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Initial design and testing of a new site investigation tool for the direct determination of *p-y* soil reaction curves: ROBOCONE

Conception initiale et expérimentation d'un nouveau dispositif d'investigation de site pour la détermination directe des courbes de réaction du sol *p-y*: ROBOCONE

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ABSTRACT: This paper presents the initial design, specification, testing and calibration of a new site investigation tool aiming to provide direct characterisation of the '*p-y*' soil reaction curves. This tool, developed within the ROBOCONE project consists of a dedicated '*p-y*' module to be attached behind the cone of a conventional CPT. The proposed module is capable of horizontal translation with respect to the CPT rod, imposing kinematic conditions different from those of the conventional pressuremeter and dilatometer, and fully resembling those of a miniature laterally loaded pile. Beyond the main design features and performance specification of this innovative module, this paper presents some initial preliminary tests to investigate the capability and output of the device in addition to its sensor calibration. Initial testing has been performed in a miniature calibration chamber. It is shown that the module can be used to apply both monotonic and complex displacement-loading histories, while obtaining the expected shape of soil reaction. The potential for implementation in 'whole-life' geotechnical design approaches will be discussed, however development of the theoretical framework for the full interpretation of the module results is outside the scope of this paper.

RÉSUMÉ: Cet article présente la conception initiale, les spécifications, les essais et l'étalonnage d'un nouvel outil d'investigation de site visant à fournir une caractérisation directe des courbes de réaction du sol "*p-y*". Cet outil, développé dans le cadre du projet ROBOCONE, consiste en un module "*p-y*" destiné à être installé derrière le cône d'un CPT conventionnel. Le système proposé est capable de subir un mouvement latéral par rapport à la tige du CPT, imposant des conditions cinématiques différentes de celles du pressiomètre et du dilatomètre conventionnels, et ressemblant totalement à celles d'un pieu miniature soumis à une charge latérale. Au-delà des principales caractéristiques de conception et des spécifications de performance de ce dispositif innovant, cet article présentera les premiers essais visant à étudier la capacité et le rendement de l'appareil, ainsi que l'étalonnage de ses capteurs. Les premiers essais ont été réalisés dans une chambre d'étalonnage miniature. Il sera démontré que le module peut être utilisé pour appliquer des séquences de force-déplacement monotones et complexes, tout en obtenant la réaction attendue du sol. Le potentiel de mise en œuvre dans les approches de conception géotechnique "tout au long de la vie" sera discuté, mais le développement du cadre théorique pour l'interprétation complète des résultats du module n'entre pas dans le cadre de cet article.

Keywords: ROBOCONE; site; investigation; tool; offshore.

1 ROBOCONE: CONTEXT AND OPPORTUNITY

To meet future net zero carbon emission targets by 2050, global installed offshore wind capacity must be increased by a factor of ~5 over the next 25 years (GWEC, 2023). This acceleration of offshore wind deployment requires a compression of typical project timelines (HMG, 2022). A key stage which could be streamlined is the typically lengthy and expensive site investigation where soil samples are obtained and returned to shore for determination of geotechnical

parameters via laboratory testing. An alternative approach could utilise specifically designed in-situ soil testing procedures to generate these parameters earlier in the project cycle, speeding up the design process.

Recent developments in both robotic and sensing technologies offer techniques that could improve the speed, and also the quality of the site investigation stage supporting advanced 'whole-life' design of ocean structures over a complete strain range (Gourvenec, 2020; Mayne, 2001; White, 2022).

The ROBOCONE project presented in this paper introduces an innovative new device with the capability of smart in-situ soil testing, aiming to improve the efficiency and quality of offshore geotechnical design and other applications.

