PISA
New Design Methods for Offshore Wind Turbine Monopiles

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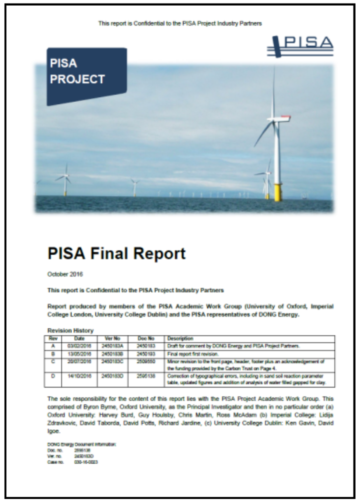
Ørsted / Royal Academy of Engineering Research Chair

University of Oxford



This report is Confidential to the PISA Project Industry Partners

PISA Final Report

October 2016

This report is Confidential to the PISA Project Industry Partners

Report produced by members of the PISA Academic Work Group (University of Oxford, Imperial College London, University College Dublin) and the PISA representatives of DONG Energy.

Revision History

Rev	Date	Ver No	Doc No	Description
A	03/02/2016	2450183A	2450183	Draft for comment by DONG Energy and PISA Project Partners.
B	13/05/2016	2450183B	2450193	Final report first revision.
C	20/07/2016	2450183C	2509550	Minor revision to the front page, header, footer plus an acknowledgement of the funding provided by the Carbon Trust on Page 4.
D	14/10/2016	2450183D	2595138	Correction of typographical errors, including in sand soil reaction parameter table, updated figures and addition of analysis of water filled gapped for clay.

The sole responsibility for the content of this report lies with the PISA Project Academic Work Group. This comprised of Byron Byrne, Oxford University, as the Principal Investigator and then in no particular order (a) Oxford University: Harvey Burd, Guy Houlsby, Chris Martin, Ross McAdam (b) Imperial College: Lidija Zdravkovic, David Taborda, David Potts, Richard Jardine, (c) University College Dublin: Ken Gavin, David Igoe.

DONG Energy Document information:
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Ver. no. 2450183D
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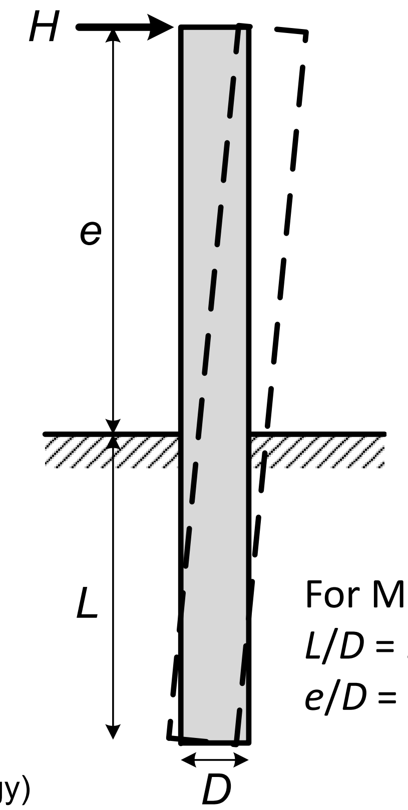
Comité Français de la Mécanique des Sols et de Géotechnique

Fondations d'éoliennes offshore

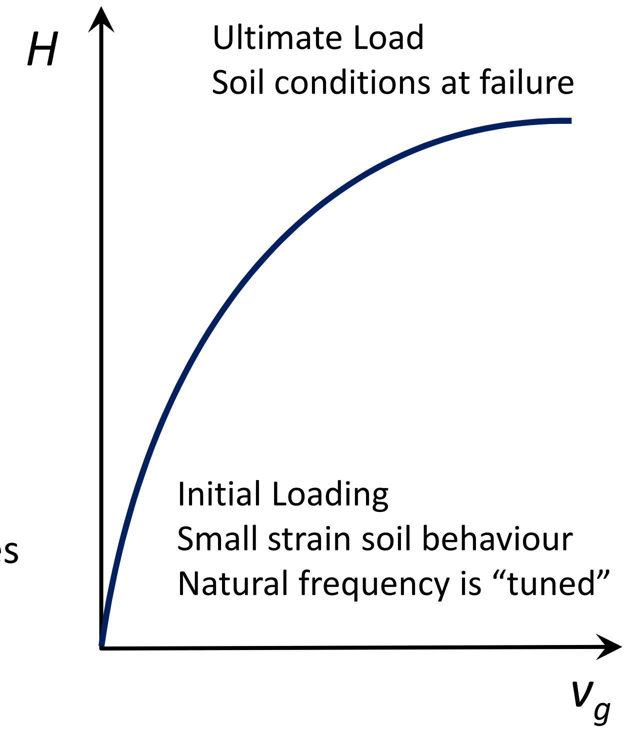
6 Décembre 2018

Monopile: Monotonic Loading

Photos from Dan Kallehave (DONG Energy)



For Monopiles
L/D = 2 to 6
e/D = 5 to 15



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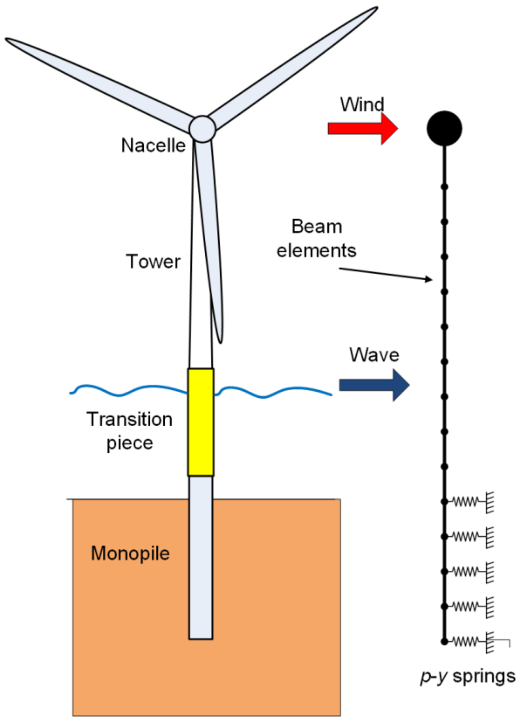
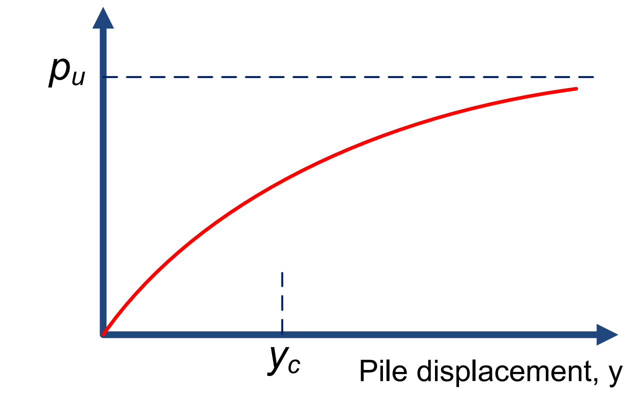
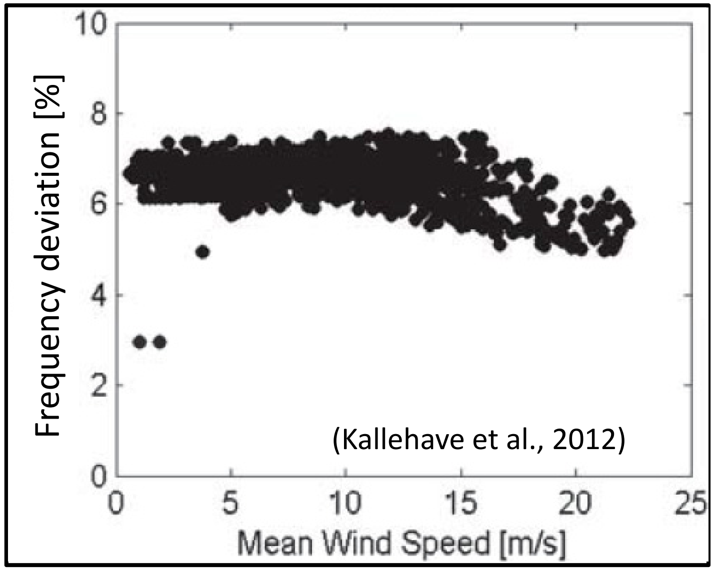
Problem Definition



