Improved p-y curves for design of Offshore Wind Turbine Foundations

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Introduction

The use of renewable energy is a hot topic in the world nowadays[1]. Wind turbines are increasing their relevance day after day, with a majority of the turbines located onshore, having several challenges which have been overcome by moving to offshore locations[2]. The current trend of installing wind farms more and more far away from the coast and into deeper waters have forced designers to develop increasingly bigger structures and foundations, which in addition suffer higher accumulated displacements due to greater amplitude of the cyclic loadings.

Presently, these foundations are designed using p-y curves, based on pseudo-static approaches, and are formulated for cyclic loading conditions based on field tests with less than 200 cycles[4,5]. Natural offshore loading conditions, which may have up to 10^8 cycles, are not captured. Some researchers have demonstrated that finite element numerical simulations can be adopted to reflect offshore cyclic behaviours[3,6,7].

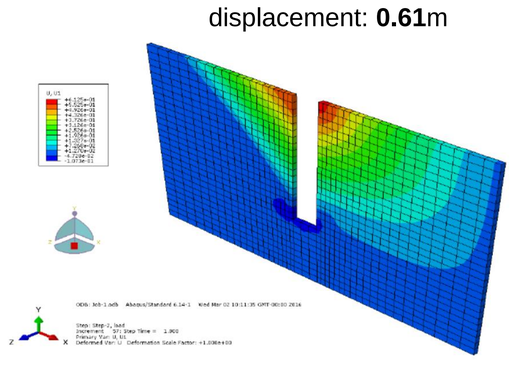
Vattenfall's Horns Rev 1 offshore wind farm.
Photograph by Christian Steiness
(https://millicentmedia.com/2012/09/11/cutting-costs-for-offshore-wind-farms/)

Aim and Objectives

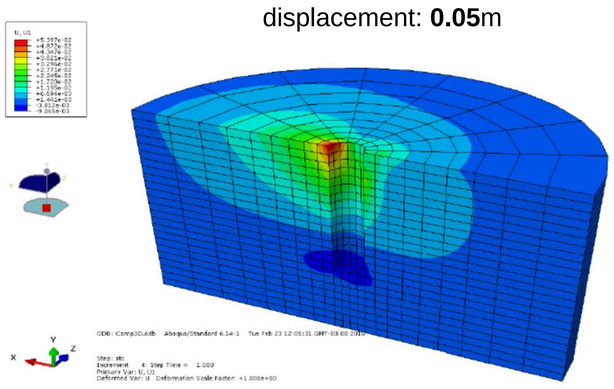
The main aim of this research is to thoroughly revise the soil resistance-pile deflection (p-y) curves used for designing monopile foundations in offshore windmills, to accommodate for dynamic cyclic lateral loads.

