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# Using Fibre Bragg Grating sensors to estimate the horizontal monopile behaviour in centrifuge

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## 1 INTRODUCTION

In the literature, reduced-scale centrifuge tests have been used to characterise the response of pile or monopile under horizontal loads (e.g. Verdure et al. 2003; Rosquoet et al. 2007; Li et al. 2010; Klinkvort and Hededal 2014; Klinkvort et al. 2019; Choo and Kim 2015; Truong et al. 2018). Through carrying out centrifuge tests, researchers were able to test monopiles as large as 50 mm in diameter (e.g. Klinkvort et al. 2019).

The present study is part of the SOLCYP+ project, which is an extension of the SOLCYP project (Puech and Garnier 2017). The main objective was to experimentally investigate the response of the model piles under horizontal load in geotechnical centrifuge and then to extrapolate the prototype pile behaviour. Fibre Bragg Grating sensors (FBGS) were used to measure the local strains and to determine the moment profile of the pile (Li et al., 2020).

## 2 MODEL PILE

In previous centrifuge tests, piles were instrumented with strain gages glued on the external pile shaft (Roesquoët et al. 2007) or even inside the tube (El Haffar 2018), with the connection wires embedded inside the tube. These methods, however, alter the pile dimension and surface roughness and as a result may lead to erroneous measurements. To accurately model the monopile behaviour, the pile must be open-ended with sand inside the pile (i.e. in-situ situation). For this purpose, the model monopile in this study has been instrumented with Fibre Bragg Grating sensors (FBGs).

The model monopile is an open-ended aluminium 2017A tube with the external diameter  $D = 50$  mm, the embedded length  $L = 450$  mm, the load eccentricity,  $le = 500$  mm and the wall thickness  $t = 2.5$  mm.

Two semi-cylindrical grooves, diametrically opposed and with a radius of 0.5 mm, have been machined along the pile shaft in its embedded part. In this way, the depth of the grooves is 0.5 mm, i.e. 1/5 of the wall thickness.

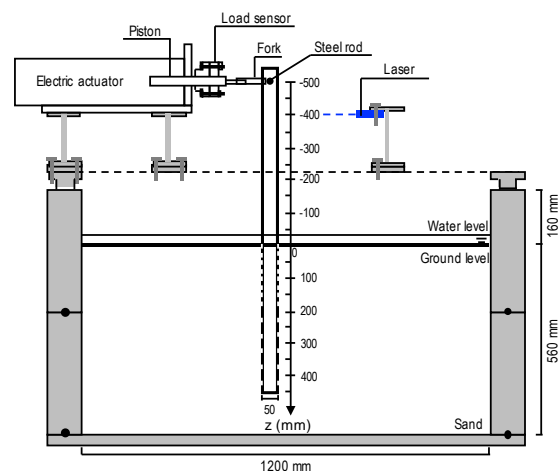
Two identical optical fibres with a diameter of 180  $\mu\text{m}$  are glued in the two grooves. On each fibre, 10 Fibre Bragg Grating sensors (FBGs) have been manufactured every  $D/2$  (i.e. 25 mm) from the ground level to the pile base. These FBGs are protected by a Teflon tube of 200  $\mu\text{m}$  in diameter. These FBGs measure the external deformations at 10 different cross sections of the pile and then, after calibration, give the bending moments of the pile at these levels.

## 3 EXPERIMENTAL SET-UP

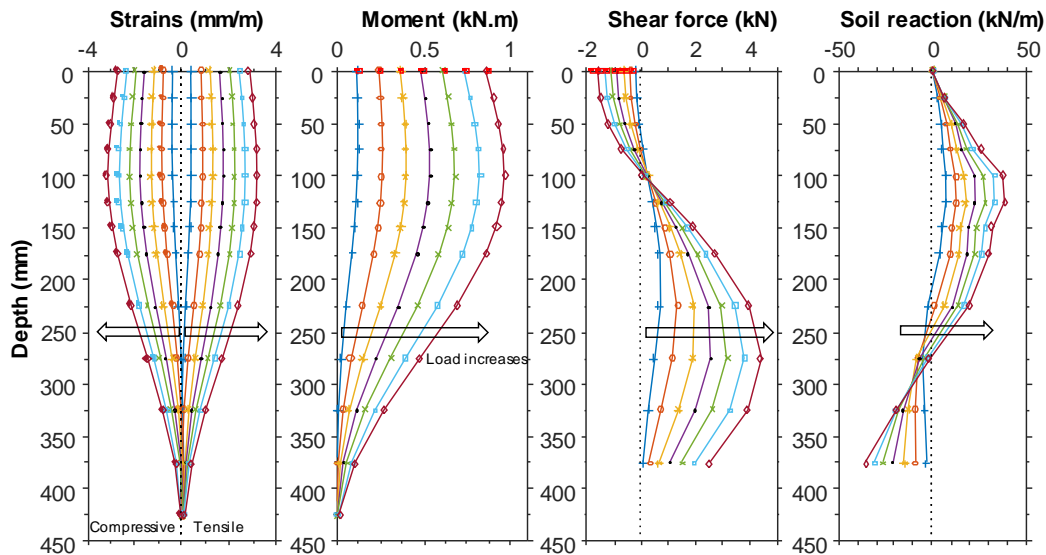
Concerning the pile installation, the instrumented model pile was pushed into the sand at 1g level by a hydraulic jack. The jacking speed was 1 mm/s and the attained depth is 450 mm, i.e., 9D. The sand level inside the pile was checked and there was no plug generated.

After pile installation, an electric actuator was mounted on two supporting beams that perpendicularly placed on the longitudinal edges of the strongbox (Figure 1).

Centrifuge test was performed at 100g level. Horizontal load was applied through the centre of the cross section by pushing the steel rod that crosses the monopile perpendicularly to the instrumentation plan. The loading point situates at 500 mm (i.e. 10D) above the ground level. The loading was displacement-controlled with a rate of



**Figure 1.** Schematic drawing of the horizontal loading system in the centrifuge at 100g.



**Figure 2.** Profile of (a) the measured strains, (b) the bending moment, (c) the shear force and (d) the soil reaction (i.e., the distributed load) for seven horizontal loads (every 0.25 kN until 1.75 kN).

1 mm/s at the actuator level and terminates at 50 mm (i.e. 1D). The measurements of the FBGS, the laser and force transducer were recorded and registered every 0.02 second (i.e., 50 Hz).

#### 4 CONCLUSION

The experimental results (Figure 2) show that:

- All the 26 FBGS survived in the 100g centrifuge test.
- At the ground level, the moments determined by FBGS are in accordance with the moments calculated from the transversal force;
- Shear forces at the ground level are slightly larger than the applied transversal forces. Such difference mainly results from the difficulty of the accurate derivation operation at the ground level.
- The pile local behaviour is characterized: under the effect of the increasing horizontal load, pile rotates at the depth 210 - 275 mm (i.e., 4.2 - 5.5D) below the ground level. Due to the large embedment depth, the pile deflection below the rotation centre was close to zero. The P-y curves at different depths were also determined.

#### 5 ACKNOWLEDGEMENTS

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