2 THE ROBOCONE PROJECT

2.1 Overview

The ROBOCONE research project is a collaboration between the University of Bristol, University of Southampton and Trinity College Dublin. The aim of the ROBOCONE project is to develop an intelligent robotic tool which upon insertion within the ground, can mimic the loading histories experienced by soil elements around geotechnical infrastructure. The device is designed to fit behind a standard 15cm^2 cone penetrometer, consisting of three modules, each capable of smart and controlled probing of the soil in three different active sensing directions (vertical, horizontal and torsional) demonstrated in Figure 1 (Creasey et al, 2023). The device aims to infer soil mechanical characteristics over an entire strain range relevant to design through the application of whole life stress paths, an example of which is also shown in Figure 1. The current focus of the project has been to develop the *p-y* module, capable of horizontal translation described in the next section.

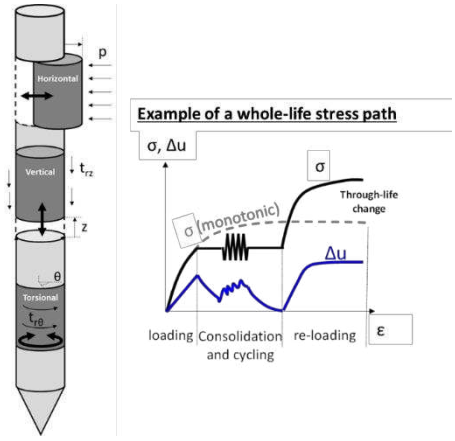

Figure 1. The ROBOCONE device and an example of a whole-life stress path that can be applied to the soil.

2.2 The *p-y* module

The ROBOCONE *p-y* module, is a cylindrical section of cone with the ability to translate horizontally within soil as highlighted by Figure 2a. The module translation aims to mimic the force and displacement history imposed by a laterally loaded pile element, so that the in-situ measured response can be scaled for pile design or used to determine soil constitutive parameters. An initial concept design for an aluminium prototype of the *p-y* module has been built at the University of Bristol (Figure 2b) with design specifications shown in Table 1. The device is capable of horizontal translation through an internal straight-line mechanism that converts vertical to horizontal linear motion driven via a motorised lead screw actuator fitted within the shaft above the module.

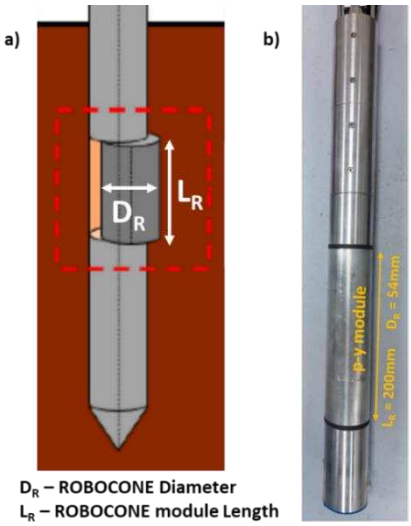

Figure 2. The ROBOCONE p-y module: (a) schematic; (b) initial aluminium prototype.

Table 1. Initial ROBOCONE p-y module specification.

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

The module is designed to fit within an enlarged section of cone with diameter 54 mm compared to the standard 44 mm cone penetrometer, enabling the housing of components of the internal mechanism, miniature sensors and cables. This enlarged section, occasionally included on a standard cone penetrometer acts as a friction reducer during soil penetration, easing resistance on the remaining cone length to be pushed to greater depths.

3 INITIAL *P-Y* MODULE TESTING

3.1 Bench verification and testing

Prior to testing the *p-y* module within soil, correct functioning of the device has been checked to ensure accuracy and reliability of both force and displacement measurements.

Measuring the total force acting on the module face as it displaces has been a challenge during the device development. All points of contact between the internal mechanism used to push the module must be connected to the shell via a load cell, so that all the load required to displace the module is measured. Figure 3 shows the method used to check the load cell configuration within the device. A central portion of the *p-y* module is placed in a loading frame and displaced up and down against an external load cell. The force measured by the external cell is then compared to the combined force measured by two internal load cells connecting the two points of contact between the internal mechanism and the outer shell. Comparison between external and internal load shows very good accuracy during both loading and unloading stages (Figure 4), a feature which was repeatable and not present in early design attempts due to the development of friction and unforeseen parallel contact points within the system, shown by the grey lines in Figure 4.

