conical designs without shear keys, presumed to “catch” the TP as the connection settles and drops, allowing radial stresses to be regained. This might be regarded by some as “engineering for failure”.

- Industry best practice and DNV code guidelines now extensively reviewed, and revised in 2011 (latest Code 2014, Refs 5, 6 & 7). There are still some anomalies in behaviour. Research is ongoing on scale & fatigue effects but situation clearer.
Offshore Wind Industry Adoption of Brittle High Strength Grouts

- Tried and tested appropriate underwater grouts were originally used to cement piles into bedrock, amongst other applications. This technique was then adopted over 12 years ago for offshore wind turbines, as a more efficient alternative to bolted flanges, which assisted in levelling towers to vertical.

- Typically, brittle high and ultra high strength grouts used have UC strengths > 100 MPa up to 200 MPa. In a geological context, this is a “Very Strong” rock which could “only be chipped by heavy hammer blows”, according to standard rock engineering strength descriptions. They exhibit high ratios of compressive to tensile strength.

- It is not difficult to envisage twin large diameter steel tubes sandwiching an annulus of such “rock” cracking & crushing, leading to progressive failure at the top and base as piles are cyclically loaded by wind and waves over long periods. Patterns of cracking measured are reputedly linked to predominant environmental load directions.

- The MP grout failures may have been related to manufacturing, installation and positioning tolerance uncertainties and out-of-roundness which in some cases have led to MPs and TPs both being slightly out of shape, with the grouted annulus thicknesses therefore varying vertically. Little to nothing is published on this.

- There have been question marks over the long term fatigue strength of HPC grouts, following work by Anders & Lohaus (2007) and Soerensen et al (2011).

- There are suggestions in the work done now that a lower strength less brittle grout may be more appropriate for use in some designs, should grout be adopted. There is a need to "bottom-out" the potential water ingress and cyclic fatigue problems.
Monopile Vs Tripod/Jacket Loading

- “Monopiles” with D/t ratios often in excess of 100 are in reality “thin-walled steel caissons” rather than piles.

- MP ability to transfer large moments is complex, but has become better understood. Design theories still have limitations & shortfalls. The use of conical TP sections [“controlled engineering for failure”] is uncertain in the long term.

- High dead weight oil & gas platforms have used API RP2A designed grouted leg-pile connections for decades, but stresses are usually predominantly compressive. However OWTs are low deadweight loaded, highly cyclic, with complex vertical & bending force coupling, with tensile stress zones in the grout.

- Dynamic load regimes experienced by the legs of tripods (Germany) and 4-leg jackets (mostly UK) are different to the predominant bending mode experienced by MPs.

- Some tripod and jacket designs include “stopper plates”. (e.g. Borkum West 2) These “belt-and-braces” designs suggest a lack of confidence in the robustness under long term cyclic fatigue conditions over a 20+ year design life.

- It is uncertain whether or not tripods/jacket grouted connections will experience fatigue degradation in time, even with the provision of shear keys. There has been extensive research especially at Leibnitz University Hannover (Refs. 10, 16, 17 & 18).
Monopile Vs Tripod/Jacket Loading

For smaller tripod/jacket piles of diameter up to ~2.5 m, work mostly in Germany led by German BSH committee has illustrated a different "push-pull" loading regime to monopiles. No theoretical reason why grout should not be used with shear keys, correctly designed and installed/constructed.

Two methods used for German AV tripods & jackets:
1. Tripods lowered onto template pre-driven pile groups [e.g. Borkum West 2] or:
2. Piles vibrated then driven through sleeves of pre-placed tripods [e.g. Global Tech 1].

Option (2) preferable, since tripod or jacket leg sits inside the pile. Outside requires more complicated sealing and has different grout stress pattern.

Similar to Ormonde Irish Sea project, where jacket legs stabbed inside pre-installed seabed pile template, with wide annulus of lower strength grout to allow for installation tolerances. Current industry favoured solution.
**RWE Gwent-Y-Mor Study 2011**

- Julian Garnsey of RWE led a study published in 2011 assessing grouted connections for the GYM monopiles (Ref. 8).