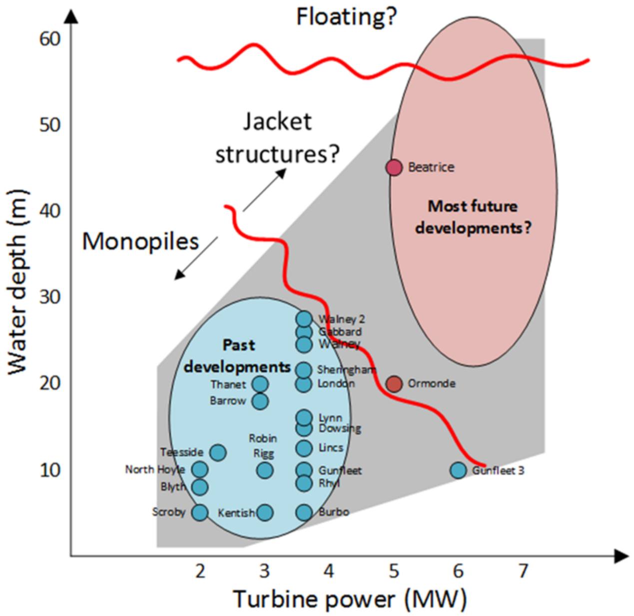


$$p(y) = \begin{cases} \frac{p_u}{2}\left(\frac{y}{y_c}\right)^{1/3} & for\ y \leq 8y_c \\ p_u & for\ y > 8y_c \end{cases}$$

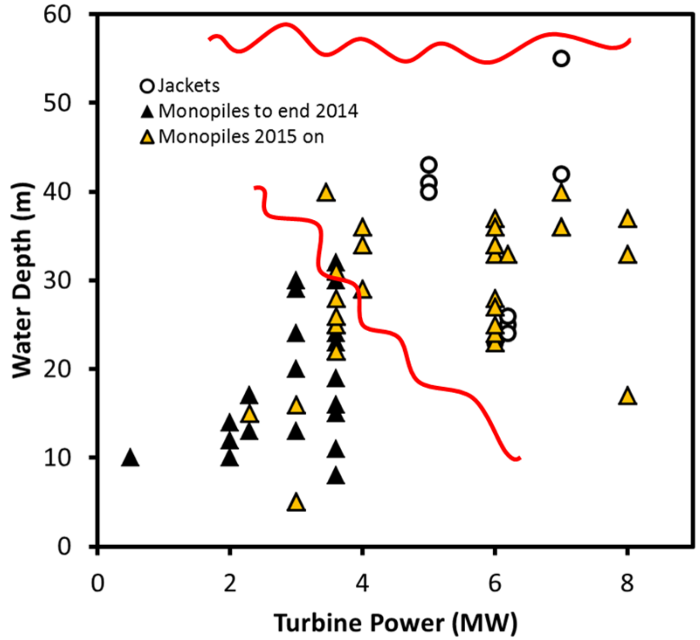
Underestimation of measured frequency



What is the limit of the Monopile?



From Guy Houlsby
2014 Rankine Lecture



With thanks to David Maloney
DNV-GL

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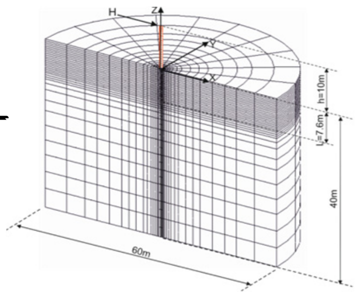
Project Overview – 2.5 years and £3.5m

3D FE

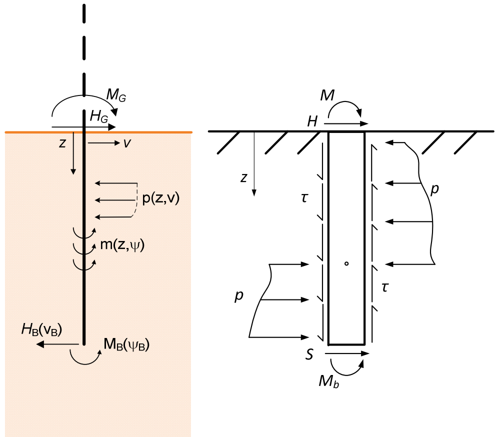


Design

Validate

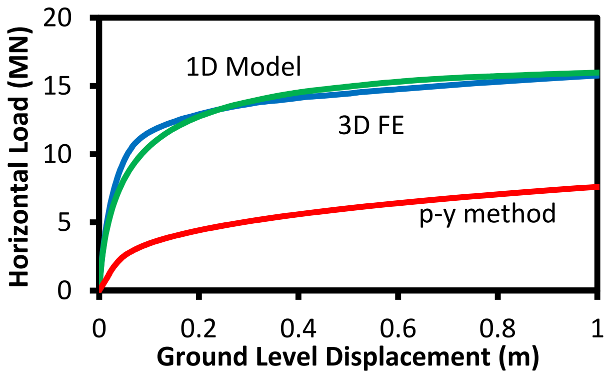
Field Tests

Simplified 1D Model



Apply

Accurate Response Prediction



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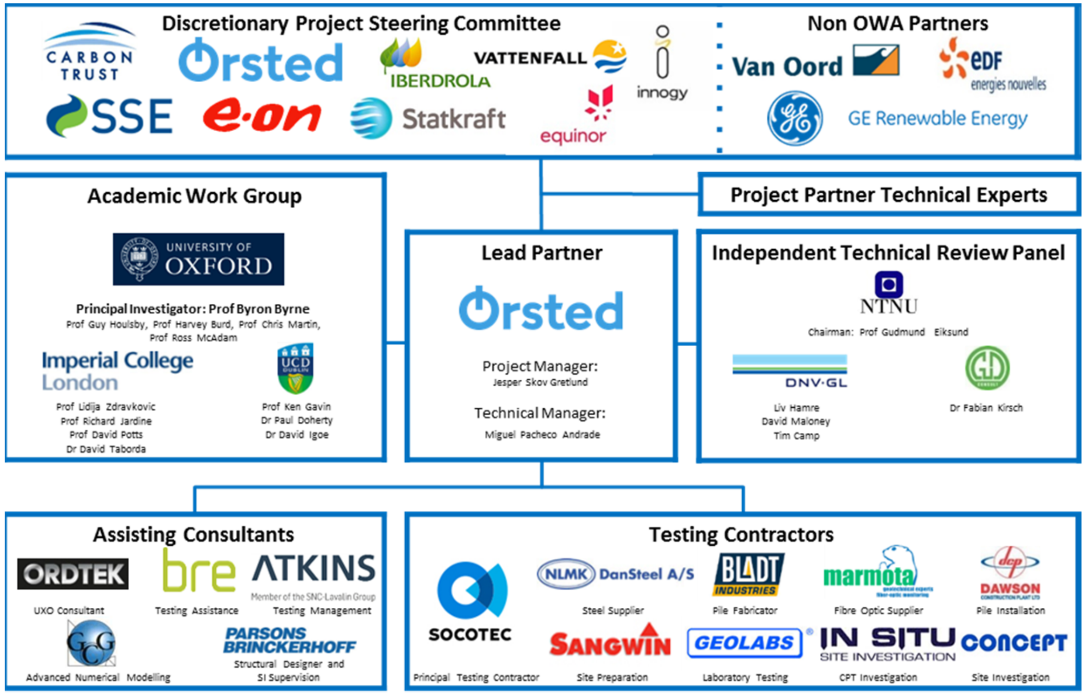
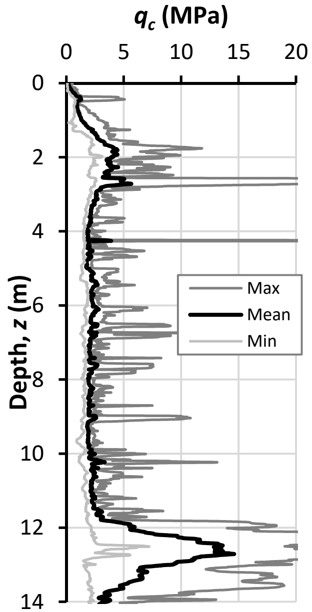
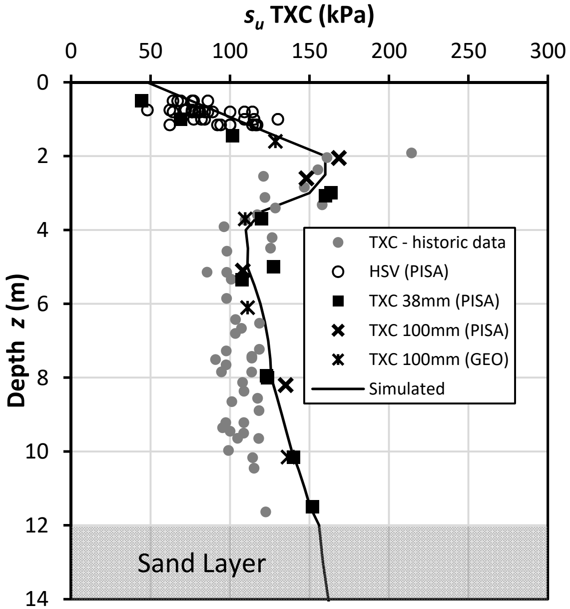
Project Structure and Timetable