Due to space limitations only the vertical displacement imposed by the electrical motor could be measured through an LVDT placed inside the ROBOCONE. Therefore, a calibration process has been carried out to convert the vertical displacement of inner mechanism to the horizontal module translation, leading to a repeatable conversion factor of 2.52 as shown in Figure 5.

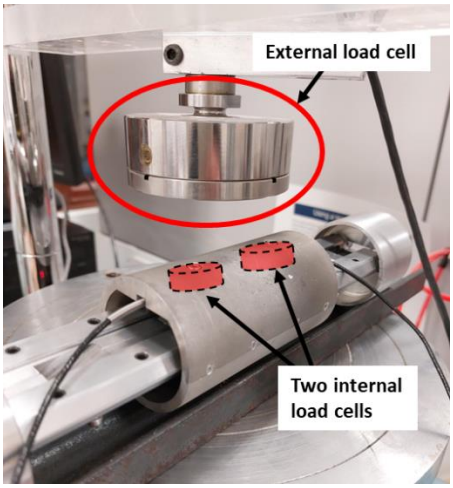

Figure 3. Test configuration for load cell investigation within the ROBCONE p-y module.

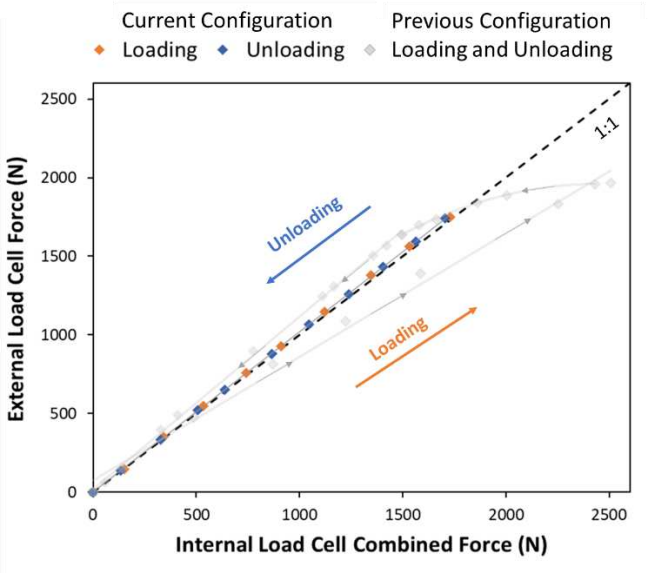

Figure 4. Comparison of external and internal load cell measurements.

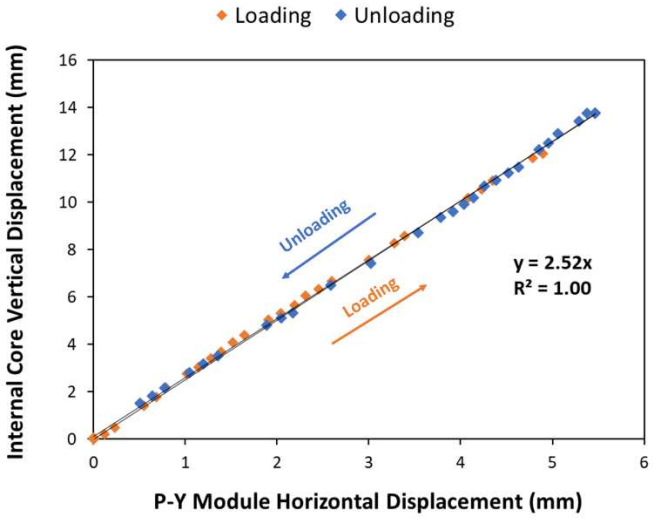

Figure 5. Comparison of vertical core displacement and horizontal p-y module displacement.

3.2 Calibration chamber testing

To investigate the capability and output of the ROBOCONE *p-y* module, initial small-scale tests have been conducted within a calibration chamber (Figure 6).

