ROBOCONE:

INITIAL DESIGN AND PRELIMINARY TESTING OF A NEW ROBOTIC SITE INVESTIGATION TOOL TO HELP THE DEVELOPMENT OF OFFSHORE RENEWABLES

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EXCEL LONDON
12 – 14 MARCH 2024

ROBOCONE: The Team

University of BRISTOL


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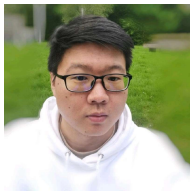
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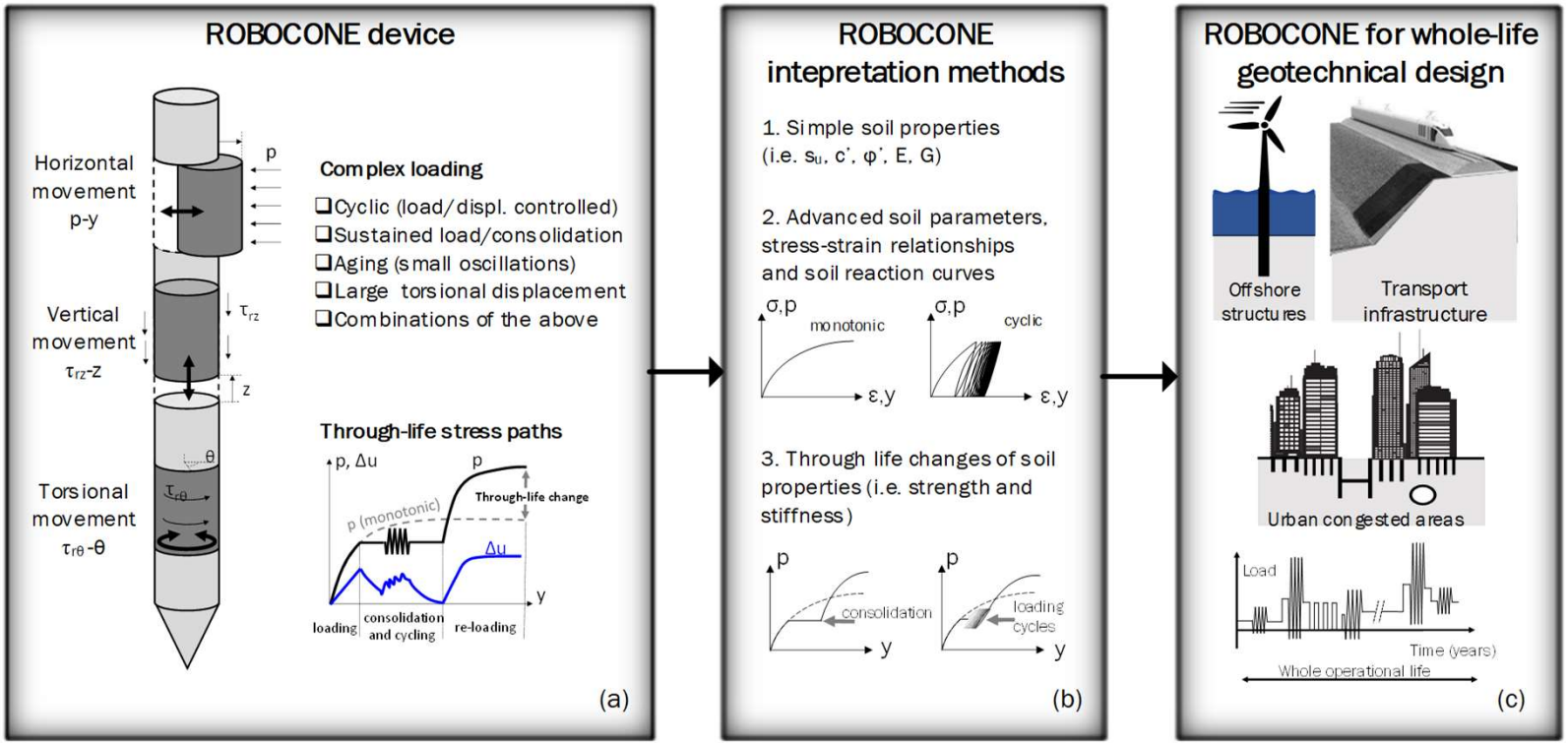
GDG GAVIN & DOHERTY GEOSOLUTIONS

Lloyd's Register

ROBOCONE: Intelligent robotics for next generation ground investigation and design



Engineering and Physical Sciences Research Council

Science Foundation Ireland For what's next

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The University of Dublin

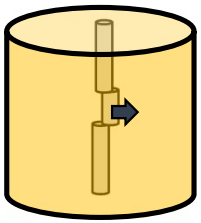
The ROBOCONE Project – Overall Plan

University of BRISTOL

Design and manufacture of ROBOCONE
University of Bristol

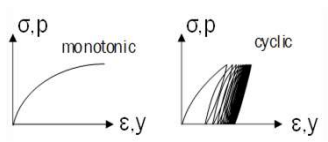
ROBOCONE Lab validation and testing - Trinity College Dublin

Large calibration chamber

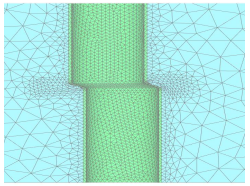


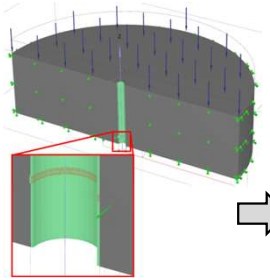
Testing

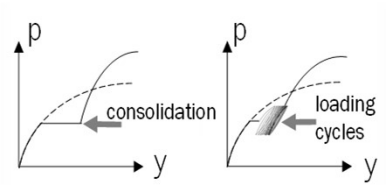
ROBOCONE Interpretation methods and FEM
University of Southampton



Stress-Strain







ROBOCONE Field performance and geotechnical design - All

Blessington (TCD)
Onsøy (NGI)

