SUT - Foundation Design for Offshore Structures

Sebastien Manceau
Kent
&
Mike Rattley
Geowynd

Contents

- Introduction
- Soil Parametrisation: Critical
- Piles
- Monopiles
- Shallow Foundations
- Suction installed foundations
- Summary

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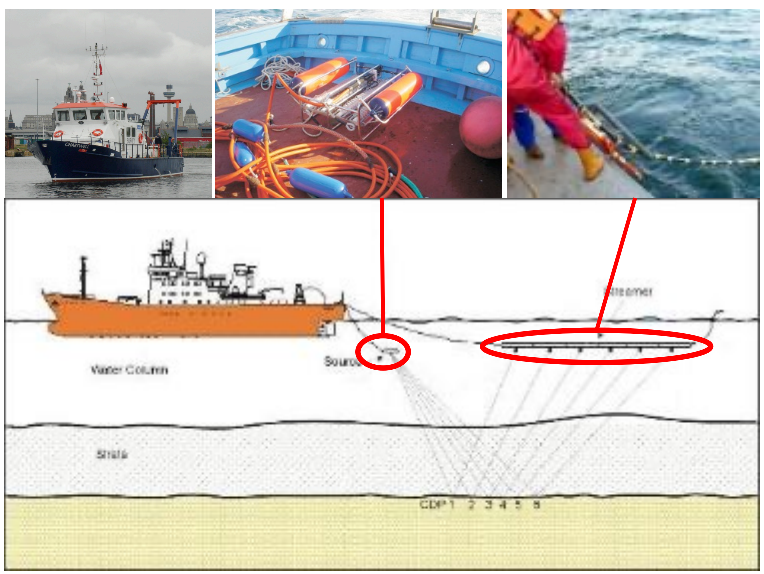
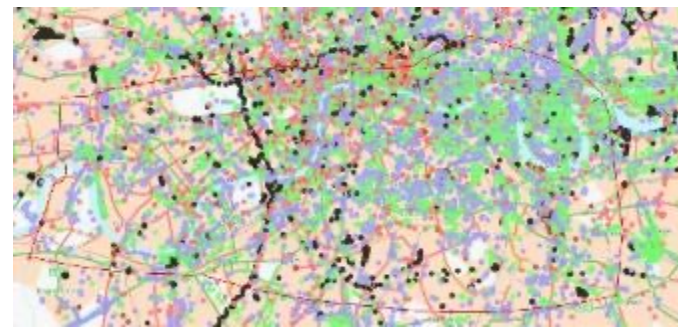
Offshore Foundations Types

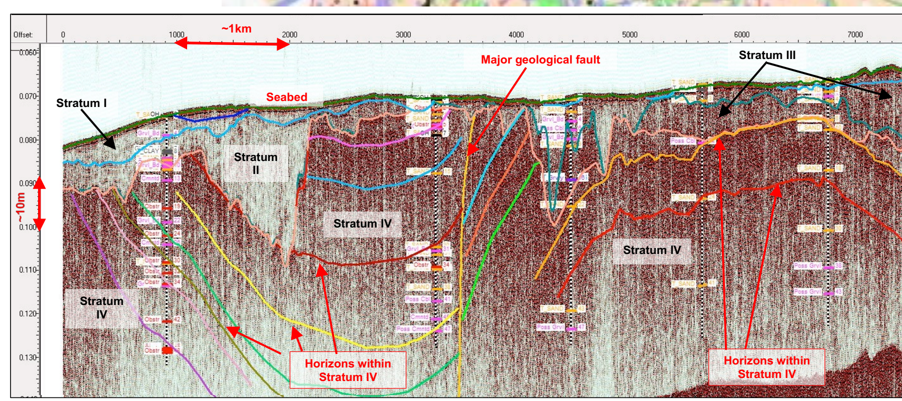
Piles	Monopiles	Shallow foundations	Suction buckets

What is Special About Offshore Foundations? Soil Data

- Large sites
- Expensive SI
- High reliance on geophysics (at least in early stages)
- Limited Geotechnical Data

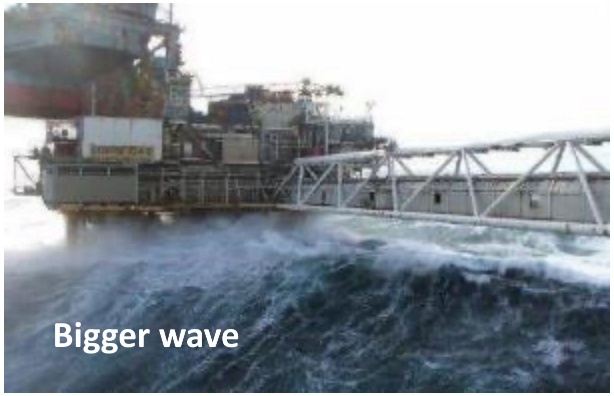






What is Special About Offshore Foundations? Loading

- Extreme irregular, cyclic environmental loading
- Unfortunate events



What is Special About Offshore Foundations? Size Matters

Bullwinkle

529m high

50,000 tonnes = 10 x Eiffel tower

412m water depth

Piles: 28no 84'' (2.134m) OD
165m long

Troll A

472m high

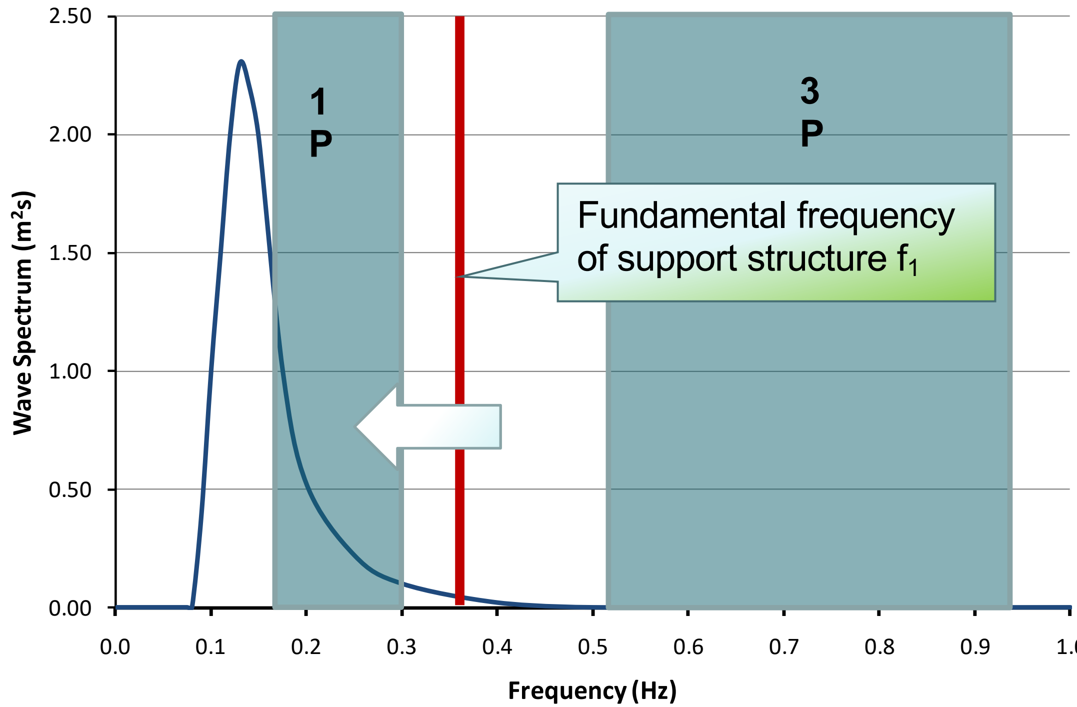
656,000 tonnes (dry)

1.2M tonnes ballasted during tow

303m water depth

What is Special About Offshore Foundations? Design Requirements

- Design for limit states
  - ULS, ALS, SLS
  - FLS for structural design
  - WSD or LRFD
- Design for performance
  - Allowable displacements
  - Natural frequency



