A New Foundation Model for Integrated Analyses of Monopile-based Offshore Wind Turbines

NTNU
Norwegian University of Science and Technology

NGI

Ana M. Page[1,2], Kristoffer S. Skau[1,2], Hans Petter Jostad[1,2], Gudmund R. Eiksund[1]

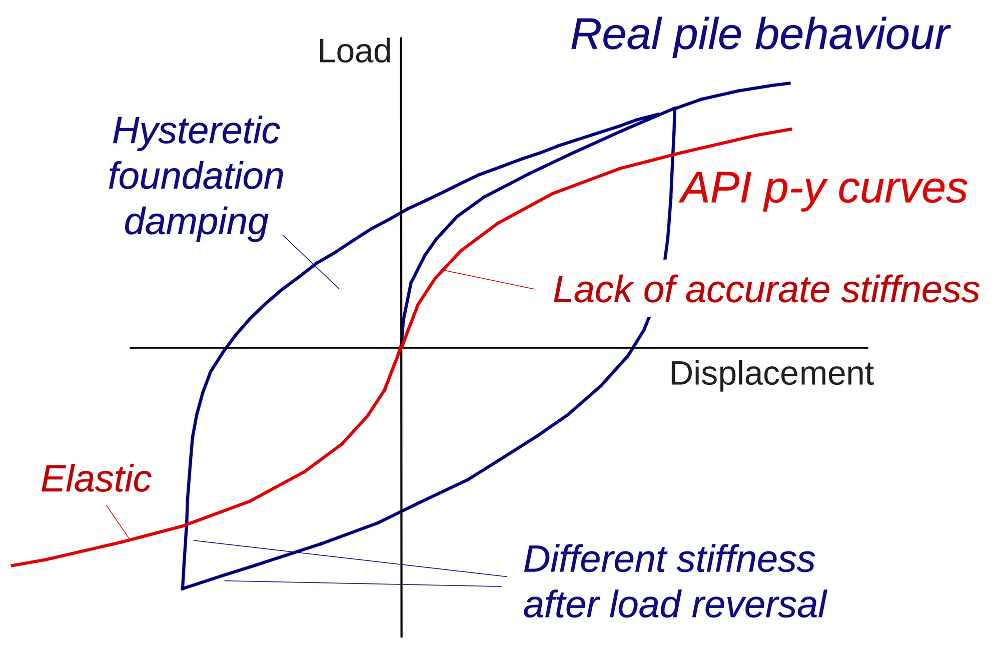
[1] Norwegian University of Science and Technology (NTNU), Trondheim, Norway

[2] Norwegian Geotechnical Institute (NGI), Oslo, Norway

Introduction

For monopiles supporting offshore wind turbines (OWT), the current design practice is to model the foundation response by API *p-y* curves [1].