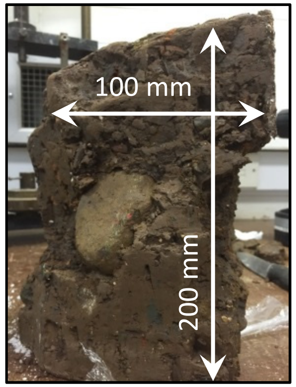


Aug 2013	Project start date
Nov 2013	Field test tender begins
Aug 2014	Design methods
Dec 2014	Pile installation
Jan 2015	Pile testing start
Jul 2015	Pile testing complete
Nov 2015	Field test factual results
Feb 2016	Close-out workshop
May 2016	Final report approved
After May 2016	Implementation

Site Selection and Characterisation







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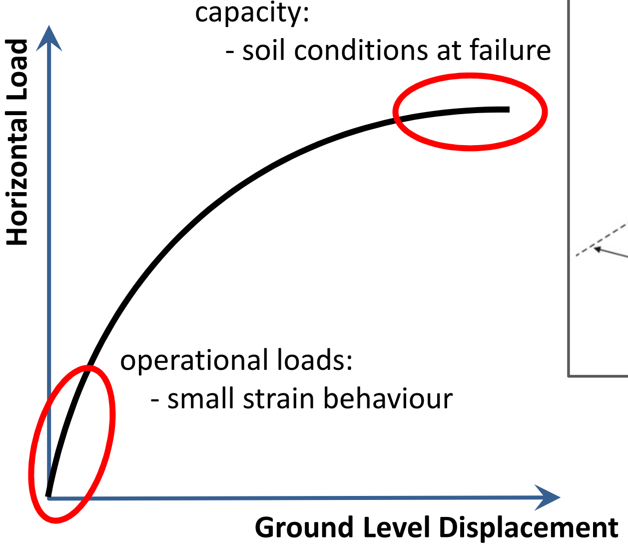
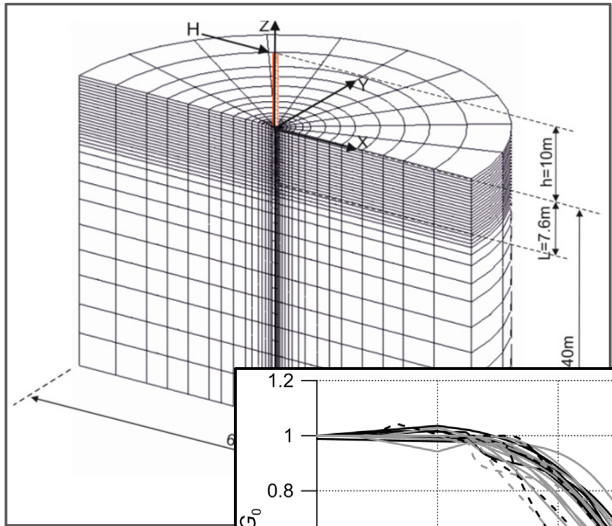
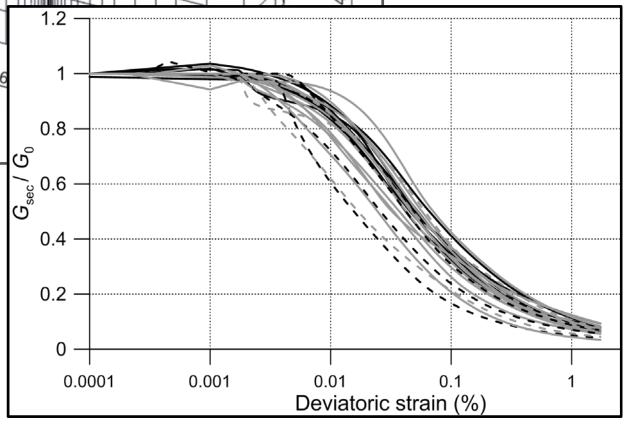
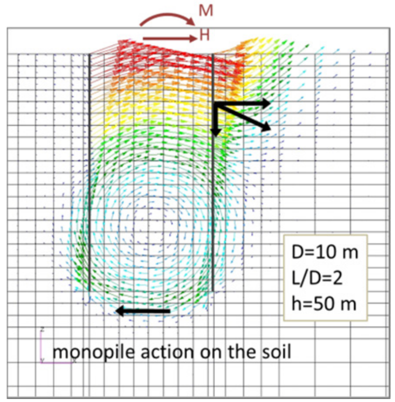
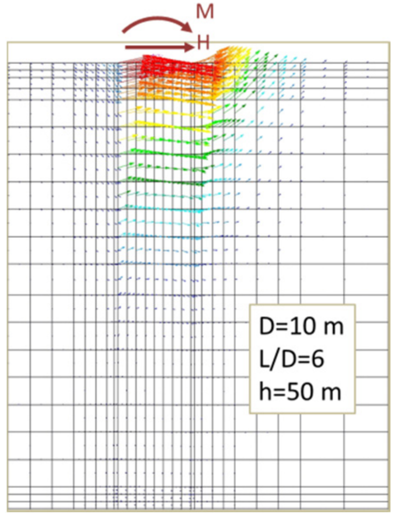
Numerical Modelling



