



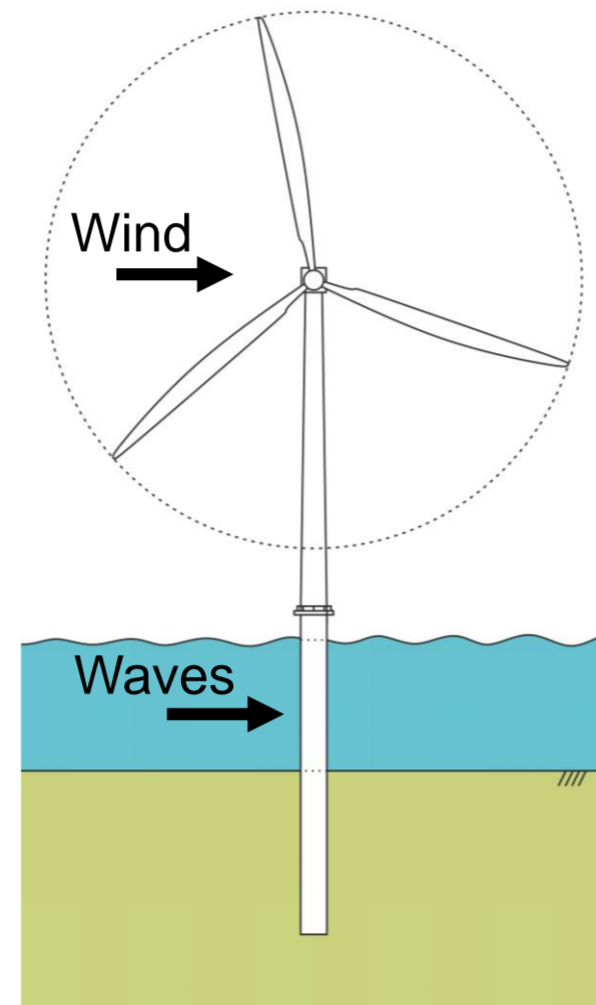
Calibration of Cyclic Loading Models for Monopile Foundations

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Introduction

- Monopile foundations support 82% of offshore wind turbines (OWT) in European waters (WindEurope 2019).
- Subject to cyclic lateral loading, causing permanent deformation and changes to stiffness and damping.
- Most current design methods do not accurately predict this response.
- A new constitutive model (HARM) captures behaviour on a cycle by cycle basis.



Aims

Phase A: (Element => Element)

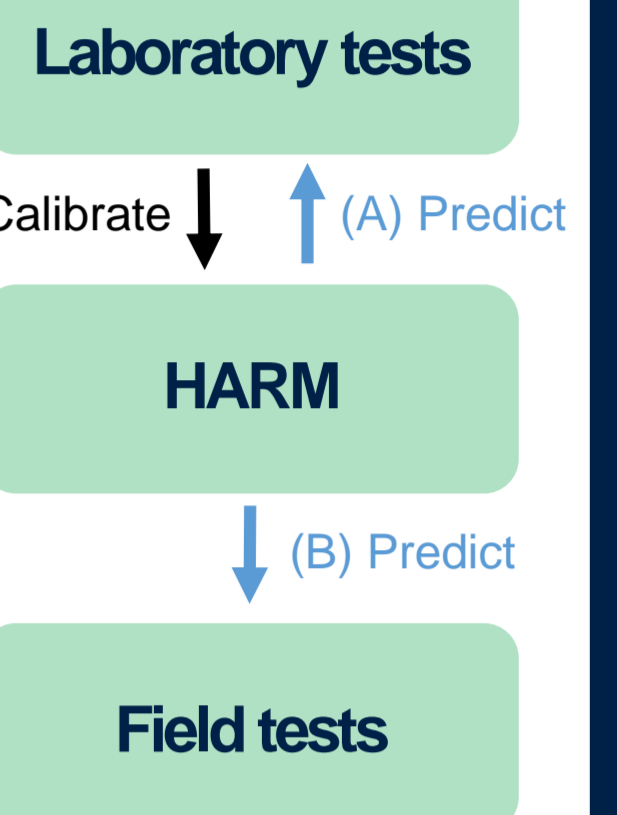
- Model calibrated to laboratory element tests, validation against similar tests. Developing model to capture key behavior.

