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Numerical analysis of a geosynthetic-reinforced piled load transfer platform – Validation on centrifuge test

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ABSTRACT

Soft soil improvement techniques using a network of rigid inclusions and geosynthetic reinforcement are investigated to improve our understanding of load transfer mechanisms towards piles. The physical modelling of the system consists in simulating fictional soft soil settlement through downward displacement of a perforated tray above a network of rigid piles placed in the centrifuge swinging basket. Tests are used to validate the results of the numerical study.

Elasto-plastic and hypoplastic constitutive models have been used to predict the behaviour of the granular mattress, which simulates a Load Platform Transfer (LPT). A two-dimensional, axisymmetrical model has been adopted, which fulfils the validation on the experimental test and the time needed for calculation.

The results of the parametric studies show that load transfer increases with mattress thickness and closer pile spacing. Geosynthetic deflection is reduced when load transfer is high.

1. Introduction

A technical solution to reinforce soft soil consists in using a network of rigid inclusions (Fig. 1). The square mesh of the inclusions is characterized by s, the center-to-center pile spacing. These inclusions possibly reach a rigid substratum. A granular mattress, with a thickness, H, and a density, ρ_d, is laid on the reinforced soft soil. Inside the mattress, the shearing mechanisms between the grains and the arching effects between the piles can transfer part of the load (term A) directly towards the inclusions. The mattress behaves like a Load Platform Transfer (LPT). To enhance horizontal reinforcement further, a geosynthetic fabric is inserted at the base of the granular mattress. When stretching, the geosynthetic transmits an additional load towards the pile (term B). This load transfer is called the membrane effect (Le Hello and Villard, 2009) The remaining load, only, then, applies on the soft soil (term C). The proportion of terms A, B and C depend on mattress thickness, pile spacing, surcharge, compressibility of the soft soil and secant stiffness of the geosynthetic J_a.

Due to such complexity, numerical modelling has been performed to obtain more information on the load distribution within the mattress and carry out parametric studies (Le Hello and Villard, 2009; Borges and Marques, 2011; Han et al., 2012; Jennings and Naughton, 2012; Nunez et al., 2013). Although numerical models tend to underestimate strain within geosynthetic fabrics, the use of numerical tools is very useful. Besides the contribution they bring to the analytical models used for designing reinforcement of piled embankments (i.e., British Standard BS 8006 (1995) and EBGEO (2011) for instance), they can be used to analyse additional features like, for example, the influence of non-uniform loading or deformation and pile moments. The plane strain configuration and, more recently, the 3D calculation are generally used for computing. The present research is based on the assumption that the embankment height above the mattress is constant, i.e., located far from the slope. Jenck et al. (2009a) have shown that, for an inclusion placed far away from the slopes of the embankment, 2D-axisymetric modelling satisfactorily agrees with the 3D case. The purpose of this paper is to validate a numerical model based on the results obtained using centrifuge testing on prototype scale.

Depending on the studies, different constitutive models of the granular LPT have been used. For example, granular LPT behaviour has been modelled using an elastic-perfectly plastic model with a