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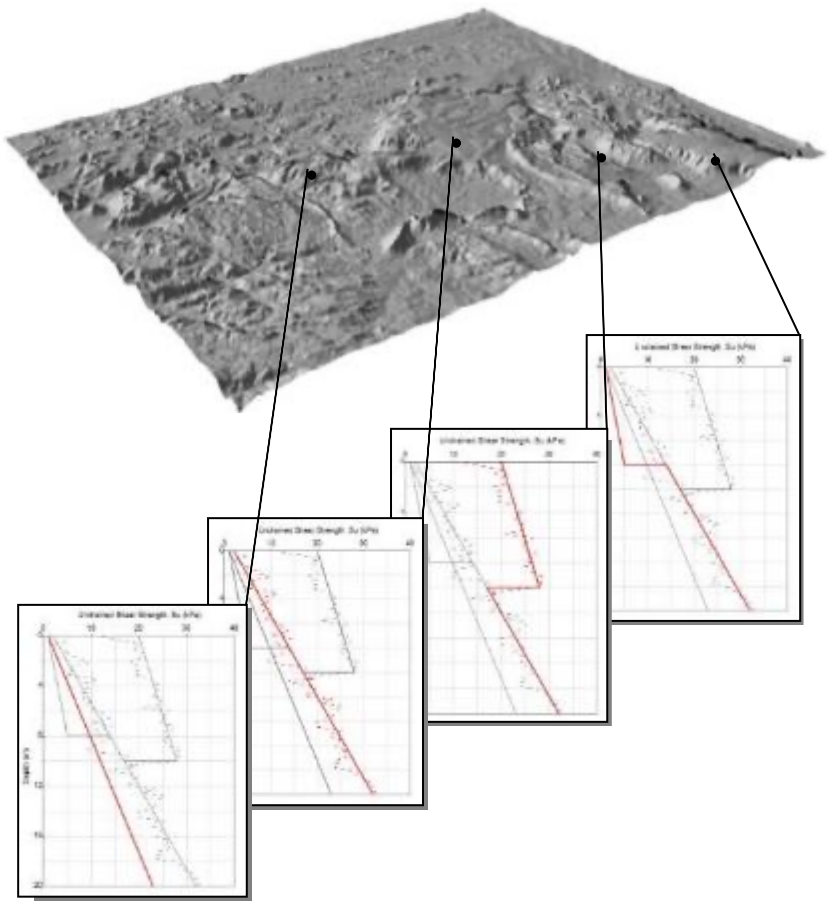
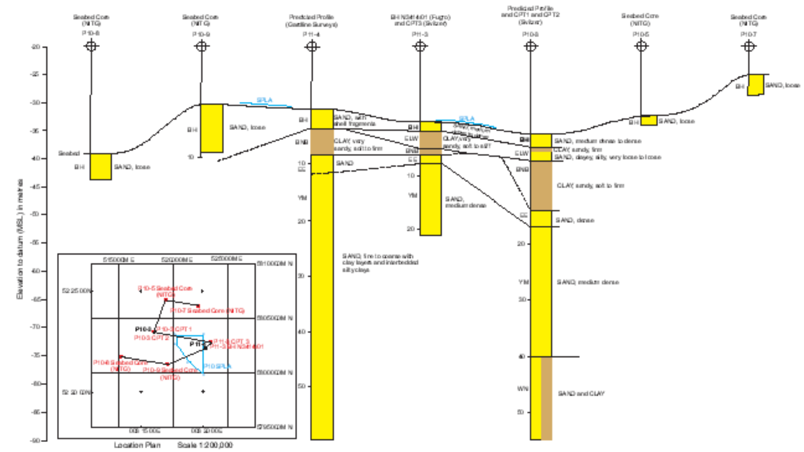
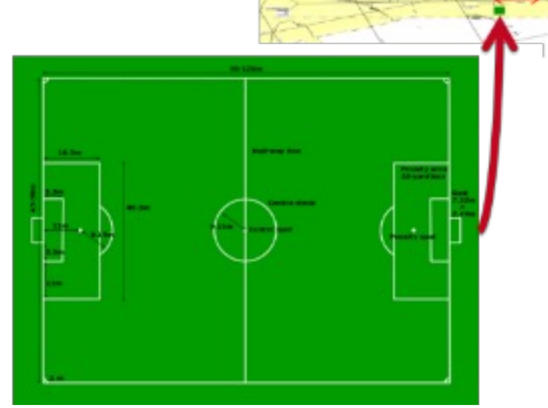
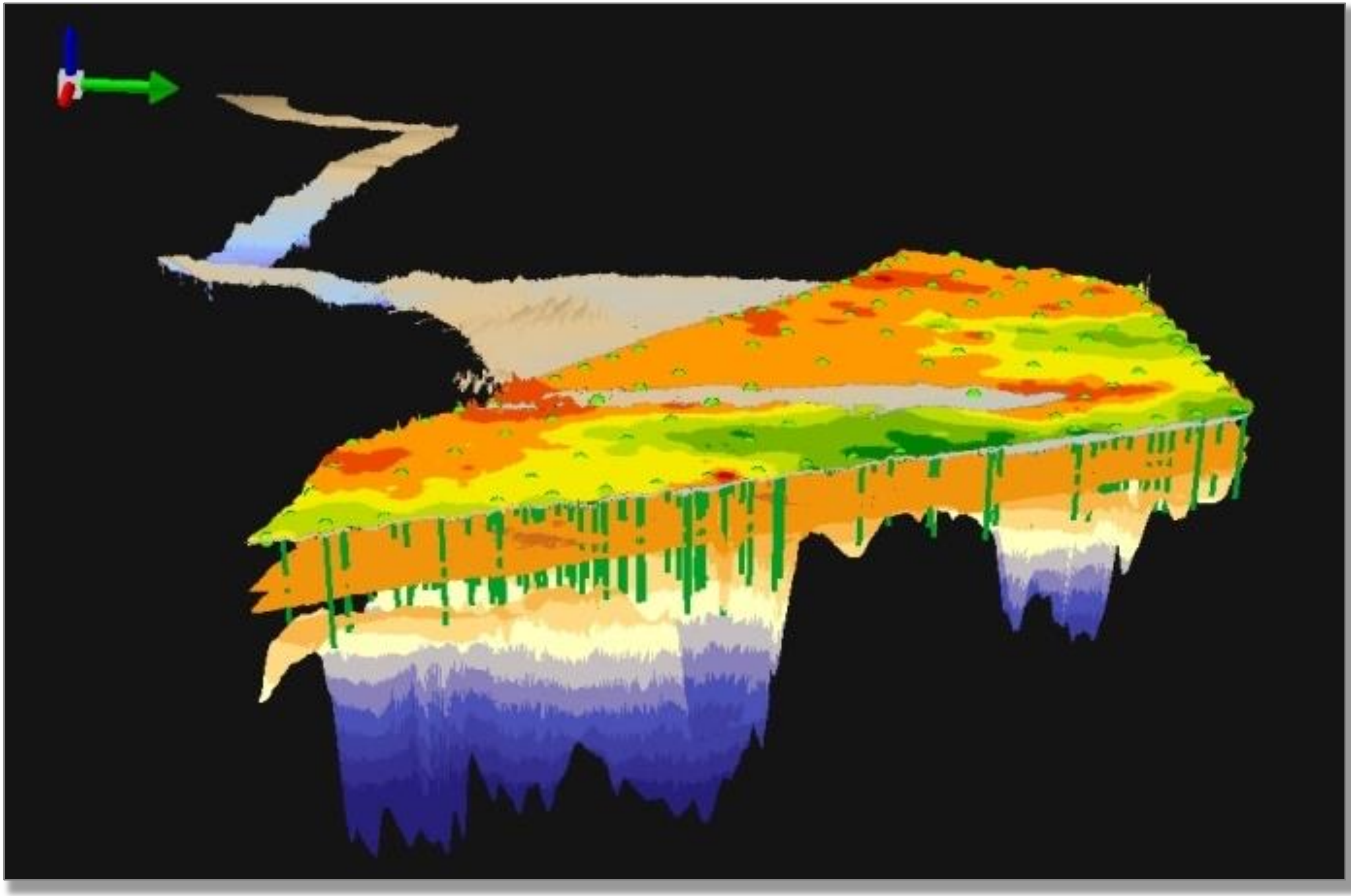
Seabed Variability & Engineering Judgement!





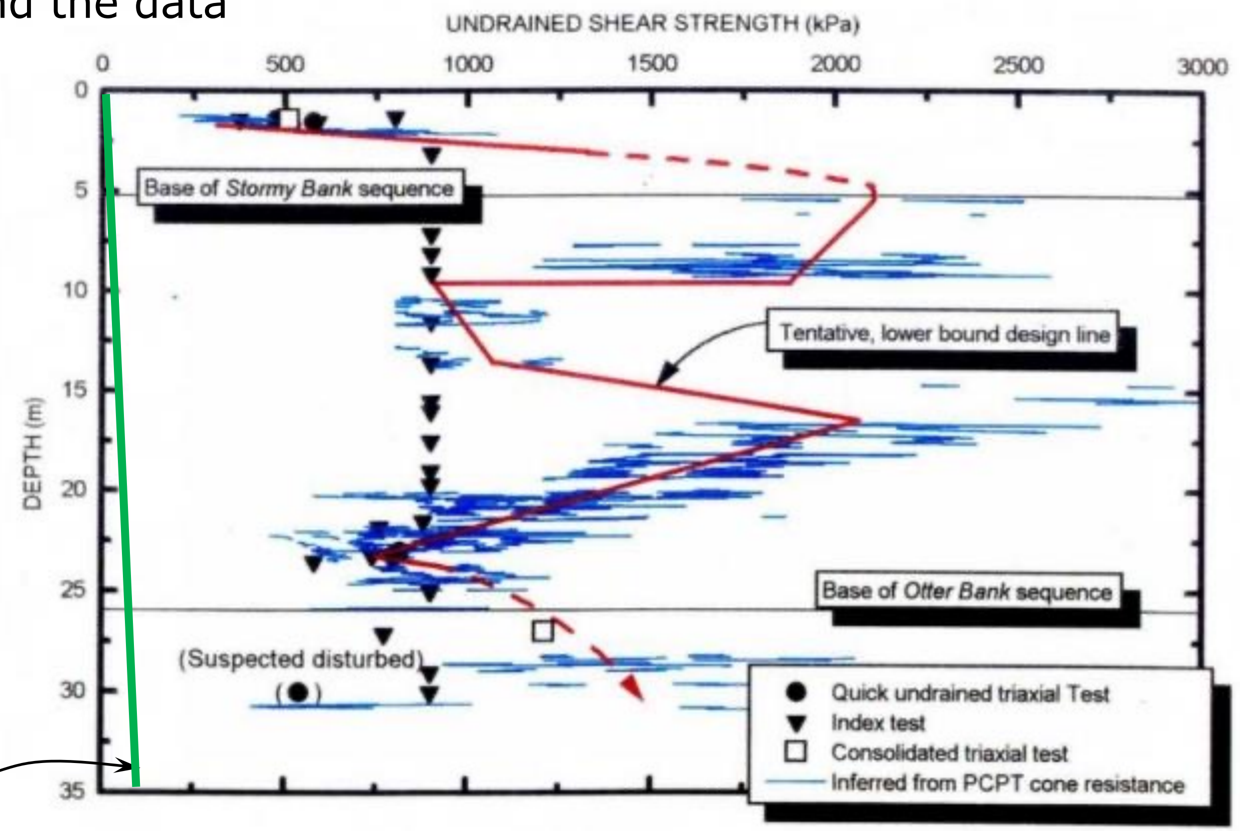


Seabed Variability & Engineering Judgement!



Soil Parameterisation: Critical!