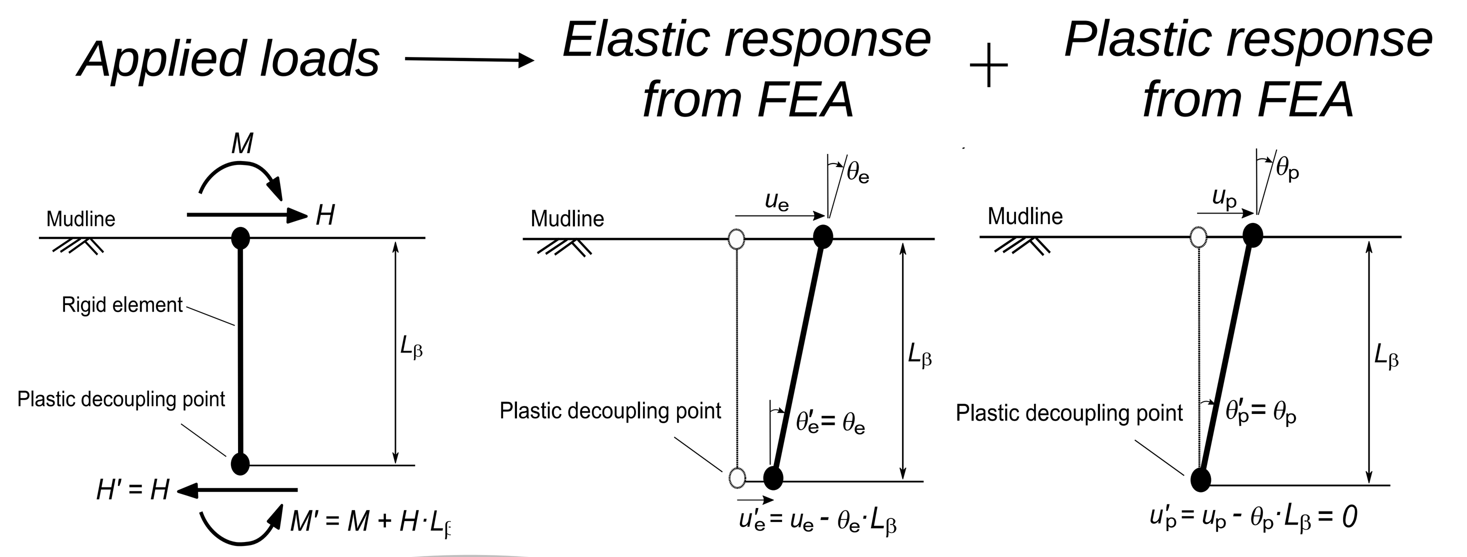
Discrepancies between the API *p-y* curves and the actual pile behaviour have been identified:

