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Behaviour of small-scale piles jacked in soft rock

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Abstract

Open-ended (OE) pile field tests in low to medium density chalk have demonstrated a unique post installation response which impacts their axial short and long-term performance. Field-scale pile tests, although crucial for the development of new empirical based design approaches, are costly and time-consuming. Alternatively, characteristics observed at the field-scale can be broadly replicated at a small-scale for a lower cost and with more flexibility. In this scope the ICE-PICK testing campaign, a numerical and experimental study on installation effects and their long-term impact pile performance, will be discussed. Focus is drawn to the small-scale experimental pile tests conducted and the advanced techniques (namely a new versatile loading frame apparatus and X-ray CT) used to study the risks associated with pile installation in soft rocks.

Introduction

Soft rock is a unique geomaterial characterised by its structured, highly porous nature. The mechanical behaviour of soft rock makes pile installation a challenging task and gives rise to risks such as pile refusal and conversely pile free-fall. Field-scale test observations show that as piles are driven in to soft rock, they generate damage zone around the pile annulus which corresponds to low driving resistance, and short-term axial capacity. Whilst field-scale tests are crucial in developing new design approaches (such as the ICP-18 (Jardine et al., 2023)), they can be expensive and time consuming to conduct. Therefore, to aid a better understanding of the complex phenomena observed in the field, small-scale 1*g* tests combined with advanced numerical simulations may be used to conduct systematic parametric studies. These can carefully investigate the mechanisms which contribute to the unique installation behaviour observed in the field which varies in different rocks.

As part of the ICE-PICK project, a large campaign of small-scale physical modelling using novel X-ray CT, after Alvarez-Borges et al. (2021), was performed. This study, facilitated by a new multi-axis loading frame (Riccio et al., 2024) is actively contributing to the numerical package of the ICE-PICK project which aims to grow the understanding of pile installation behaviour in soft rock (Previtali et al., 2023). This paper highlights the development of the multi-axis frame as well as some brief insights into the extensive experimental test campaign.

The ICE-PICK multi-axis frame

The multi-axis frame (Fig. 1) was designed to fulfil criteria for pile installation and loading in soft rock ($UCS \approx 1-3$ MPa). It was also developed to be compact enough to fit within the University of Dundee SMART Lab CT scanner.

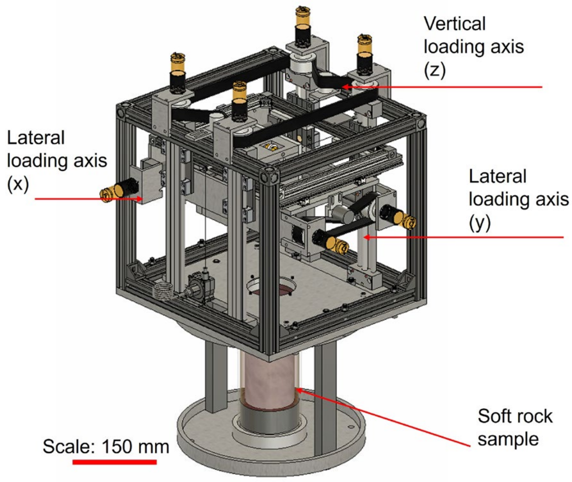

Figure 1. Multi-axis loading frame in small-chamber arrangement prepared with a soft rock sample for testing

Despite its size (see Fig. 1), it was able to actuate vertical and horizontal loads up to 5kN and 500 N, respectively. Details associated with the development may be found in (Riccio et al., 2024). Tests performed in different soft rock samples using the frame consisted of installation, lateral monotonic and cyclic, and long-term axial tests to study pile set up. Continuous testing (i.e., install and then subsequent test stages) meant that the impact of installation could be evaluated. Whilst wished-in-place conditions adopted in experimental and numerical simulations may be appropriate for granular materials, neglecting the installation process in soft rock overlooks a significant precursor to pile performance.

Examples tests and discussion

Examples here consist of 15.4 mm piles axial tested after slow jacking into 100 mm diameter samples of calcarenite from Gravina Di Puglia, Italy ($UCS \approx 2\ \text{MPa}, e_0 \approx 1$) after Ciantia and Hueckel (2013) and a white chalk from the St. Nicholas at Wade site (SNW), UK ($UCS \approx 3\ \text{MPa},\ e_0 = 0.85$). Jacking forces for both are shown in Fig 2a.

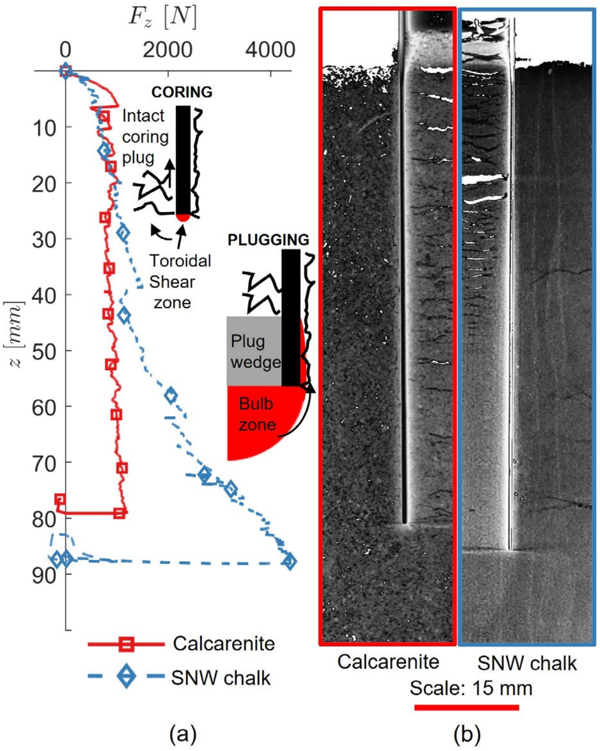

Figure 2. (a) Pile installation response of 15.4 mm piles installed in a highly porous calcarenite and white chalk (b) X-ray CT observations for both tests

Both cases exhibited a similar force-displacement response at shallow 'unconfined' penetration (<20-30 mm). In the chalk however, a marked increase in load at ~50 mm was observed, which grew until the end of insertion, contrasting the calcarenite case. Post-test X-ray CT (Fig 2b) showed that changes in jacking resistance for the chalk was associated with the formation of a plug. Both tests showed that a damage zone formed around the annulus of the pile, which was approximately the thickness of the pile wall, consistent with field observations reported by Jardine et al. (2023). In the chalk case, at deeper penetration depths, the plug led to a punching mechanism, contributing to a higher damage extent. Differences in installation stem from variability in the constituent materials (e.g., $d_{50,\text{calcarenite}} = 86\ \mu m$ vs $d_{50,\text{chalk}} = 5\ \mu m$), porosity and strength. In both cases, the installation process, paired to the bonded state of the far field material and marked destructurisation of near-pile material contributed to a low uplift capacity.

Conclusion

In summary, a new multi-axis loading frame was developed offering insight into the installation characteristics of piles installed in different soft rocks. X-ray CT revealed insights into pile insertion in soft rock not seen previously whilst also providing valuable data for validating numerical models.

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