July 2022 — December 2025

Outline

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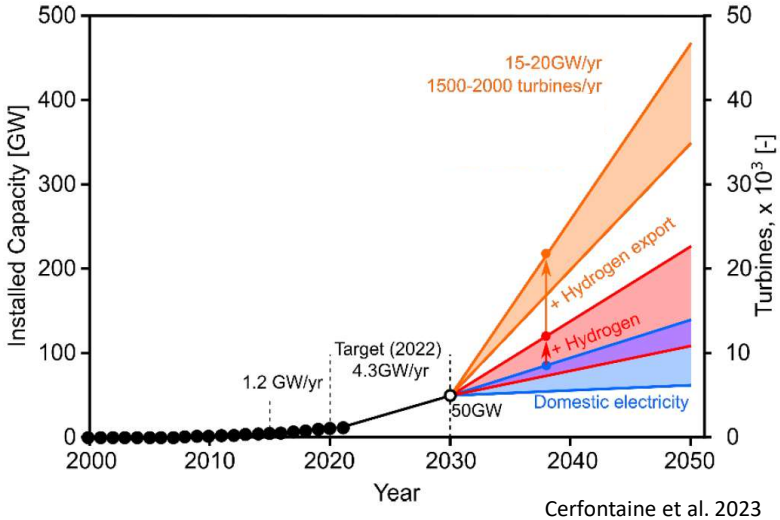
1. ROBOCONE: Context and Opportunities
2. The ROBOCONE Device
3. The P-Y Module Challenges
4. P-Y Module Initial Testing
5. Path to Interpretation, Design (UoS) and Scaling Up Through Field Testing (TCD)
6. Conclusions

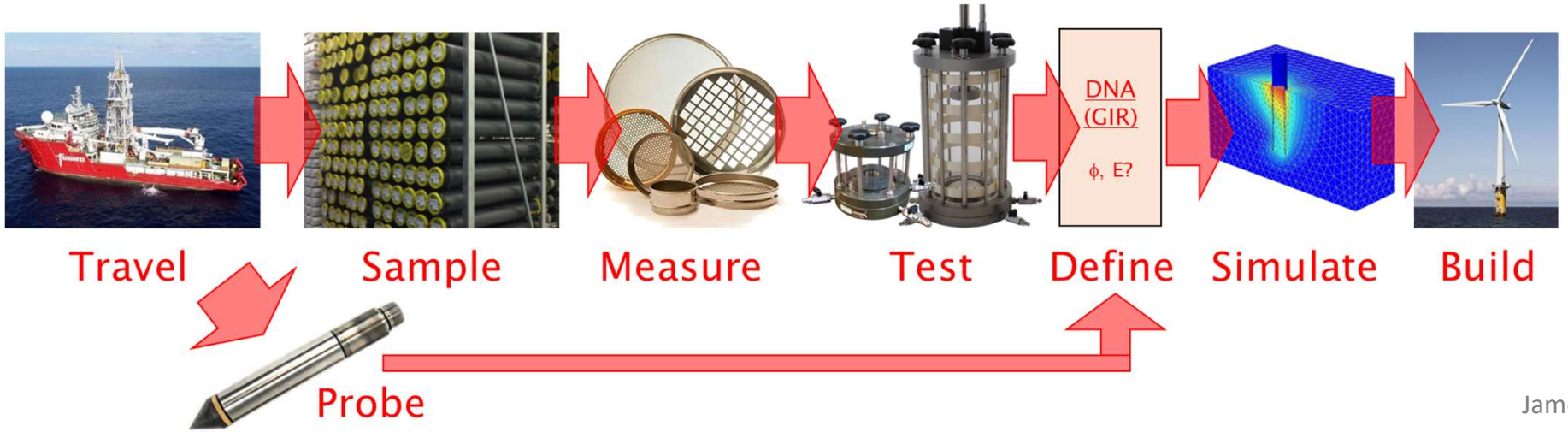
ROBOCONE: Context and Opportunities

- Large increase of UK offshore wind capacity required to meet future net zero targets
- Improved and advanced site investigation is essential to speed up the pre-construction stage for offshore foundations
- **We must speed up the current process to build offshore windfarms!**