- The project assessed eight generic concepts:
  1. Grouted conical without shear keys;
  2. Grouted cylinder with shear keys;
  3. Bolted flange;
  4. Bracket support;
  5. Swaged Connection;
  6. Integrated MP and TP;
  7. Pinned Connection;
  8. Clamped Connection

- The bolted flange proved the most promising for further detailed investigation, but was not selected because the change would have impacted on the project schedule.

- Five concept variants emerged from this process as potential solutions:
  1. Grouted conical without shear keys and an axial bearing system
  2. Grouted cylinder with shear keys and an axial bearing system
  3. Bolted flange internal to the transition piece above high tide level
  4. Conical grouted connection without shear keys and an axial bearing system
  5. Conical grouted connection without shear keys.

- Concluded best solution is shear keys in the middle third and a longer connection plus necessary “back-up” elastomeric bearing support, allowing lower strength grout. This more robust connection with reduced contact pressures at the ends and a less brittle grout would reduce cracking around the shear keys and connection ends. Necessary to confirm zero water ingress does not adversely affecting the grout matrix, which would lead to a simplified seal specification.
RWE Gwent-Y-Mor Study 2011

The methodology developed resulted in a numerical weighting for EIGHT criteria as follows, with the subsequent ranking shown:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Integrity</td>
<td>26</td>
</tr>
<tr>
<td>Revenue Stream</td>
<td>23</td>
</tr>
<tr>
<td>Programme</td>
<td>19</td>
</tr>
<tr>
<td>Ease of Installation</td>
<td>10</td>
</tr>
<tr>
<td>Certification/Insurance</td>
<td>8</td>
</tr>
<tr>
<td>Ease of Maintenance</td>
<td>7</td>
</tr>
<tr>
<td>Operational Cost</td>
<td>3</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>3</td>
</tr>
<tr>
<td>Ease of Fabrication</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1: Weightings of assessment criteria

<table>
<thead>
<tr>
<th>Concept</th>
<th>Ranking</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical connection with shear keys, and a bearing system</td>
<td>1st</td>
<td>+44</td>
</tr>
<tr>
<td>Bolted Flange Connection</td>
<td>1st</td>
<td>+44</td>
</tr>
<tr>
<td>Cylindrical connection with shear keys</td>
<td>3rd</td>
<td>+21</td>
</tr>
<tr>
<td>Conical Connection without shear keys, and a bearing system</td>
<td>4th</td>
<td>+13</td>
</tr>
<tr>
<td>Conical Connection without shear keys</td>
<td>5th</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3: Ranking of shortlisted concepts taking into account weighted scores but neglecting effect on project programme

<table>
<thead>
<tr>
<th>Concept</th>
<th>Ranking</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical connection with shear keys, and a bearing system</td>
<td>1st</td>
<td>+25</td>
</tr>
<tr>
<td>Cylindrical connection with shear keys</td>
<td>2nd</td>
<td>+13</td>
</tr>
<tr>
<td>Conical Connection without shear keys, and a bearing system</td>
<td>3rd</td>
<td>+2</td>
</tr>
<tr>
<td>Conical Connection without shear keys</td>
<td>4th</td>
<td>0</td>
</tr>
<tr>
<td>Bolted Flange Connection</td>
<td>5th</td>
<td>-36</td>
</tr>
</tbody>
</table>

Table 2: Ranking of shortlisted concepts taking into account weighted scores

Dr. C. R. Golightly GO-ELS Ltd. – Offshore Wind Structures: Gambling With Grout – Worth The Risk?
JIP Conical Connection Solution 2011

- A Joint Industry Project [JIP] was carried out by DNV to investigate the structural capacity of these connections from autumn 2009 to January 2011 (Refs 5, 6 & 7).
- Axial capacity found to be more sensitive to diameter and surface/positioning tolerances than allowed for in existing design standards.
- Design procedure with conical shaped connections was developed.
- January 2011 JIP on capacity of cylindrical shaped grouted connections with shear keys initiated. Analytical design equations developed for ULS and FLS.
- Recommended design methodology supported by laboratory tests.
Trelleborg Spring Bearings Solution – MP to TP Support

- Several projects adopted or are adopting retro-fitted/new Trelleborg spring bearings (BELWIND [330], Robin Rigg [360], Sheringham Shoal [540], Greater Gabbard 120], Rhyl Flats [158] and Gwent Y Mor [960]). For a normal monopile foundation six bearings are required (see Ref. 11).

