Offshore Windfarm Design
OE 5662

Foundations

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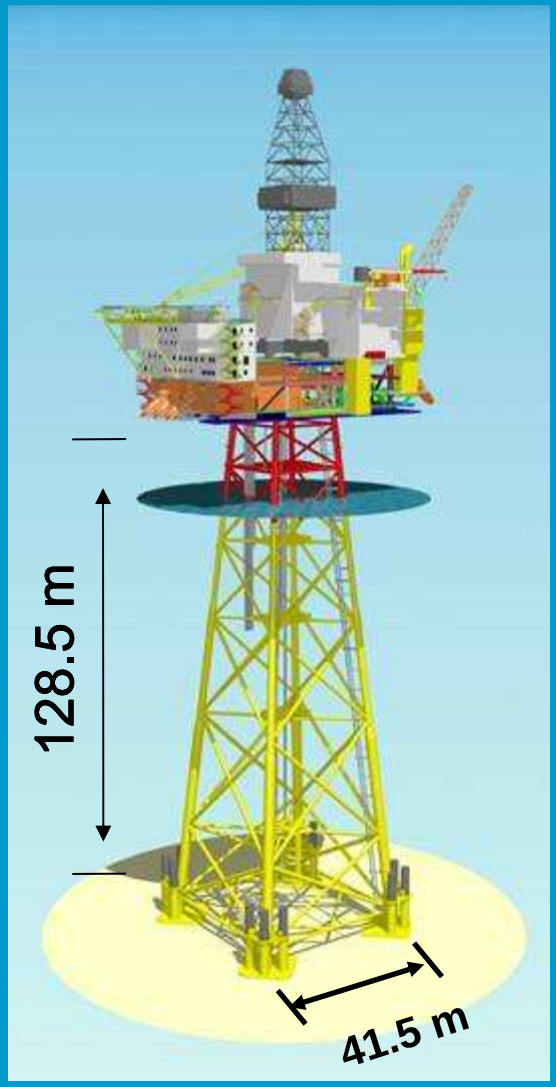
Design of Foundation

Ringhorne platform
Norway

DECK	20.000 mt
WAVE LOAD	41.5 MN
JACKET	7.200 mt
FOUNDATION	2.880 mt



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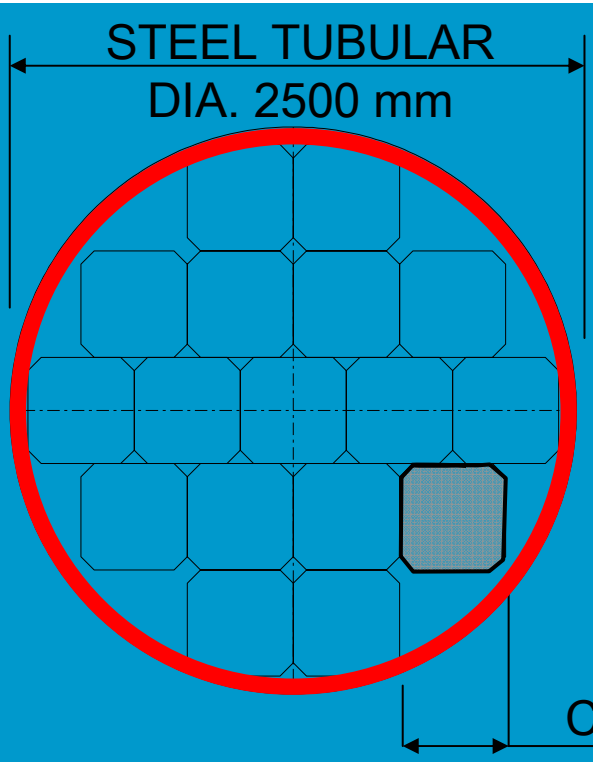

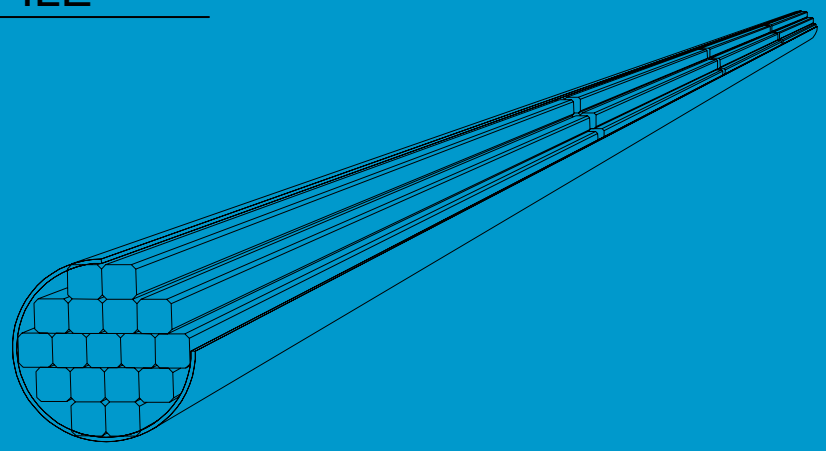

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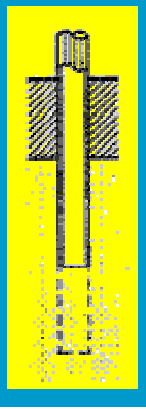
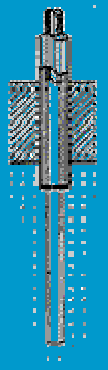
Design of Foundation