UK offshore wind market

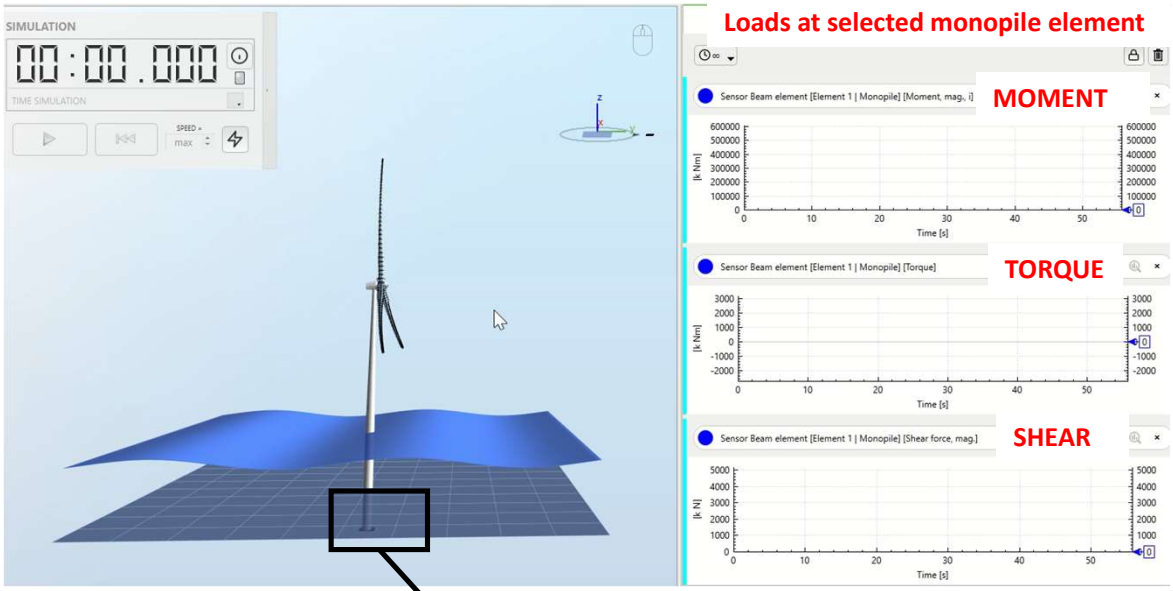


Cerfontaine et al. 2023

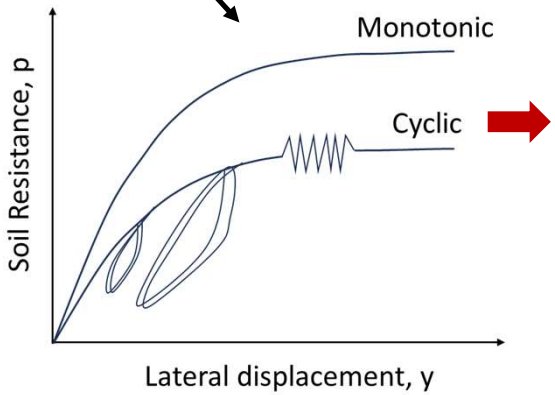


ROBOCONE: Context and Opportunities

Offshore Design



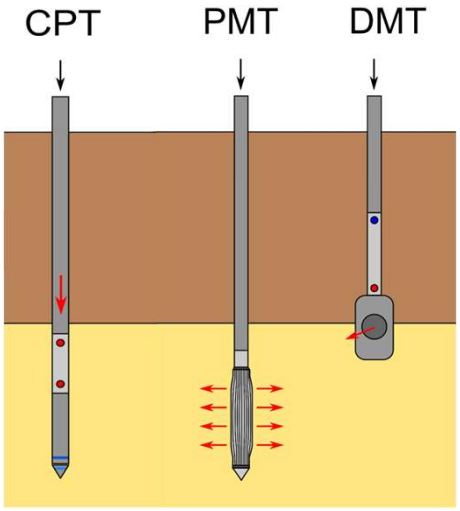
Loads at selected monopile element



Complex whole life response

Offshore Site Investigation

- The Cone Penetration Test (CPT) is the most widely used offshore in-situ test
- CPT data used to find lateral resistance-displacement (p-y) parameters required in the design of laterally loaded piles through empirical correlations
- Pressuremeter (PMT) and Flat Dilatometer (DMT) testing are sparsely utilised

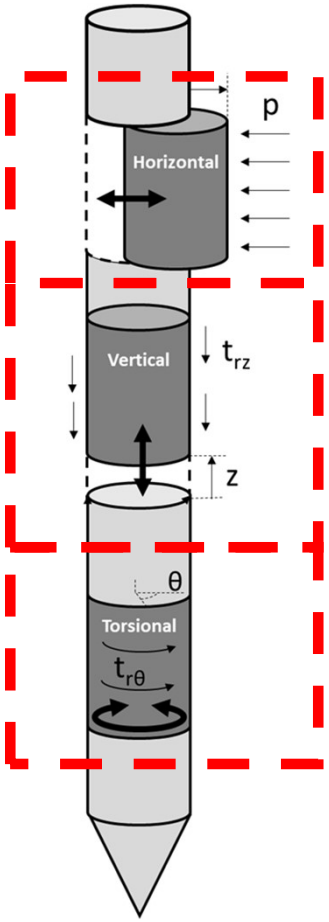


Limitations

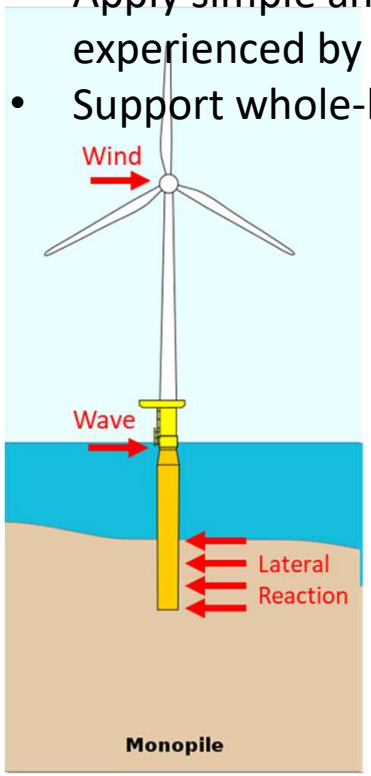
- Neither test simulate real offshore pile-soil interaction
- Neither test apply the complex loading offshore structures experience over their 'whole life'
- Neither test can directly measure p-y curves, both monotonic and cyclic
- **We need innovation in ground investigation!**

What is ROBOCONE?

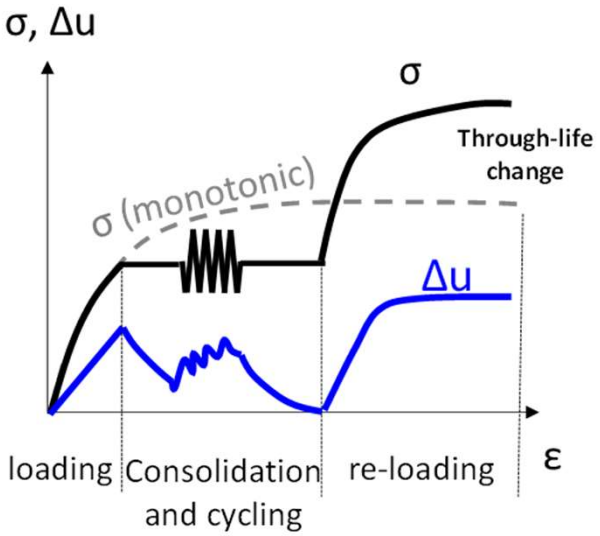
- An intelligent robotic tool which upon insertion within the ground, can mimic the loading histories experienced by soil elements around geotechnical infrastructure.



- Apply simple and complex loading, replicating stress and strain paths experienced by soil elements over an entire structure lifetime
- Support whole-life design approach