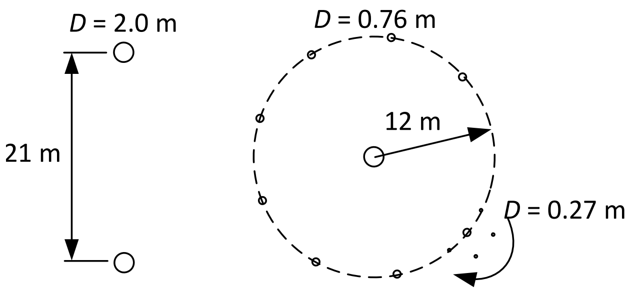


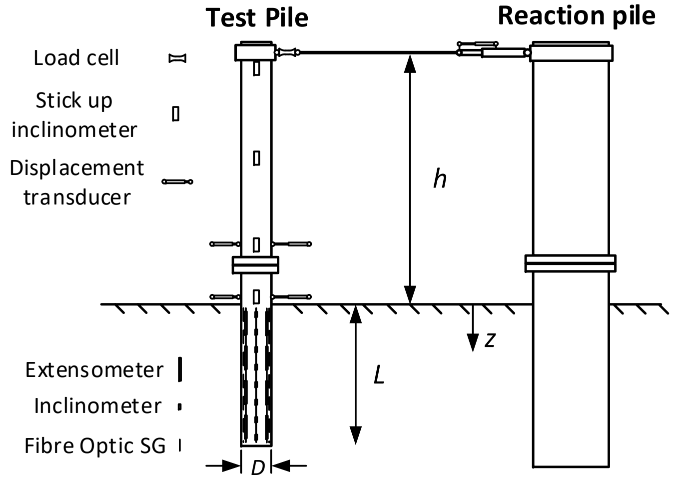


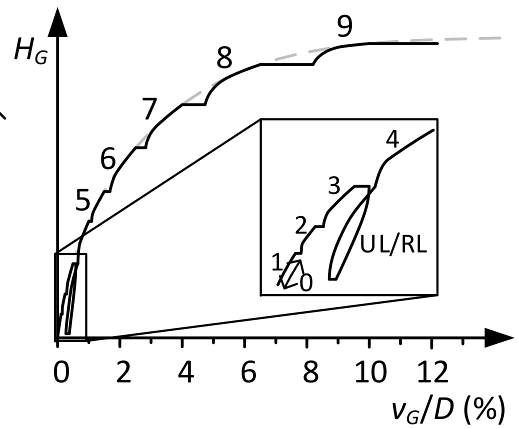




Field Test Campaign – 28 Pile Tests







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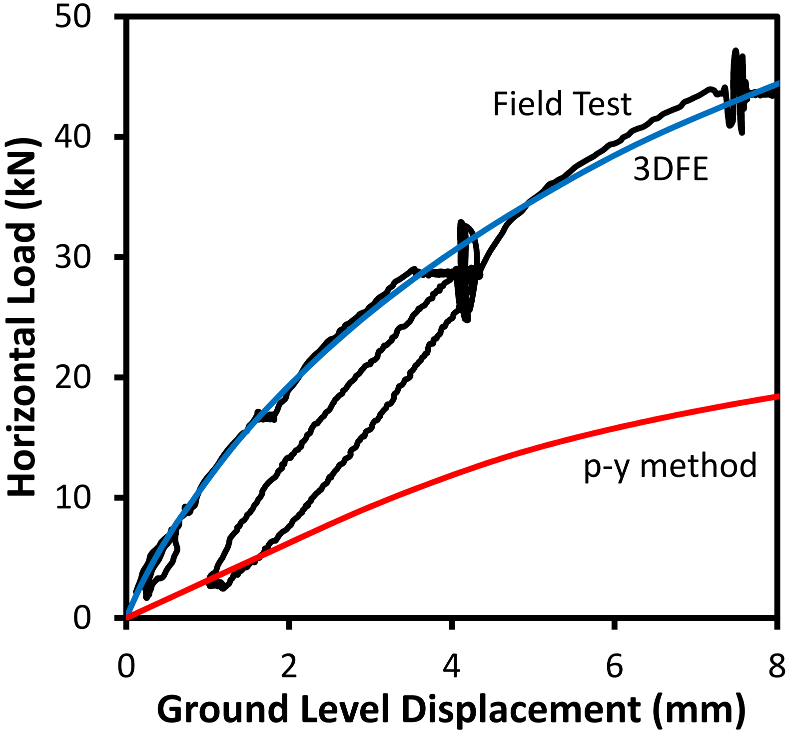
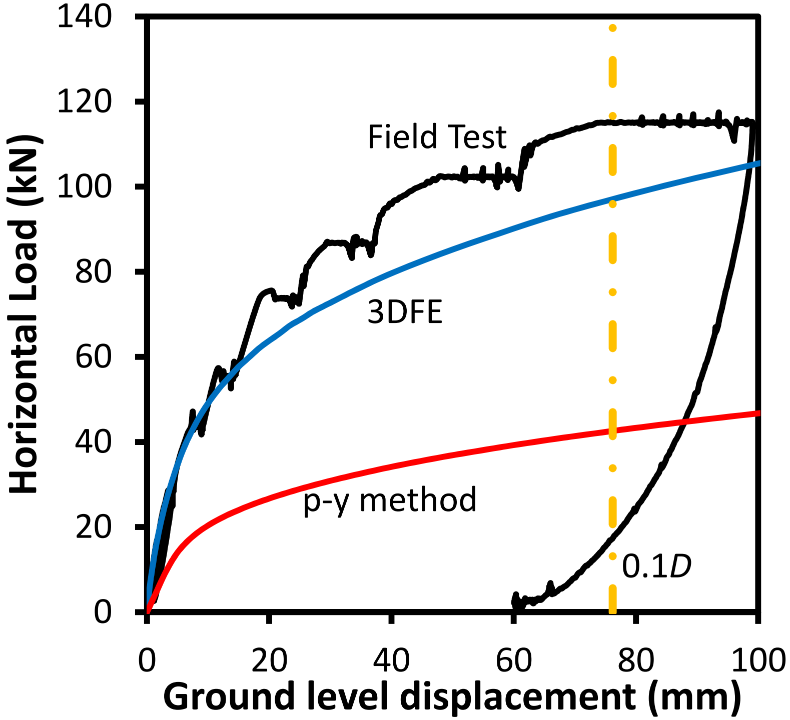
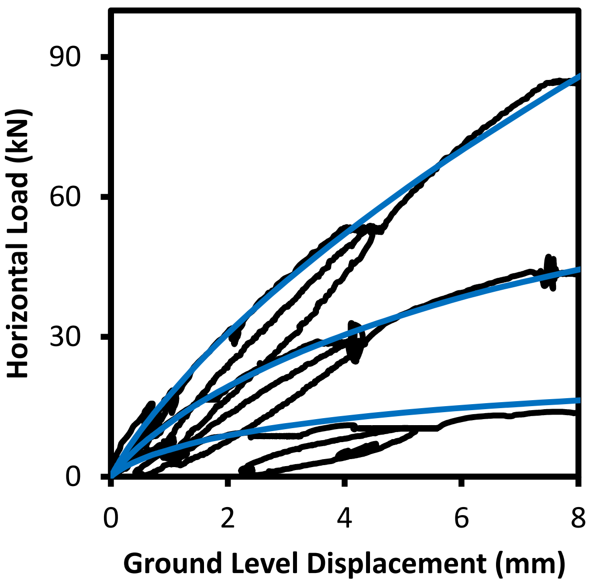
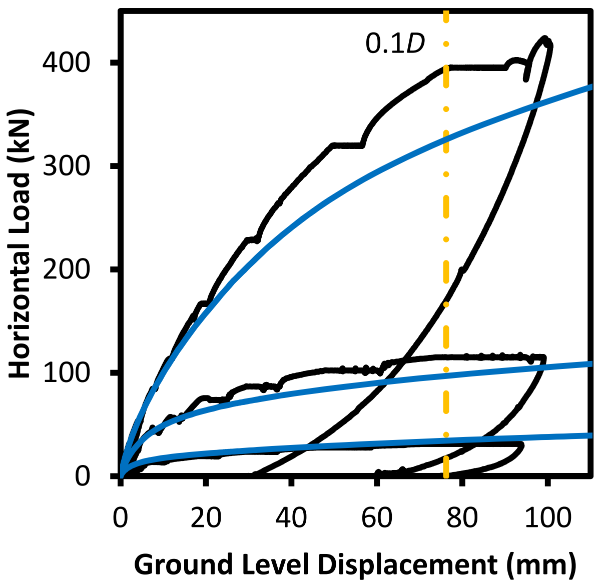
Cowden Test Results: D = 0.762 m, L/D = 5.25