- Soils are highly variable
- Soil response is an outcome of soil type and geological history
- Impacts of sampling method and measurement process
- Critical to understand the data



Normally consolidated, also West of Shetland

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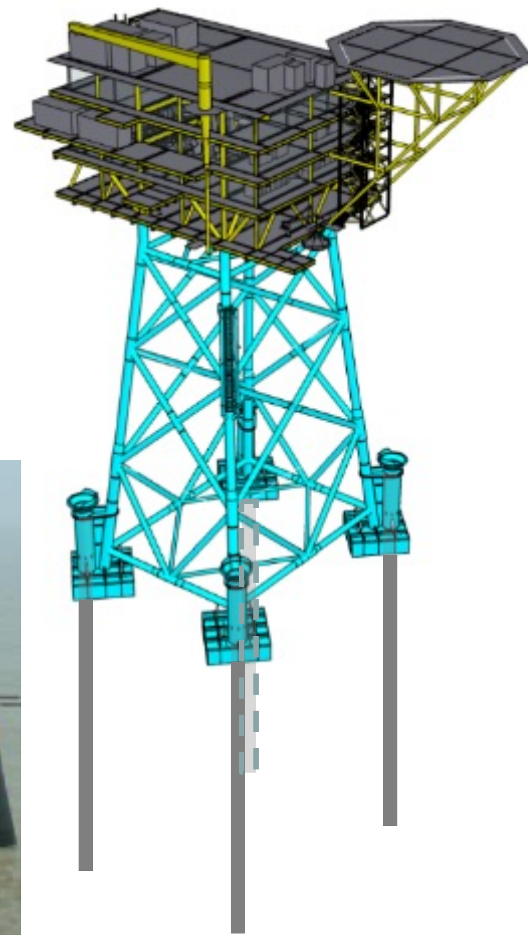
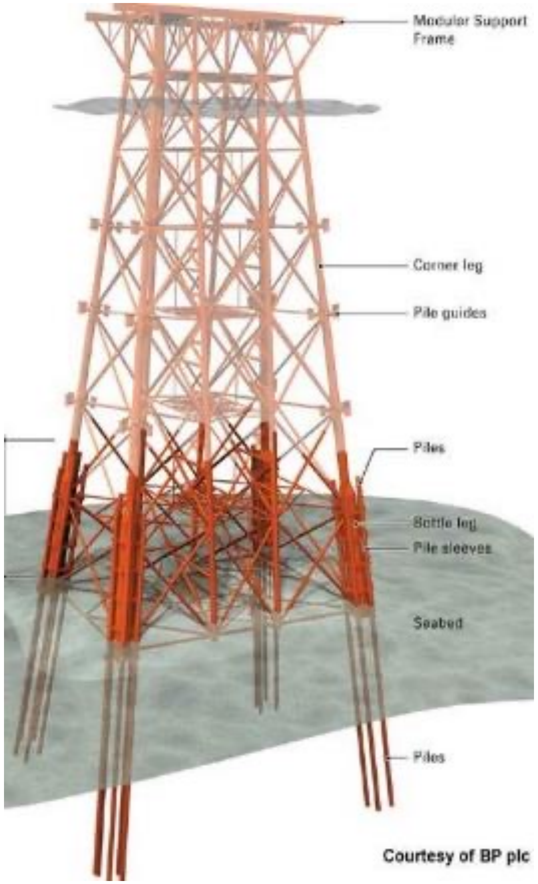
Oil & Gas and Offshore Wind Substations

- One-offs structures
- Typically post-piled
  - Jacket lowered to seabed on mudmats
  - Piles driven trough legs, or
  - Piles driven through sleeves



Oil & Gas and Offshore Wind Substations

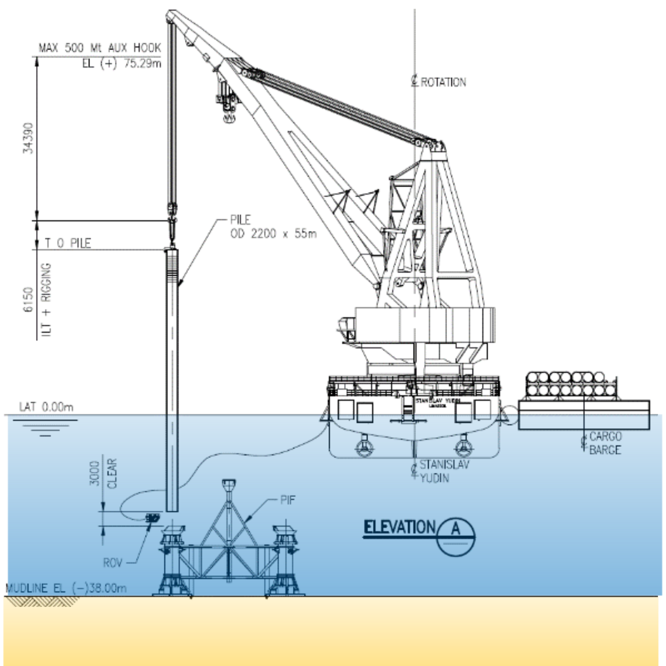
- Loading
  - Large vertical load
  - Small horizontal loads and moment
  - ‘Low’ cyclic component
- Pile design governed by
  - Axial compressive capacity
  - Groups?
  - ULS

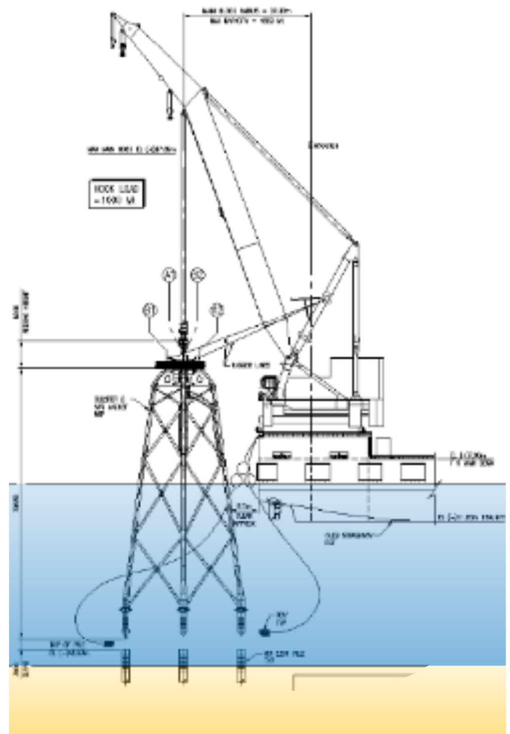


Courtesy of BP plc

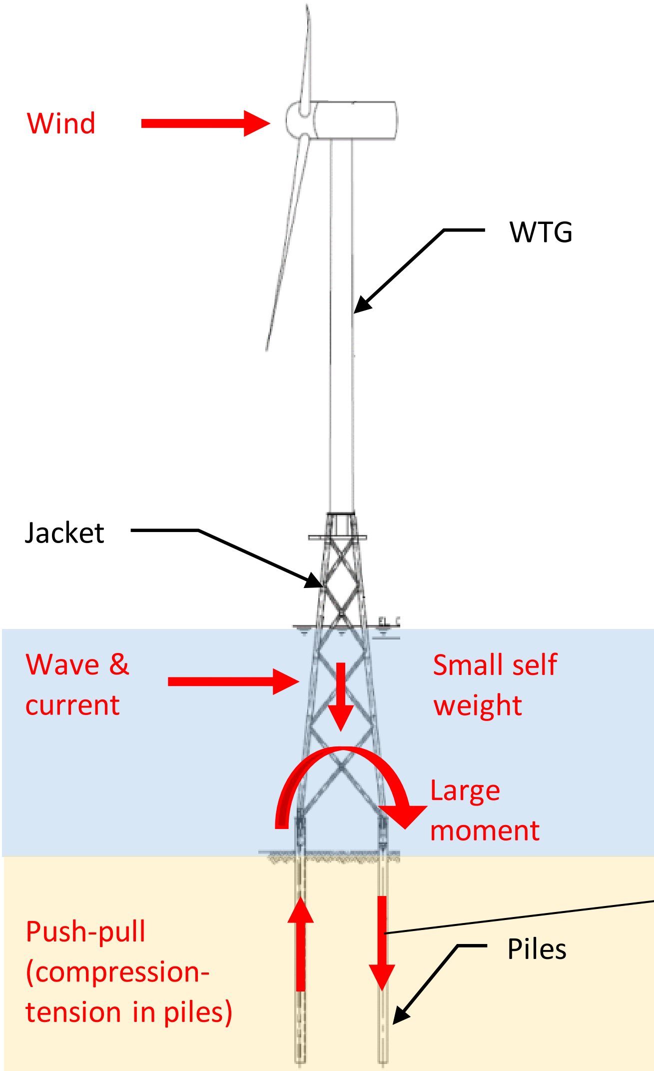
Offshore Wind WTGs

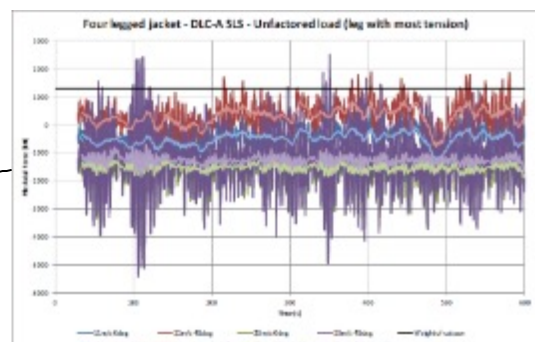
- 50-100 structures – serial fabrication and installation
- Typically pre-piled