Phase B: (Element => Pile)

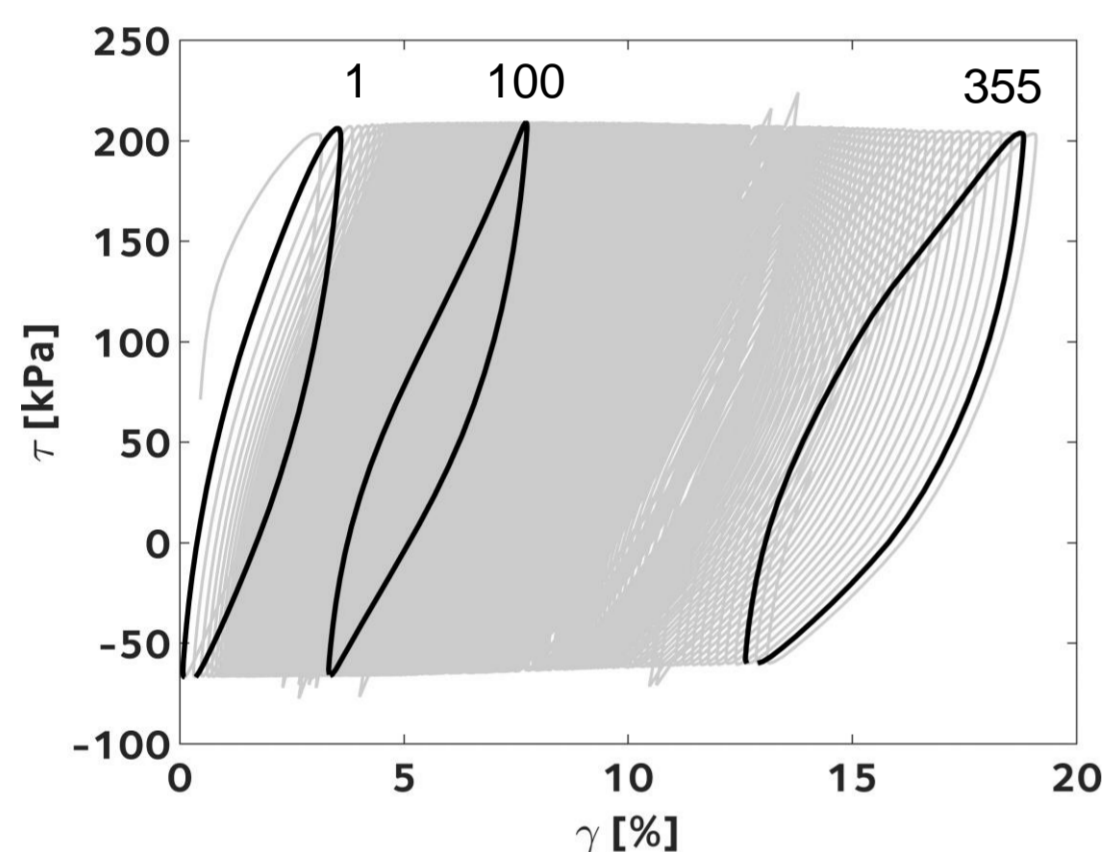
- Pile at macro/Winkler/FEA (0D/1D/3D).

Research Objective:

- To make the connection between element tests and monopile behavior for prediction of long-term cyclic response.

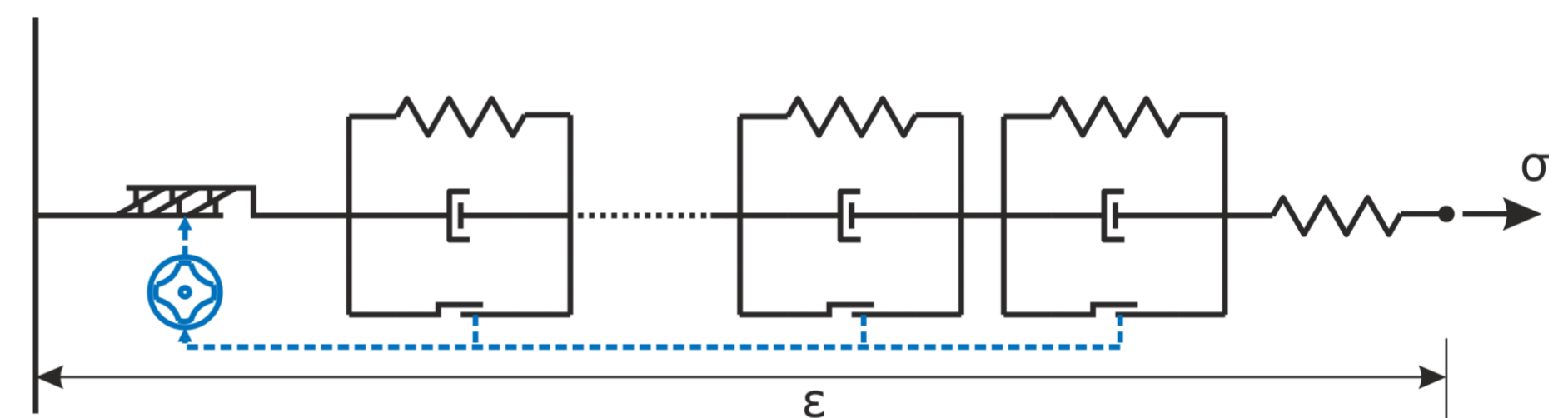


Soil Element Response



- Example CSS (Cyclic Simple Shear) response for stiff offshore clay.
- Ratcheting, rate-dependent strain, reduction in secant stiffness and increase in damping observed.
- Similar response observed at pile level.

