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Conference Paper · August 2024

DOI: 10.1201/9781003431749-35

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Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-35

Centrifuge modelling of tapered wall jacked into dense sand

Modélisation physique d'une parois conique fonçée dans du sable dense

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ABSTRACT: A series of static penetration tests of trapezoidal walls in dense Fontainebleau sand were performed in the geotechnical centrifuge at Gustave Eiffel University. The models of wall with three different shapes (straight profile with thickness D=16mm, 0.75 degree and 1.5 degree of taper angle) but with the same volume were used. The soil mass was instrumented with five stress cells located at two levels at 2D, 4D and 6D distance from the wall axis to follow the stress state changes during the model penetration. Moreover, three pressure sensors were integrated on the model surface to track the changes of normal stress during the continuous penetration of the wall. Thus for the three walls of different geometry the evolution of the following variables is considered during monotonic penetration of the wall: 1) total vertical force; 2) horizontal stresses in the soil mass; 3) normal stresses on the wall surface.

RÉSUMÉ: Une série de pénétrations statiques d'une paroi dans du sable de Fontainebleau dense est effectuée dans la centrifugeuse géotechnique de l'Université Gustave Eiffel. Le volume de chaque paroi est identique mais leur profile varie: rectangle d'épaisseur D=16mm ou trapèze d'angle 0.75° ou 1.5°. Pour suivre l'évolution des contraintes pendant le fonçage continu du modèle, le massif du sol est instrumenté: cinq capteurs de contrainte distribués à deux niveaux à la distance de 2D, 4D et 6D de l'axe de paroi. Trois capteurs de contrainte sont de plus intégrés dans la paroi afin de mesurer la contrainte normale lors du fonçage de la paroi, dont l'effort vertical de fonçage est enregistré. Ainsi pour les 3 géométries, on compare pendant le fonçage, l'évolution: 1) des efforts de fonçage; 2) des contraintes horizontales dans le massif; 3) des contraintes normales à la paroi.

Keywords: Installation effects; dense sand; pushed-in piles.

1 INTRODUCTION

The installation of displacement piles induces significant changes of displacement, strain, and stress fields in the surrounding soil. These effects are considered in the physical modelling of tapered piles/trapezoidal walls in centrifuge in the present study. The testing program includes the installation of pushed-in continuous walls with observation of displacement patterns and stress evolution in the vicinity of the model. In addition, the tapered piles are installed in-flight by driving and pushed-in mode to evaluate their bearing capacity. Some studies on interface friction are also planned within this project (Foray et al., 1998; Bałachowski, 2006). This paper focuses on the installation of tapered walls with stress evolution in the soil mass and on the model surface.

Tapered piles are characterized by a gradually decreasing cross section with depth. Timber piles are traditional examples of such structures (Christin et al., 2013). Nowadays, concrete precast or cast-in place piles (Khan et al., 2008; Lee et al., 2009), steel or composite tapered piles are also applied (Sakr et al., 2004). They can be also used for densification of sandy subsoil (Zil'berberg & Sherstnev, 1990; Stuedlein et al., 2016).

2 PHYSICAL MODEL SETUP

In the range of Geolab (2021) European project, a series of centrifuge tests was performed at Gustave Eiffel University (Nantes, France) in the GERS-CG lab (Gers-CG, 2023). This geo-centrifuge (Thorel, 2022) has a radius of 5.5m and a total mass of 2tons can be embarked in the swinging basket.

2.1 Soil mass preparation and instrumentation

Prior to each test, the homogeneous soil mass was prepared using sand raining technique to achieve designed relative density 0.68 and the dry bulk density of 1620 kg/m^3 measured with boxes disposed at the bottom of the container. Uniform Fontainebleau quartz sand (NE34) with d_{50}=0.206 mm was used with parameters described in (Andria-Ntoanina et al., 2010; Beroya-Eitner et al., 2022). The container with a transparent glass (Figure 1) and inside dimensions of 800×450 mm enables visual observation of soil behaviour during wall installation.

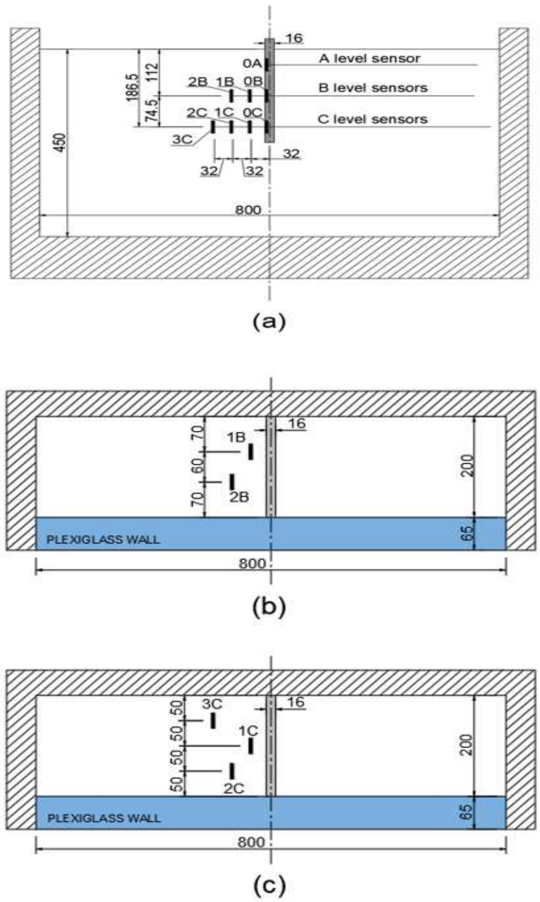

Figure 1. Centrifuge model setup and soil instrumentation: (a) vertical cross-section, (b) B level horizontal cross-section, (c) C level horizontal cross-section. (All dimensions in [mm]).