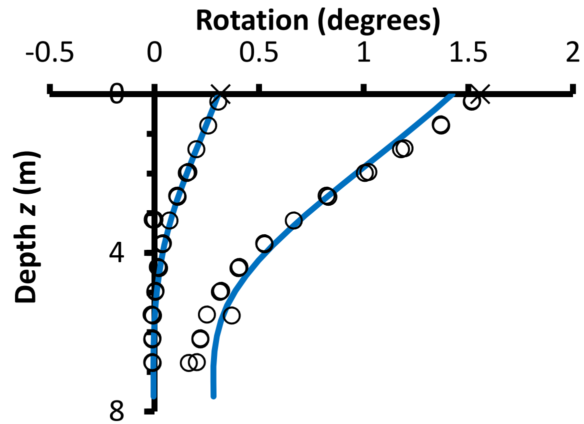


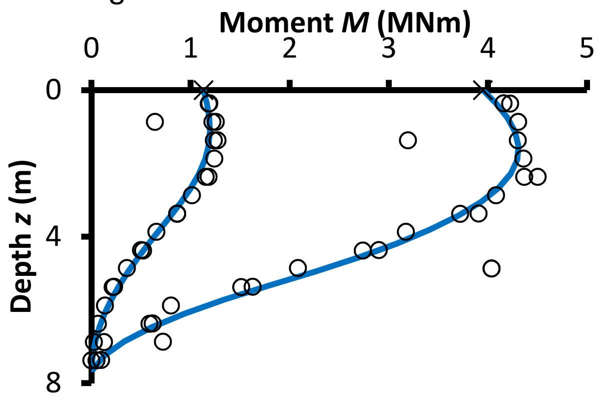


Cowden Test Results: D = 0.762 m, L/D = 3, 5.25, 10

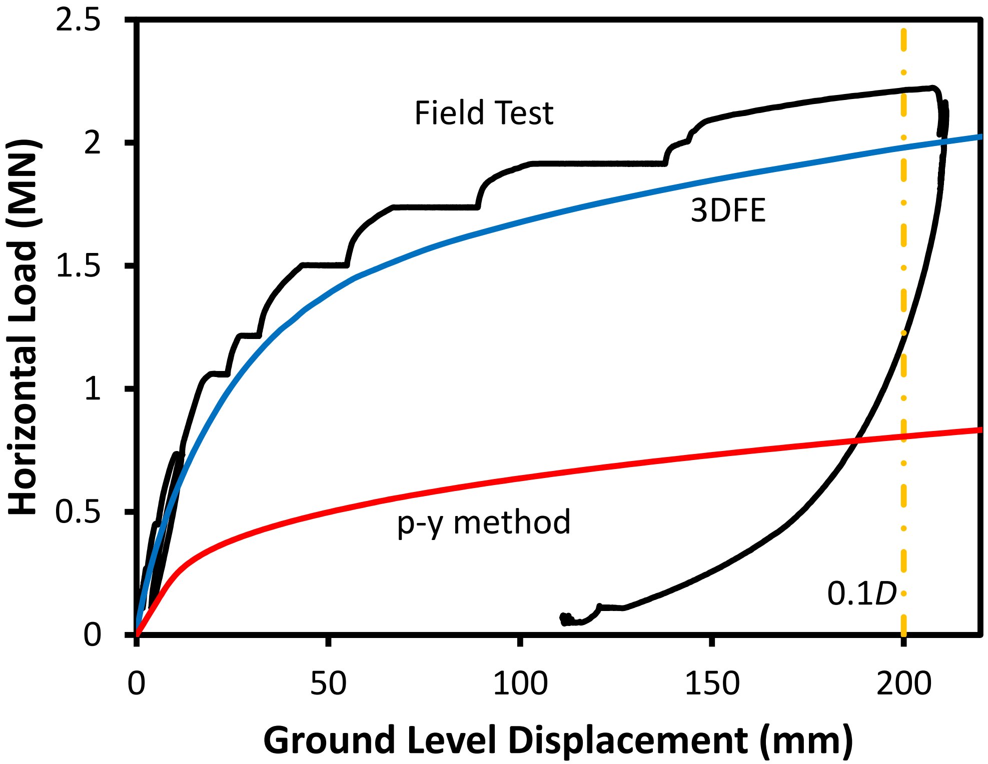




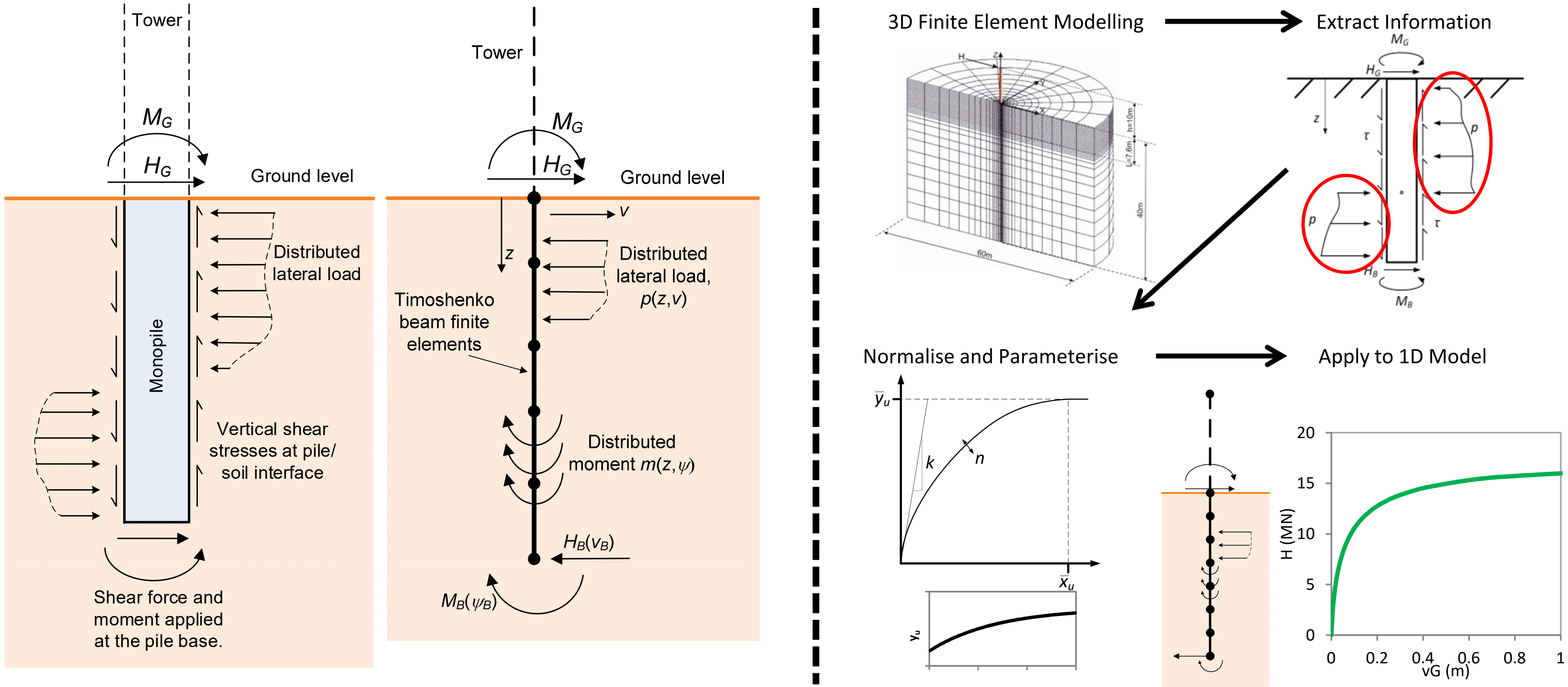




Cowden Test Results: *D* = 2 m , *L*/*D* = 5.25



New Design Method



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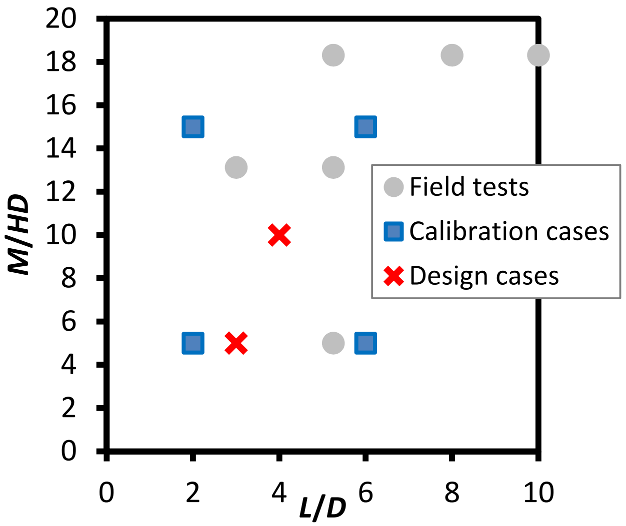
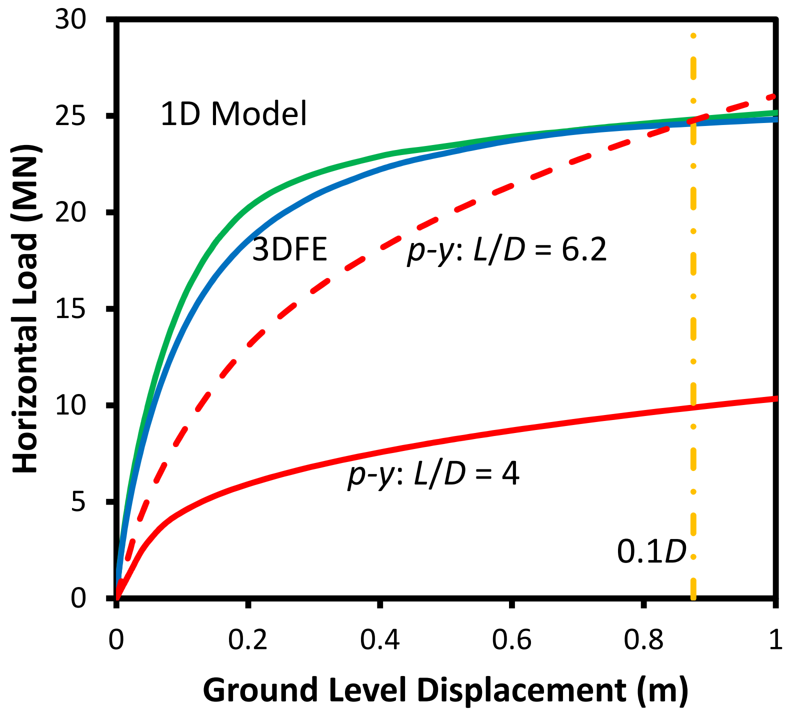
Design Case: *L/D* = 4, *M/HD* = 10 and *D* = 8.75m



Calibration (11 Calculations)
D = 5, 7.5, 10 m
L/D = 2, 6
M/HD = 5, 15
t/D = 60, 80, 110



Design Improved from *L/D* = 6.2 to *L/D* = 4: SAVING = 35%!

