Geotextiles and Geomembranes 45 (2017) 1–10

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Load transfer mechanism and deformation of reinforced piled embankments

Diego F. Fagundes [a, *], Márcio S.S. Almeida [b], Luc Thorel [c], Matthieu Blanc [c]

[a] Federal University of Rio Grande - FURG, Rio Grande - RS, School of Engineering, Brazil
[b] Federal University of Rio de Janeiro, COPPE, Rio de Janeiro, RJ, 21945-970, Brazil
[c] LUNAM Univ., IFSTTAR, Department GERS, Laboratory Geomaterials and Models in Geotechnics, Route de Bouaye, CS4, 44344, Bouguenais Cedex, France

ARTICLE INFO

Article history:
Received 3 May 2016
Received in revised form
3 September 2016
Accepted 5 November 2016

Keywords:
Geosynthetic
Piled embankment
Centrifuge modelling

ABSTRACT

A series of twenty-eight centrifuge tests was performed on piled embankments with basal geosynthetic reinforcement to assess the influence of pile spacing, embankment height, pile cap size and geosynthetic stiffness on the load transfer mechanism and surface settlements. The measurements of the forces on the piles made it possible to assess the load transfer mechanisms, and 100% efficiency was achieved for all tests performed. The results showed that for the thicker mattress and/or closer piles, the surface settlements were smaller or negligible. Geosynthetic maximum deflections were also examined experimentally and analytically, the latter based on BS8006 (2010) and its further corrigendum in 2012. Close agreement in the predictions of the maximum reinforcement deflection was reached with BS8006 (2012) by adopting a slight modification in the ratio of diagonal and orthogonal maximum deflection ($y_d/y = \sqrt{2}$).

1. Introduction

The piled embankment technique with basal reinforcement geosynthetic is a commonly used method to design structures on soft soils as the embankment construction is faster without the wait for the compressible layer consolidation. Also, the volume reduction of material used (compared to other solutions) results in a smaller environmental impact and the maintenance of the construction is very limited (Filz et al., 2012).

The load transfer mechanisms of piled embankment reinforced with a basal geosynthetic platform are shown in Fig. 1(a). The arching effect is defined as the part of the embankment load directly transferred to the piles, and the remaining total load not transferred by arching effect is the vertical stress applied on the subsoil and the basal Geosynthetic Reinforcement (GR). The GR in tension allows the transference of this remainder of the load back to the piles. This mechanism is called the membrane effect and its magnitude depends on the support provided by the soil beneath the geosynthetic layer and the GR stiffness (Van Eekelen et al., 2013). All these mechanisms are strictly dependent on the area ratio values $\alpha = \pi.d^2/4s^2$, where d is the pile diameter, or the cap diameter if there is one, and s is the pile spacing (Fig. 1(b)). In the present paper, the load transfer efficiency E is the result of the arching and the membrane effect combined. The efficiency E is the expression of the embankment's ability to transfer the load F to the piles, as defined by:

$$E = \frac{F}{(\gamma H + w_s)s^2} \quad (1)$$

A minimum embankment height needs to be employed in order to improve the load transfer mechanism. In this way, the load on the GR and the subsoil decreases, resulting in less settlement at the embankment surface. In the present paper, the term 'critical height', H_c (Fig. 1), is defined as the embankment height above which differential settlements at the base of the embankment do not produce significant differential settlement on the embankment surface.

In the case of very soft soils the presence of a working platform underneath the geosynthetic is mandatory (Almeida and Marques, 2013) in order to support the pile-driving equipment. Also, the component of soil reaction, in some cases, is negligible as the settlement of the working platform creates a space between the embankment and the soil underneath (Van Eekelen et al., 2015). A

* Corresponding author.
E-mail addresses: dffagundes@furg.br (D.F. Fagundes), almeida@coc.ufrj.br (M.S.S. Almeida), luc.thorel@ifsttar.fr (L. Thorel), matthieu.blanc@ifsttar.fr (M. Blanc).