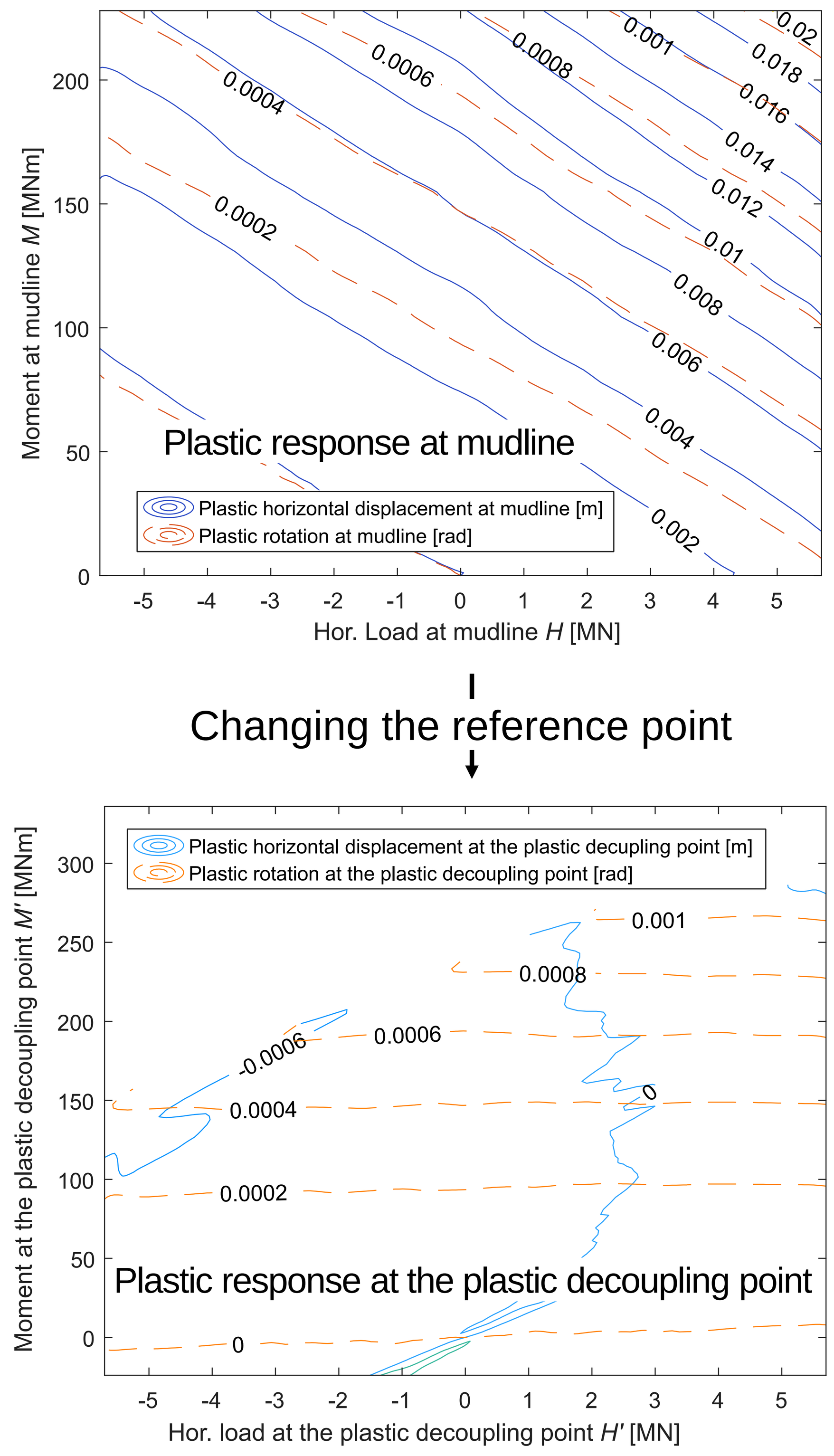


Their applicability to predict pile behaviour in integrated analyses of OWT has been questioned, and new foundation models are needed.

Findings from Finite Element Analyses

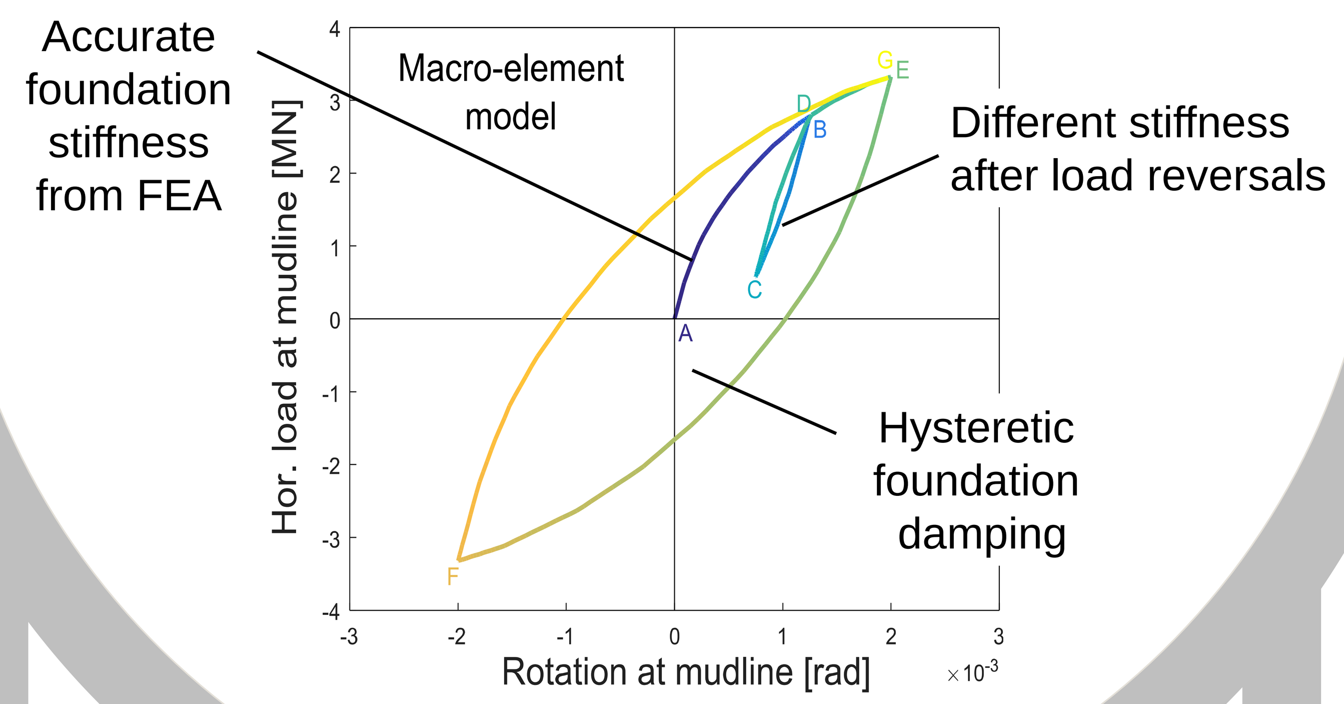
3D Finite Element Analyses (FEA) of the soil volume and the foundation have been performed for different soil profiles with the software PLAXIS 3D. A 6 m diameter steel pile, with a wall thickness of 0.06 m, embedded 36 m in an overconsolidated clay is considered. The soil response is reproduced with the NGI-ADP [2], a constitutive model which mimics the behaviour of cohesive soils.