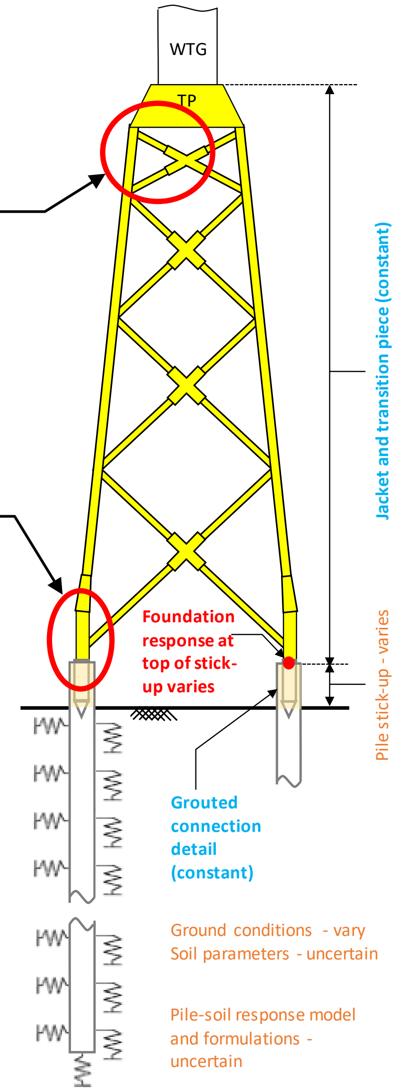
Offshore Wind WTGs





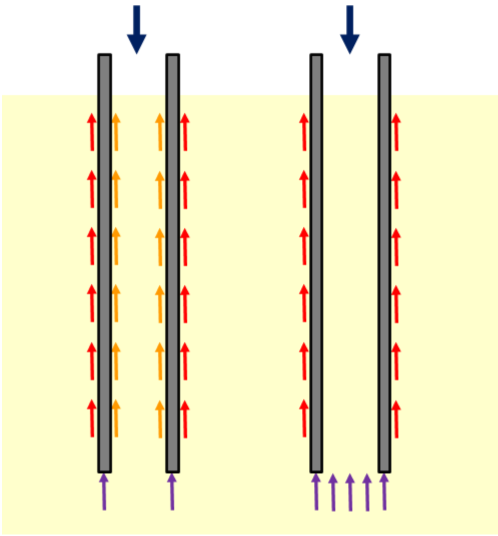
ULS and FLS design in this zone may be governed by stiff foundation response

ULS and FLS design in this zone may be governed by soft foundation response



Axial Capacity – API method

Unplugged vs plugged



Clay

- Shaft: $f_s = \alpha\ su$
- End bearing: $q = 9\ s_u$

Sand

- Shaft: $f_s = \beta\ \sigma'_{v0} \leq f_{s\_lim}$
- $q = N_q\ \sigma'_{v0} \leq q_{lim}$

Reliable?

- Pile load test databases give Qc/Qm
- Large standard deviation
- Particular bias in sand with D_r and L/D

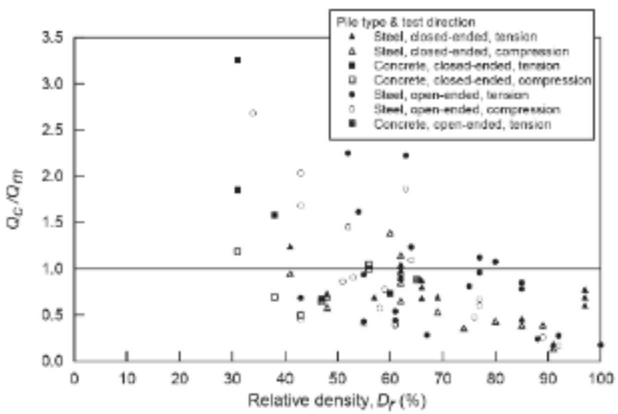


Figure 13. Distribution of Q_c/Q_m with respect to relative density, D_r: API (1993) shaft procedure for sands

Axial Capacity - ‘CPT-based’ methods

‘CPT-based’ methods:

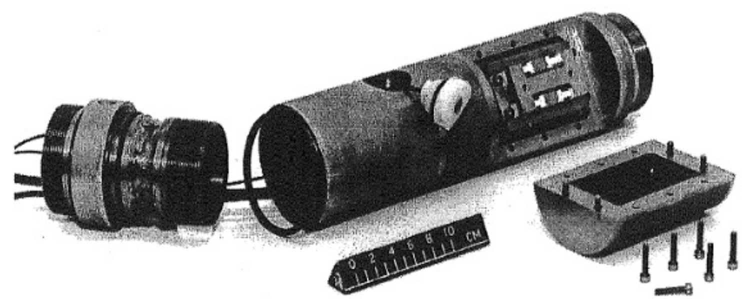
- Fugro-05, Kolk et al (2005)
- ICP (2005), Jardine et al (2005)
- NGI (2005), Clausen et al (2005)
- UWA (2005), Lehane et al (2005)

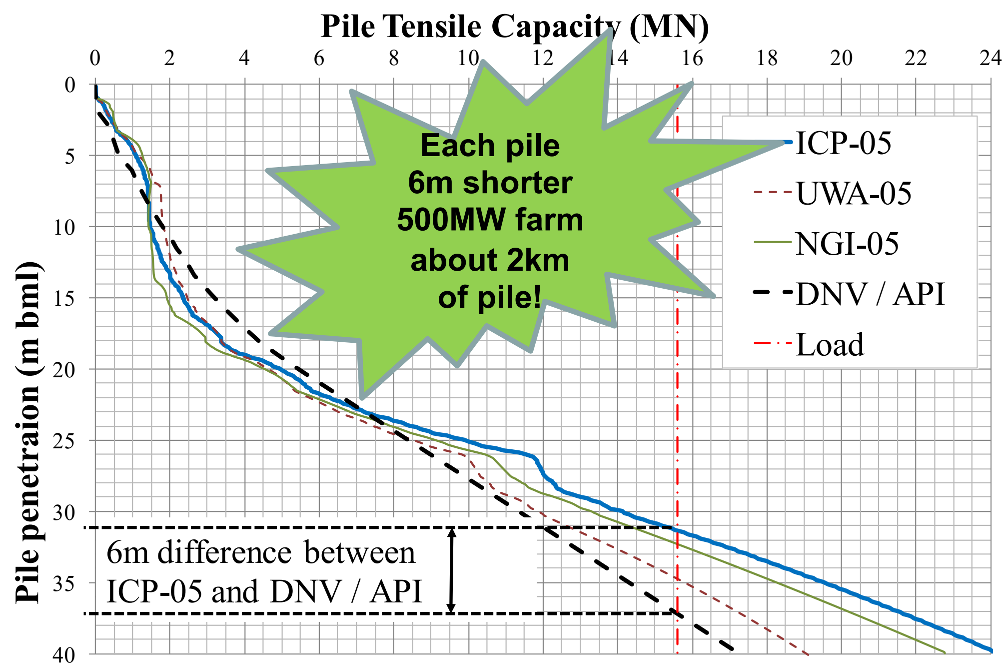
Pros

- Better understanding of behaviour (radial stresses, ‘friction fatigue’ …)
- Improved pile load test databases
- Improved reliability

Cons

- Require higher quality of ground investigation (CPT & lab testing)
- Not all applicable to clay
- Industry ‘politics’





Pile Driving

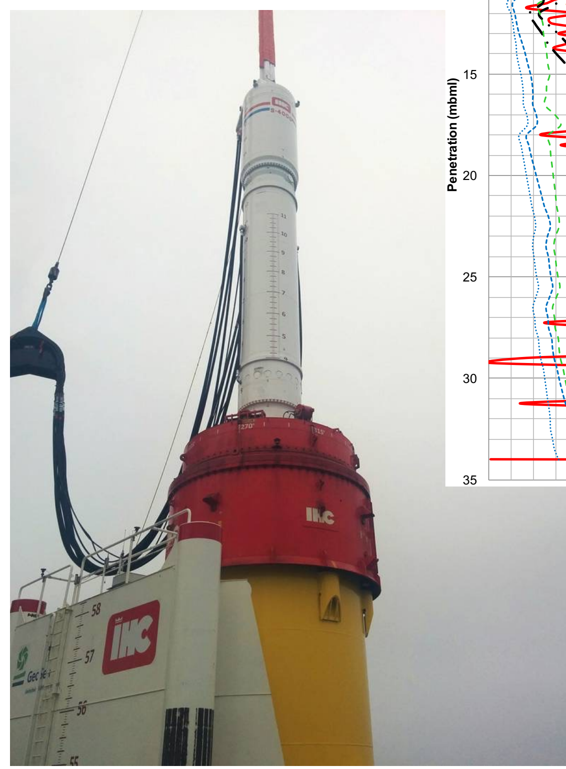
Reliable assessment of driveability for:

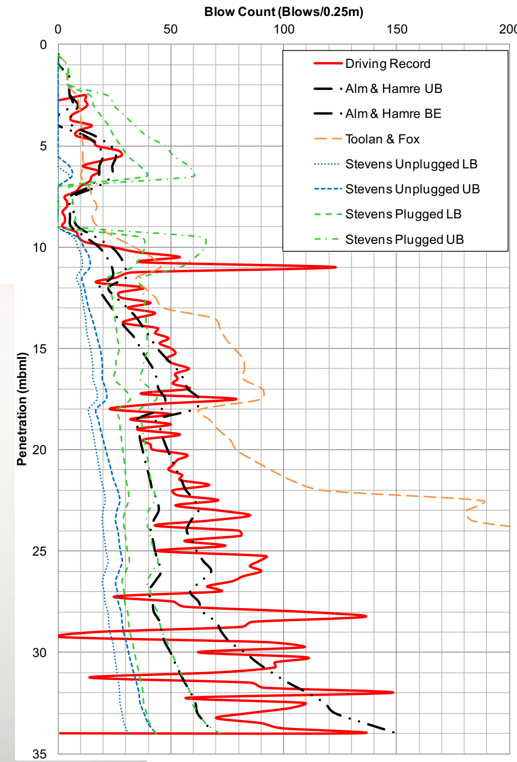
- Installation feasibility & planning
- Stress checks and fatigue during driving

Uncertainties from:

- Modelling of hammer and driving equipment
- Ground – stratigraphy, parameters
- Method used – From back analyses of installation records databases

Uncertainties best managed through back analyses of specific driving records in similar conditions (when available)





Other Challenges

- Cyclic loading and degradation of axial shaft capacity
- Challenging ground conditions for driven piles (e.g. carbonate soils, chalk …)
- Other installation techniques and associated design methods (drill & grout, vibro, jacking…)
- Seismic