Driven

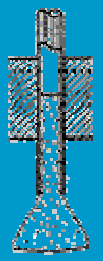
Controlled drilling

Uncontrolled drilling



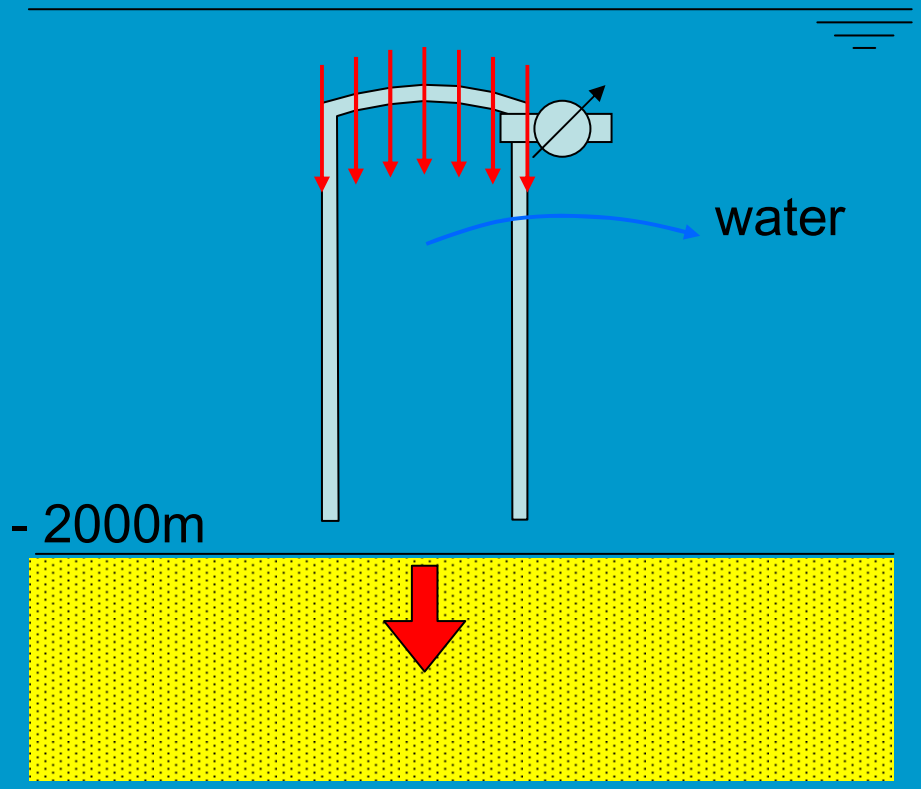
Insert pile

Grouted pile



Belled pile

Design of Foundation
Suction piles



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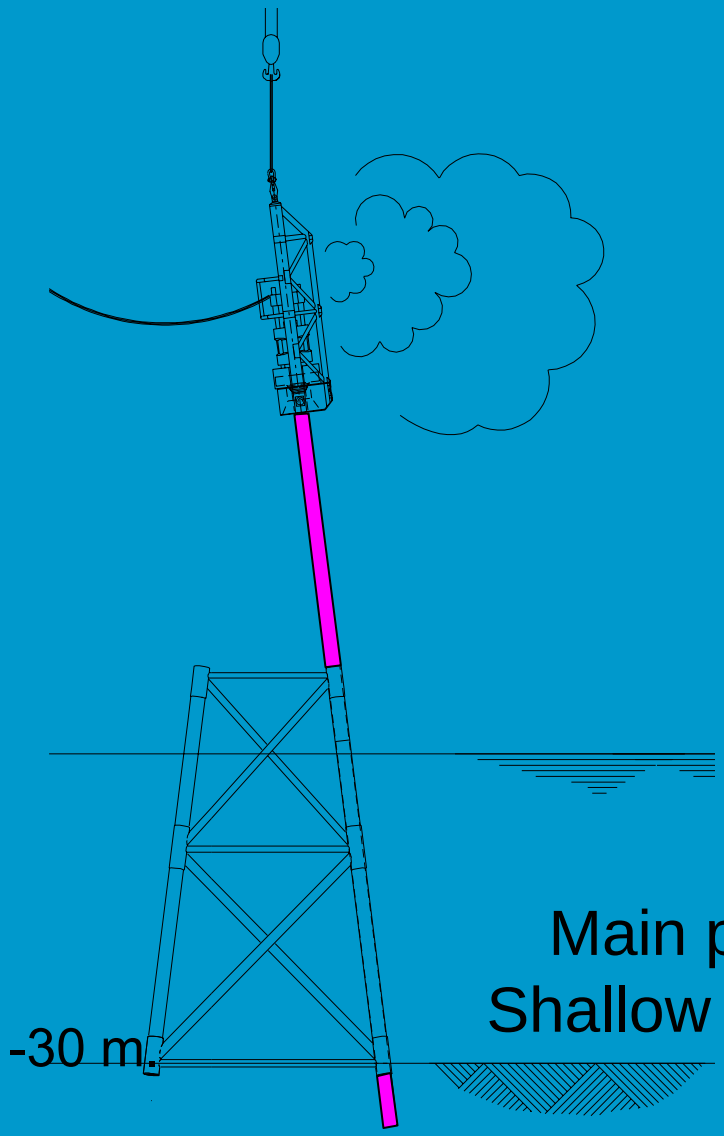

Main pile
Shallow water

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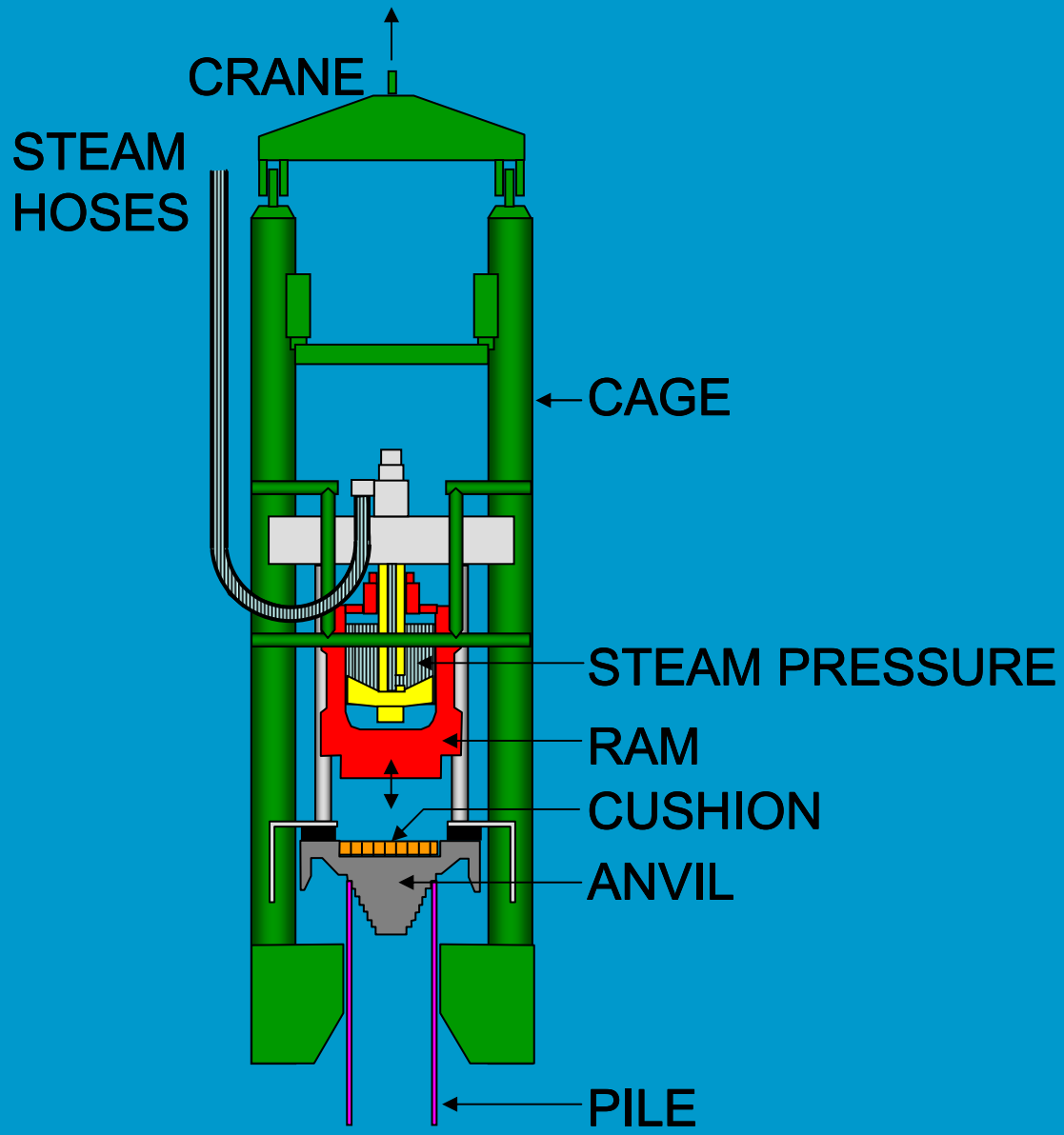

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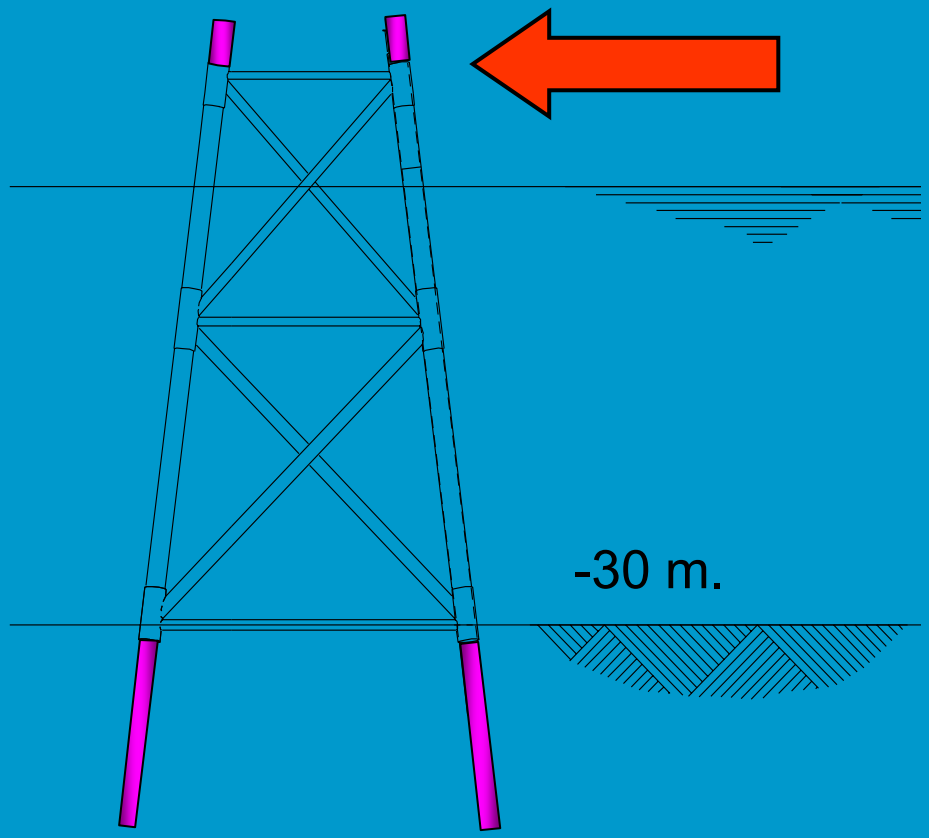