- Where elastomeric bearings were not fitted during construction and slippage occurred later, they may be retrofitted by welding new brackets to the inside of the TP. The solution is used on installed wind farms where grout problems occur but also as a precaution.

- At the start of construction, the bearings can be fitted so that they are unloaded and just resting at the top of the MP. If slippage occurs at a later stage, the bearings are gradually loaded to assist the grout in supporting the weight of the TP and tower assembly.

- A further function of the bearing is preloading to carry the static vertical load from the start with the aim of preserving the strength of the grout.

- Long Term Measurement & Condition Monitoring is Essential
Pile Swaging and Slip Joints

- Many developers such as E.On for Amrumbank and Humber Gateway have reverted to bolted flanges, with some considering integral MP & TP, pile swaging, quick coupling lock rings, internal/external mating, or slip joints as reliable long term solutions. All require control on verticality, careful driving. Costly.
- e.g. Beatrice project (DownVInD), where pile swaging (Hydra-Lok® system) used for jackets, which secures structures by expanding piles radially into surrounding sleeve in substructure. Easily monitored and quicker, but more expensive.
Integral and External Mating?

Dr. C. R. Golightly GO-ELS Ltd. – Offshore Wind Structures: Gambling With Grout – Worth The Risk?
Van Oord @ Luchterduinen and Gemini [NL]:

"Next year in July we will start with piling the first foundations. Those are quite innovative as it is a combined monopile and transition piece. We are piling on the flange on which the wind turbine tower will be mounted. After piling the secondary steel will be attached to pre-mounted brackets. By doing this we prevent a grouted connection between the mono pile and transition piece. At the same time this concept is cheaper than a foundation in two parts".
Fatigue Life (Lohaus & Anders 2007; Soerensen et al, 2011)

Lohaus & Anders (Ref. 13)
"The fatigue strength of UHPC in high-cycle fatigue seems to be lower compared to normal strength concrete. Regarding UHPC in grouted Joints nearly bilinear load-deflection curves for specimens with shear keys in uniaxial compression are shown, which represent two different load-bearing mechanisms and a very ductile failure”

Soerensen et al (Ref 19)
• BASF 140 MPa high performance grout, a cementitious binder material containing microsilica and other added minerals. Prepared at ultra-low water/cement ratio using superplasticizing admixture. Aggregate natural sand (0-4 mm). Strength after 28 days curing in water at 20°C.
• In air, fatigue life comparable to ordinary concrete, but in water grout exhibited drastically shorter fatigue life at stress levels in excess of 60% of static compressive strength.
• In air, loading frequency (0.35 Hz, 5 Hz, and 10 Hz) had no influence on the fatigue strength, but in water the fatigue capacity was much lower at 0.35 Hz than at either 5 Hz or 10 Hz. Reduction in fatigue life in water was particularly severe at the lowest frequency 0.35 Hz.
• Reduced fatigue capacity postulated due to water trapped during cyclic loading, exerting internal pore pressures high enough to cause progressive crack formation (“micro-wedging”?). Effect more pronounced at low loading frequencies, with time available for water ingress and subsequent pressure build-up during each load cycle. Research ongoing.
• Fatigue life reduction in water was not observed at the lowest stress level investigated (45% of the static compressive strength).
Fatigue Life (Lohaus & Anders, Ref. 13; Soerensen et al, Ref. 19)

High-cycle Fatigue of “Ultra-High Performance Concrete” and “Grouted Joints” for Offshore Wind Energy Turbines

L. Lohaus and S. Anders

Fig. 58.1. Comparison of different fatigue tests on UHPC mixes
Main Conclusions: Offshore Wind Foundations

1. Initially the relatively new offshore industry perhaps understandably used conservative monopile, piled tripod (Germany) & 4-leg jacket (UK) solutions. CAPEX investment still limited compared to other energy industries.

2. European Offshore Wind Industry has developed alternative foundation solutions, monopiles, piled tripods, BARD tripiles, 3 & 4-leg jackets, truss towers, concrete GBS, twisted jackets, guyed & A-frame MPs, monopod or triple/quad suction caissons.

3. The OW industry must be more realistic about excessively conservative offshore turbine lateral nacelle tilt criteria [0.5 deg.], based upon sound engineering analysis. This impacts whole structure costs. Development of tilt-tolerant DD turbines can reduce costs.