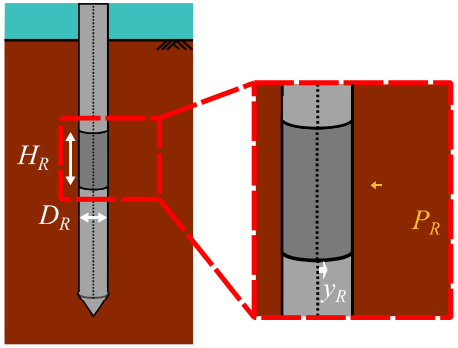


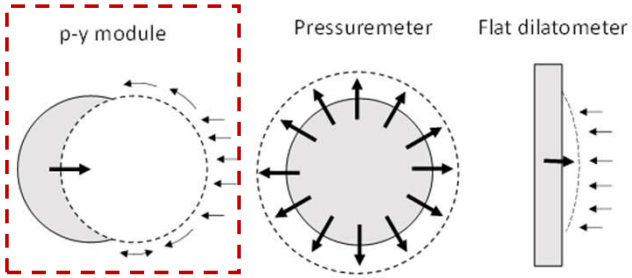
Example of a whole-life stress path



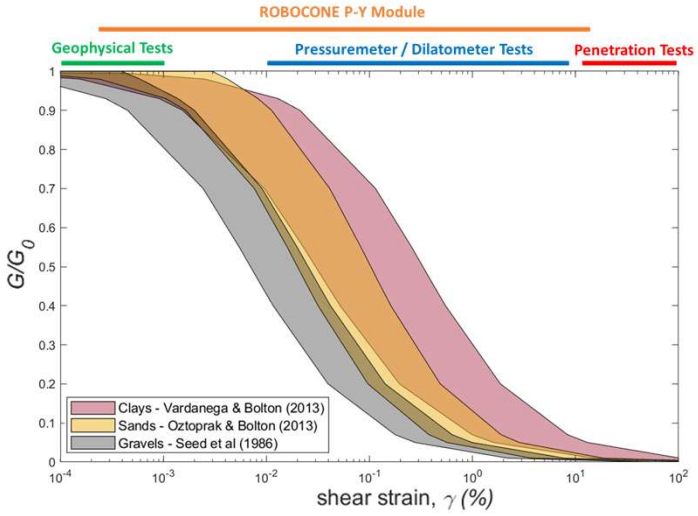
ROBOCONE: The P-Y Module

Overview





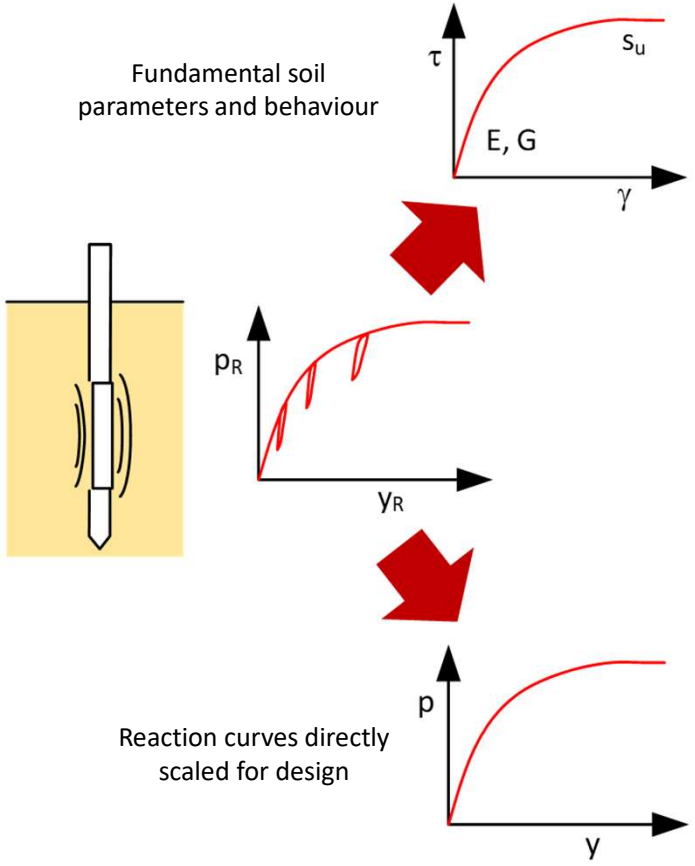
Induce different soil reaction to those produced by the pressuremeter or flat dilatometer



Apply complex stress paths over an entire strain range relevant to design

Interpretation of Data

Fundamental soil parameters and behaviour



Reaction curves directly scaled for design

ROBOCONE: The P-Y Module

Current Developments

Module diameter	54 mm
Module height	200 mm
Displacement range	0-13 mm
Displacement resolution	< 0.1 µm
Force capacity	~ 5-6 kN

The P-Y Module: Challenges

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- Miniaturisation
- Selecting Straight-Line Mechanism
- Driving Resistance
- Force / Displacement Capacity
- Force / Displacement Resolution
- Sensor Configuration
- Robustness
- Sealing
- Rod Bending and Reaction
- Fine Control
- Mechanical Backlash

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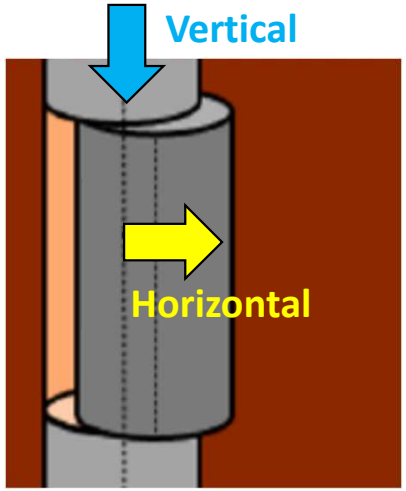
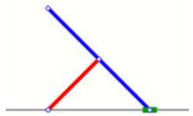
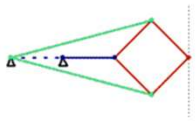
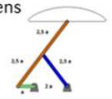
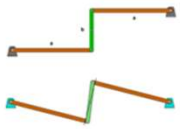
The P-Y Module: Straight-Line Mechanism

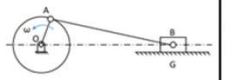
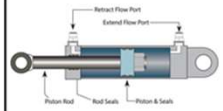
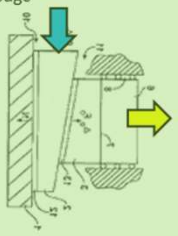
Identify mechanical system to transform **vertical** or **rotary motion** into straight-line **horizontal** motion



Main drivers for selection:

- Perfect straight-line motion
- High displacement range
- Displacement resolution
- Force capacity
- Robustness

Mechanism or System	Description	Strengths / Weakness
Scott-Russel 	Linkage transforming vertical to horizontal motion. Consists of three links all equal with a rolling or sliding connection.	+ Compact + Exact straight-line - Weakness at revolute joints - Rapid wear
Peaucellier- Lipkin 	Planar linkage transforming rotary to straight-line motion.	+ Compact + Exact straight-line - Complex revolute joints - Fragile mechanism with high stress
Hoekens 	A four bar linkage converting rotational to straight line motion.	+ Compact - Approx. straight line - Weak revolute joints
Watt 	Three bars bolted together in a chain. The three bars pivot around two bolts on the central bar to move a central point in a near straight line.	+ Compact - Approx. straight line - Weak revolute joints
Rack-Pinion 	A circular gear (pinion) connected to a linear gear (pinion) to convert rotational to straight line motion.	+ Exact straight line + Produces high forces + Accurate movement - High friction

Mechanism or System	Description	Strengths / Weakness
Screw-Nut mechanism 	Very simple mechanism that converts rotational to linear motion and torque to a linear force.	+ Exact straight line + Resilient + High forces - High wear rate
Slider-Crank 	A four link mechanism with three revolute joints and one sliding joint. Rotation of the crank drives linear motion.	+ Exact straight line + Resilient - Bulky due to sliding pair - High friction
Hydraulic or Air Flow Piston 	A hydraulic or air flow cylinder or motor that acts as a mechanical actuator used to give a unidirectional force through a unidirectional stroke.	+ High energy / force + Easy control - Requires maintenance - Difficult to fit in small cone and achieve high forces
Wedge 	Very simple mechanism consisting of two wedges. Vertical motion on the upper wedge transfers to horizontal motion in the lower wedge as the two slide over one another	+ Robust with high force + Easy control + Exact straight line + Easily customisable - High friction - Bulky

