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Centrifuge investigation of load transfer mechanisms in a granular mattress above a rigid inclusions network

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A B S T R A C T

Reinforcing compressible soils by rigid inclusions is a method to reduce and homogenize settlements under many types of structures. A granular mattress, set between the structure and the group of inclusions, transfers by arching effects a part of loadings to the piles embedded in rigid substrate. A geosynthetic can be added between the heads of the rigid inclusions and the granular mattress. In addition to the arching effect, a membrane effect happens caused by the stretching of the geosynthetic sheet. An experimental mobile tray device, especially designed to test this reinforcement technique in centrifuge at 20*g*, consists in simulating the settlement of the soft soil located between the inclusions. An initial pretension can be applied to the geosynthetic. A parametric study of the load transfer mechanisms in the mattress is conducted with three different thicknesses of granular mattress, two different rigid inclusions networks and different initial pretensions in the geosynthetic.

The efficacy of the load transfer and the settlements at the surface of the granular mattress are studied and discussed. With and without geosynthetic reinforcement, load transfer mechanisms are better for thicker load transfer mattresses and for higher mesh densities. The improvement made by a geosynthetic reinforcement is clearly shown trough both load transfer and differential settlement reduction.

1. Introduction

Reinforcement of soft soil with vertical rigid piles is now a widespread technique for both embankments and floor slabs (Simon and Schlosser, 2006) (Fig. 1). A famous example is the Rion–Antirion bridge in Greece, with its piers put on a granular platform, installed on a network of vertical steel piles that reinforces the soft soil on the sea bed (Garnier and Pecker, 1999; Rault et al., 2006). In the granular mattress, installed above the reinforced soil, “arches” develop and transfer the load through the piles (Fig. 2(a)). However, the understanding of the *arching effect* (Terzaghi, 1943) is not complete, as many parameters play a role, such as the height of the mattress *H*, the pile spacing *s* or the area ratio α which is the proportion of pile area in an unit cell: $\alpha = (\pi.a^2/4)/s^2$ with *a* the pile diameter (or the cap diameter if there is one). The improvement due to the presence of a geosynthetic reinforcement between the piles and the granular mattress needs to be clarified. The geosynthetic transfers, directly to the piles, a part of the weight of the embankment which is not already transferred by arching. This mechanism, called *membrane effect* (Le Hello and Villard, 2009), translates the ability of a geosynthetic to adapt itself to support by tension the force acting initially perpendicularly to its plane (Fig. 2(b)). More the subsoil settles under the geosynthetic, more the membrane effect will be efficient (because of the large deformation inside the geosynthetic sheet).

The physical modelling approach has been used in the past for piled embankments using 1g models in axisymmetrical tests (Dinh, 2009; Thorel et al., 2010), a 2D geometry (Hewlett and Randolph, 1988; Low et al., 1994; Horgan and Sarsby, 2002; Jenck, 2005; Jenck et al., 2005, 2007; Chen et al., 2008) or a 3D configuration (Bergdahl et al., 1979; Demerdash, 1996; Kempfert et al., 1999). Rigid inclusions reinforced with geosynthetic have also been studied with 2D (Eskişar et al., 2012) and 3D (van Eekelen et al., 2012a, 2012b) models.

In centrifuge, some studies about piled embankments without geosynthetic reinforcement have been conducted: with 2D models (Barchard, 2002) and more recently with 3D models (Ellis and Aslam, 2009a, 2009b; Baudouin, 2010; Baudouin et al., 2010; Okyay, 2010). And, on the other hand, numerous of centrifuge tests have studied the improvement due to geosynthetic most of the

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Notations

α	(%) area ratio
a	(mm) pile diameter
d_{max}	(mm) maximum grain size
E	(%) efficacy of the load transfer mechanism
ε	(%) deformation of the geosynthetic
F	(N) vertical pile load
ϕ	(°) friction angle of the load transfer platform
g	(m/s^2) earth gravity
H	(mm) thickness of the load transfer platform (granular mattress)
J	(kN/m) secant stiffness of the geosynthetic
N	(–) g-level
q_0	(kPa) stress applied by the water tank on the load transfer platform
Q	(N) load applied by the water tank on an unit cell
ρ	(g/cm^3) mean density of the load transfer platform
s	(mm) pile spacing
σ_{ss}	(kPa) vertical stress on the soft soil (the mobile tray)
σ_{tot}	(kPa) total vertical stress (mobile tray and piles)
T	(kN/m) tensile strength of the geosynthetic
W	(N) weight of the load transfer platform on a unit cell
ψ	(°) dilatancy angle of the load transfer platform
$\Delta\omega$	(mm) simulated settlement of the subsoil by the mobile tray
$\Delta\omega_C$	(mm) settlement on the load transfer platform above the centre of a unit cell
$\Delta\omega_P$	(mm) settlement on the load transfer platform above a pile

time in slope stability problems (Porbaha and Goodings, 1996; Sharma and Bolton, 1996, 2001; Viswanadham and König, 2004, 2009; Raisinghani and Viswanadham, 2011; Rajabian et al., 2012). However the use of a geosynthetic layer in the granular mattress above a rigid inclusions has never been studied in centrifuge.