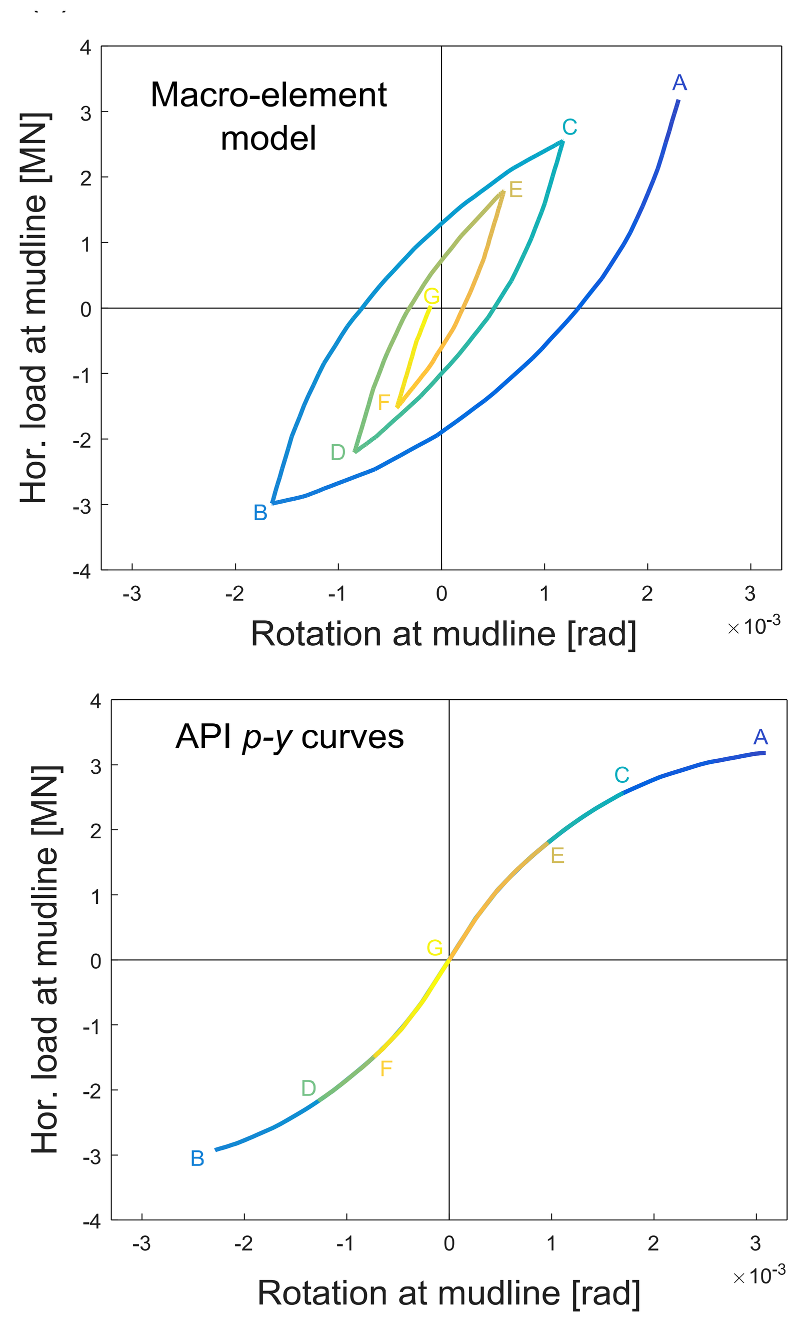
A new foundation model

The model follows the macro-element concept, where the response of the foundation and the surrounding soil is reduced to a force - displacement relation at mudline.