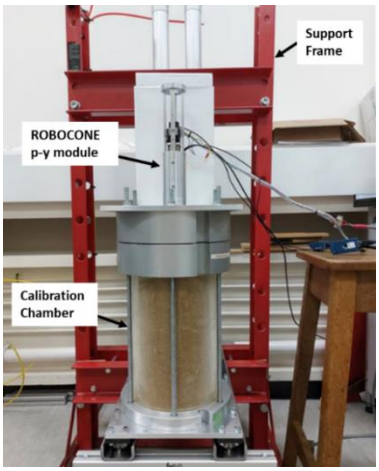

Figure 6. Initial small-scale testing of p-y module within a calibration chamber.

Within the chamber, the *p-y* module was displaced in dry Redhill sand (D_{50} = 0.17mm) with different vertical stresses applied. Varying load and unload loops were trialled and measurements of lateral force on the module face and lateral displacement were recorded. A typical force-displacement curve obtained is shown in Figure 7, where the module was displaced with two unload-reload loops during loading. The data shows load-displacement trends as expected and demonstrates the system capability to apply complex load histories.

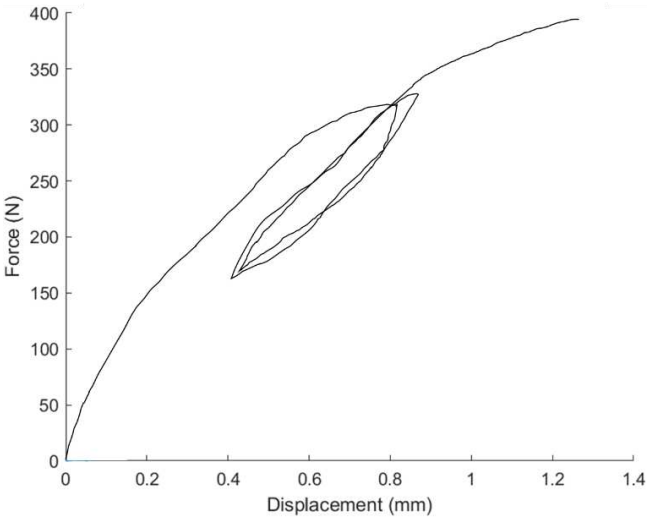

Figure 7. A typical force-displacement curve obtained within Redhill sand.

During testing, an assessment of the device's mechanical operation showed that the internal mechanism successfully transferred force to displace the module within sands and the sealing effectively prevented ingress of small dry sand particles.

4 CONCLUSIONS

Within the context of offshore wind design, the opportunity for an intelligent robotic site investigation tool has been highlighted. The initial design and specification of a horizontal (*p-y*) modular section of ROBOCONE has been presented, alongside preliminary bench verification and chamber tests in sand that validate its ability to impose complex stress paths and obtain force-displacement curves. It is essential that these tests are carried forward using a fully developed device with a larger range of soil types to obtain 'whole-life' soil reaction curves, supporting the advanced design of complex infrastructure.

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REFERENCES

Creasey, J., Hajjar, A.E., Diambra, A., et al. (2023). Motivation and demonstration of robotic tooling for ground characterization: the ROBOCONE. Proc. 9th Int. Conference on Offshore Site Investigation and Geotechnics 2023.

Gourvenec, S. (2020). Whole-life geotechnical design: What is it? What's it for? So what? And what next? Proc. 4th Int. Symp. Frontiers in Offshore Geotechnics. 206-246.

GWEC. (2023). Global Wind Report 2023. Global Wind Energy Council.

HM Govt. (2022). British Energy Security Strategy: Secure, clean and affordable British energy for the long term. 4/22.

Mayne, P. (2001). Stress-strain-strength-flow parameters from enhanced in-situ tests. Proc, Int. Conf. In-Situ Measurement of Soil Properties & Case Histories, Bali, Indonesia, 27-48.

White, D. (2022). CPT equipment: Recent advances and future perspectives. Proc. 5th Int. Symp. on Cone Penetration Testing, CPT22.