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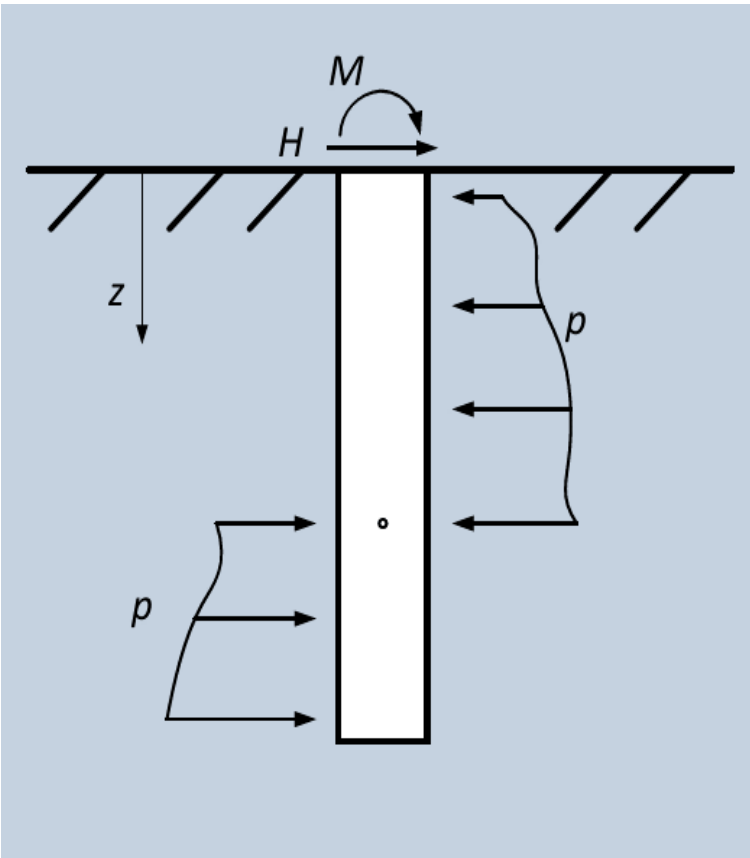
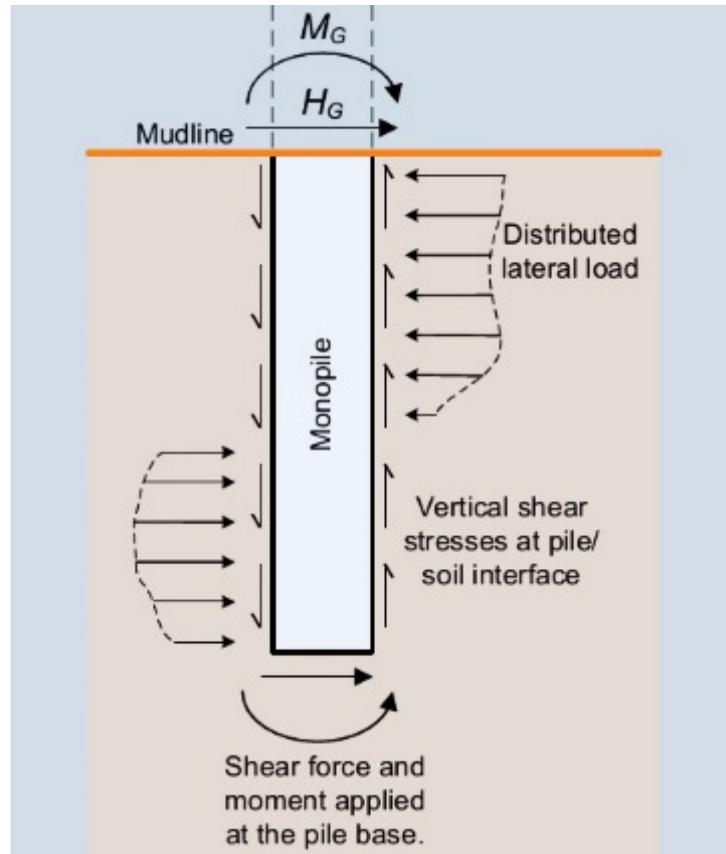
Piled Jacket and Monopile Foundations – Lateral pile response



One set of springs:
p-y **springs**

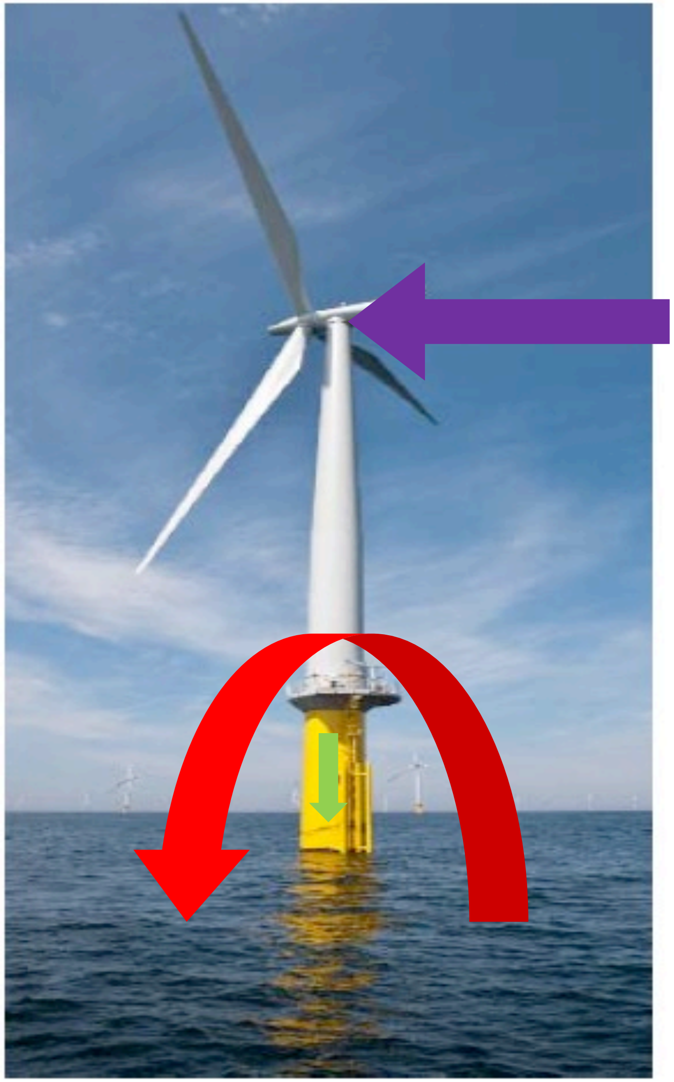


Four set of springs:
p-v*, *H-v*, *m-ψ* and *M-ψ

Monopile Foundations – Example OWF design criteria (25 year lifespan)

- **50 year storm (ULS)**
  - Wind (Turbulence)
  - Waves
  - Current
  - Ice
- **Permanent Deformation (SLS)**
  - 0.25° Installation
  - 0.25° Design
- **Fatigue (FLS)**
  - Eigenfrequency
- **Earthquake (EQ)**
  - Extreme Level (ELE)
  - Abnormal Level (ALE)
- **Ship Collision (ALS)**
- **Corrosion**
- **Driveability (Installation)**