In the framework of the French national project ASIRi ("Amélioration des Sols par Inclusions Rigides" in French) (IREX, 2012), several experimental approaches have been investigated including geosynthetics: full-scale tests with the CNAM ("Conservatoire National des Arts et Métiers") (Briançon et al., 2009), 2D Schneebeli models at INSA Lyon (Jenck, 2005; Jenck et al., 2005, 2007), and recently centrifuge tests at IFSTTAR (detailed in this paper). Analytical methods and numerical simulations of rigid inclusions reinforced by geosynthetic have also been conducted in the scope of this project (Briançon and Villard, 2008; Jenck et al., 2009; Le Hello and Villard, 2009; Chevalier et al., 2011) and also by other authors (van Eekelen et al., 2003, 2011; Kempfert et al., 2004).

This paper is focused on the role played by a geosynthetic layer installed within the load transfer platform, in terms of both efficacy of the load transfer and reduction of settlements. First is presented the centrifuge model, based on the mobile tray device (Rault et al., 2010), then the experimental parametric campaign, that includes both tests with and without geosynthetic layer, is detailed. Finally, an analysis of the results is presented, showing the influence of: i) the geosynthetic, ii) the height of the mattress, iii) the area ratio and iv) the pretension of the geosynthetic layer.

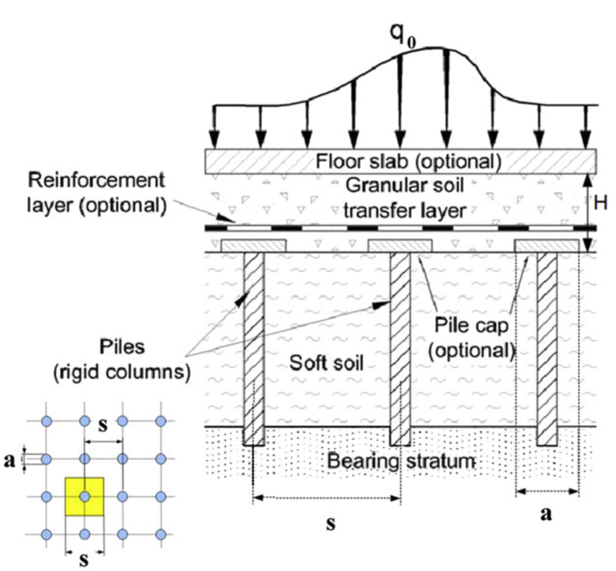

Fig. 1. Constituents of the pile supported earth platform system (Simon and Schlosser, 2006) and definition of a unit cell in a network of piles.

2. Centrifuge modelling

2.1. Physical modelling

Centrifuge modelling is a powerful tool for the study of geotechnical structures using reduced scale physical models. It is particularly relevant when stress gradient or free surface is important, like in arching phenomenon. In centrifuge modeling, the similarity of the conditions between the model (reduced scale) and the prototype (full scale) is guaranteed by the scaling factors. These scaling laws are presented in Table 1 (Phillips, 1869; Corté, 1989; Garnier et al., 2007). In the IFSTTAR centrifuge, the model size that may be installed in the swinging basket is 1.40 m in length × 1.15 m in width × 1.50 m in height. The maximum weight is 2000 kg for experiments performed at 100 g. The g level N of the test series is 20 corresponding to a reduce scale of 1/20; this choice is issued from an optimisation between the instrumented pile diameter a, the granular mattress thickness H, The maximum grain size d_{max}, the geotextile performance and its recommended scaling law (Viswanadham and König, 2004; Garnier et al., 2007).

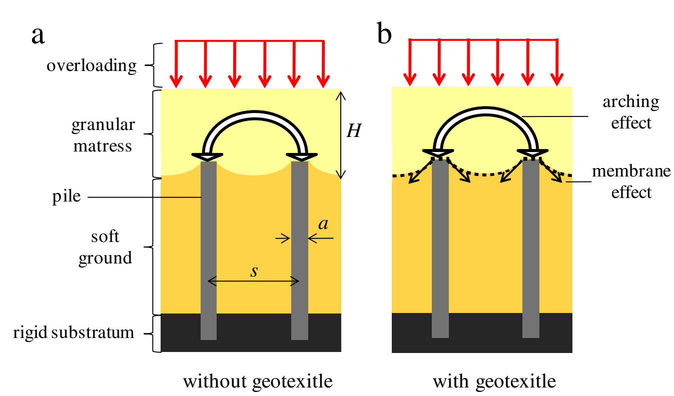

Fig. 2. Schematic representations of the load transfer mechanisms in a granular mattress - (a) without geotextile - (b) with a geotextile layer.