Main pile connection above water-level

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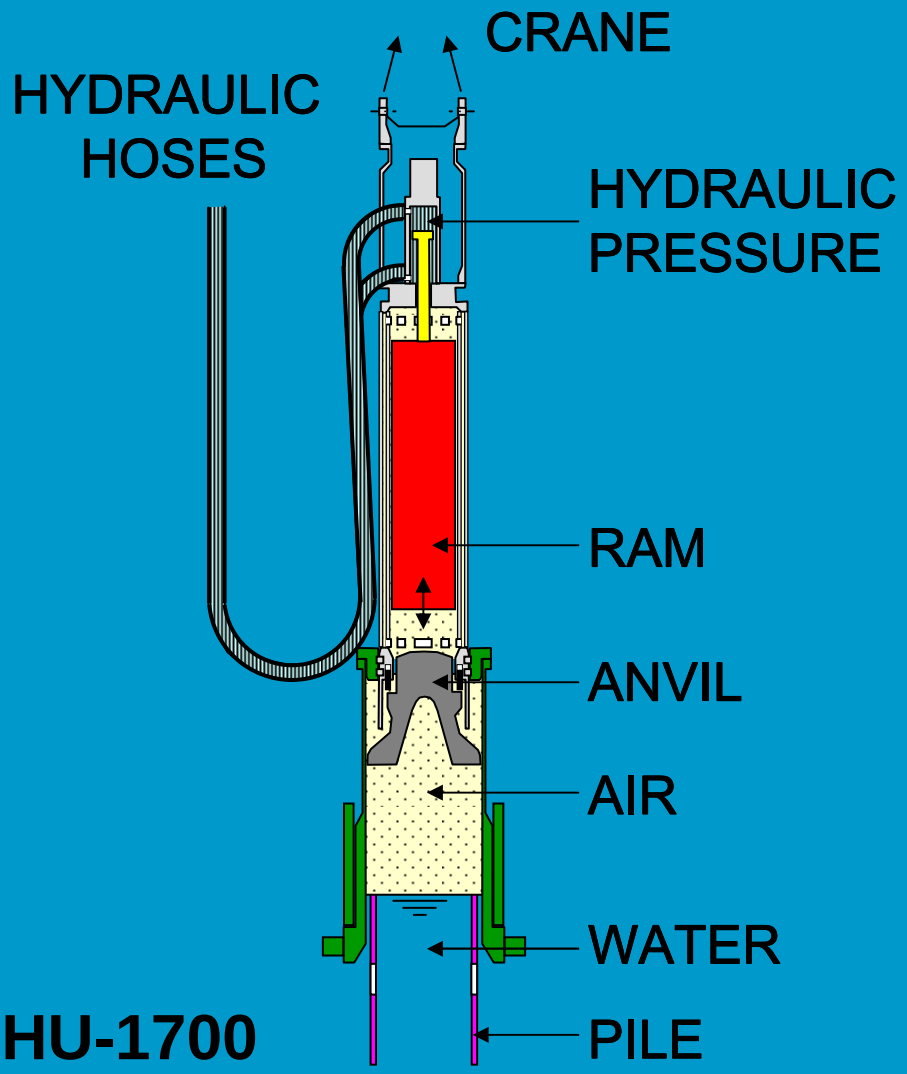
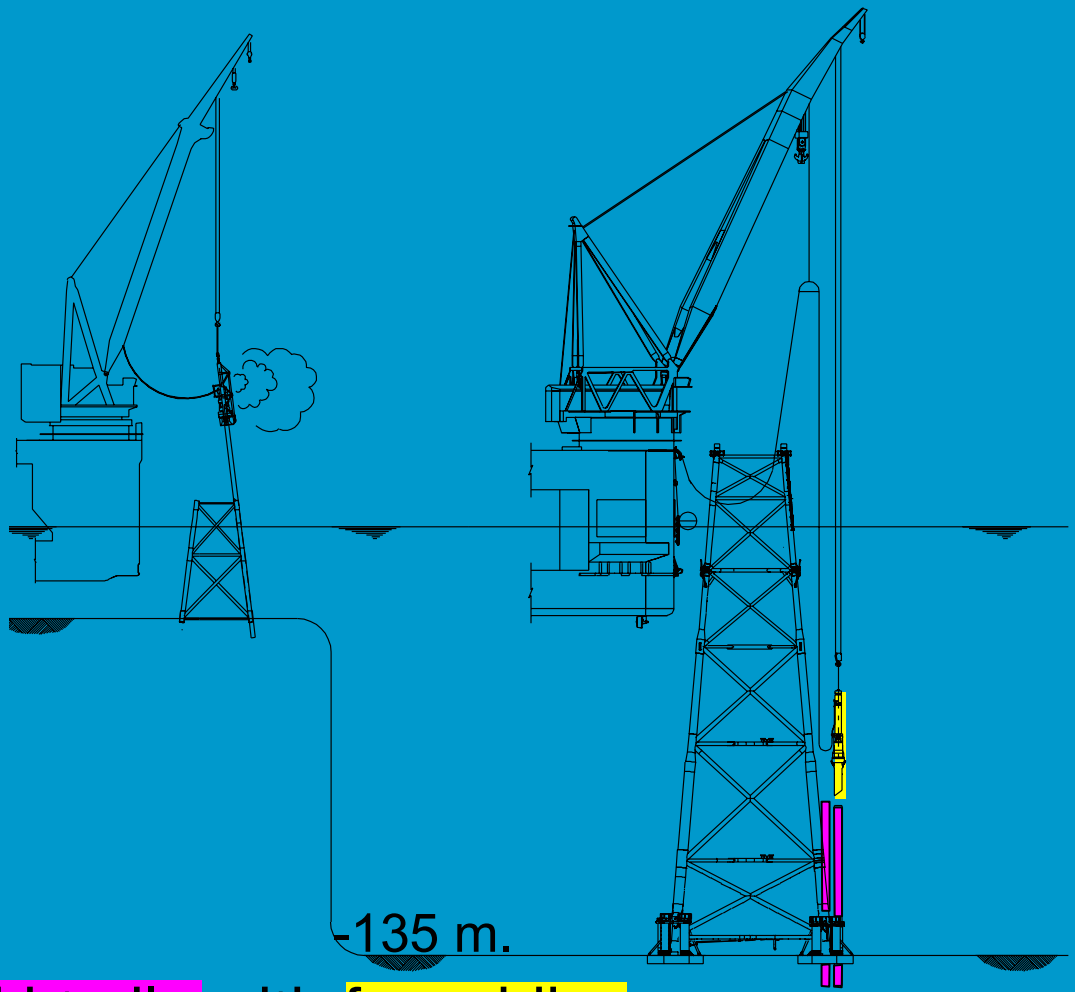


HYDRAULIC HAMMER MHU-1700



Skirt pile with free-riding underwater hammer

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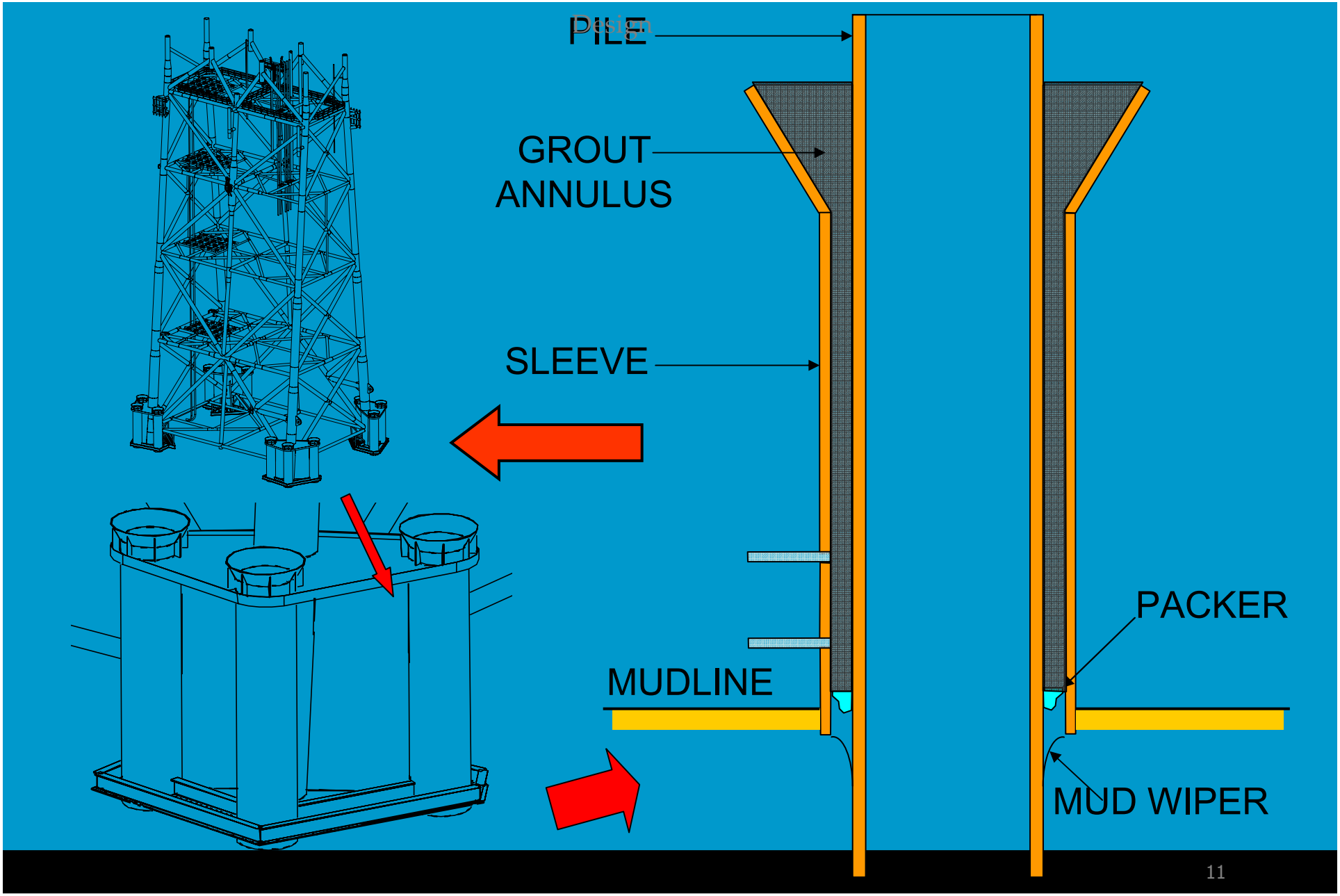