Often critical, therefore initial soil stiffness critical

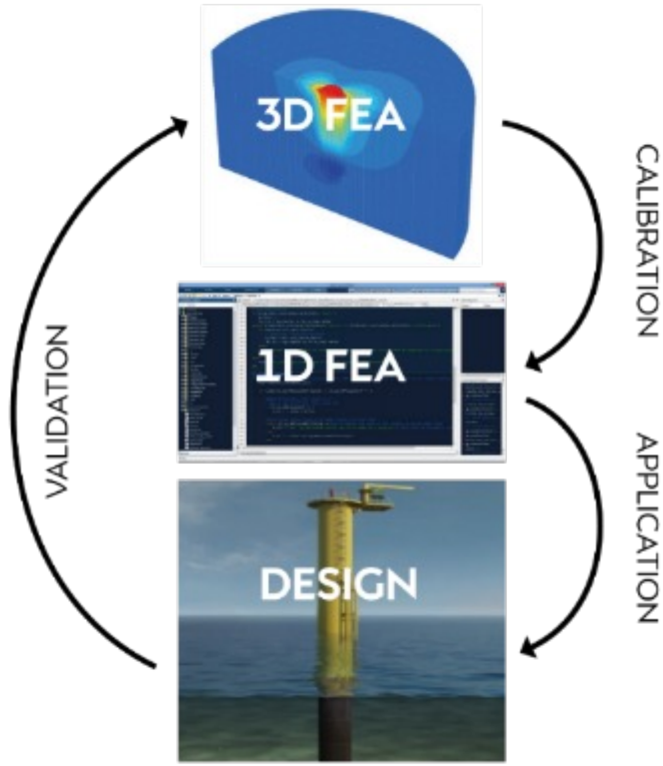


Monopile Foundations – Lateral behaviour

American Petroleum Institute

Pile Soil Analysis

REDucing costs in offshore WINd



Closed form solution

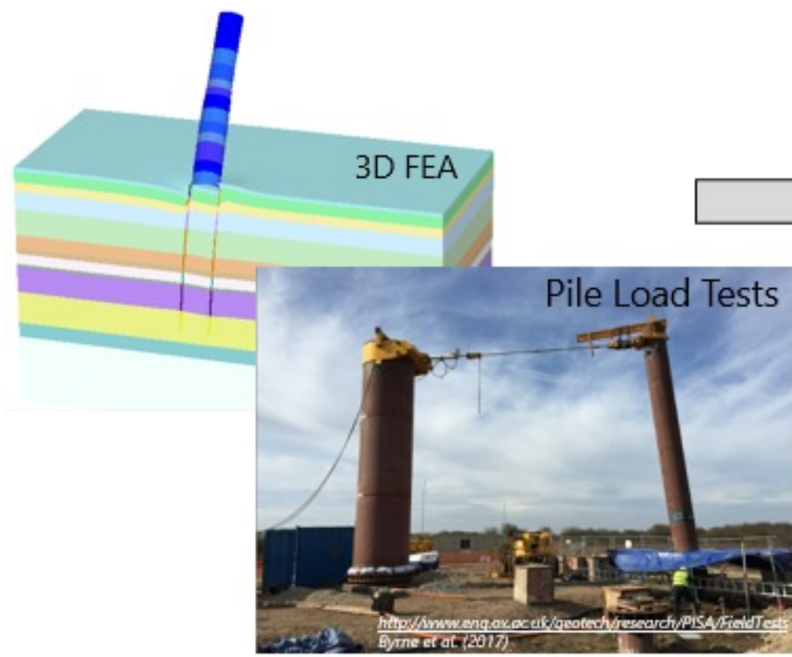
Old standardised formulas

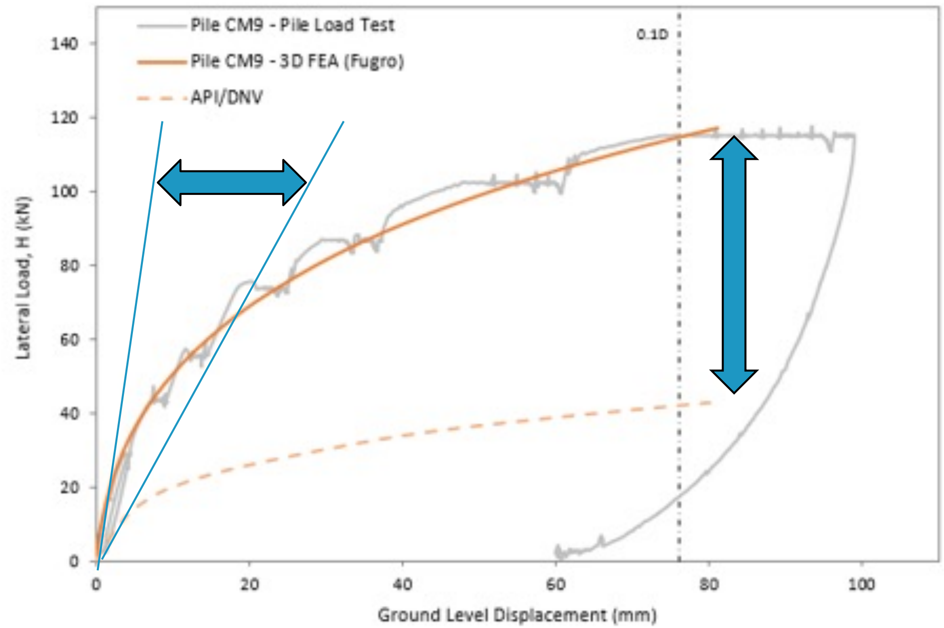
Site specific

New framework

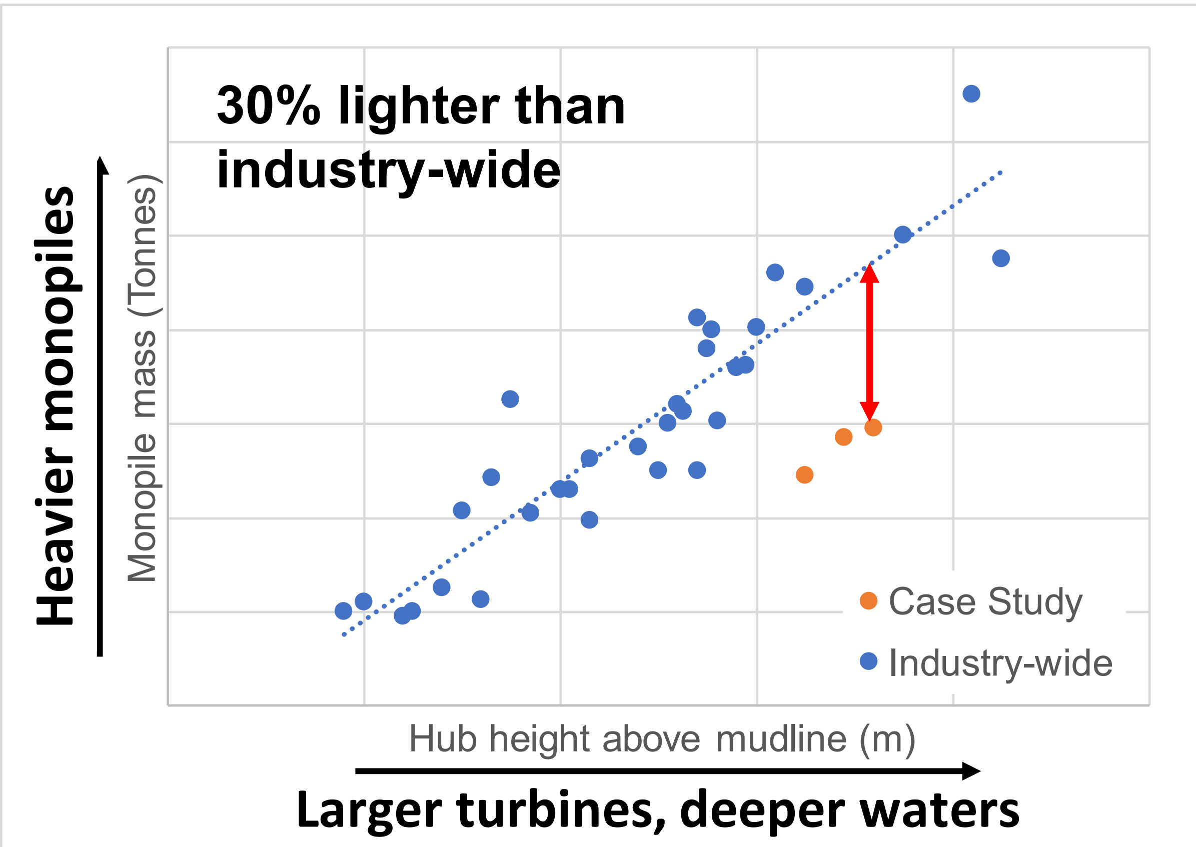
Monopile Foundations – Lateral behaviour

- Standard API/DNV/ISO p-y curve approach is not adequate to optimise foundations and achieve economic design
- Standard p-y significantly underpredicts ultimate strength and stiffness in some soils
- May overpredict in other soils





Outcomes



Saving
£ 45 M in materials
£ 10's M in easier and faster T&I

Easier to lift + Less time offshore = **Improved safety**

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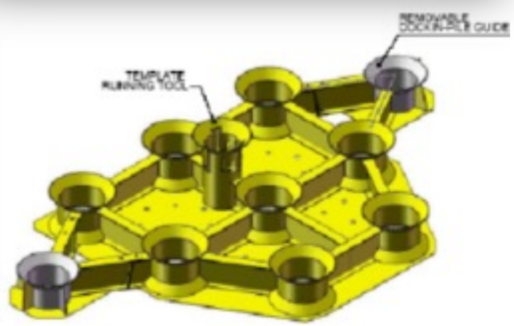
Shallow foundations – Types

- Oil and gas platforms (mudmats for pre-piled stability, permanent GBS)
- Subsea structures (manifolds, templates, protection structures, etc)
- Wind turbines (GBS)
- Spudcan foundations for jack-up rigs
- Size varies greatly from a few metres up to 10s of metres

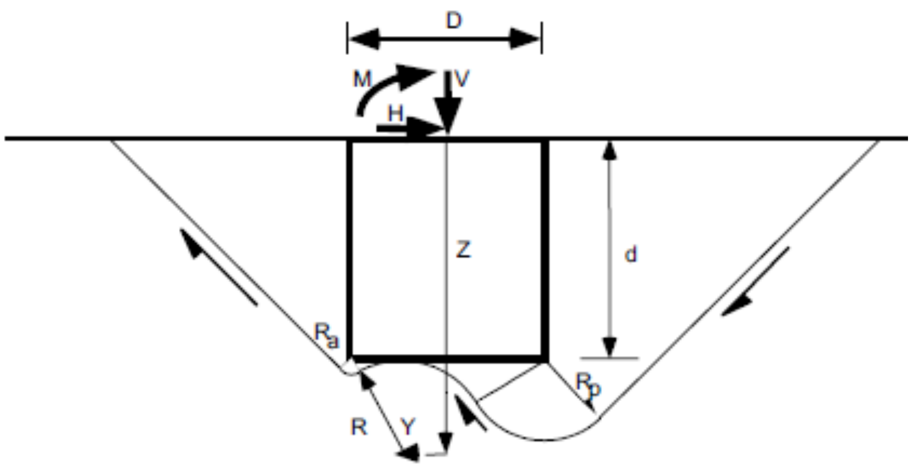


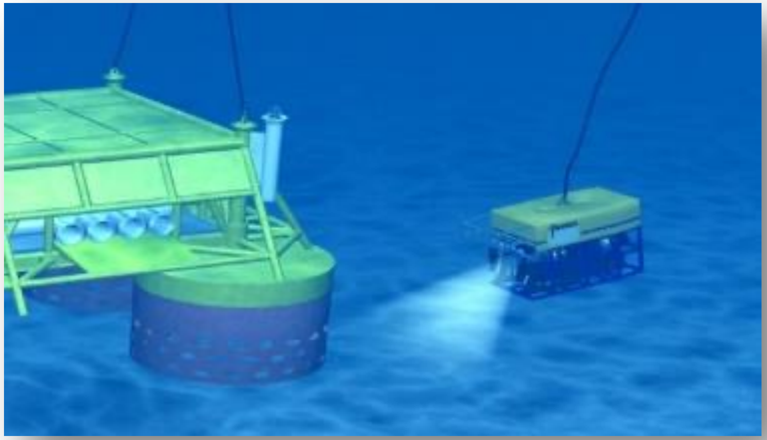





Shallow foundations – Types

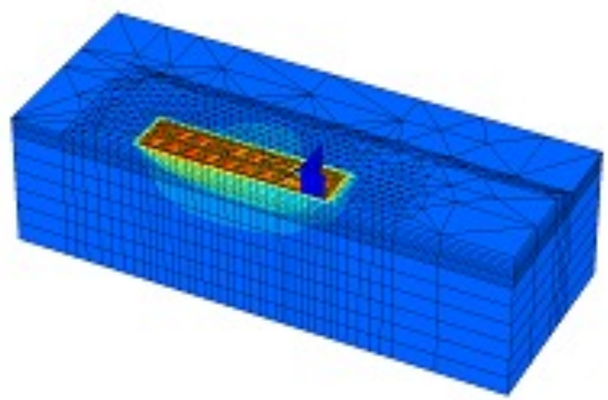
- Axial and lateral / rotational components of soil support cannot be decoupled (unlike pile design)
- Principle applies regardless of size
- Design process considers capacity and settlements for both short-term and long-term response