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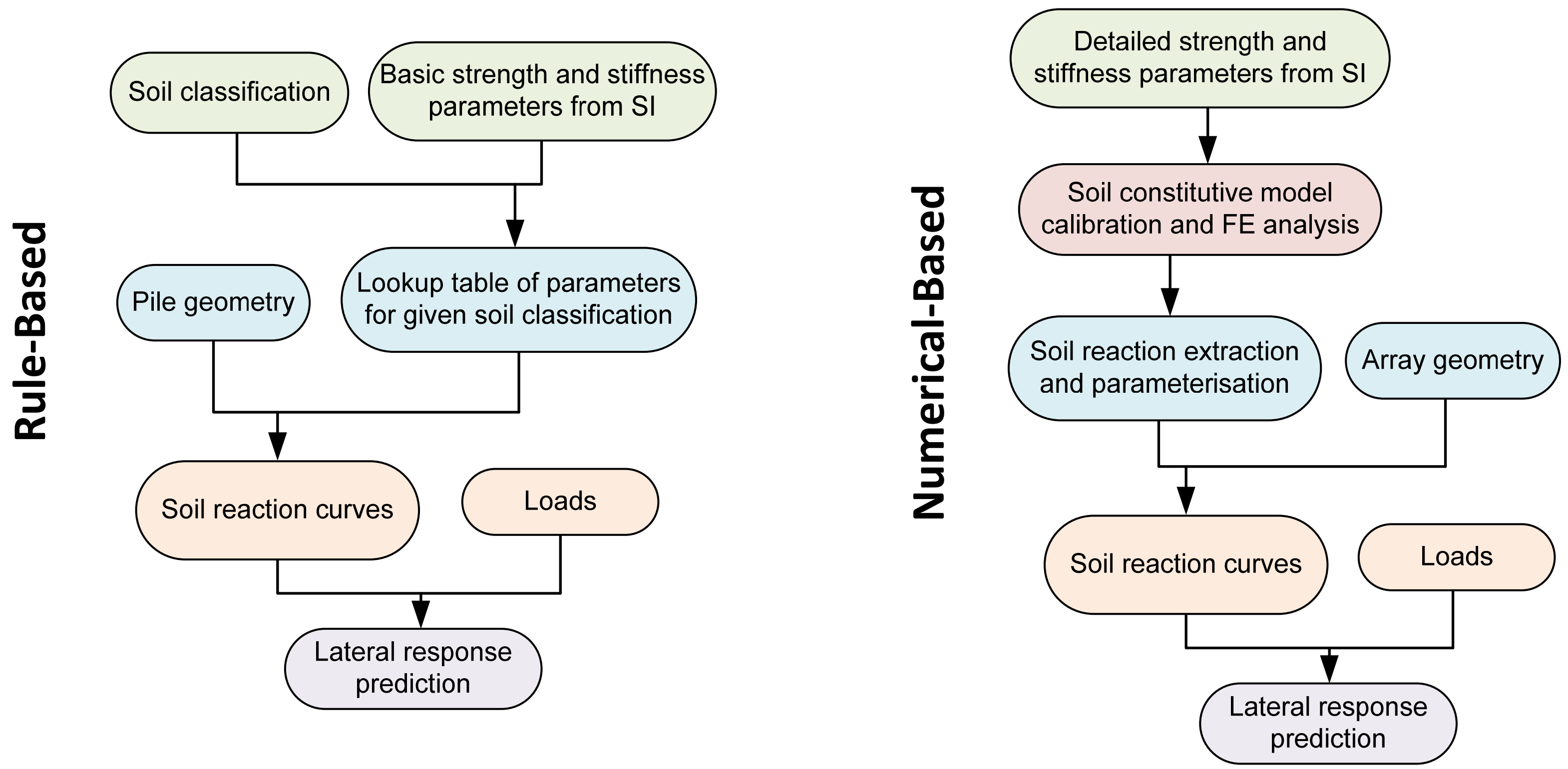
Design Method Application



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Progress of Offshore Wind in the UK


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Offshore wind power cheaper than new nuclear

By Roger Harrabin
BBC environment analyst

1 hour ago | Business | 179

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Energy from offshore wind in the UK will be cheaper than electricity from new nuclear power for the first time.

Nuclear: £92.50 MWh

2015 Offshore Wind: £114 to £120 MWh

2017 Offshore Wind: £57.50 MWh

Substantial savings to the UK tax payer underpinned by robust mathematical / scientific principles and sound engineering design

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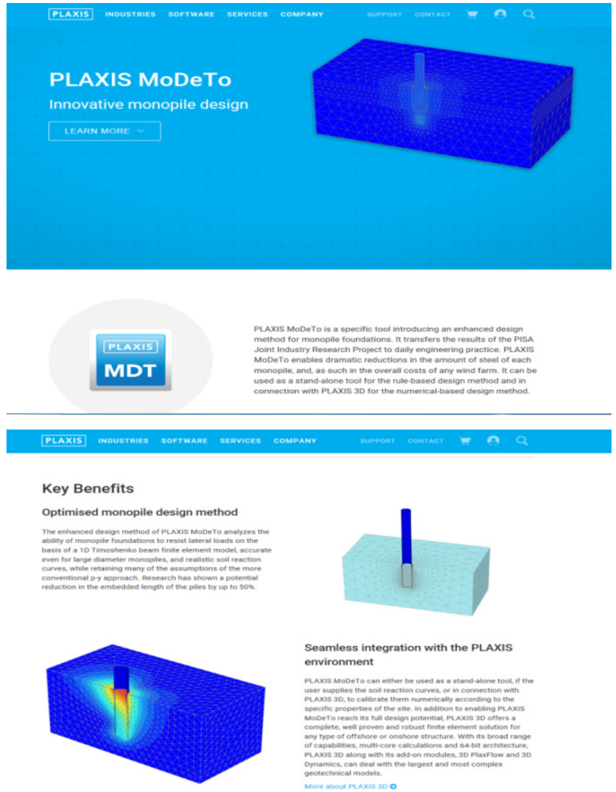
Postscript: PLAXIS MoDeTo

- First commercial application of the PISA Method, developed by Plaxis in partnership with Oxford University and Fugro
- Validated against experimental results from both test sites
- Rule-based and numerical-based design using user-defined or automatically calibrated soil response curves
  - Rule-based: Stand-alone tool. User-defined SRC
  - Numerical-based: SRC calibration from PLAXIS 3D FE model
- More info: http://www.plaxis.com/modeto



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Postscript: PISA2 Layered Soils

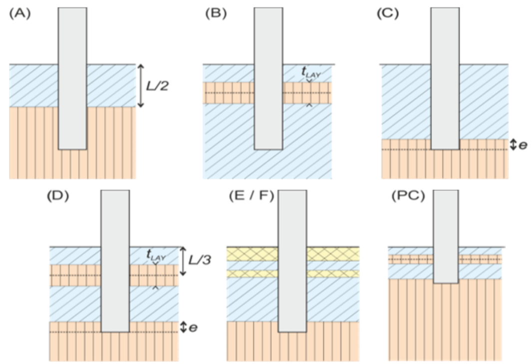
New Homogeneous Soils

London clay
Bothkennar clay

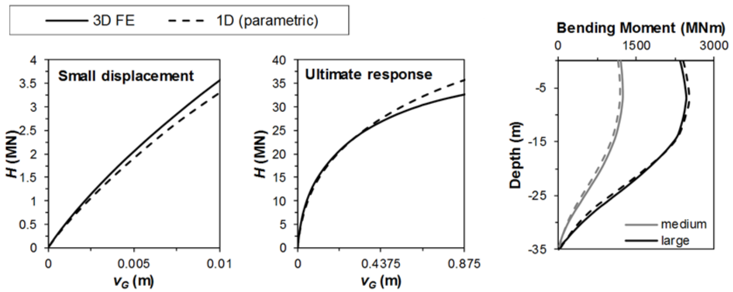
Dunkirk sand
(relative density 45%, 60%, 90%