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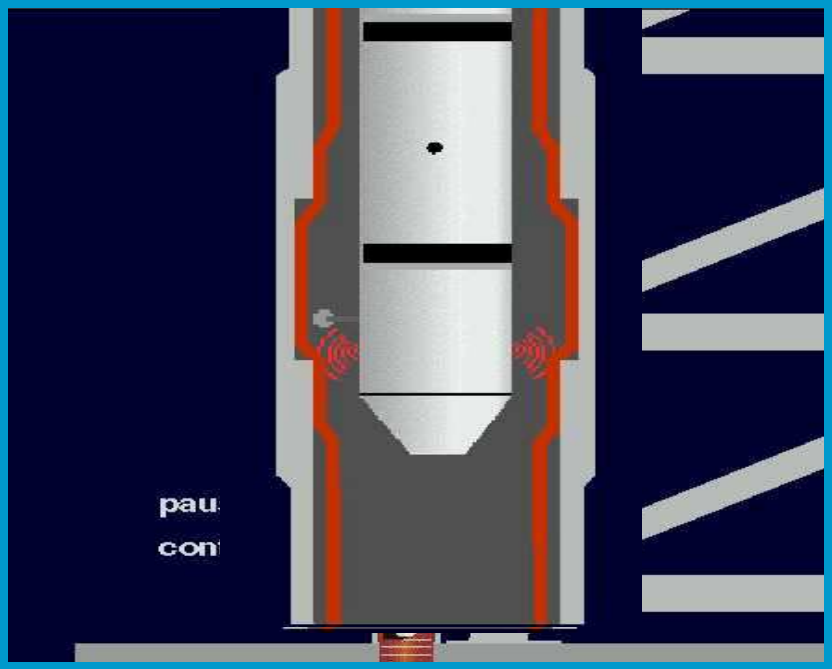
Foundations

SWAGING



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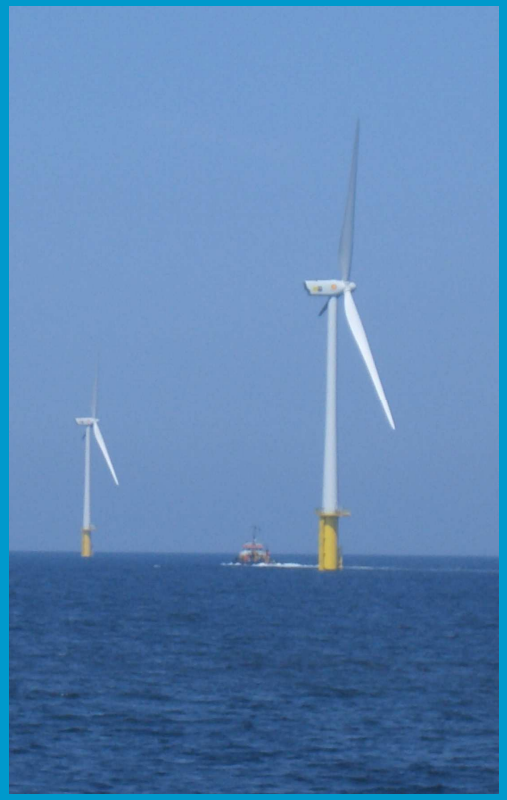
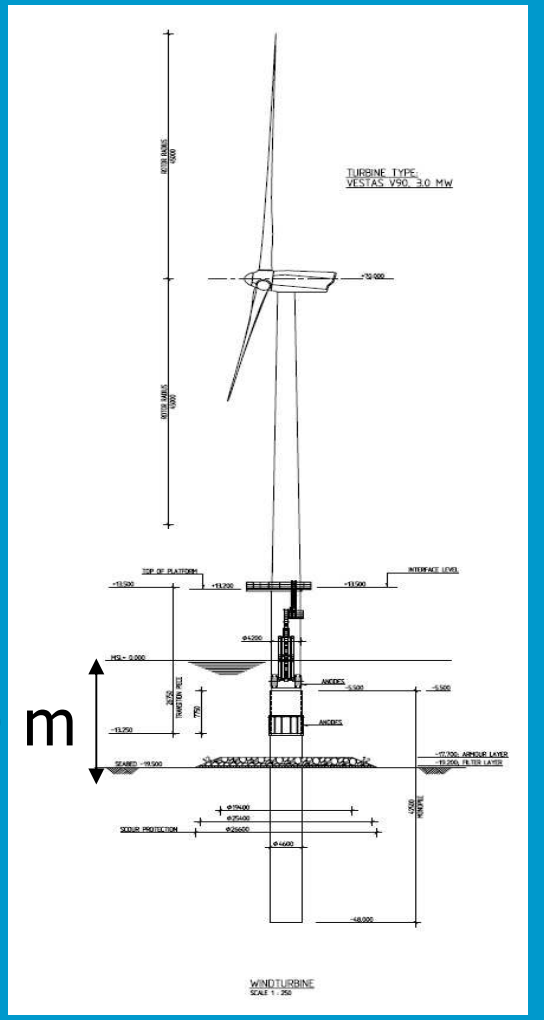
Design of Foundation



Egmond aan Zee Wind Farm, The Netherlands

NACELLE	**100 mt**
WAVE LOAD	**41.5 MN**
TP	**170 mt**
FOUNDATION	**250 mt**



20 m

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Installation of Foundation

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Foundations

Differences Oil & Gas Platforms - Wind Turbines

Oil & Gas Platforms

- relatively stiff
- structural dynamics not critical
- wave loads dominant
- straight forward relation force-response
- 'prototype'

Offshore Wind Turbines

- relatively flexible
- structural dynamics very critical
- wind and wave loads both important
- complex, uncorrelated loading
- generally large numbers

Foundations

Design

Some differences 'oil/gas' platform ⟷ wind turbine foundation

1. Size of loads
2. Ratio vertical – horizontal loads
3. Required distance between turbines
4. Water depth
5. Breaking waves / wave slamming

Foundations

Design

Some differences 'oil/gas' platform ⟷ wind turbine foundation

6. Scour

7. Accessibility - maintenance / inspection

8. GBS - blockage, stability, scour

9. Piles - penetration / dimensions determined by horizontal rather than vertical loads
   (for mono-piles)

Foundations

Fixed **Floating**

- Gravity base structures
- Piled
  - driven piles
  - drilled piles
  - suction piles

Foundations

Gravity foundations

- Loading situation very different from piled foundation
- Substantial vertical loading required (stability)
- Generally impractical support structure for wind turbines in relatively shallow water

Foundations

Piled foundations

- Flexibility / Adaptability :

  - soil conditions
  - water depth
  - scour
  - diameter and wall thickness
  - tension & compression
  - penetration and number
  - track record / experience
  - different installation methods

Foundations

Design

Typical North Sea wind farm design conditions:

- Relatively shallow water (10 – 25 m)
- Generally sandy soil conditions
- "Walking" sandbanks (Sand waves)
- Scour (influence of current and waves)
- Large cyclic loads on monopile

Design of Foundation
Design criteria & considerations

- **loads:**
  - magnitude of the permanent load of the platform
  - wind / wave / current
  - ratio vertical / horizontal loads
  - quasi static / cyclic
- **water depth**
- **sea floor**
  - soil type
  - current -> scouring
- **fabrication, transportation & installation**
  - available construction sites / equipment

Foundations

Choice of foundation type (1)

- Loads
  - wind / wave / current
  - horizontal and vertical
  - quasi static / cyclic
- Water depth
- Soil conditions

Foundations

Choice of foundation type (2)

- Storage requirements
- Transportation / Installation

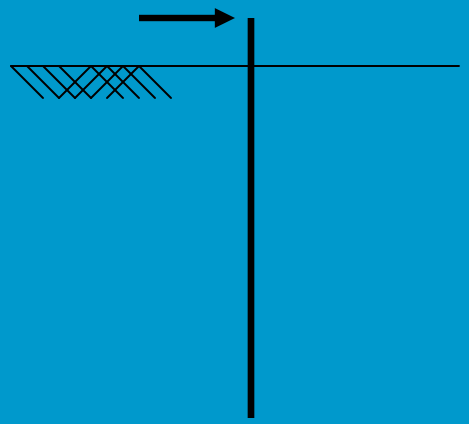
equipment requirements

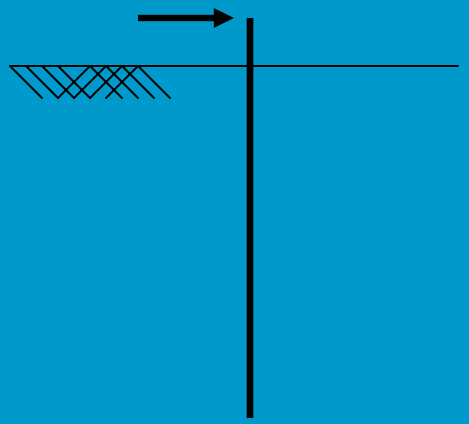
- Available construction sites / equipment
- Economics

Foundations

Laterally loaded piles

infinitely stiff vs. elasticity





- p-y curves
- cyclic effects
- scour (1 – 2D)