4. For OW foundation costs to reduce [must be halved - US DoE], innovative solutions are needed, selected/tailored to specific site conditions. Conservative risk averse attitudes in a relatively new industry will change as experience is gained & investment increases.

5. Main Foundation Risks: Grouted connections, piling noise mitigation, over-conservative long, stiff, heavy pile design, pile tip buckling, internal & external corrosion, scour protection and J-tubes, unplanned drilling/re-driving, tilt and settlement.

6. The industry current push [Project PISA] to move to ~10 m dia., 1200 Tonne, 60 m + length monopiles in ~40 m WD may be questionable & should be challenged.
Main Conclusions: MP-TP Grouted Connections

1. Discovery from late 2009 onwards that > 70% of UK Monopile connections failed, settled, slipped and cracked. This was a systemic design error over a long period.

2. Bolted flange or other direct connections are possible. If MP grouting is adopted use of shear keys & robust grout seals is essential with overlap lengths of at least 1.25 *D required [Schaumann]. Studies by Centrica/RES [Race Bank] and RWE [Gwent-Y-Mor] indicate that the cost differences between bolted flanges and grouting are in fact minimal.

3. Developers are now (2015) adopting:
   - Non shear keyed conical [Anholt, London Array],
   - Bolted flanges [Amrumbank, Humber Gateway],
   - Retro-fitted bearings [Robin Rigg, Sheringham Shoal]
   - Shear keyed with new elastomeric bearings [BELWIND].
   - New single piece MP-TP [Achterduinen]

4. Reviews of retro-fitted elastomeric bearing installations show these should be robust, with condition monitoring and displacement measurement required over the design lifetime.

5. It is questionable whether or not non shear keyed conical [1°-3°] sections and/or will remain “fully robust” for fatigue design lifetimes of 20+ years?

6. Questions regarding long term fatigue behaviour under high loading with water ingress?

7. Measurement, Monitoring and Mitigation for offshore structures is essential for long term design life O&M cost minimisation. The BELWIND project is state-of-the-art (Refs. 3 & 4)

FOUNDERATION MONITORING SYSTEMS:
ANALYSIS OF 2 YEARS OF MONITORING AT THE NORTH SEA

Abstracts

The Offshore Wind Infrastructure Lab (OWI-lab) has a mutual partnership with Parkwind to perform foundation monitoring. A first monitoring system, which is installed on a monopile foundation of a 3 MW Vestas turbine at the Belwind wind farm, has now been running for almost two years. Recently two additional monitoring systems were installed at the Northwind wind farm. The motivation is gaining the insights that are crucial to minimize construction and installations costs of the future planned wind turbines at the Belwind concession and to extend the lifetime of existing structures and reduce their operation and maintenance costs.

Offshore Wind Farms

The foundation monitoring system has been installed at the Belwind and NorthWind wind farm in the Belgian North Sea.

Facts Belwind: 55 Vestas 3MW V90 turbines, Monopile foundations, 46 km offshore, Water Depths: 16 – 30m
Facts Northwind: 72 Vestas 3MW V112 turbines, Monopile foundations, 37 km offshore, Water Depths: 16 – 29m

Retrofit installed brackets and bearings now prevent the transition piece to completely slip downwards. The monitoring system however continues to measure the slippage of the transition piece and the loads taken by the installed brackets and bearings.

An advanced grout monitoring system has recently been installed in two turbines of the Northwind wind farm. This system will allow to measure the strains inside the grout. This will be done by using optical strain sensors embedded in reinforced bars that have been installed inside the grout during installation.


Majority of OW developments have been in the Southern North Sea, a relatively flat shallow water continental shelf, mainly dense sand, stiff glacial clayey soils & soft sediment filled paleo-valleys. Not globally representative. Most coastal areas are steep, rocky, with thin (< 5 to 10 m) soil cover. Piling is costly for fixed or floating structures. Soils insufficient for drag or suction caisson anchoring.