Theoretical Model: HARM



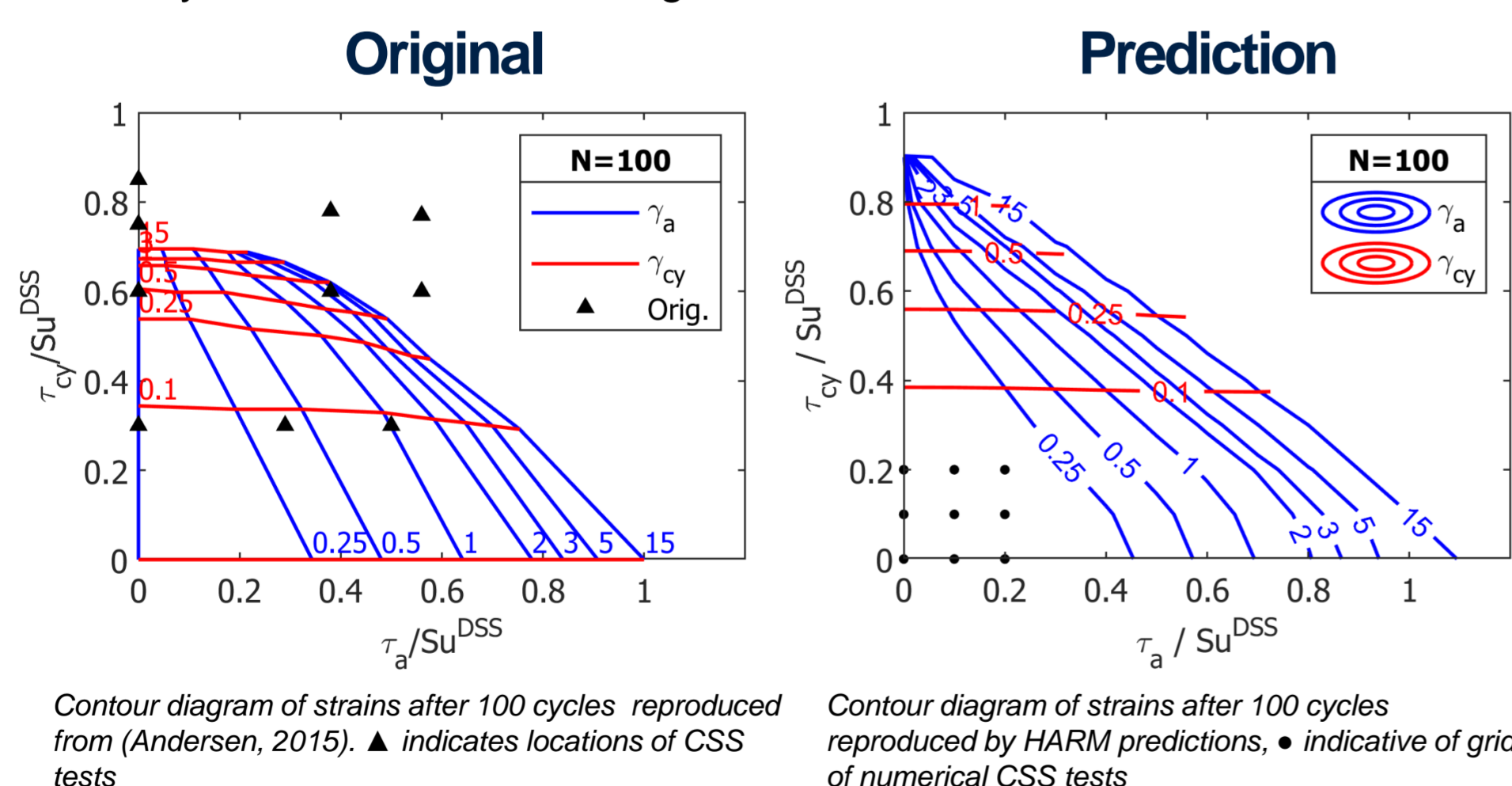
- Able to predict continuous stress-strain response.
- Able to capture ratcheting and rate-dependent behaviour, changes in secant stiffness and damping.
- Extension of kinematic hardening model to include ratcheting element, formulated in Hyperplasticity framework (Houlsby et al. 2017).

Test Prediction

- 0D HARM used to reproduce industry-standard contour diagrams for Drammen Clay (Andersen, 2015).
- Useful tests of model across a range of cyclic conditions and magnitudes.