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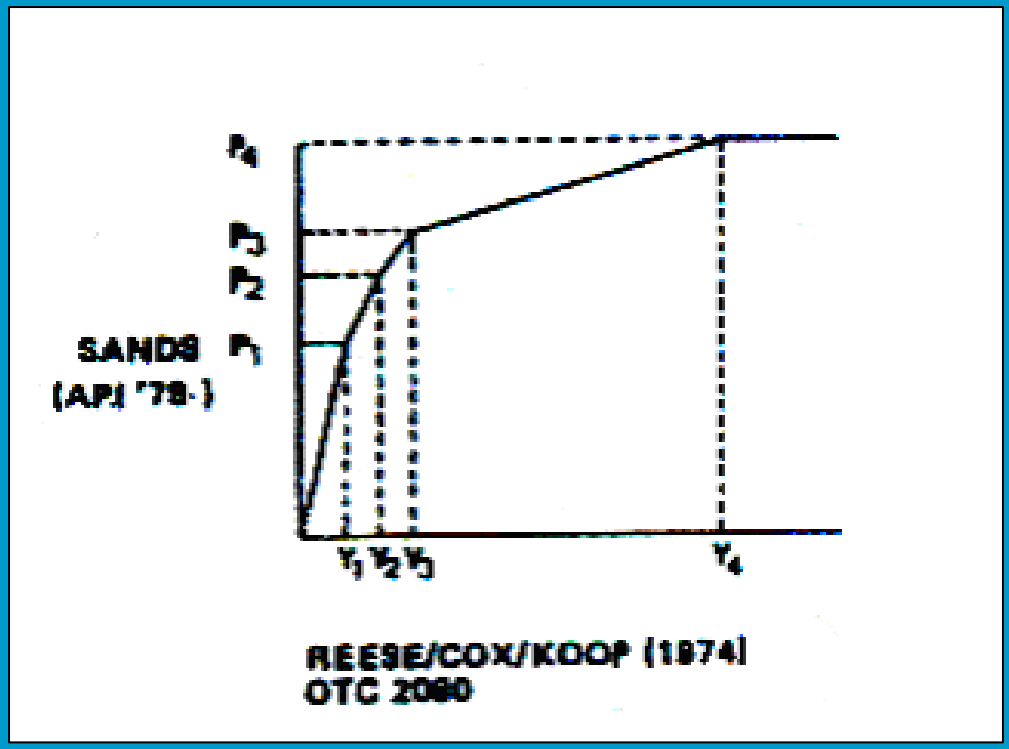
Foundations

Lateral pile behaviour



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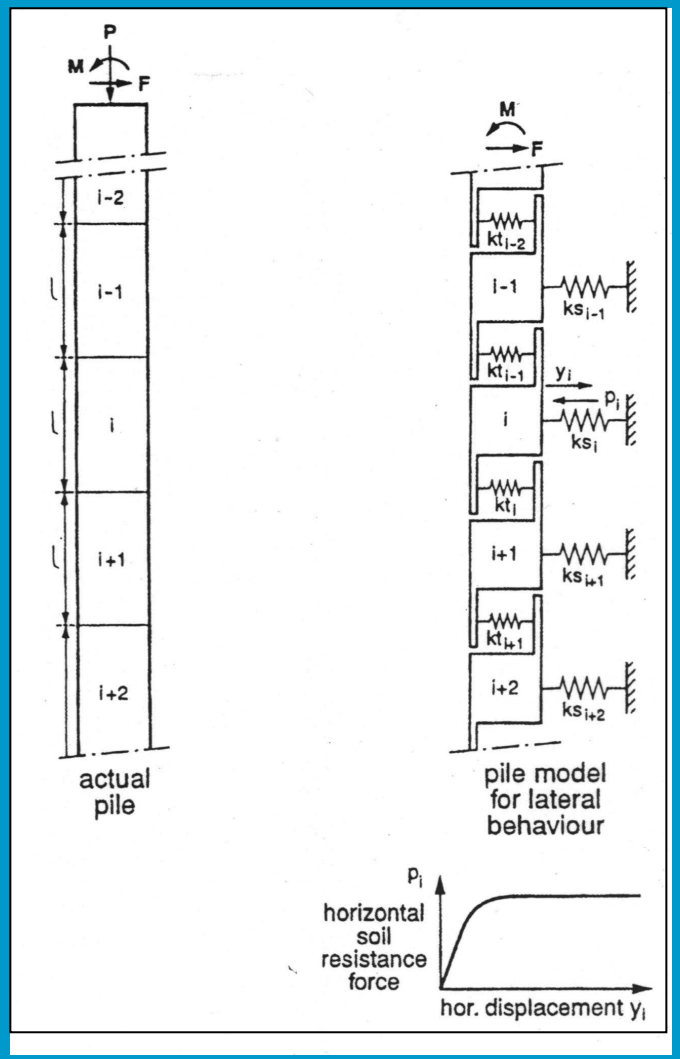
Conceptual model for lateral pile behaviour



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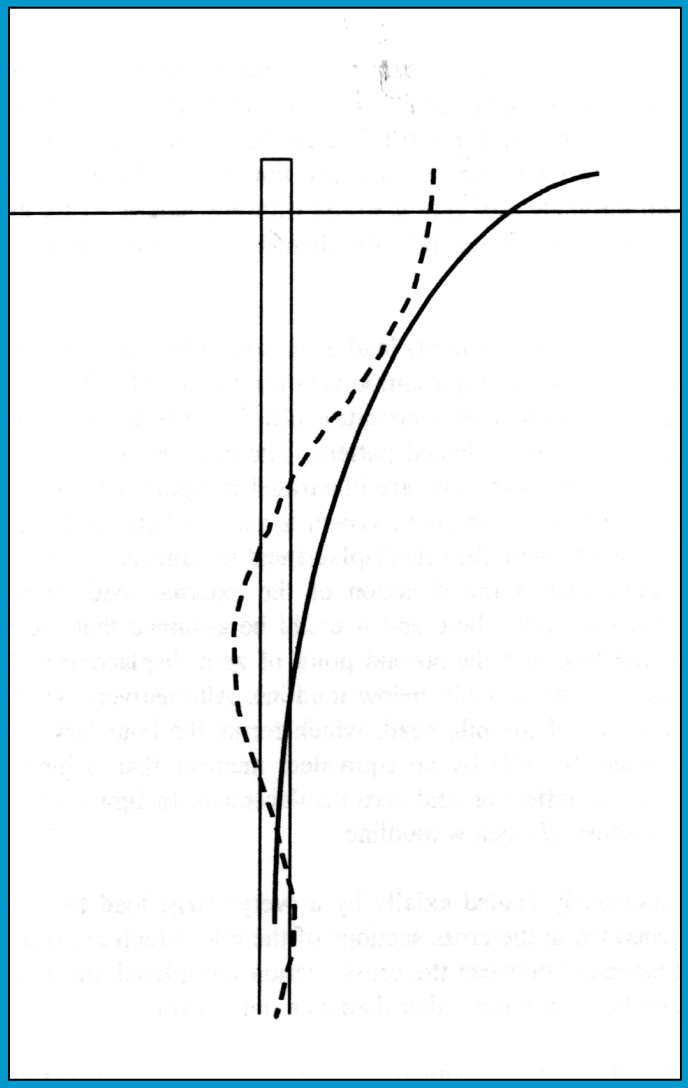
Foundations

Deformation of a pile
with and without head restraint



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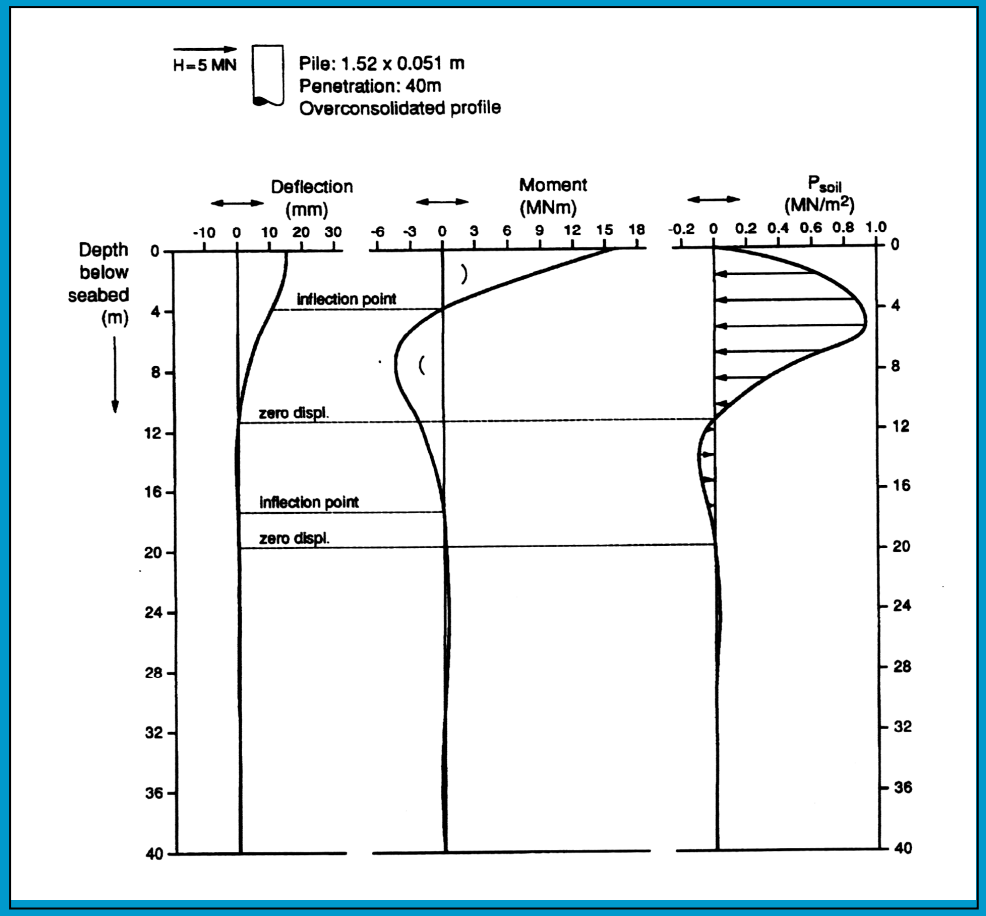