Source: Statoil Global Offshore Wind 2014
Comparison Oil Drilling Semi-Sub Vs Offshore Wind Floater
## The Future: Offshore Floating Wind Leaders

### HYWIND
Statoil [NO]  

### PELASTAR
Glosten [US]  
[pelastar.com](http://pelastar.com)

### WINDFLOAT
Principle Power [PO/US]  

### IDEOL
IDEOL Partners [FR]  

### WINFLO
DCNS-Alstom [FR]  

### INFLOW
EDF-IFP-Nenuphar [FR]  

### GICON
GICON-Fraunhofer [DE]  

### FUKUSHIMA
Mitsubishi-Hitachi [JA]  
[fukushima-forward.jp/english/](http://fukushima-forward.jp/english/)

### DEEPCWIND
30 diverse members [US]  
[composites.umaine.edu/our-research/offshore-wind/deepcwind-consortium/](http://composites.umaine.edu/our-research/offshore-wind/deepcwind-consortium/)

### SANDIA
Sandia Labs [US]  

Floating Wind Platforms – Semi-Sub - Spar - TLP - Taut Buoy

Vertical Axis Wind Turbines [VAWT] – Pros and Cons

ADVANTAGES
- Omni-directional
  - accepts wind from any direction
- Components mounted at sea level
  - ease of service & maintenance
  - lighter weight composite structures
- Can theoretically use less materials to capture the same amount of wind

DISADVANTAGES
- Rotors lower at reduced wind speeds
- Centrifugal force over-stresses blades
- Poor self-starting capabilities
- Often requires support at turbine rotor top
- Rotor needs removing for bearings replacement
- To date, poorer performance & reliability than HAWTs

Closing Thoughts – Future of Offshore Wind Energy

Aim: Most Efficient Abstraction of Kinetic Energy From Moving Turbulent Air [OFFSHORE WIND]

- How Would That Be Done in 2015 From A Standing Start? Fixed Structure Top Heavy 3 Bladed Onshore HAWT on Fixed Steel Towers?
  
  >> No. Too Expensive and Subsidy Dependent

- What Will The Global Mix Be Between Fixed Vs Floating?
  
  >> Deeper Waters/Sloping Seabeds >> FLOATING VAWT

- Will There be a Real Offshore Wind “Gamechanger” - or not? Yes there must be soon.
  
  >> [$$$$ ECONOMICS $$$]


www.oes.org.uk/recentmeetings.asp
www.ice.org.uk/topics/energy/Recorded-lectures


www.istructe.org/journal/volumes/volume-91/issues/issue-1/articles/research-capacity-of-cylindrical-shaped-grouted-connections


References (3)


www.stahlbau.uni-hannover.de/170.html?&no_cache=1&L=1&tx_tkinstpersonen_pi1%5BshowUid%5D=14&tx_tkinstpersonen_pi1%5Bpublikationen%5D=1


http://proceedings.ewea.org/offshore2011/programme/info2.php?id2=566&id=104%20&ordre=1

20. “Monopile Retrofits and Designs Going Forward: Room for Grout?”, April 11\textsuperscript{th} 2011.


22. London High Court of Justice; Judgement Before: Mr. Justice Edwards-Stuart. Between : MT Højgaard a/s [Claimant] and E.ON Climate and Renewables UK Robin Rigg East and West Ltd. [Defendants]. November 2013. Queen's Bench Division; Technology and Construction Court. Neutral Citation Number:  [2014] EWHC 1088 (TCC); Case No:  HT-12-148.

www.bailii.org/ew/cases/EWHC/TCC/2014/1088.html

Contact Details

Dr. C.R. Golightly, BSc, MSc, PhD, MICE, FGS.
Geotechnical and Engineering Geology Consultant
Rue Marc Brison 10G, 1300 Limal, Belgium
Tel. +32 10 41 95 25
Mobile: +44 755 4612888
Email: chris.golightly@hotmail.com
skype: chrisgolightly
Linked In: linkedin.com/pub/5/4b5/469
Twitter: @CRGolightly
Academia.edu: https://independent.academia.edu/ChristopherGolightly


"Ignore The Geology at Your Peril” – Prof. John Burland, Imperial College.

All my students know how to respond to the question “What happens when you use land-based technology in the ocean?” They learn from day one to answer in unison: “You die.”

‘The Silent War’ – John Craven

Dr. C. R. Golightly GO-ELS Ltd. – Offshore Wind Structures: Gambling With Grout – Worth The Risk?