→ Calibrated 1D model

(a) Application to layered soil



(b) General Dunkirk sand model



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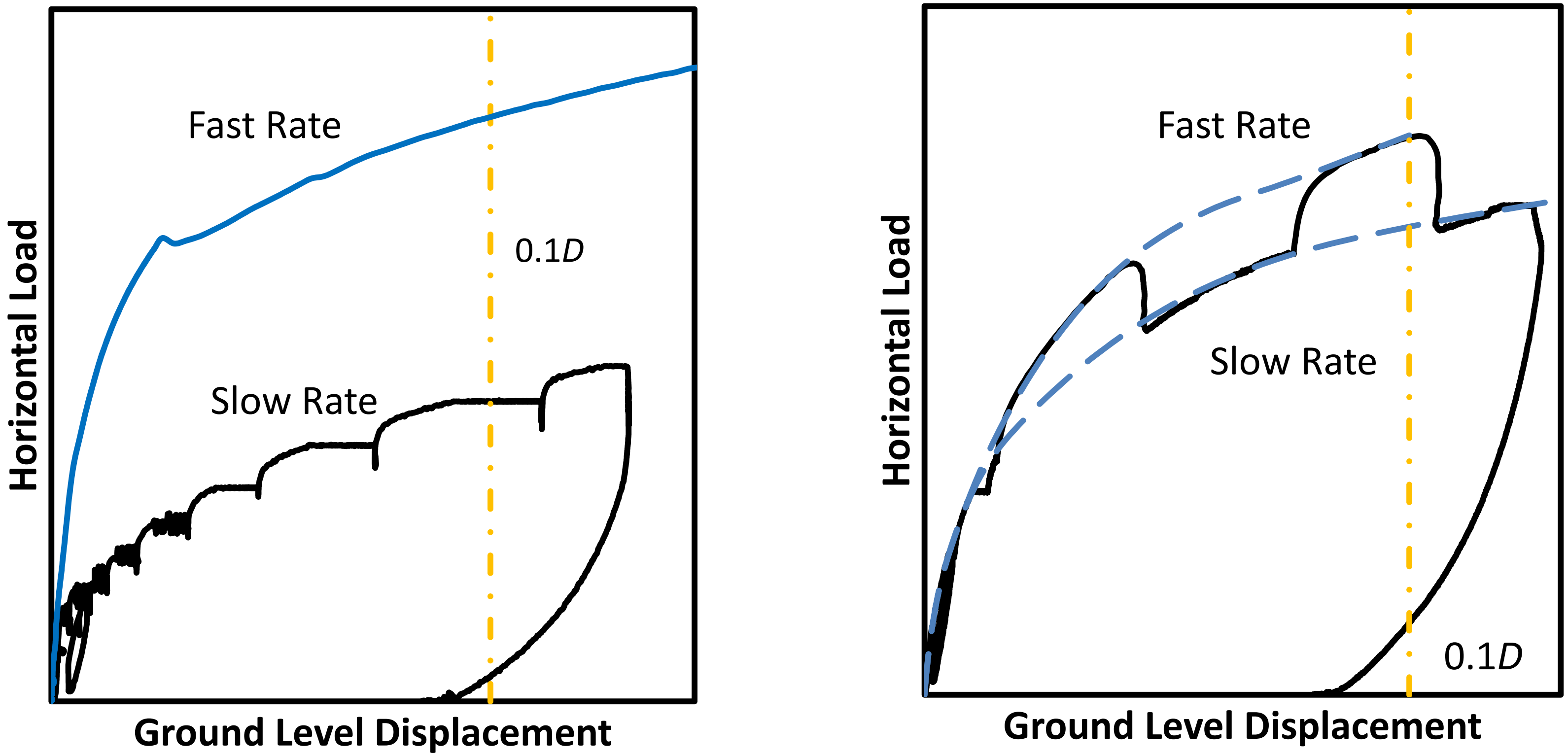
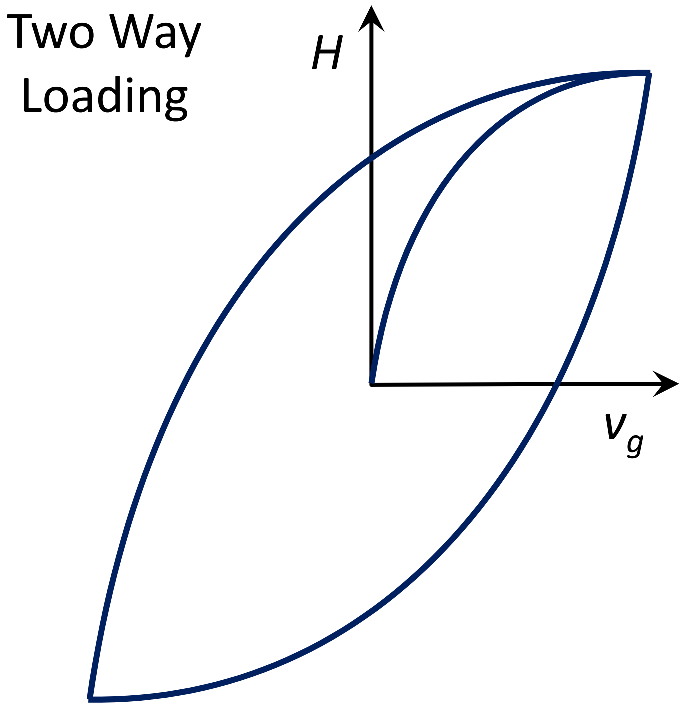
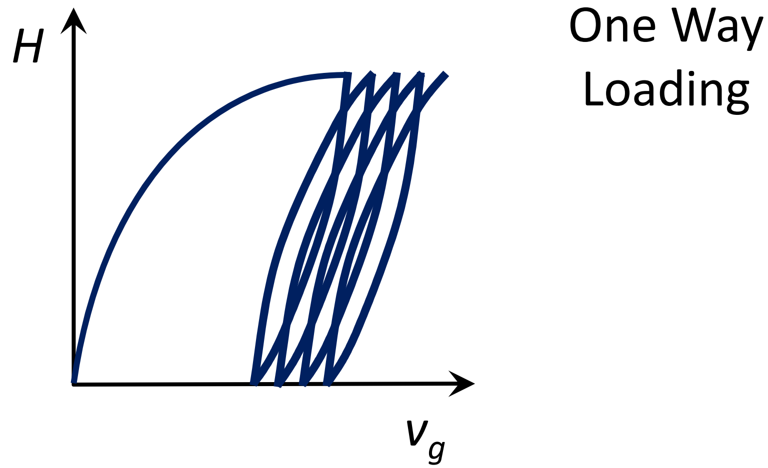
Rate Effects



Monopile Cyclic Loading: Basics





- Monotonic loading response is an *essential input* for any cyclic loading calculation
- Cyclic loading models must capture hysteresis, ratcheting behaviour and stiffness change

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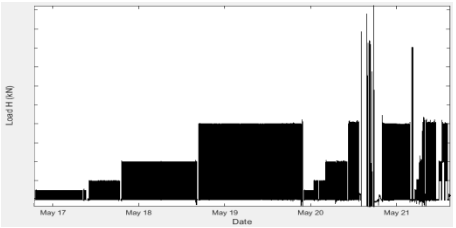
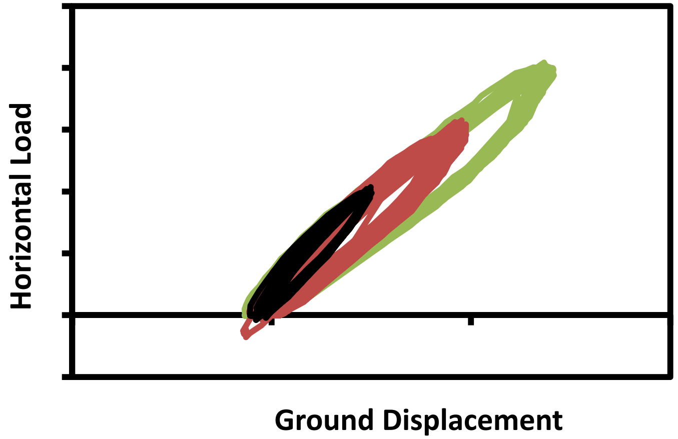
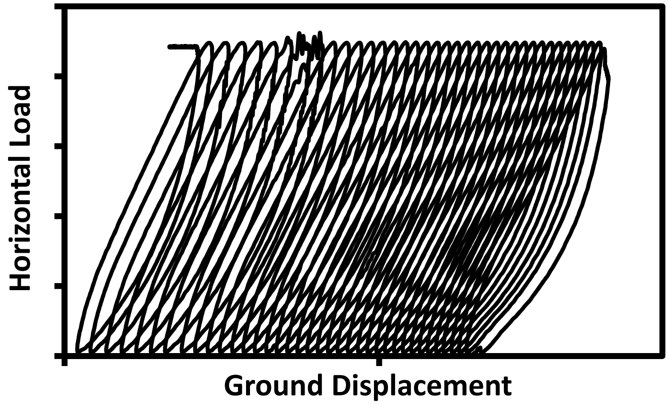