Kyowa small-sized soil pressure transducers having an outer diameter of 30 mm and a pressure-sensing surface diameter of 23 mm were used. Five sensors where placed in the soil mass at two levels (Figure 1b, 1c). Additional three sensors were fixed on the model surface (Figure 2). All transducers were calibrated in centrifuge under loading-unloading cycles induced by the increased gravity.

2.2 Model walls

Three model walls were used: straight wall (denoted as ‘S’) with 0° taper angle, tapered wall with 0.75° taper angle (denoted as ‘T1’) and wall with 1.5° taper angle (denoted as ‘T2’), see Figure 2a-c. Each model was equipped with three normal stress sensors fixed on its surface (Figure 2d). The model wall was fitted to the container width of 20 cm to reduce any gap in the contact wall-glass. At final embedment only a few sand grains were trapped between the model and transparent wall.

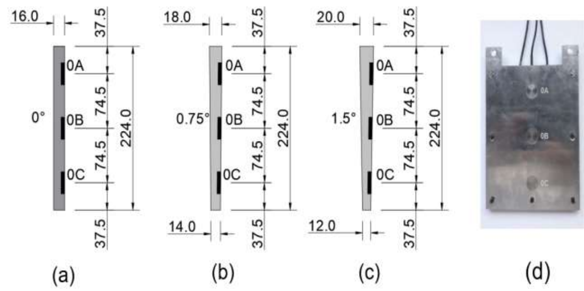

Figure 2. Instrumented models with a taper angle of: (a) 0° (standard S wall), (b) 0.75° (T1), (c) 1.5° (T2) and (d) model wall – front view.

2.3 Test execution

Three monotonic pushed-in tests with tapered walls were completed on single series. The centrifuge operated at an acceleration level of 25g. In each test, the wall was pushed into the subsoil with 0.1 mm/s rate to the depth of 224 mm, which gives the wall slenderness 14.

3 RESULTS

3.1 Total force mobilization

The mobilization of axial force during wall installation is given (Figure 3) for each wall type. It can be noticed that the total force required for monotonic installation of the wall was slightly lower for the models with higher taper angles compared to the straight profile. At final embedment the penetration force for T2 (respectively T1) constitutes only about 0.75 (resp. 0.9) of corresponding axial force for straight wall.

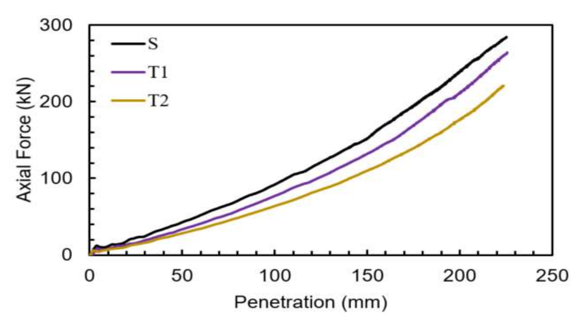

Figure 3. Axial force mobilized during wall installation (model scale).

3.2 Horizontal stress in the soil mass

The horizontal stress development (at fixed altitude) in the soil mass during installation of the wall is shown in Figure 4. A distinct peak in horizontal stress was observed in the soil mass just before the wall base has passed the level of the stress cell. This tendency can be noticed for the sensors in upper (B) and lower (C) levels. Once the wall base has moved below the position of the stress cells, a continuous decrease in normal stress was observed for the straight wall model. In contrast for tapered models the stress cells at the upper level exhibit further slight re-mobilization of horizontal stress, especially for the wall with higher taper angle. The maximum value of horizontal stress gradually decreases with distance from the wall. For the stress sensors placed at a given distance to the wall the highest maximum horizontal stress is noticed for the straight wall.

