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Square shallow foundation on four rigid inclusions subjected to uncentered vertical load: Centrifuge modelling

Semelle carrée sur quatre Inclusions Rigides sous chargement vertical excentré: Modèle réduit centrifugé

L. Thorel*, M. Blanc, A. Neel, A. Jagu, Ph. Audrain, P. Gaudicheau, S. Lerat
University Gustave Eiffel, GERS-CG Lab., Nantes, France
**luc.thorel@univ-eiffel.fr*

ABSTRACT: The load eccentricity effect of a square foundation resting on 4 Rigid Inclusions is investigated with small scale centrifuged models. 3 tests have been performed on instrumented models with the robot of Uni Eiffel Centrifuge laboratory. The kinematics of the foundation and the load transfer towards the Rigid Inclusions are presented.

RÉSUMÉ: L'effet d'un chargement excentré sur une fondation carrée reposant sur 4 Inclusions Rigides est étudié sur des modèles réduits centrifugés. 3 essais ont été réalisés sur des modèles instrumentés en utilisant le robot téléopérateur du laboratoire Centrifugeuses Géotechniques de l'Uni Eiffel. La cinématique de la fondation et le transfert des charges vers les Inclusions Rigides sont présentés.

Keywords: Rigid inclusions; centrifuge; kinematics; load transfer; eccentricity.

1 INTRODUCTION

In the framework of the French National Project ASIRI+ devoted to the reinforcement of soft soils by rigid inclusions (https://asiriplus.fr), the behaviour of a square foundation on 4 Rigid Inclusions (RI) is studied with centrifuged models. This "composite foundation" includes, from top to bottom in Figure 1: 1) a shallow foundation; 2) a granular Load Transfer Platform (LTP); 3) deep foundations (RIs) installed in a soft clay; 4) a sand layer where the RI tips penetrate. The forces transmitted to the RIs as well as the kinematics of the shallow foundation are presented, for three different eccentricities.

2 EXPERIMENTAL SETUP

The set of experiments is inspired from in field tests' geometry (Briançon *et al.*, 2000). The scaling laws (*e.g.* Garnier *et al.*, 2007) applied for designing the centrifuge tests leaded to a reduced scale of 1/16.9, corresponding to a g-level of N=16.9. The results are presented at model scale.

The reconstituted soil mass includes, from the bottom to the top: 1) a filtration geotextile to avoid sandy particles to move towards the drainage circuit; 2) a dense saturated Hostun HN31 sand; 3) the soft soil, prepared in 3 layers with a loading programme adapted to a slightly over consolidated clay, is made of a mixture of kaolin clay and Fontainebleau sand NE34 (Baudouin, 2010); 4) the LTP, made of dense well-graded Hostun sand (Baudouin *et al.*, 2008). The rigid inclusions are jacked at 1mm/min, in the lab (under earth gravity), guided accurately together 4 by 4.

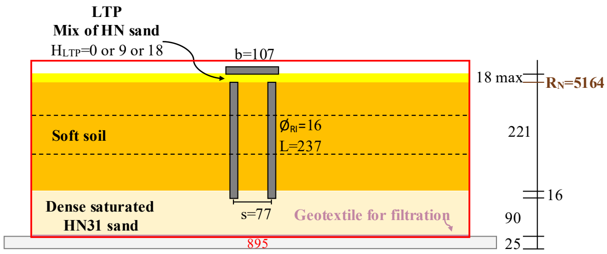

Figure 1. Scheme in elevation of the composite foundation in the circular container tested in the centrifuge (in mm).

The model foundation is made of aluminium (Figure 2), as well as the instrumented RIs (Figure 3). The foundation includes an upper part, with a T-shape, used to be hanged and downward loaded, inducing only a main rotation around the x-axis.

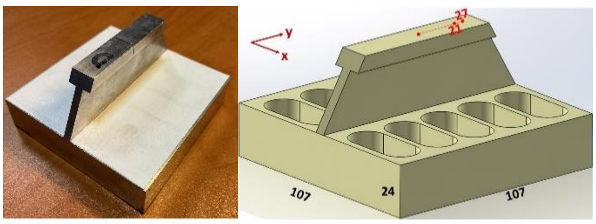

Figure 2. Square foundation small scale model.