The P-Y Module: Sensor Configuration & Measurements

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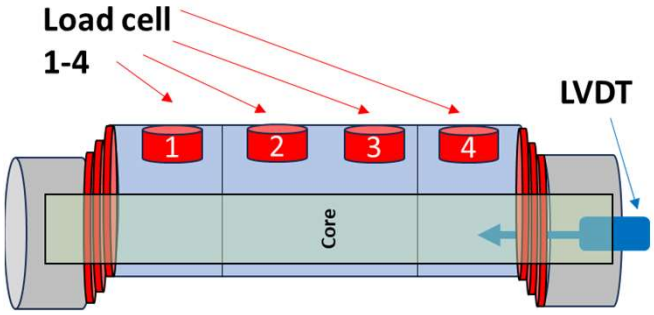
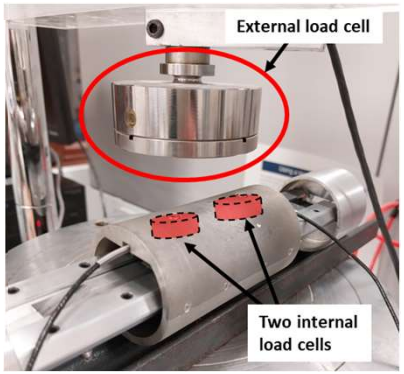
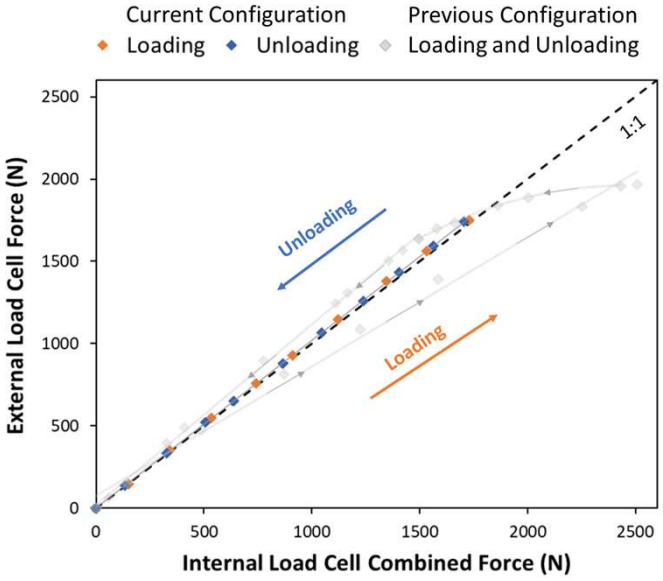
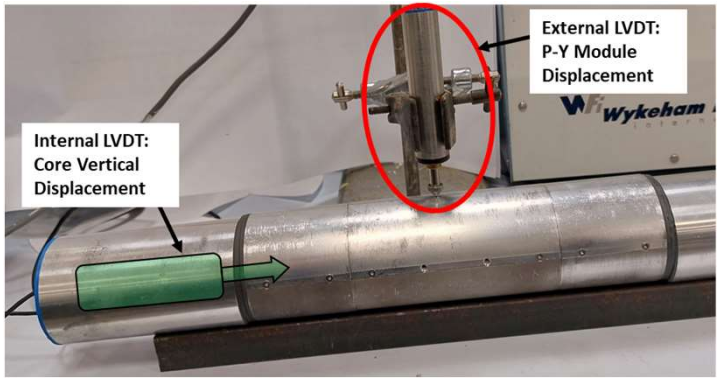
Force Measurement - Load Cells