Comparison with API *p-y* model response

In contrast to the API *p-y* curves, the new model can reproduce different foundation stiffness for unloading and reloading and foundation damping depending on the loading history, which is observed in real pile behaviour.



Calibration and implementation

The calibration of the foundation model requires two types of input:

- Elastic stiffness matrix.
- A table containing the moment, horizontal displacement and rotation at mudline from non-linear FEA with H = 0.

The macro-element model is being implemented in the OWT load simulation code *3DFloat* [4] via a *dll* interface.

Model formulation

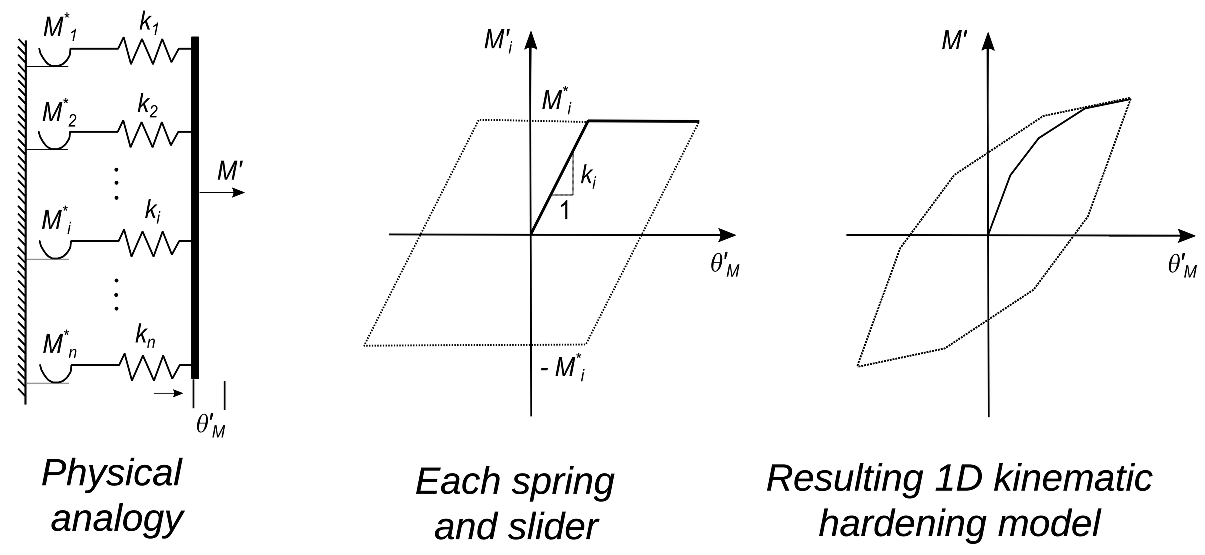
The relation between displacements and forces at the plastic decoupling point:

$$u' = u'_e + u'_p = u'_e(H') + u'_e(M') + \underbrace{u'_p(H') + u'_p(M')}_{0}$$

$$\theta' = \theta'_e + \theta'_p = \theta'_e(H') + \underbrace{\theta'_e(M') + \theta'_p(M')}_{\theta'_{M'}(M')} + \underbrace{\theta'_p(H')}_{0}$$

Where:

- $u'_e(H'), u'_e(M')$ and $\theta'_e(H')$ can be calculated with an elastic stiffness matrix.
- The relation between $\theta'_{M'}(M')$ and M' is elasto-plastic, and can be reproduced by a 1D kinematic hardening model [3]:



The model is composed of a rigid element connecting mudline with the plastic decoupling point, an elastic stiffness matrix and a 1D kinematic hardening model

Discussion and conclusions

A simple macro-element foundation model for piles with an intuitive physical analogue has been developed. The formulation is based on trends observed in FEA of the soil and the foundation.

A fixed plastic decoupling point is assumed in the formulation. This assumption seems to be acceptable for fatigue load levels, but needs to be checked for higher load levels.

Acknowledgements

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