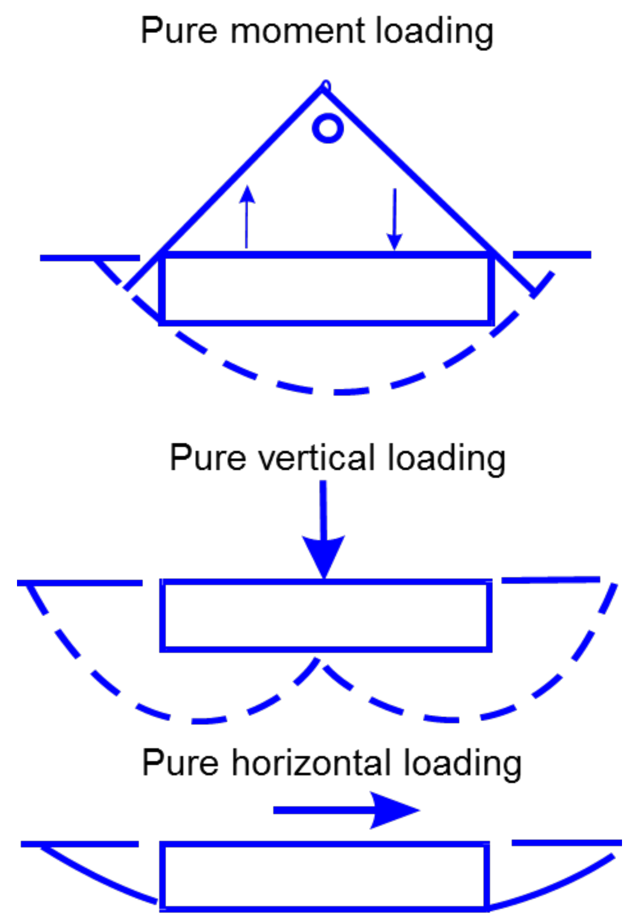


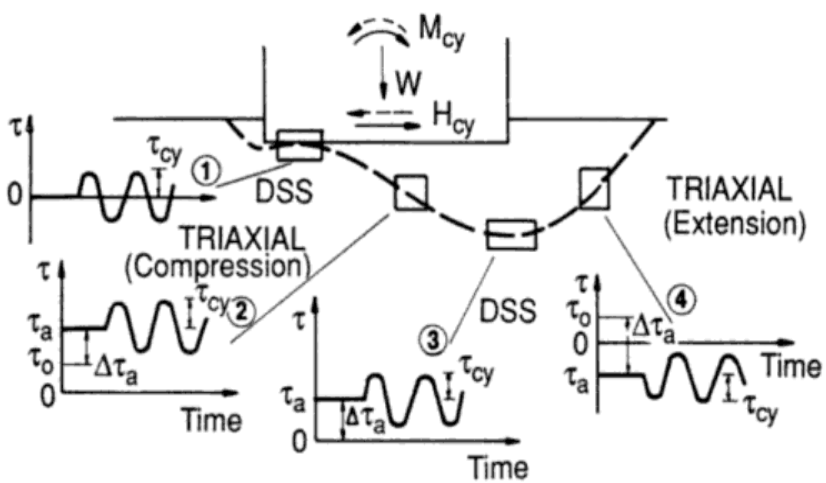


Gravity Based Foundations – Load regimes

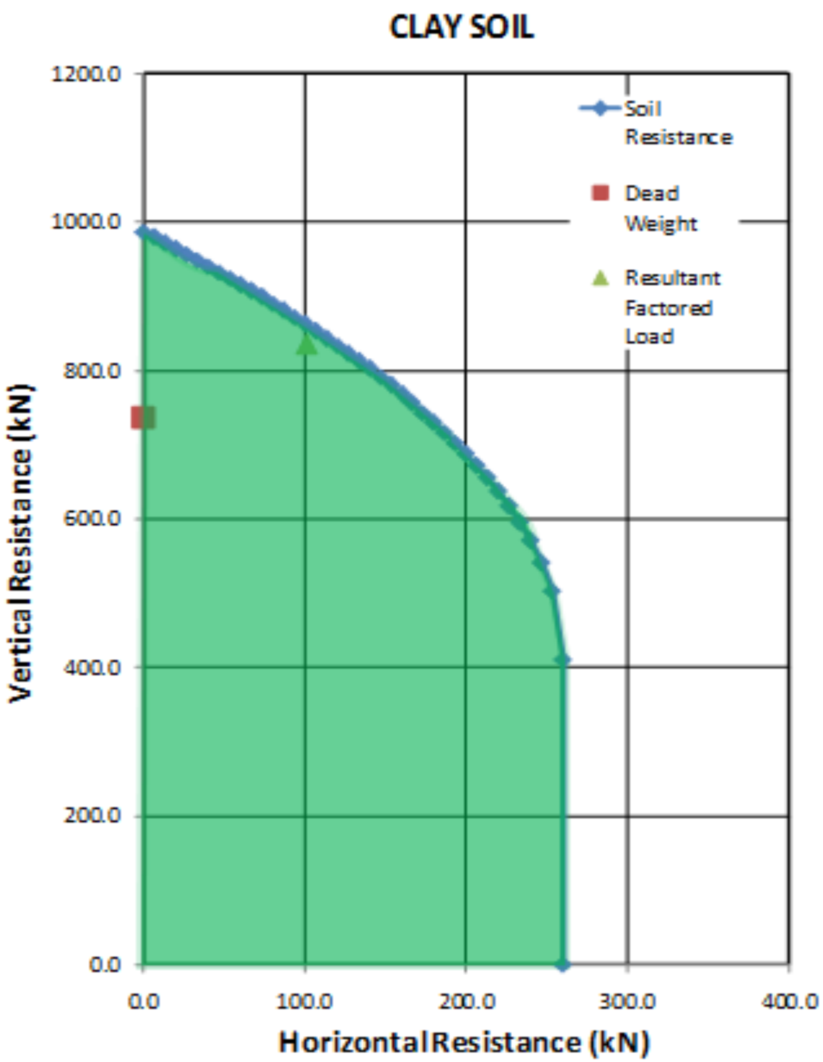
- Overturning
- Torsion
- Bearing
- Sliding