2D vs. 3D models

Max horizontal displacement: **0.61**m



Max horizontal displacement: **0.05**m

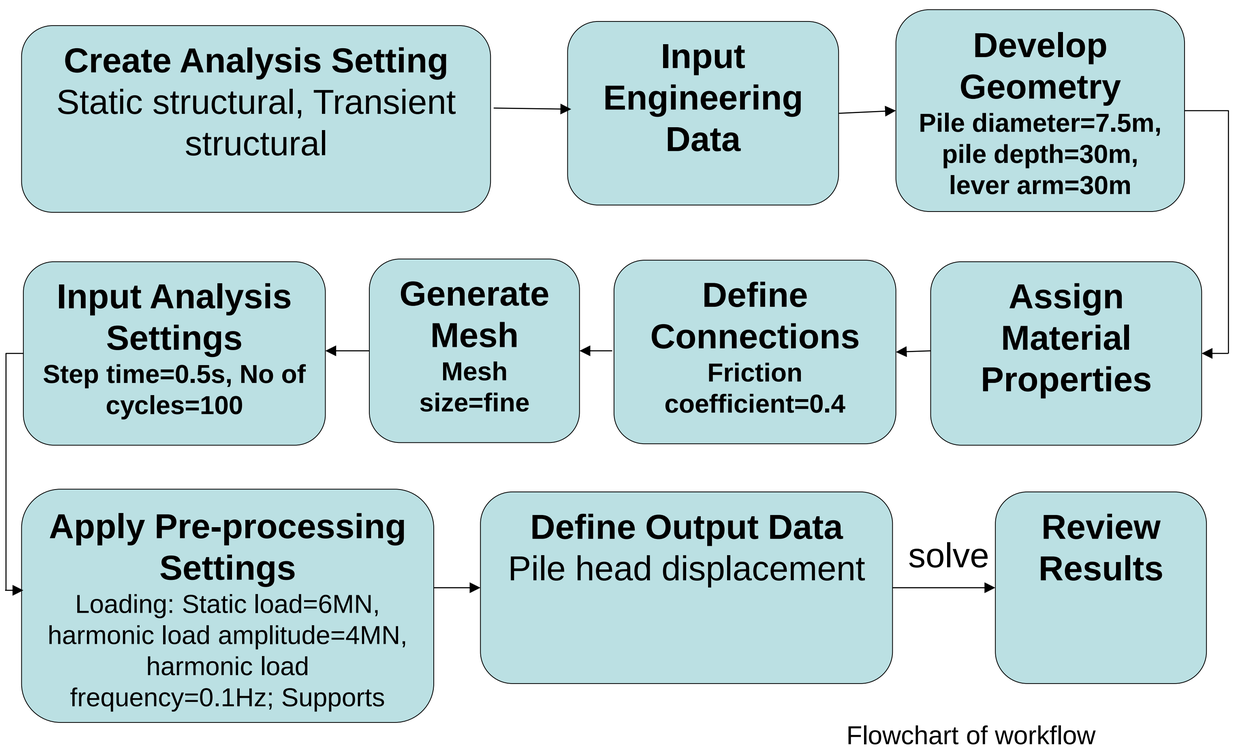


A first comparison has been made, demonstrating the unsuitability of 2D models to capture the features of a 3D model.

Therefore: 3D modelling was adopted

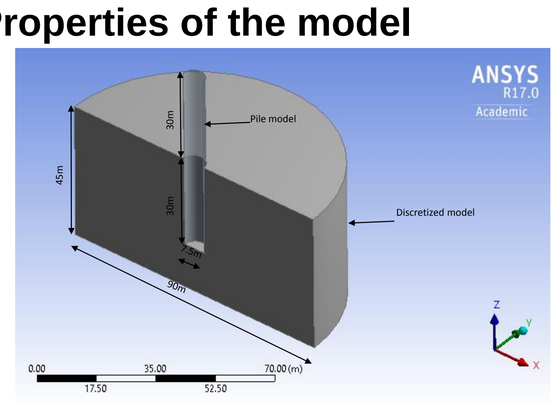
Methodology

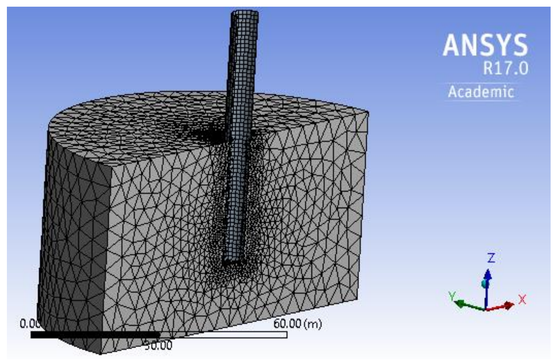
A three dimensional finite element model was developed, using ANSYS 17.0 software. A kinematic hardening law, coupling the elastic moduli and the hardening parameter, has been adopted. The flow chart of the model is:



Flowchart of workflow

Properties of the model





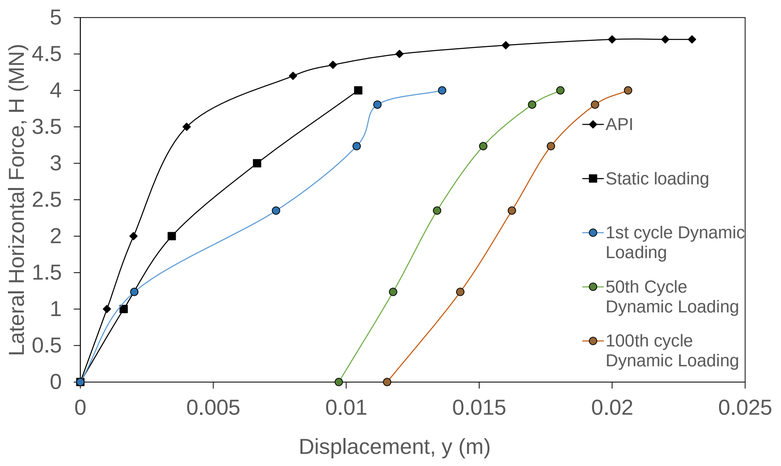
Amplitude of loading: 4MN

Parameter	Symbol	Value	Unit
Oedometric stiffness parameters	κ	600	-
	λ	0.55	-
Poisson's ratio	Y	0.25	-
Unit buoyant weight	γ'	15.5	KN/m^3
Internal friction angle	Ø'	35	deg
Dilation angle	ψ	5	deg
Cohesion	c	0.1	kN/m^2
Yield surface parameter	α	0.127	-
	k	1.8	kPa
Plastic potential	β	4.05*10^{-2}	-