A (white) scotch tape is stuck on the top surface.

The RIs are instrumented with a force sensor intimately linked to the top surface cap (Figure 3).

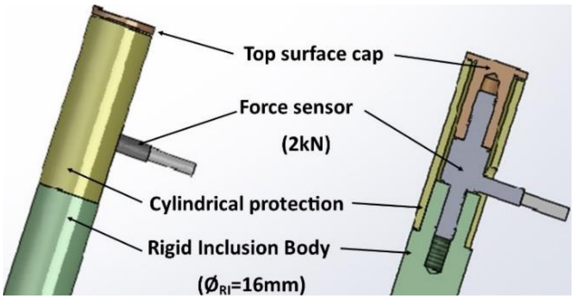

Figure 3. Drawings of Instrumented Rigid Inclusion.

To optimise the clay consolidation time in centrifuge, 4 tests are performed during the same centrifuge flight, thanks to the Uni Eiffel Robot (Gaudicheau *et al.*, 2014). A special tool has been developed for the foundation carriage and loading (Figure 4). The 4 foundations are stored on a board fixed on the container, and are installed on the expected location (where the RIs have been pre-installed) before being loaded (Figure 5).

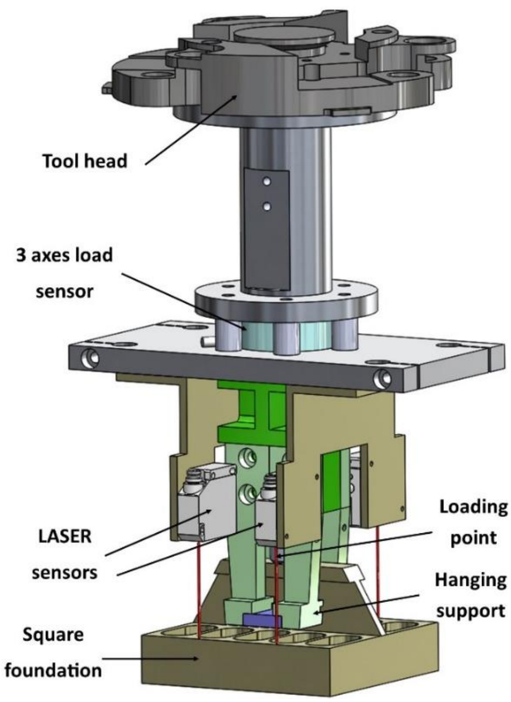

Figure 4. Multi-use tool for the centrifuge robot.

3 EXPERIMENTAL PROGRAMME

The centrifuge tests are performed in the same circular container, with an LTP height of 18mm (0.3m in prototype scale), and with 3 eccentricities e reported to the spacing s: e/s = 0, 0.27 & 0.35 (or to the foundation width b: e/b = 0, 0.19 & 0.25).

After a consolidation phase during about 2 hours in flight, the series of foundation loading start. The vertical loading of the foundations is performed in displacement control conditions at a velocity of 1mm/min. If the eccentricity is positive, the vertical loading generates a negative rotation around the x-axis (θ_x). The data acquisition is performed at a frequency of 10Hz, thanks to HBK Quantum DAS.

The laser sensors installed on the multi-use tool are pointed towards the foundation to access to its solid rotation. The distance between the laser rays is 100mm in the x direction and 40mm in the y direction. This induces a better accuracy of the rotation around y-axis (θ_y) than x-axis (θ_x).

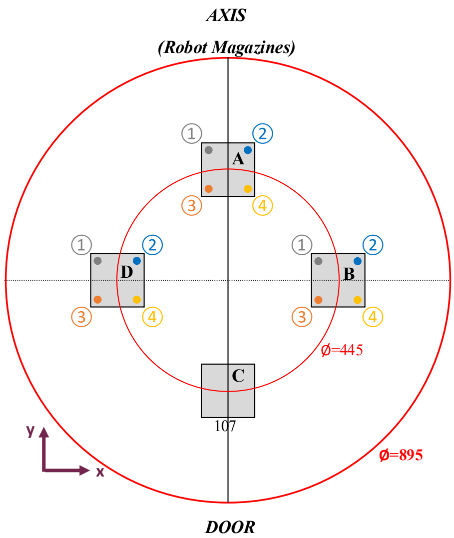

Figure 5. Top view implementation in the container (mm).