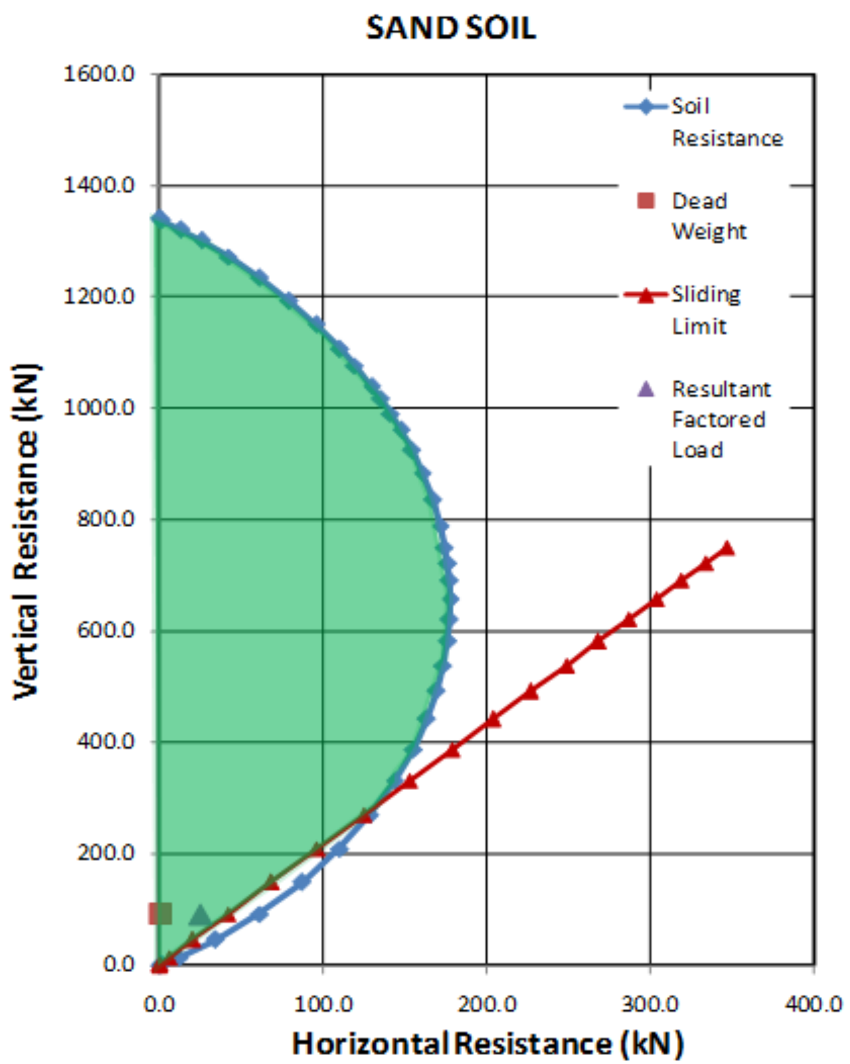






Gravity Based Foundations - Envelopes





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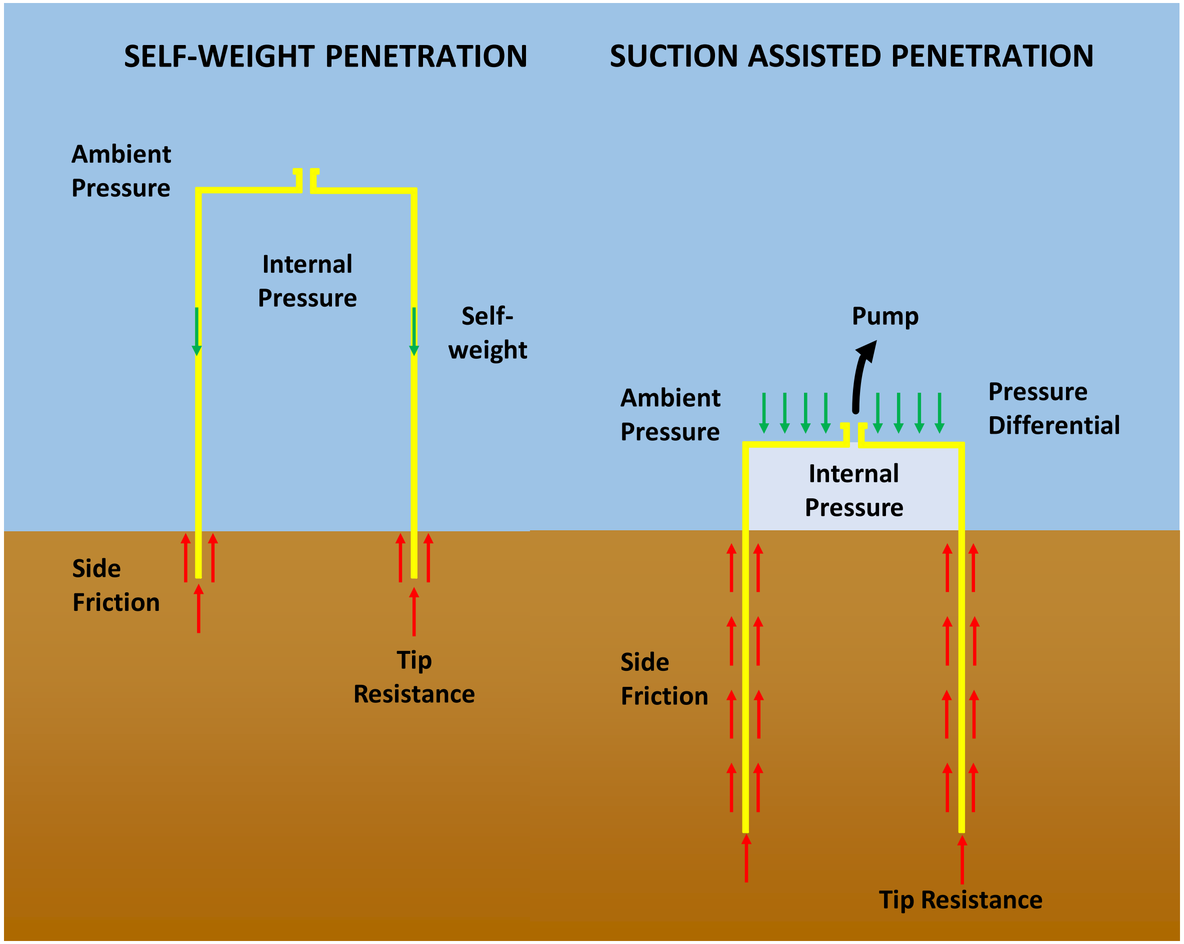
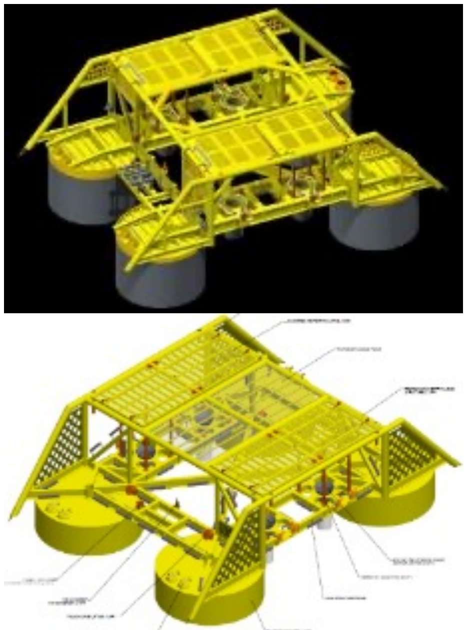
Suction Installation

- Differential pressure provides penetration force
- Plus (in sand) concentrated flow net around tip reduces effective stress
- Rapid
- Quiet
- Reversible



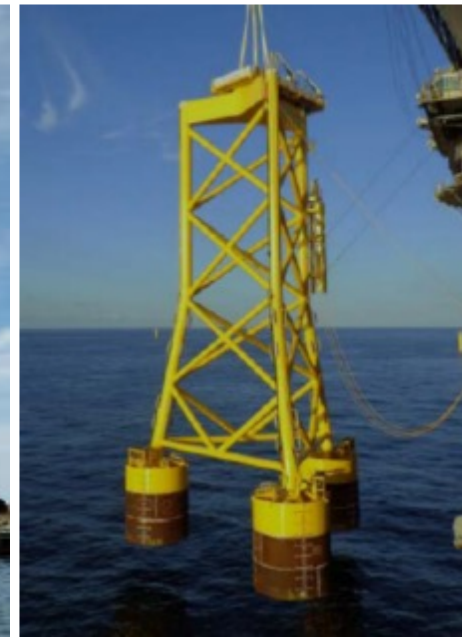
Suction Caissons - Applications



Shallow foundations

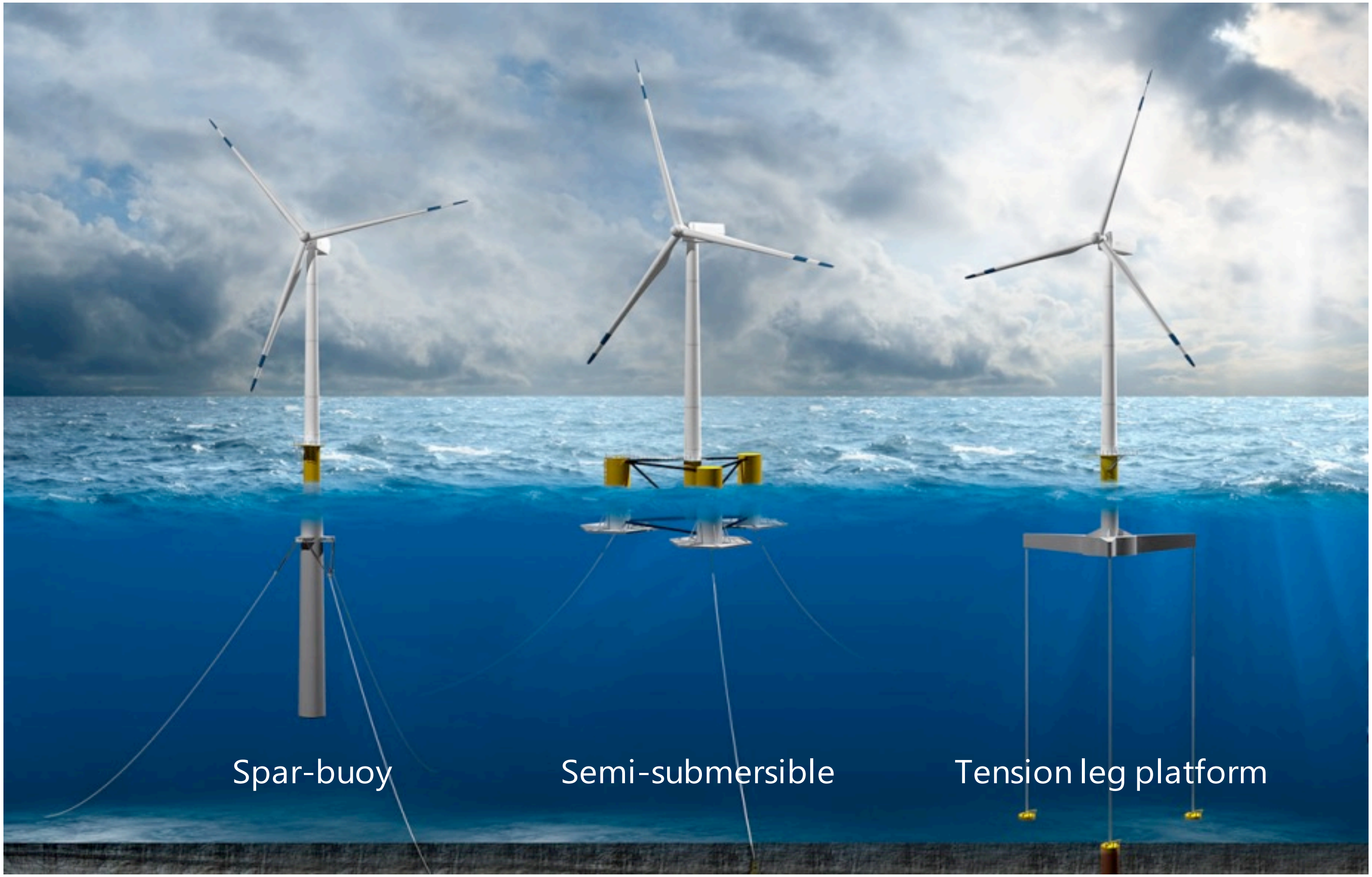
Piles & anchors

Monobucket foundations



Jacket foundations

Suction Caissons – Design challenges OW



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Summary

- Successful foundation design for offshore structures requires:
  - Understanding the design situations and associated load conditions
  - Stable>get it in>make sure it's safe once in>extend life or get it out
  - An understanding of geological variance, the ability to 'read' geotechnical data and understanding of lab testing and soil mechanics first principles. See it>do it>understand it
  - Potential foundation solutions could vary. Think about risk, cost and schedule
  - Cyclic loading effects on design can be critical, particularly for offshore wind

THANK YOU