Jacket foundations for OWT's
Pre-piled vs Buckets

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OWT Foundations fixed to seabed
OWT Jackets
For Deeper waters and Bigger Turbines

Design drivers:
• Foundation stiffness/damping
• Lifting weight <1000T
• 30-60m water depth

Discussions:
• Tripod or Quatropod
• Piles vs Buckets
• Installation aspects
• Soil conditions
Jacket Beats Monopile?

Industrial fabrication of jackets, examples from ST³ Offshore yard in Stettin
Pre-piled Quatropod or Tripod?

Owec Tower – Quatropod (Alpha Ventus)

Hochtief tripod (Baltic II)
Suction Bucket Quatropod or Tripod?
Quatro pod jacket
Static un-determined foundation system

Don't worry, the steak was so tough I put it under the wobbly leg.

Pre-piled jacket

Twisted jacket?

Suction Bucket Jacket
Installation of pre-piled foundations

1. Pile driving
2. Transit of Jackets to offshore installation site
3. Deployment of jacket on location and grouting
Pre-piling Templates

- Geosea: Thornton banks
- Geosea: Borkum West
- Illustration Jumbo shipping
- IHC concept
- Norwind concept
- Boskalis: Wikinger
Pile Stabs and Grouting

Baltic II tripod installation (HGN Joint Venture)

OWEC Tower pile stabs

Long term performance?
How to make the piles fit?

Tight installation tolerances - Instrumented pile templates

1. Level the piles sleeves or measure the elevation difference

2. Measure the elevation difference from pile sleeve datum to pile top

NGI's Hose level system with remote read-out units

GeoSea’s piling template (Thornton)
Woodpeckers in action

Required precision in pile top elevation metrology: +/-5mm

Pre-piled OWT foundations:
2009 Alpha Ventus
6 off Quatropod jackets
2010 Ormonde
42 off Quatropod jackets
2011 Thornton
49 off Quatropod jackets
2011 Borkum West
41 off Tripods
2013-14 Baltic II
41 off Tripod jackets
2016- Wikinger
70 off Quatropod jackets
2017- Beatrice
84 off Quatropod jackets
= more than 1250 pre-driven piles
Installation of Bucket foundations

1. Lift-off and lower buckets through the splash zone (vents open)
2. Positioning above seabed, landing and self weight penetration (vents open)
3. Close vents and start pumping out entrapped water from the buckets. Penetrate by suction to target depth
4. Recover pump skids and backfill possible gap beneath the top of the buckets by pumping in grout
Suction Penetration

Newton's law:
Penetration resistance = Foundation weight + Suction pressure \times cross section area of bucket

Geotechnical limits (Piping, Heave, etc)
- Soil plug lift
- Piping
- Excessive heave

Structural limit (buckling)
- Water escaping beneath the skirt tip during start of suction, "vacuum cleaning" sand from a seabed with lot of pebbles

Cavitation limit (depth)
- Pump impeller damage due to cavitation
Difficult soil conditions
The Geometry of the buckets must be designed accordingly

Bucket foundations penetrated in layered soil, illustration NGI

Long & slender suction piles for soft clay or short & stubby buckets for sand

NorthEast Gateway Suction "bucket"

Exxon Diana Suction "pile"
Mitigation - Reducing the penetration resistance

Cyclic Penetration in stiff clay

Suction bucket after penetration and recovery in Stiff and "Sticky" clay during Dudgeon penetration Trials 2013 (Statoil)

Theoretical example

Start pumping out water from bucket

Weight penetration

Lower bound pressure limit (vacuum in bucket) for 25m water depth

Required suction without cycling

1st cycle

Pump cavitation

2nd cycle

3rd cycle

Novel monitoring solutions solving geotechnical problems and offshore installation challenges

P. Sparrevik & J.M. Strout
Norwegian Geotechnical Institute,
Oslo, Norway

Mitigation - Reducing the penetration resistance

Skirt tip Water injection

OWA Penetration trials 2014

Gullfaks C Penetration tests 1985 (Statoil)

Scour protection and Bucket foundations

What is the resistance when penetrating steel skirts through a pre-laid scour protection layer?
What happens with the gravel when the skirts are penetrating through it?

Self-Weight Penetration Tests
Dirdal 2016

Illustrations and video: NGI
Statoil’s Sleipner T Suction Bucket Jacket installed by Saipem 1996 (Very dense sand) Ø 15m Buckets penetrated ~5.5m
Pre-piled vs Bucket foundations

Summary

Pre-piled jacket
+ Not sensitive to soil conditions
+ Lighter jacket (offshore lift)
- In total longer installation time (split operations)
- Noise during pile driving
- Grouted connections

Suction Bucket jacket
+ Shorter installation time in one go
+ Less noise during installation
+ Less steel in total
+ Simpler removal
- More sensitive to soil conditions
- Heavier jacket (offshore lift)
Soil conditions are important!

However, we can save 700 lire and two months by not doing a Geotechnical investigation.
Floating OWT's?
Suction buckets without vents

Link: https://youtu.be/Ij_Hivd7gWI