The load tests (Table 1) are devoted to eccentric loading, for investigation the load repartition and the kinematics of the square foundation.

Table 1. Load test configuration.

Test	e/s	Comment
A	0.35	
B	0.27	
C	NA	H loading, not included
D	0	

4 DISCUSSION

The results of loading (Figure 6) show the behaviour up to a settlement of 1/10th of the foundation width (107mm), at model scale. The settlement is calculated at the centre of the foundation.

For the vertical centred load, it can be seen that the loads are almost the same on the RIs until the symmetry is lost, generating a slight rotation towards RI 2 and 4.

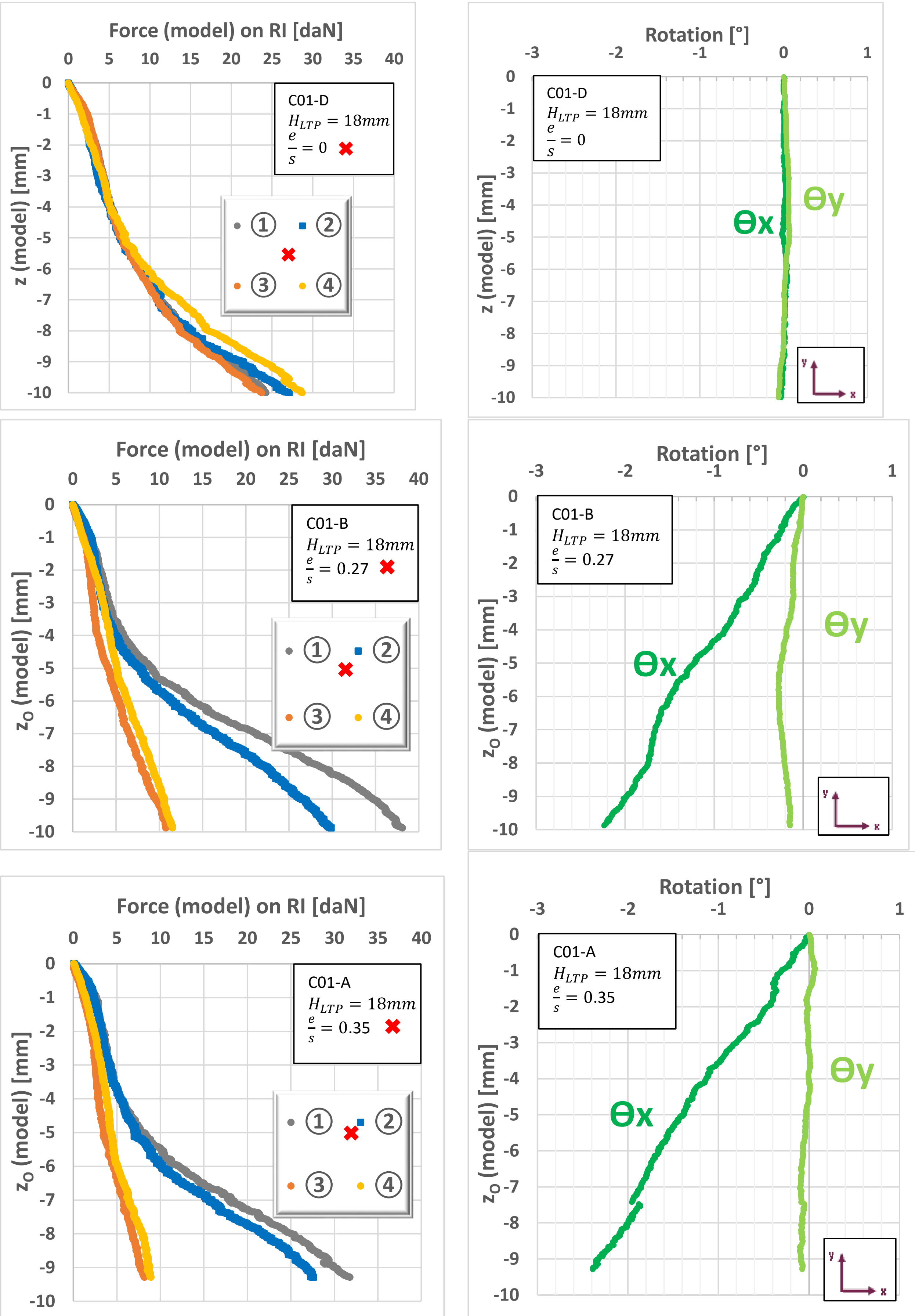

Figure 6. Forces transmitted to the Rigid inclusions(left) and rotations (right) versus settlement for 3 eccentricities: 0 (top), 0.27 (middle), 0.35 (bottom).

When an eccentric load is applied, the rotation of the foundation is immediately visible. The load transfer towards RIs 1 and 2 is emphasised after a settlement of few millimeters, showing a complex behaviour that includes first a mechanism inside the LTP and then the mobilisation of the RIs in an asymetrical way.

It can be observed that, even if a careful process has been followed in the preparation of the soil model, the RIs installation and the location of the loading points, very small rotations are observed on the *y* axis. This shows that there is small uncertainties relative to the loss of symetry.