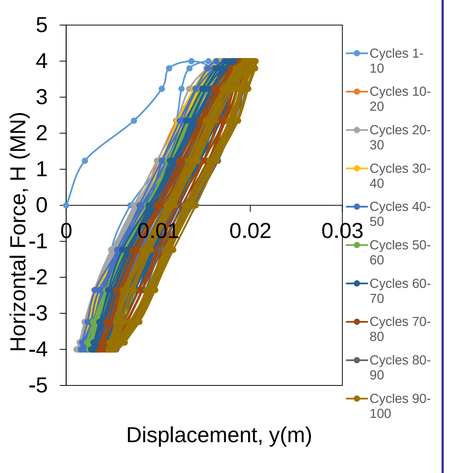
$$E = 60MPa * \frac{5}{6} * \sqrt{2} * \left(\frac{\sigma_y}{\sigma_{at}}\right)^{\lambda}$$

σ_y denotes the soil vertical effective stress and σ_{at} is the atmospheric pressure.

Results



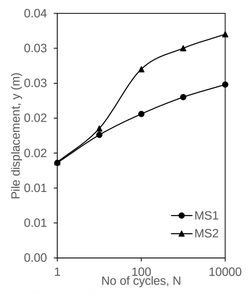
Comparison plot of the p-y curve between current design methods and numerical simulation



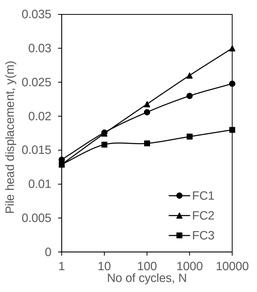
P-y plot during cyclic loading

Parametric analysis

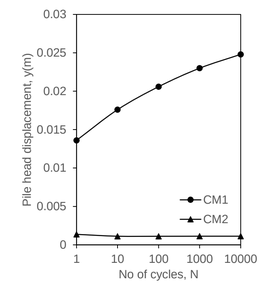
(up to 10^4 cycles)



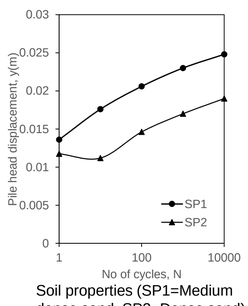
Shape of soil geometry (MS1=Cylindrical, MS2= prismatic)



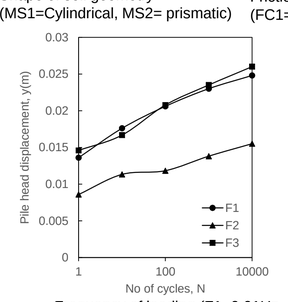
Friction coefficient in the contact (FC1=0.4, FC2=0.2, FC3=0.5)



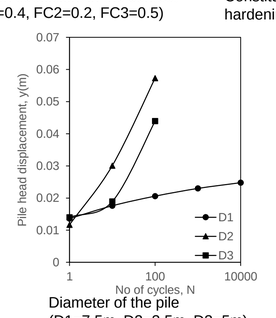
Constitutive model (CM1=Kinematic hardening, CM2=Isotropic hardening)



Soil properties (SP1=Medium dense sand, SP2=Dense sand)



Frequency of loading (F1=0.01Hz, F2=0.001Hz, F3=0.2Hz)



Diameter of the pile (D1=7.5m, D2=2.5m, D3=5m)

Discussion and Conclusion

- The work shows that FE analysis with advanced constitutive models can be used to study monopile-soil interaction problem. Comparison with widely used *p-y* curve has been carried out. It appears from the limited data that current standards for sandy soils underestimates the pile displacement and overestimates the soil resistance at large lateral horizontal forces.
- Based on the parametric analysis, it was observed that the model geometry shape, friction coefficient, choice of constitutive model, soil properties, loading frequency and pile diameter have strong influence on the pile head displacements.

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