0D Model

Single element macro model
Simple for model development
Captures element behaviour

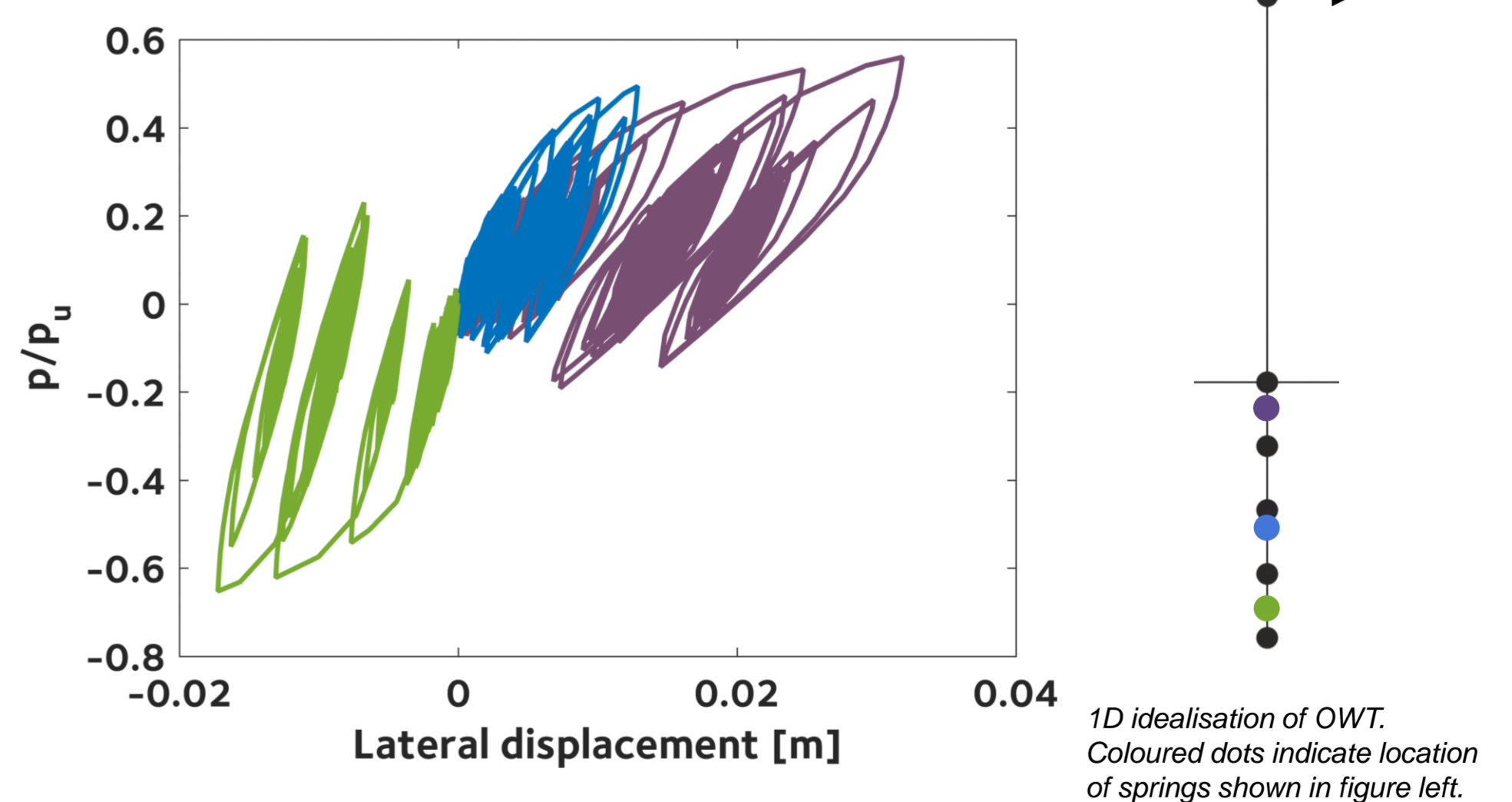


1D Model

Springs distributed with depth
Can model layered soils
Response identifiable along pile

Storm Prediction

- 1D HARM used to predict response to unidirectional storm-type loading for a clay site.



Summary

- HARM formulated to capture key mechanisms of cyclic loading of clays.
- Contour diagrams provide a test for the model outside of calibration tests.
- Cyclic response along the pile identifiable with 1D HARM with the model capable of predicting response to continuous storm loading.
- HARM promising for use in design of monopile foundations.

References:

- WindEurope, 2019. *Offshore Wind in Europe – Key trends and statistics 2018*.
Houlsby, G.T. et al., 2017. A model for nonlinear hysteretic and ratcheting behaviour. *International Journal of Solids and Structures*, 120.
Andersen, K. 2015. Cyclic soil parameters for offshore foundation design. *ISFOG 2015*