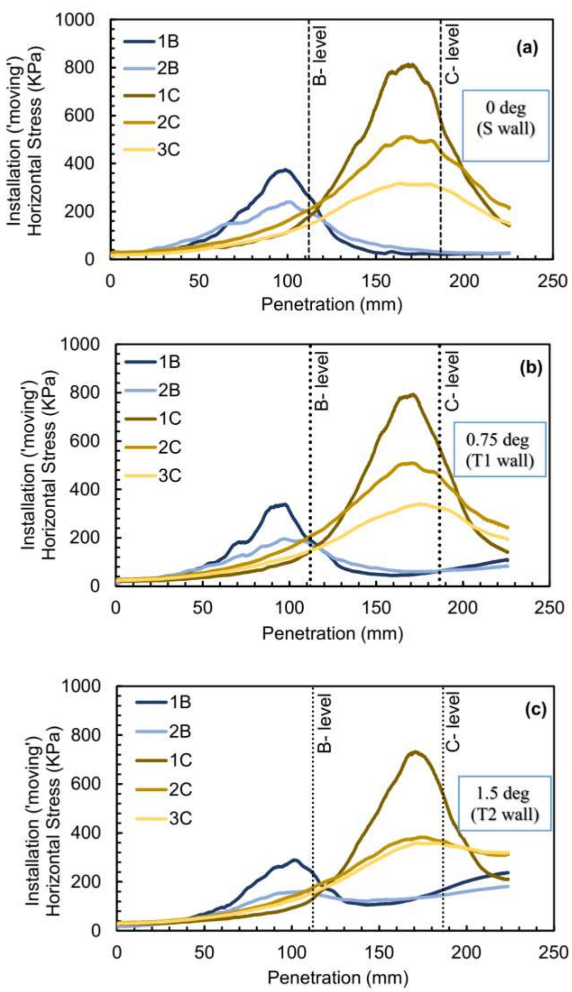

Figure 4. Stress distribution in the soil mass during wall installation (a) standard (S), (b) tapered (T1), and (c) tapered (T2).

3.3 Normal stress at the wall interface

The mobilization of normal stress at three positions (moving downwards) during tapered wall pushed-in is given in Figure 5. The observed maximum normal stress on the wall increases with the taper angle. At final stage of penetration, a sharp increase of normal stress is observed near the base due to mobilization of base resistance. One should also notice that the normal stress sensors on the tapered wall capture not only horizontal stress component but the vertical one as well. The latter can considerably influence the recorded values especially in case of the stress cell located in the vicinity of the base.

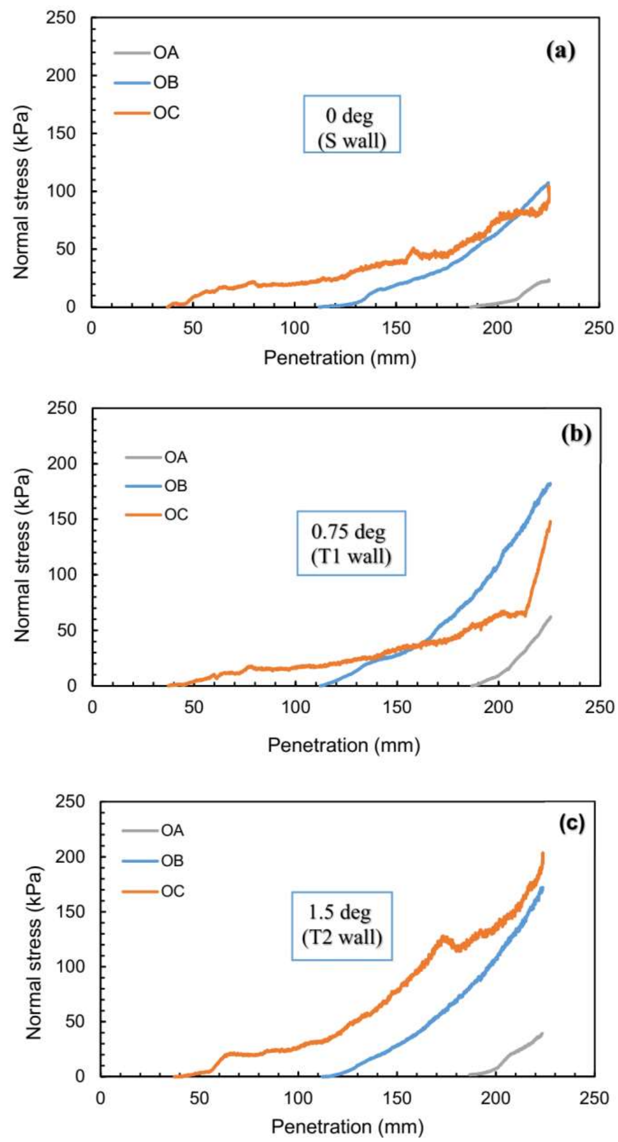

Figure 5. Normal stress mobilization on the wall during installation (a) standard (S), (b) tapered (T1), and (c) tapered (T2).

4 CONCLUSIONS

The installation of the continuous wall induces modifications in horizontal stress in the soil mass, normal stress at the model interface, and reduced axial force necessary for the penetration of tapered walls. The lateral stress modification in the vicinity of models is a function of taper angle. While the highest level of horizontal stress in the soil mass is observed for the straight wall, the normal stress on the wall surface is the largest for the model with the highest taper angle. The maximum horizontal stress in the soil mass for T1 and T2 wall is about 0.95 and 0.8 of the corresponding stress for the straight wall. However, at the end of installation both horizontal and normal stresses are significantly higher for tapered walls than for the standard one. The resulting installation effort is the lowest for T2 wall as higher shaft friction of tapered walls does not compensate the lower contribution of the wall base. The test results on walls can be qualitatively applied to describe the behaviour of tapered pile models.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 101006512.

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