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Advancing offshore site investigation with the ROBOCONE p-y module: experimental and numerical investigation

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ABSTRACT: Enhancing the efficiency and quality of in-situ soil characterisation is essential to accelerate timelines for offshore projects. ROBOCONE is a novel site investigation tool that integrates a cylindrical p-y module capable of horizontal translation with a standard CPT cone. The measured load-displacement response of ROBOCONE can be used to infer soil parameters required for geotechnical design or directly scaled into p-y curves for lateral pile design. This study evaluates the performance of the ROBOCONE prototype through a series of calibration chamber tests in dry sand. To complement and interpret the experimental data, a finite element model employing an advanced bounding surface plasticity model is developed, capturing the stress-dependent shearing behaviour of sands. Good agreement is observed between the experimental and numerical results, demonstrating the validity of ROBOCONE as a next-generation in-situ testing tool. The findings support further optimisation of ROBOCONE's geometry and its integration into offshore foundation design framework.

1 ROBOCONE P-Y MODULE: CONTEXT AND OPPORTUNITY

Achieving net-zero carbon emissions by 2050 will require a roughly 5x increase in global offshore wind capacity over the next 25 years (GWEC, 2023), demanding significantly faster project delivery timelines. One opportunity for acceleration lies in the site investigation phase, which is often time-consuming and costly. Purpose-designed in-situ testing methods offer a viable alternative, enabling earlier determination of geotechnical parameters and faster progression through design stages. Advances in robotic systems and sensing technologies now provide further potential to enhance both the efficiency and data quality of site investigations, supporting improved whole-life design of offshore structures across a wide strain range (Gourvenec, 2020; White, 2022).

The ROBOCONE project introduces an innovative new device – the p-y module, which is a cylindrical section of cone capable of horizontal translation within the soil as shown in Figure 1a. Its movement is designed to replicate the force–displacement response of a laterally loaded pile element, allowing direct in-situ p-y curve measurements to be scaled for pile design or used to derive soil constitutive parameters. The module, built from aluminium or steel is designed to fit behind a standard 15cm^2 cone penetrometer as shown in Figure 1b.

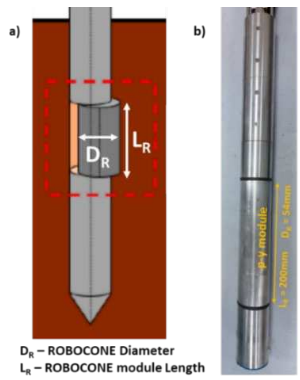

Figure 1: The ROBOCONE p-y module: (a) schematic; (b) initial aluminium prototype (Creasey et al., 2024)

2 INTERPRETATION OF CALIBRATION CHAMBER TEST RESULTS

A series of tests were undertaken with the ROBOCONE p-y module in a small and large-scale calibration chamber shown in Figure 2a and b respectively with dimensions shown. The chambers were both filled with sand, compacted in layers to achieve a specific relative density (D_r) and the ROBOCONE tests were performed at varying vertical stresses (σ_v) in the small chamber and depths in the large chamber.

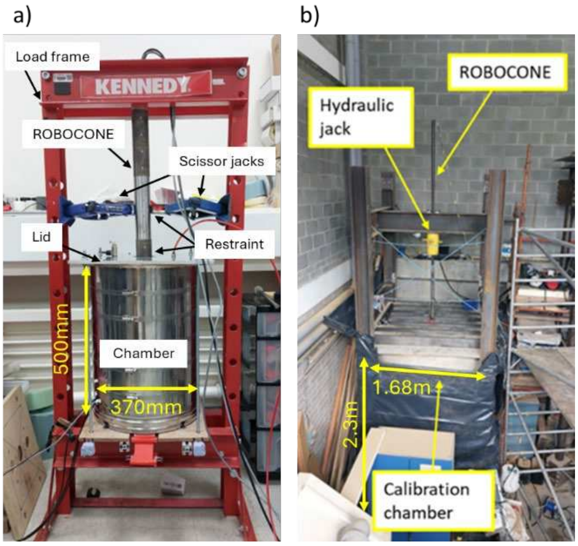

Figure 2: ROBOCONE p-y module tests conducted in sand within the a) small calibration chamber and b) large calibration chamber

3D finite element modelling was undertaken to replicate the test setup and conditions of the small and large calibration chamber as shown in Figure 3a. The shearing stress-strain behaviour of the sand is represented by SANISAND-MS model, with the model parameters being calibrated against the Leighton Buzzard sand. Further details on the FE model including modelling phases can be found in Wen et al. (2024).

Using this FE model and an analytical solution (API, 2014), a comparison was formed with the experimental data. A typical test is shown in Figure 3b, for the small calibration chamber with Leighton Buzzard sand used as a sample at D_r = 20% and σ_v = 50kPa. It can be seen that at this stress level and density, the ROBOCONE measured p-y curve was comparable to both the FEA and analytical method. The API approach matches well at the small displacement range with a similar p-y curve stiffness up to ~1mm. The FEA however tends to yield reasonable agreement at larger displacement levels, showing a reduction in stiffness and similar p-y curve shape beyond 1mm. It should be noted when testing in many sands that obtaining a full p-y curve up to the ultimate soil resistance is not possible as it requires an exceptional force capacity from the p-y module.

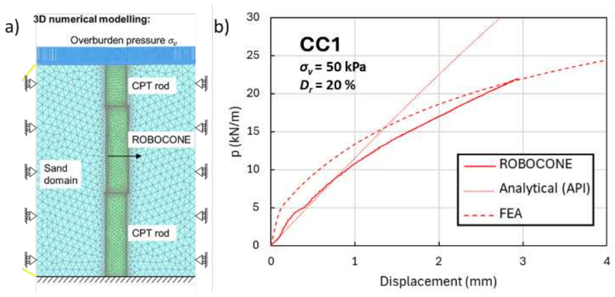

Figure 3: ROBOCONE p-y module a) finite element mesh of system and b) small calibration chamber test in sand comparison with FEA and Analytical

3 CONCLUSIONS

The ROBOCONE p-y module successfully measured p-y curves in sand in a small and large calibration chamber. The curves varied with stiffness and ultimate soil resistance as expected at varying stress levels and depths. Reasonable agreement between measured p-y curves to the numerical modelling and analytical analyses proves the potential of ROBOCONE p-y for advancing offshore site investigation.

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