Pile behaviour under lateral loading

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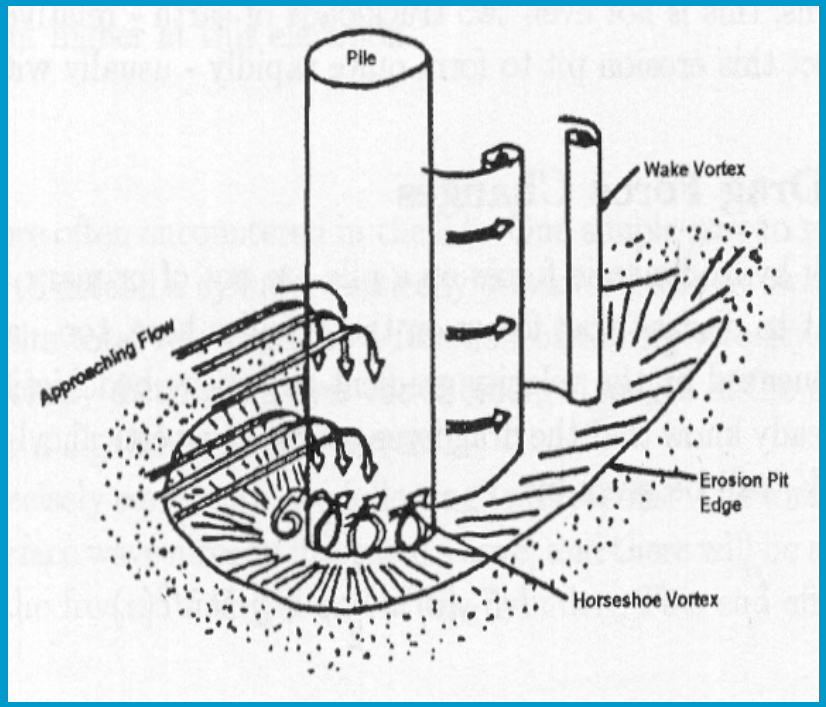
Foundations

Scour



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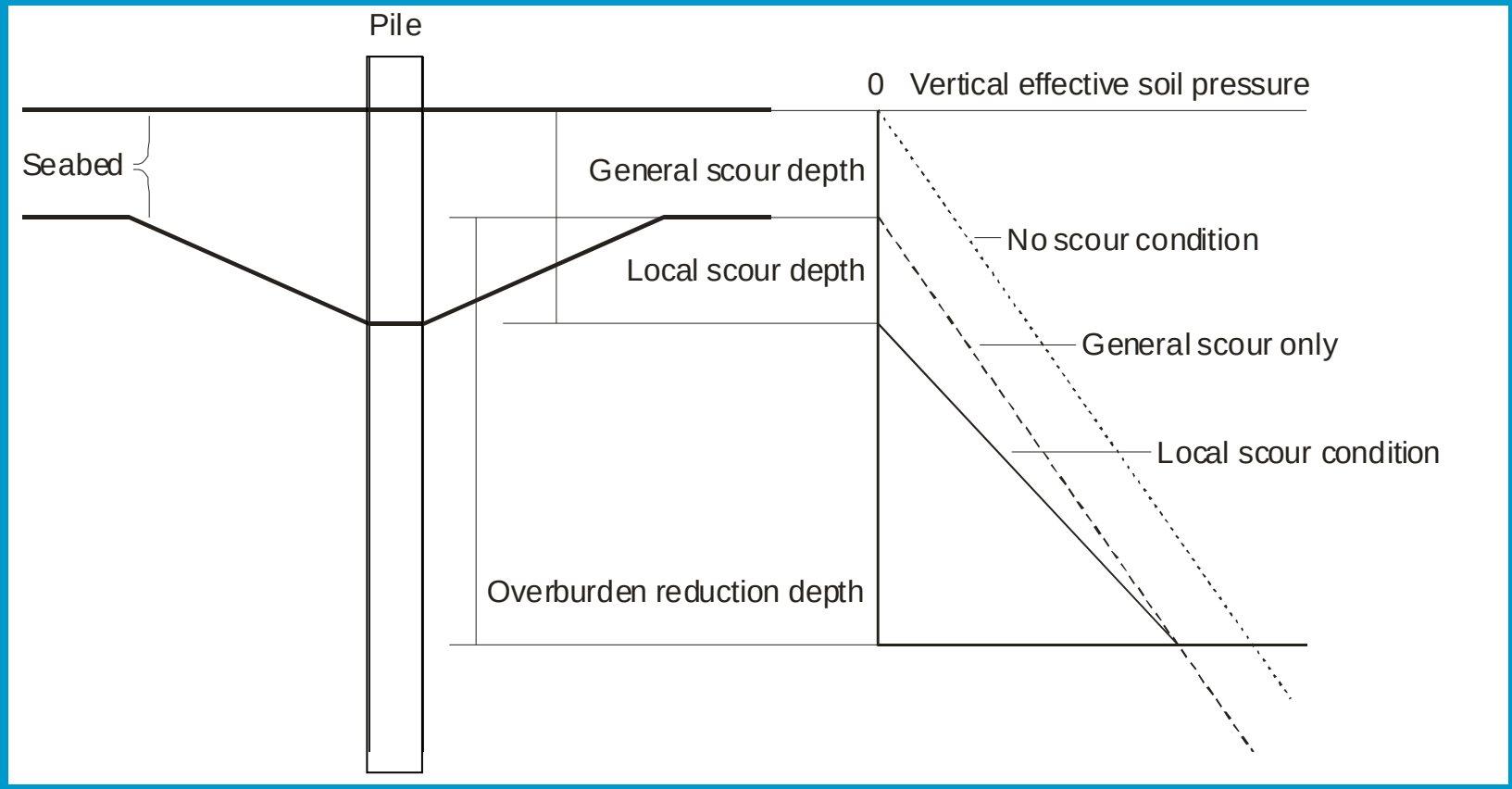
Foundations

Scour



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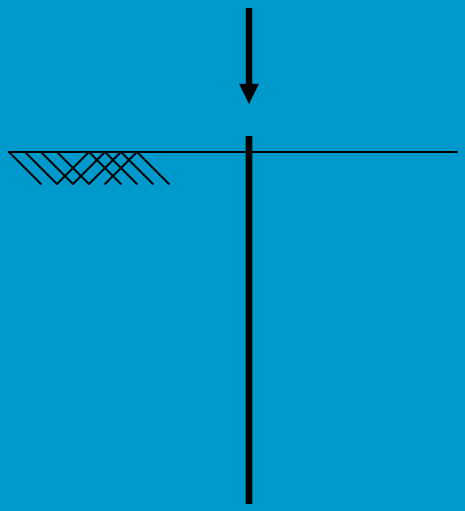
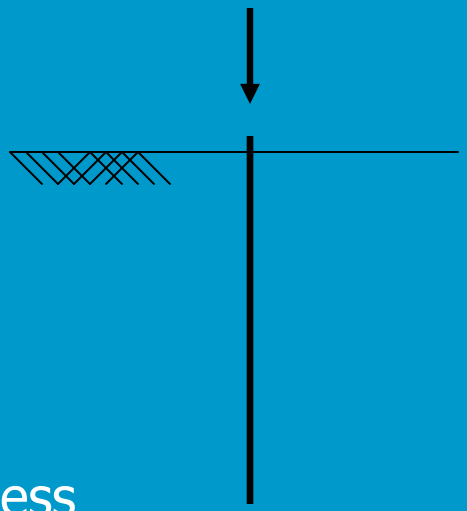
Foundations