Cyclic Testing





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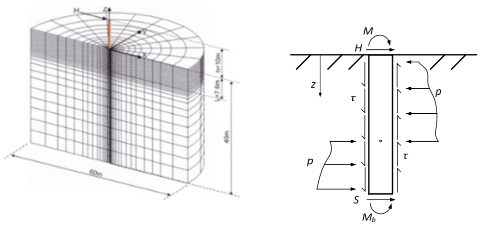
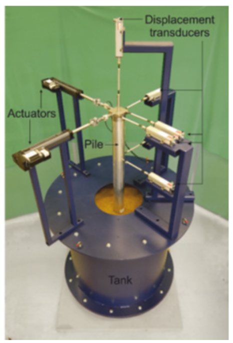
Oxford – Ørsted Collaboration 2018-2023

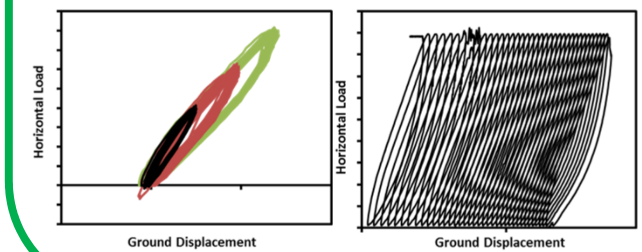
WP1: Modelling



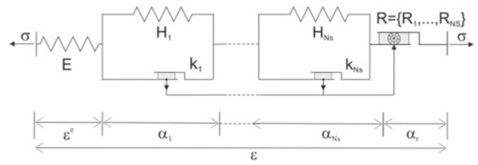
WP2: Calibration Methods



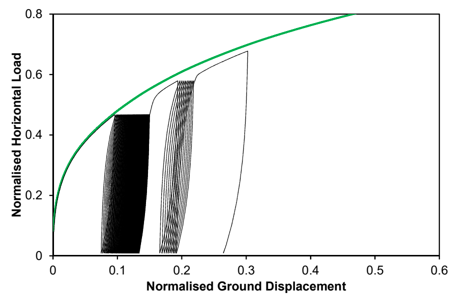
WP4: Field Testing



WP3: Theoretical Methods



WP5: Application to Design



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Publications

- The work will be disseminated as widely as possible
- A number of conference papers are now available
- 8 Papers on the field testing / numerical modelling / new design methods submitted for journal publication
  - 5 now accepted for publication in *Géotechnique* and will be available as Open Access in the near future
  - 3 under review
- Papers to come through in the future include
  - Papers on cyclic loading experiments
  - Papers from the PISA2 project

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Concluding Remarks

- New and different design approaches needed for accurate modelling of laterally loaded piles with low L/D ratios
- Rule-based method with design equations or numerical-based method incorporating the use of finite element modelling for optimised design procedure capable of being evolved
- A very high quality database of medium scale pile tests has been gathered, covering a range of diameters, lengths and loading conditions
- PISA2 expands the database and covers layered soil profiles, and the PLAXIS tool MoDeTo will allow more widespread use of the method
- PISA Design is being applied to next generation wind farms in the UK

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Postscript: 2017 BGA Fleming Award Winner

"The Fleming Competition is held annually to commemorate the life and work of Dr Ken Fleming and to recognise excellence in the practical application of geotechnics in a project or a part of a project. Entries are invited from teams which will typically include representatives from *Clients, Main Contractors, Consulting Engineers, Specialist Contractors* and so on. The award will be presented to the **Project Team which most demonstrates excellence in geotechnical design and construction**. There will be an emphasis on teamwork across the different disciplines involved in the project. Consideration will also be given to projects which are innovative."

Wednesday 6 December 2017 – Institution of Civil Engineers

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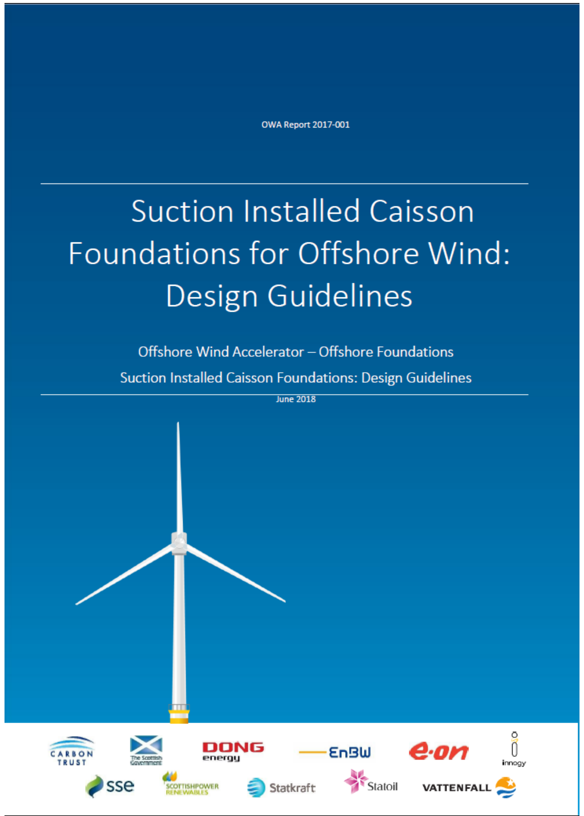
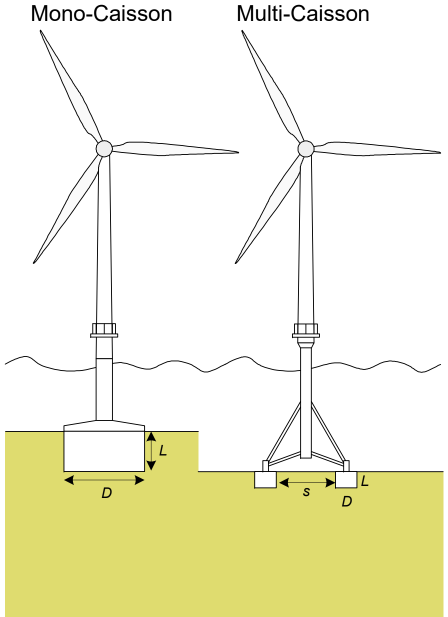
Acknowledgements

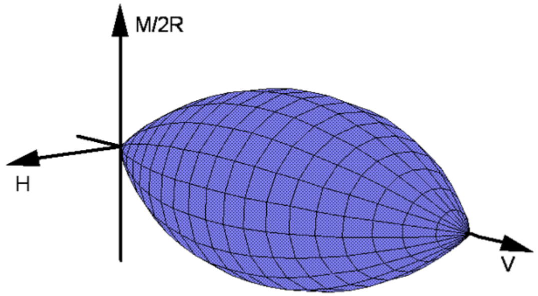
The PISA Project was funded by the UK Department for Energy and Climate Change (DECC) and the PISA Industry Partners under the umbrella of the Offshore Wind Accelerator (OWA) programme designed and led by the Carbon Trust.

The following project partners provided financial and technical support: Alstom Wind, DONG Energy, E.ON, EDF, Iberdrola, innogy, SSE, Statkraft, Statoil, Van Oord and Vattenfall.

Suction Installed Caissons – Guidelines – Out Shortly







$$\sqrt{\left(\frac{H}{h_0 V_0}\right)^2 + \left(\frac{M}{m_0 D V_0}\right)^2 - \frac{2aHM}{h_0 m_0 D V_0^2}} - 4\frac{V}{V_0}\left(1 - \frac{V}{V_0}\right) = 0$$