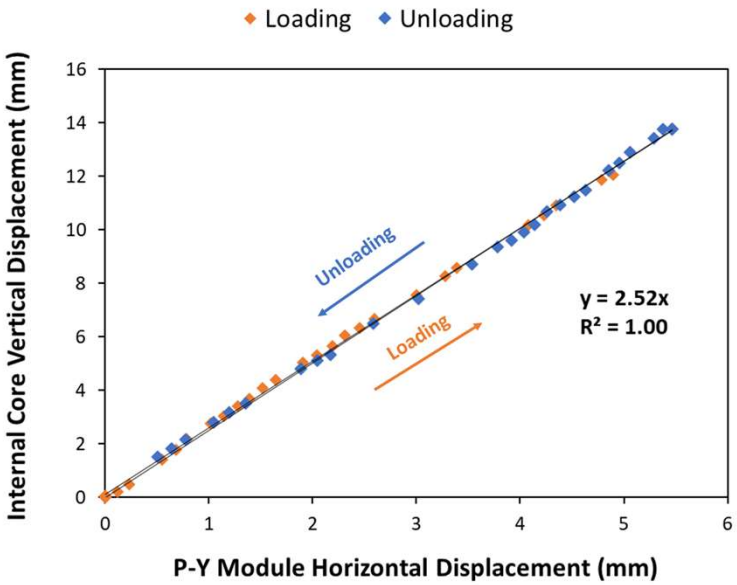






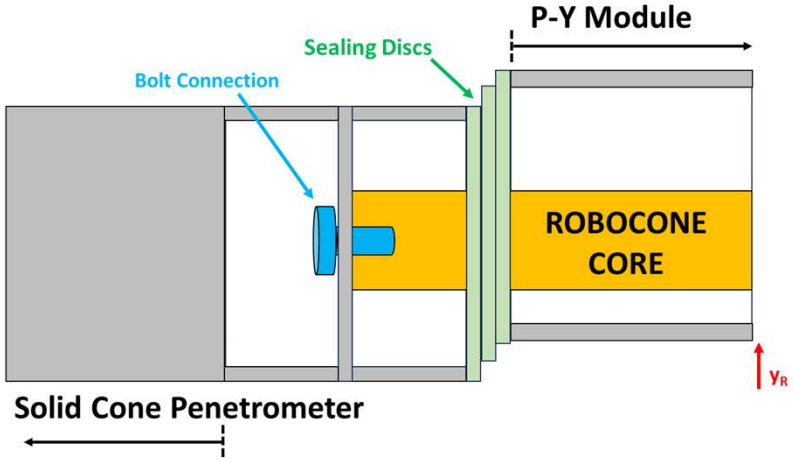
Displacement Measurement - LVDT

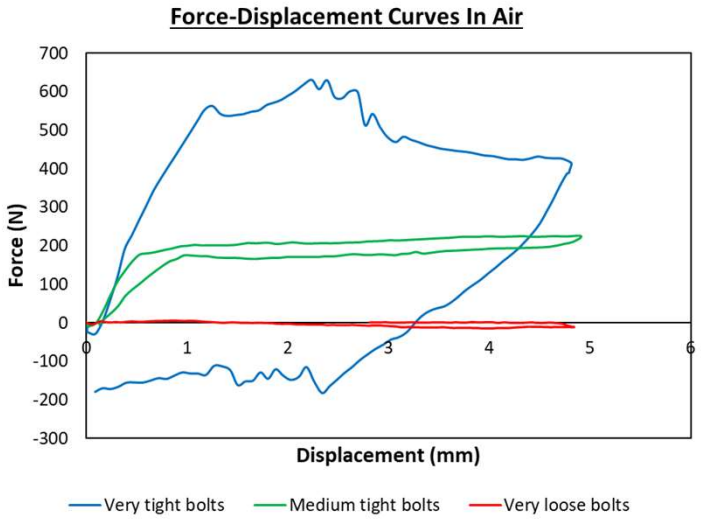




The P-Y Module: Sealing

Frictional Resistance





Frictional resistance in sealing dependent on tightness of connection

Effectiveness Against Soil Ingress

Kaolin Clay Powder

Marine Clay Slurry

No ingress of soil particles ✓ **… so far**

The P-Y Module: Rod Bending and Reaction

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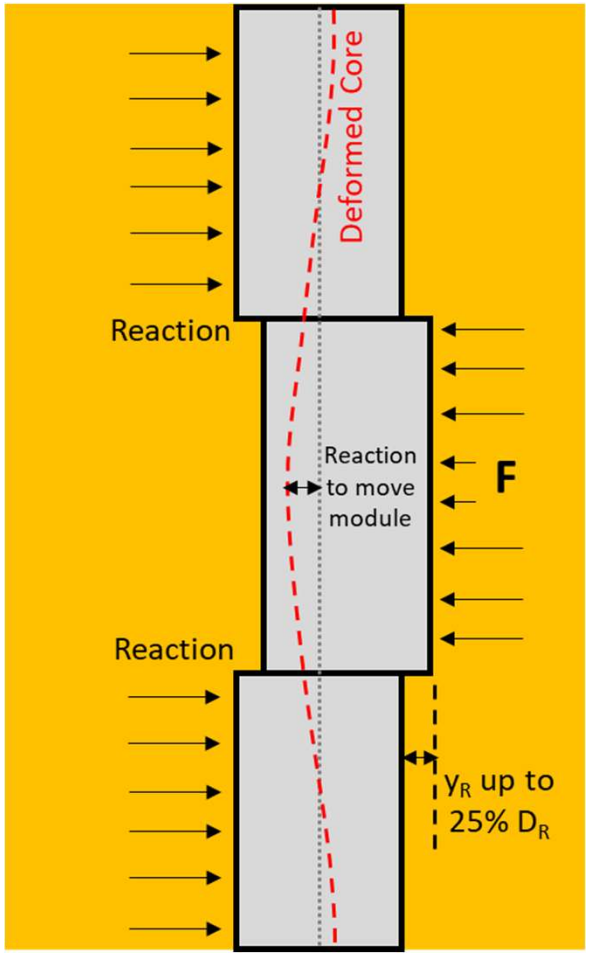
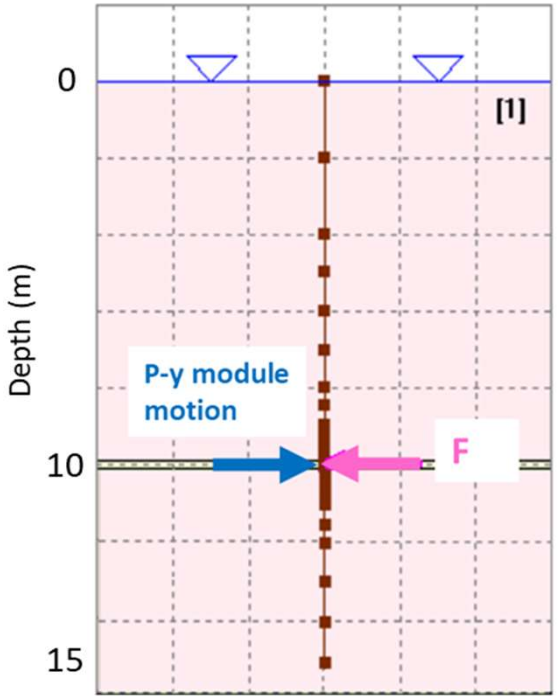
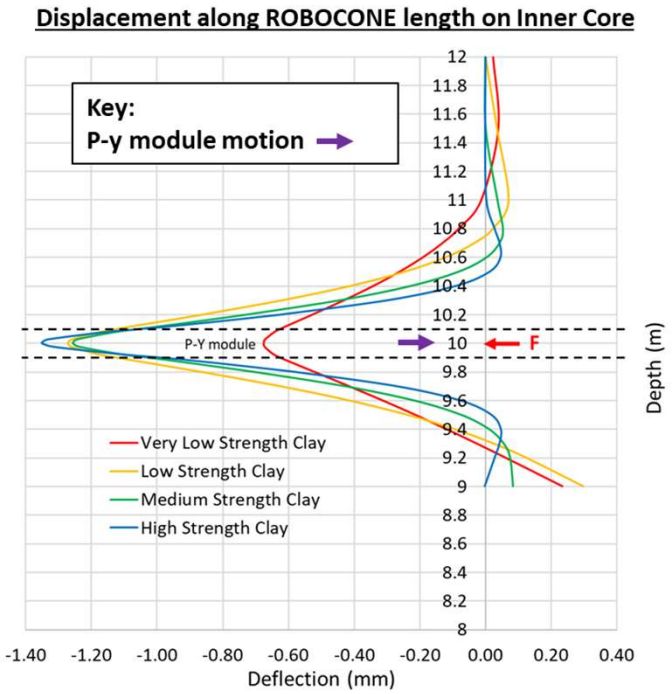
Bending and Reaction