axially loaded piles

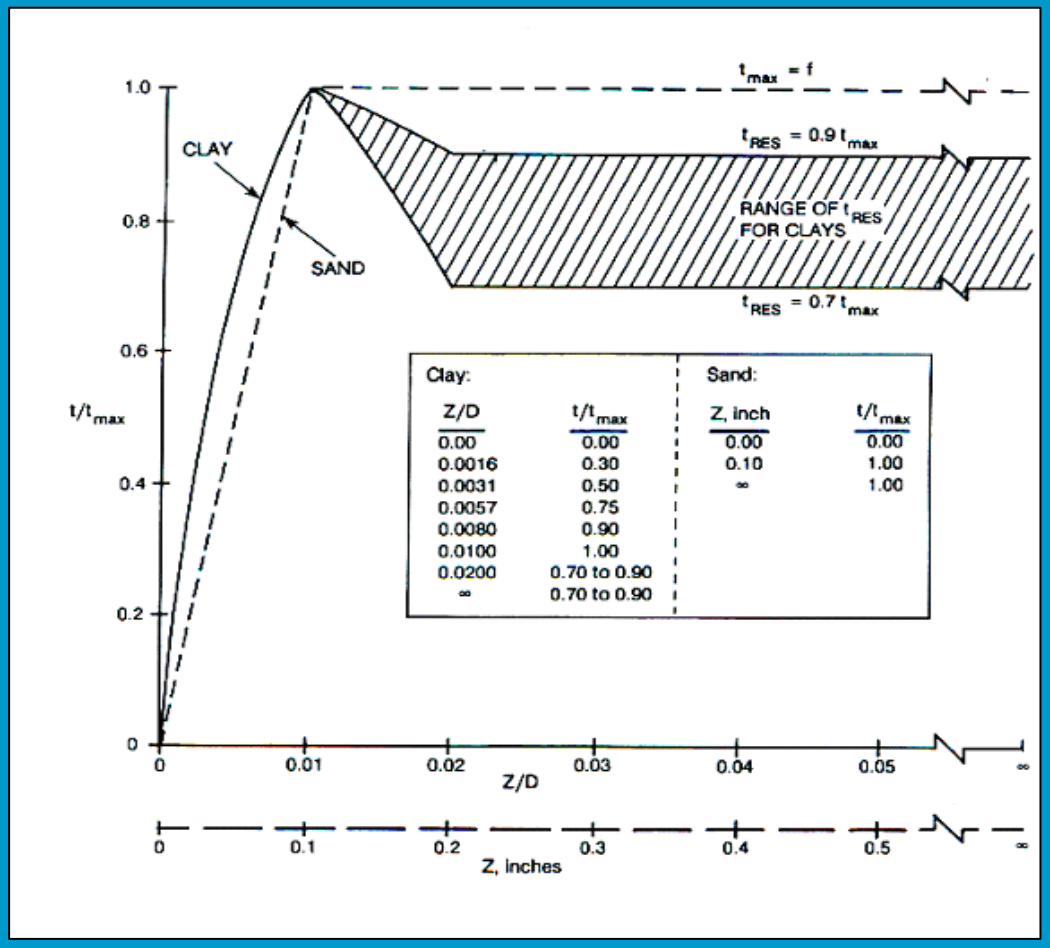
infinitely stiff vs. elasticity





- t-z curves
- cyclic 'degrading' less
- tension < compression

Foundations



Clay: Z/D	Clay: t/t_{max}
0.00	0.00
0.0016	0.30
0.0031	0.50
0.0057	0.75
0.0080	0.90
0.0100	1.00
0.0200	0.70 to 0.90
∞	0.70 to 0.90

Sand: Z, inch	Sand: t/t_{max}
0.00	0.00
0.10	1.00
∞	1.00

Typical axial pile load transfer-displacement (t-z) curves

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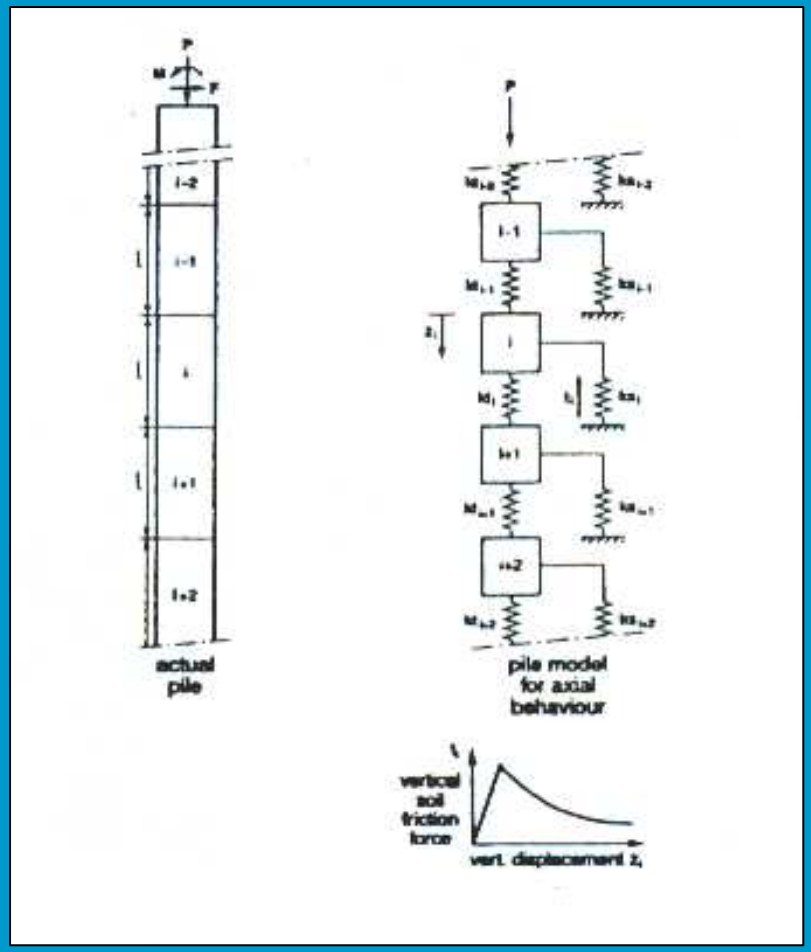

Conceptual model for axial pile behaviour

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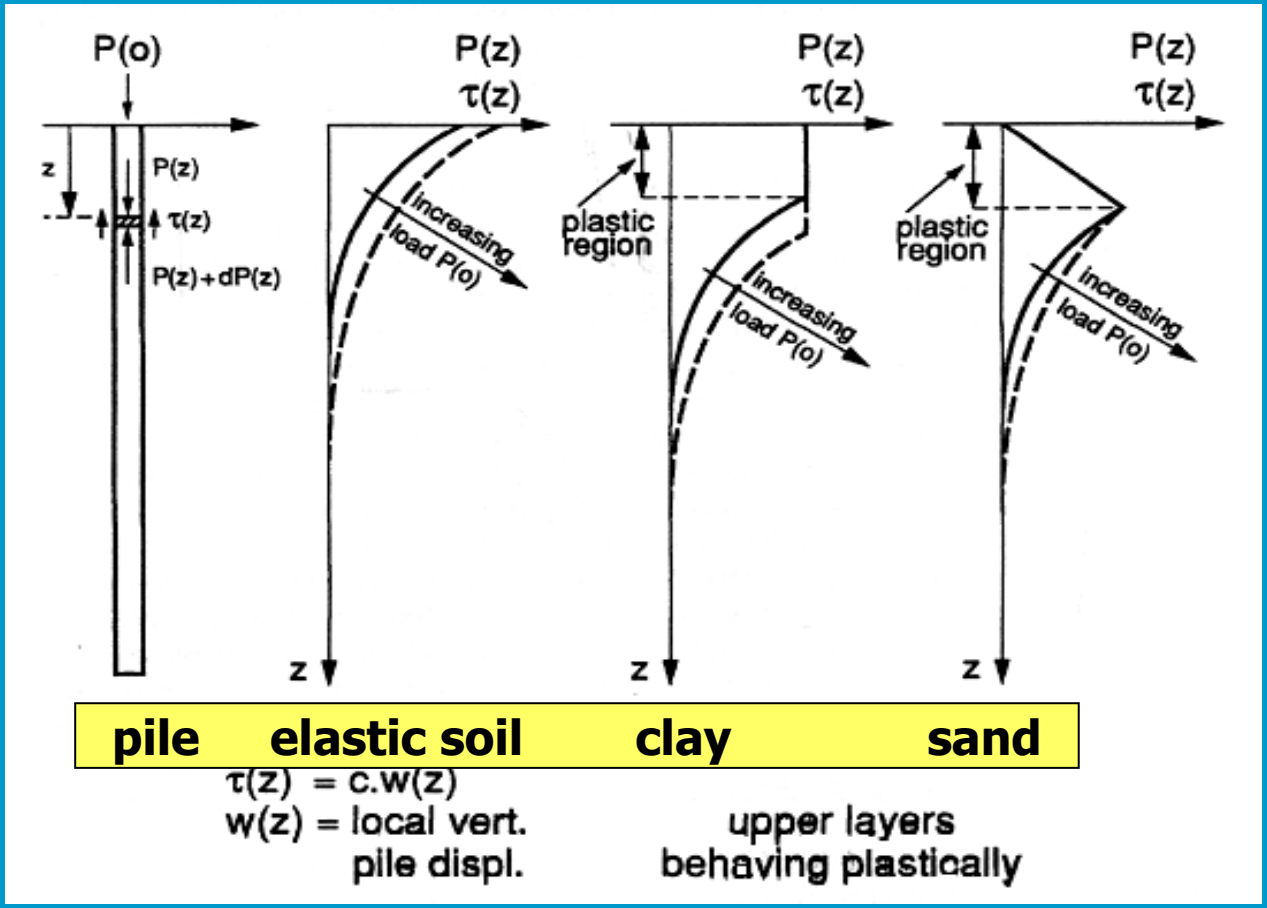