The total load variation applied on the foundation is in the same proportion than to the sum of the load variation on RIs (Figure 7), whatever the eccentricity is. Two distinct mechanisms of load transfer may be identified. The initial slope for small settlements (and loadings) is about 0.38, when the final slope is close to 0.74, showing a progressive mobilisation of the RIs. For a similar settlement of the foundation center (*e.g.* the end of the curves correspond to the Service Limit State, 10% of the foundation width), loads decrease with the increase of the eccentricity, both for the total load and the transfered loads to the RI.

It could be said that to reach the same settlement at the centre of the foundation: 1) stronger force is required for centred load than for eccentred; 2) similar load proportion is transfered to the soft soil. In any case, the load transmitted to the RIs is smaller than the load applied to the foundation, but the ratio does not seem to be affected by the eccentricity.

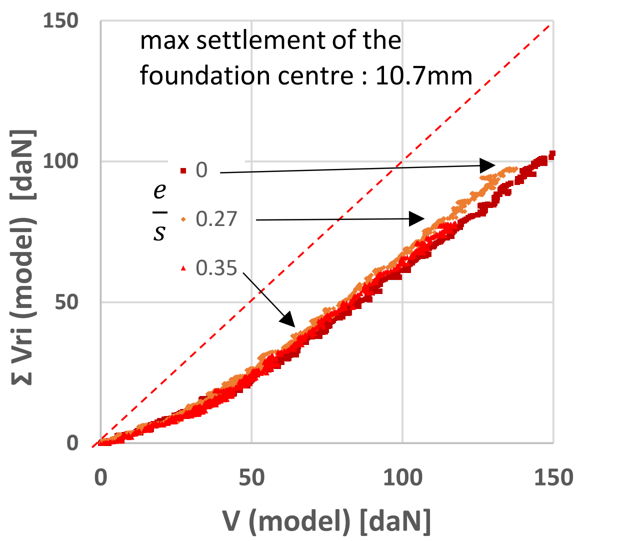

Figure 7. Total force variation applied on the RIs vs the total force variation applied on the foundation.

5 CONCLUSIONS

A series of centrifuge tests has been developed to investigate the eccentricity effect on complex foundation system made of a shallow square foundation resting on four rigid inclusions.

The first results show that for a settlement of 10% of the width of the foundation, the rotation reach a value of about 2 degrees, and that the rear RIs are overloaded up to 3 times the front RIs.

During the loading of each foundation, two mechanisms seem to appear: 1) load transfer mainly in the LTP; 2) a load transfer more active towards the RIs.

Additional investigation is under process for other test configuration such as the LTP height.

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