Modelling using Oasys ALP



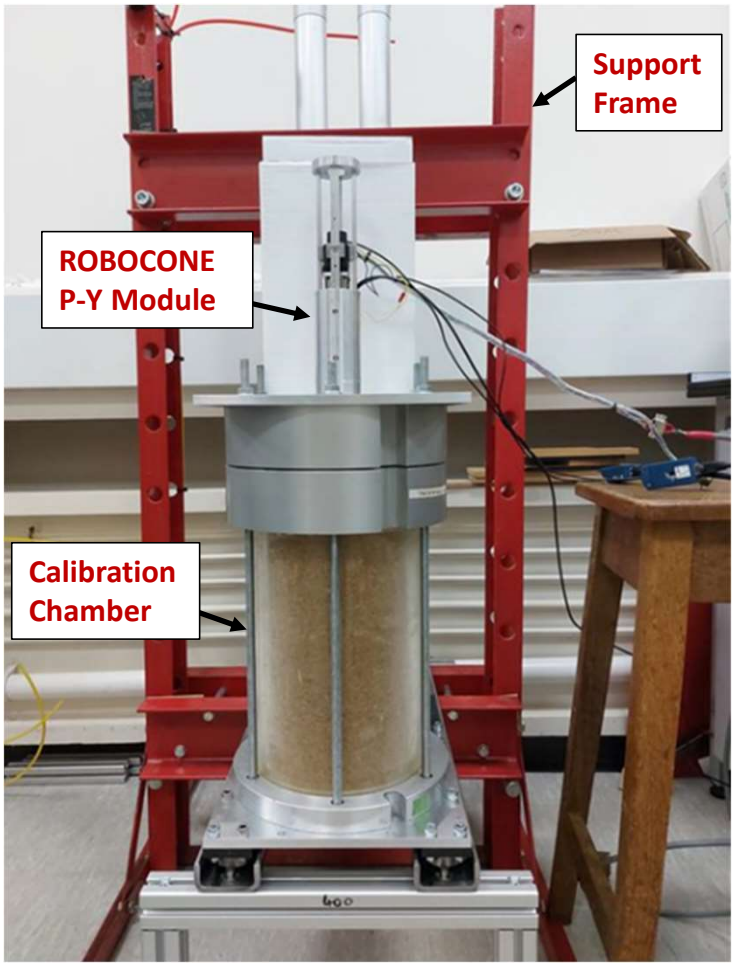
Verification and Optimisation



Maximum deflection at tip = 0.3mm
Maximum deflection = 1.35mm

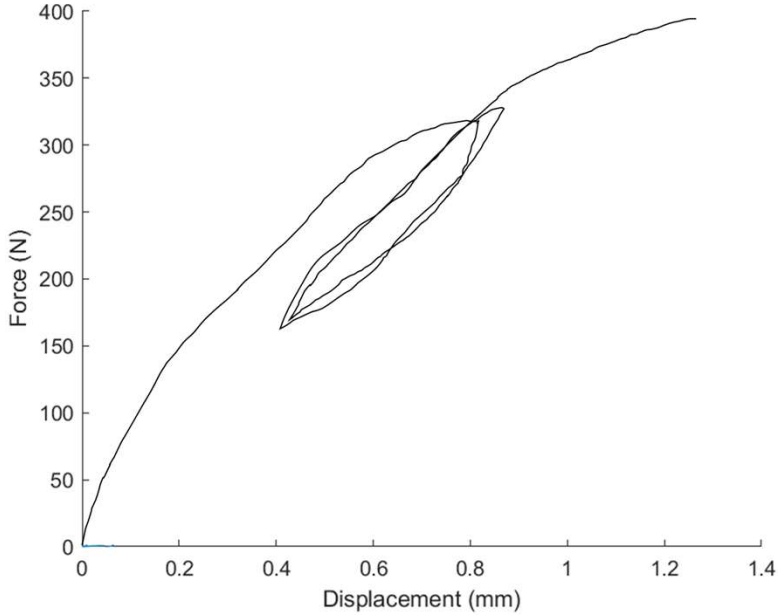
- Maximum cone string deflection is minimal and bending moment is acceptable
- Optimum height above CPT tip for p-y module identified as >1m

ROBOCONE: P-Y Module Initial Testing



Typical force-displacement curve in dry Redhill sand (D_{50} = 0.17mm)

P-Y Module Displaced



- Device capable of obtaining soil p-y curve
- System capable of applying complex load histories

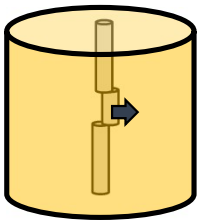
The ROBOCONE Project – Overall Plan

University of BRISTOL

Design and manufacture of ROBOCONE
University of Bristol

ROBOCONE Lab validation and testing - Trinity College Dublin

Large calibration chamber



Testing

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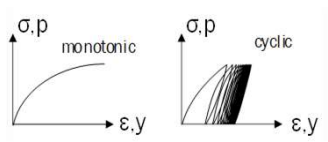

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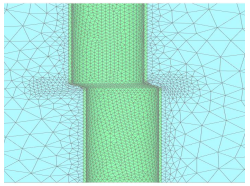
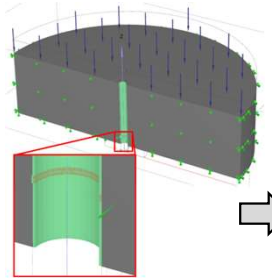
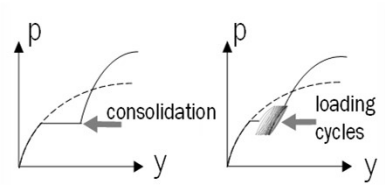






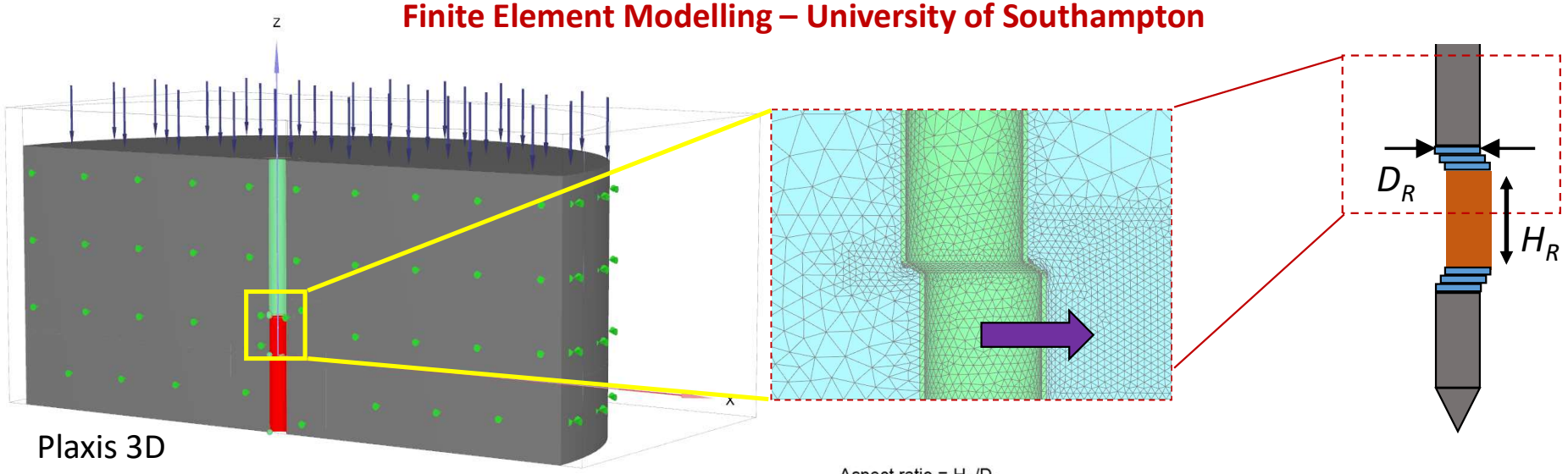
ROBOCONE Field performance and geotechnical design - All