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Notation

A	Load directly transferred to the inclusions (kN)
B	Load transfer due to the vertical component of the tension force above the pile (kN)
C	Load applied on soft soil (kN)
c	Cohesion of the LPT material (kPa)
d	Pile diameter (m)
E	Stiffness (Mohr Coulomb model) (MPa)
E_F	Load transfer efficacy(%)
E_{50}	HS Parameter: secant stiffness in standard drained triaxial test (MPa)
E_{oedo}	HS Parameter: tangent stiffness for primary oedometer loading (MPa)
E_{ur}	HS Parameter: unloading/reloading stiffness (Pa)
e	Void ratio of the LPT for $\Delta\omega \neq 0$ m (−)
e_0	Initial void ratio of the LPT (−)
e_{d0}	Minimal void ratio of the LPT material (−)
e_{c0}	Void ratio at the critical state of the LPT material (−)
e_{i0}	Maximal void ratio of the LPT material (−)
F_m	Average load transferred to the inclusions (kN)
g	Earth gravity (m s^{-2})
H	Thickness of the granular mattress above reinforced soft soil (m)
$H_{\mathrm{arch.}}$	Radius of the arching arch (m)
HS	Hardening Soil (−)
HYP	HYPoplastic (−)
h_s	HYP parameter: controls the overall slope of the compression curve (normal compression line and critical state line) (MPa)
J_a	Average short term secant stiffness of the geosynthetic reinforcement (kN/m)
J_{cross}	Short term secant stiffness of the geosynthetic reinforcement in the cross direction (kN/m)
J_{mach}	Short term secant stiffness of the geosynthetic reinforcement in the machine direction (kN/m)
K_0	Coefficient of lateral earth pressure (−)
LPT	Load Platform Transfer (−)
l_0	Initial length of a geosynthetic (m)
MT	Mobile Tray (centrifuged device) (−)
m	HS parameter: power for stress-level dependency of stiffness (−)
n	HYP parameter: controls the curvature of the compression curve (normal compression line and critical state line) (−)
N	Scale factor (−)
PP	PolyPropylene (geosynthetic reinforcement) (−)
p_c	Confining pressure for the triaxial test on the LPT material (kPa)
p_m	Mean pressure in the LPT (kPa)
q_0	Surcharge applied at the LPT surface (kPa)
q	Deviator stress (kPa)
R_{eq}	Numerical model equivalent radius (m)
r	Distance to the pile axis (m)
s	Center-to-center pile spacing (m)
U_{rr}	Horizontal displacement of the node of the numerical model (m)
U_{zz}	Vertical displacement of the node of the numerical model (m)
U^{g}_{zz}	Vertical displacement of the geosynthetic node (m)
U^{g}_{rr}	Horizontal displacement of the geosynthetic node (m)
T	Tensile force in the geosynthetic (kN/m)
$T_{\max}$	Maximum tensile force in the geosynthetic (kN/m)
T_{rr}	Radial component of the tensile force in the geosynthetic (kN/m)
z	Vertical distance to the pile head (m)
α	Coverage area ratio of the rigid pile to a square soft soil mesh (%)
$\underline{\alpha}$	HYP parameter: controls the dependency of peak friction angle on relative void ratio of the LPT (−)
β	HYP parameter: affects the size of the response envelope (bulk and shear stiffness) (−)
Δe	Relative value for e (−)
$\Delta\omega$	Displacement of the tray (m)
$\Delta\omega_C$	Vertical displacement of the mattress top at the model centre (m)
$\Delta\omega_{C'}$	Vertical displacement of the mattress top at the model centre for the 3D model (m)
$\Delta\omega_P$	Vertical displacement of the mattress top above the inclusion (m)
$\Delta\omega_{C-P}$	Differential settlement at the centre of the model (m)
ΔU^{g}_{zz}	Incremental vertical displacement of the geosynthetic (m)
ΔU^{g}_{rr}	Incremental horizontal displacement of the geosynthetic (m)
δ^{g}	Deflection of the geosynthetic (m)
$\delta^{F}_{\mathrm{exp}}$	Deflection supplied by load efficacy for experiment (m)
δ^{F}_{HS}	Deflection supplied by load efficacy (HS model) (m)
$\delta^{F}_{\mathrm{HYP}}$	Deflection supplied by load efficacy (HYP model) (m)
$\delta^{g}_{\mathrm{num}}$	Deflection supplied directly by the FE code (m)
$\delta^{\Delta\omega}_{\mathrm{exp}}$	Deflection supplied by displacement for experiment (m)
$\delta^{\Delta\omega}_{\mathrm{HS}}$	Deflection supplied by displacement (HS model) (m)
$\delta^{\Delta\omega}_{\mathrm{HYP}}$	Deflection supplied by displacement (HYP model) (m)
ε_1	Vertical strain (%)
ε_a	Axial strain in the triaxial tests with the LPT material (%)
ε_g	Deformation of the geosynthetic (%)
$\varepsilon_{\max}$	Deformation of the geosynthetic for $T = T_{\max}$ (%)
ε_v	Volumic strain in the triaxial tests with the LPT material (%)
ϕ_m	Mobilized internal friction angle of the LPT material (°)
ϕ_c	Internal friction at the critical state of the LPT material (°)
ϕ_p	Internal friction at the peak state of the LPT material (°)
$\phi_{g/s}$	Internal friction angle between the geosynthetic and the LPT material (°)
ψ	dilatancy angle of the LPT material (°)
ν	Poisson's ratio of the LPT material (−)
ρ_s	Volumic mass of the granular skeleton (kg m^{-3})
ρ_d	Volumic mass of the LPT material (kg m^{-3})
σ_{zz}	Vertical stress (kPa)
σ_{zz0}	Vertical stress under the mattress for $\Delta\omega = 0.00$ m (kPa)
σ_{rz}	Shear stress in the LPT (kPa)