Pile behaviour under axial loading

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Foundations

'conventional pile' **vs.** **'monopile'**

overturning moment

axial pile forces
(batter piles / vertical piles)

bending of pile
(vertical pile)

required penetration

vertical load
horizontal load

vertical load
horizontal load
(stiffness)

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Foundations

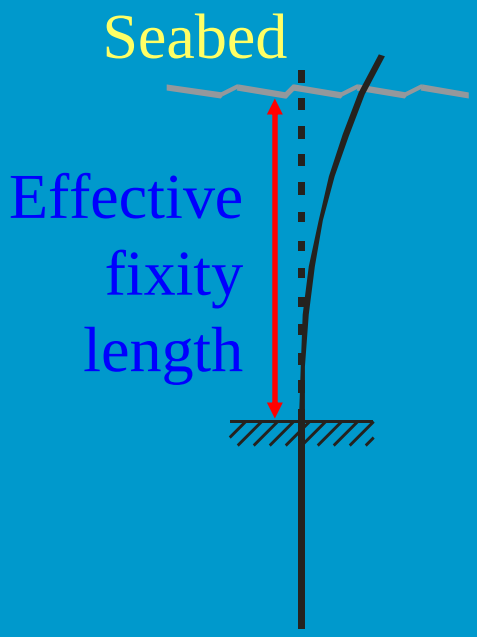
Foundation model

- Fixed at some distance below seabed (Effective Fixity)
- Apply (un)coupled rotational and lateral spring
- Determine stiffness matrix
- Use enhanced foundation model

Note: soil not homogeneous ; " soil ≠ soil "

Foundations

Foundation Model: Effective Fixity Depth



Configuration	*Effective fixity length*
Stiff clay	3.5 *D* – 4.5 *D*
Very soft silt	7 *D* – 8 *D*
General calculations	6 *D*
Experience with offshore turbines	3.3 *D* – 3.7 *D*

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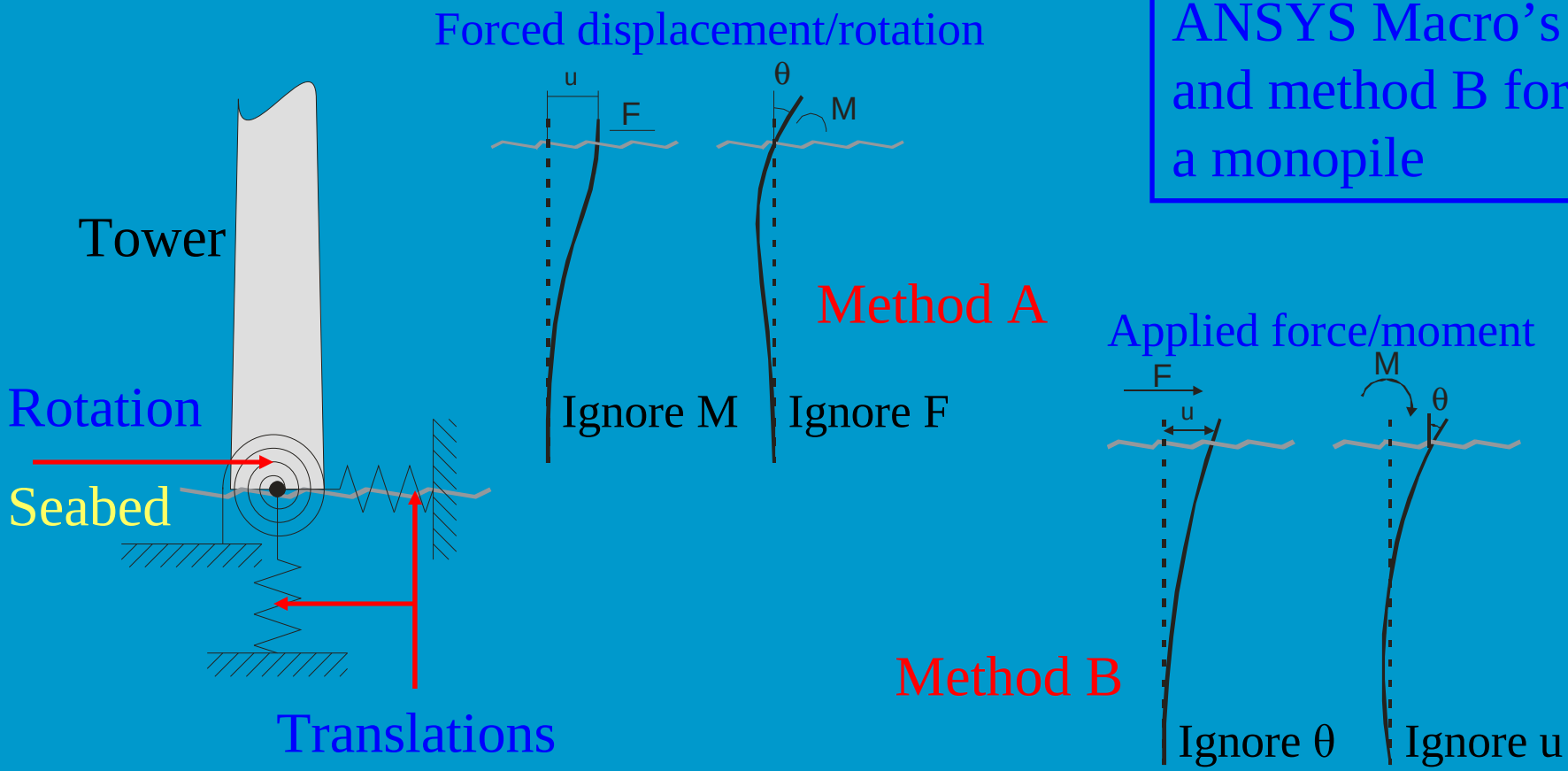
Foundations

Foundation Model: Uncoupled springs

In exercise: Use ANSYS Macro's and method B for a monopile



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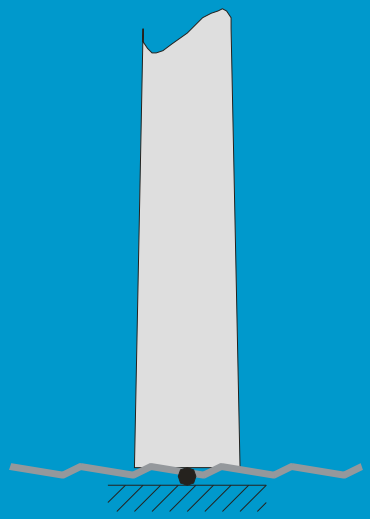
Foundation Model: Stiffness Matrix



$$\begin{bmatrix} H \\ M \end{bmatrix} = \begin{bmatrix} k_{xx} & k_{x\theta} \\ k_{\theta x} & k_{\theta\theta} \end{bmatrix} \cdot \begin{bmatrix} u \\ \theta \end{bmatrix}$$

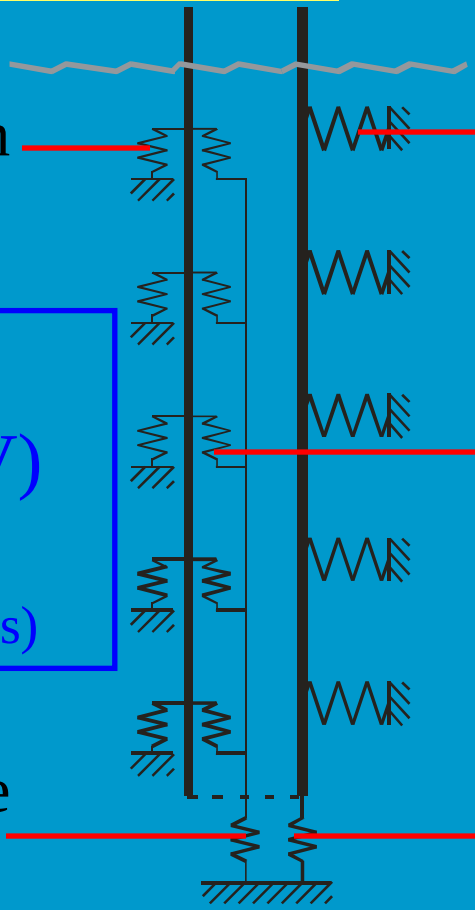
Stiffness matrix

Run two load cases with FEM model with py-curves

(See next slide)

Foundations

Enhanced Foundation Model



External shaft friction
(t-z curves)

Lateral resistance
(p-y curves)

Use:
Standards (API/DNV)
Existing software
(In exercise: ANSYS Macro's)

Internal shaft friction
(t-z curves)

Pile plug resistence
(Q-z curves)

Pile point resistance
(Q-z curves)

Foundations

Pile Fabrication / transportation / lifting / positioning / driving

- Fabrication →
- Lifting / Transportation
  - D/t → pile (tip) integrity
  - lifting tools
  - welded appurtenances (SCF's)
- Positioning → verticality
  - monopiles
  - jackets / towers / tripods
- Driving

Foundations

Pile Fabrication / transportation / lifting / positioning / driving

Foundations

Pile Fabrication / transportation / lifting / positioning / driving

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Pile Fabrication / transportation / lifting / positioning / driving

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