Blessington (TCD)
Onsøy (NGI)

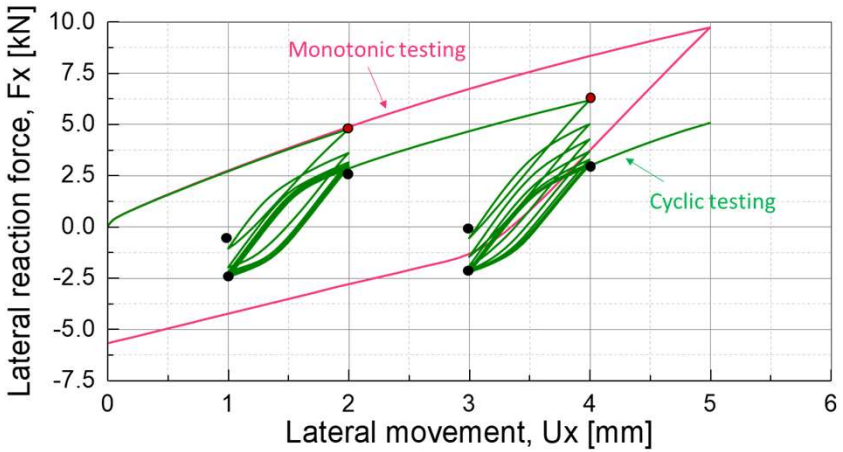
July 2022 — December 2025

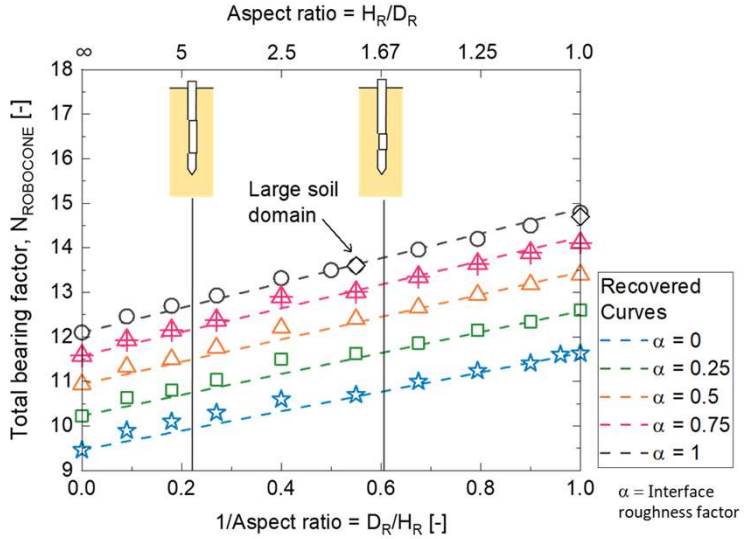
The ROBOCONE Project – Interpretation & Design

Finite Element Modelling – University of Southampton



Plaxis 3D





How can we infer our soil parameters from ROBOCONE?

- Undrained shear strength (s_u)
  Bearing factor (linked to geometry, interface roughness)
- Small-strain shear module (G)
  Stiffness factor (linked to geometry)

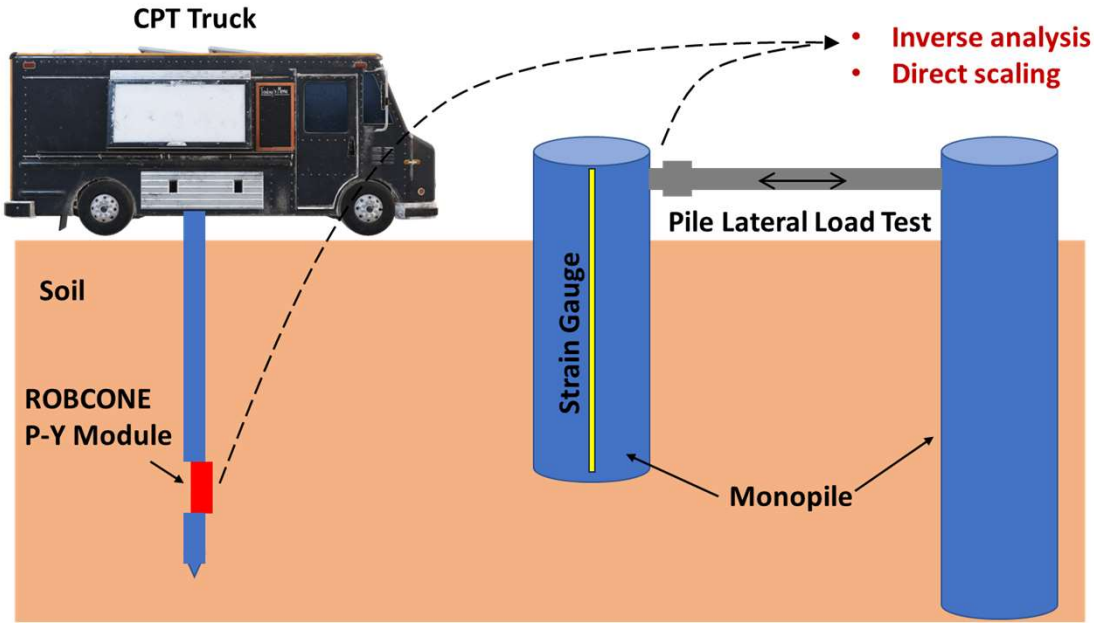
The ROBOCONE Project – Scaling Up to Design

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Large-Scale Testing – Trinity College Dublin

Large Chamber Testing

In-situ Field Testing



- Large Chamber Tests - Asses the quality of measured data and mechanical function in a realistic testing environment
- In-Situ Field Testing – Relationship between ROBOCONE data and lateral pile tests

Conclusions and Final Remarks

- ROBOCONE is an in-development geotechnical tool for intelligent in-situ soil testing
- The p-y module aims to mimic the kinematics of a laterally load pile
- By applying simple and complex loading conditions, fundamental soil properties and/or reaction curves will be derived to support modern whole-life design approaches
- Ongoing project between University of Bristol, Southampton and Trinity College Dublin which, beyond the mechanical tool development, will include numerical interpretation modelling, large scale calibration and field testing.

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