http://dx.doi.org/10.1016/j.geotexmem.2016.11.002
0266-1144/

List of notations

a	pile square size (mm)
A	parameter of the Hewlett and Randolph (1988) method (−)
B	parameter of the Hewlett and Randolph (1988) method (−)
C	parameter of the Hewlett and Randolph (1988) method (−)
C_C	coefficient of curvature (−)
C_U	coefficient of uniformity (−)
d	pile diameter, pile size or pile cap size (mm)
$D_{g,10}$	diameter at 10% passing (mm)
$D_{g,50}$	diameter at 50% passing (mm)
$D_{g,90}$	diameter at 90% passing (mm)
E	efficiency of the load transfer mechanism (%)
E_{cap}	efficiency based in the failure at the pile cap in the Hewlett and Randolph (1988) method (%)
E_{crow}	efficiency based in the failure at the "crown" in the Hewlett and Randolph (1988) method (%)
E_{impr}	difference between the load efficiency for tests with and without geosynthetic (%)
E_{min}	minimum value between E_{crown} and E_{cap} in the Hewlett and Randolph (1988) method (%)
E_{max}	maximum load efficiency (%)
e_{max}	maximum voids ratio (−)
e_{min}	minimum voids ratio (−)
F	vertical pile load (N)
g	earth's gravity (m/s^2)
H	embankment height (mm)
H_c	critical height of the embankment (mm)
H_{arch}	height of the smallest semi-spherical arch along the diagonal between piles (mm)
J	secant stiffness (MN/m)
K_p	parameter of the Hewlett and Randolph (1988) method (−)
N	scale factor (g-level) (−)
s	centre to centre pile spacing (mm)
T_{rp}	tensile load per meter run (kN/m)
w_s	vertical stress applied to the embankment (surcharge) (kPa)
W_T	line load equally distributed on the GR strip (kN/m)
W_{Tmin}	minimum line load equally distributed on the GR strip equivalent to 15% of the total load (kN/m)
X_m	parameter X in a model scale ($_m$) (−)
y	orthogonal maximum deflection of the geosynthetic (m)
y_d	diagonal maximum deflection of the geosynthetic (m)
Δu	differential settlement on the embankment surface ($\Delta\omega_D - \Delta\omega_T$) (mm)
$\Delta\omega$	simulated settlement of the subsoil using the mobile tray (mm)
$\Delta\omega_D$	settlement on the embankment surface between the diagonal piles, model scale (mm)
$\Delta\omega_M$	settlement on the embankment surface between the piles, model scale (mm)
$\Delta\omega_T$	settlement on the embankment surface above a pile (mm)
α	area ratio (%)
β	parameter of the Hewlett and Randolph (1988) method (−)
ε	strain in the geosynthetic (%)
ϕ'	friction angle of the embankment fill (°)
γ	unit weight of the embankment fill (kN/m^3)
ρ	density of the embankment fill (g/cm^3)
ρ_{dmax}	maximum dry density of the soil (g/cm^3)
ρ_{dmin}	minimum dry density of the soil (g/cm^3)
ρ_s	density of the sand particles (g/cm^3)
σ_r	vertical stress on the reinforcement geosynthetic (kPa)
ψ	dilatancy angle of the embankment fill (°)

Mobile Tray Device MTD, used in the present study, was especially developed to study in centrifuge the behaviour of piled embankments subjected an imposed settlement of the soft ground (Rault et al., 2010). It is worth mentioning, however, that the working platform can be temporary, by using supporting beams and plates, or even not exist, when a light pile-driving equipment is used (e.g., for timber piles).

Piled embankments with GR have been studied using small-scale models (Chen et al., 2008; Jenck et al., 2007; Van Eekelen et al., 2012a; b), large-scale tests (Wachman et al., 2010; Briançon and Simon, 2012; Xing et al., 2014; Rowe and Liu, 2015; Chen et al., 2016) and centrifuge tests (Blanc et al., 2013, 2014).

Previous studies performed at the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR) (e.g., Thorel et al., 2010; Okyay et al., 2013) focused on the geometries and conditions typically adopted in France, such as low area ratios α, up to 5%, low embankment heights H (0.7–1.8 m) and high surcharge values at the embankment surface, typically $w_s = 80$ kPa. The influence of geosynthetics Geolon® PP-25 on the behaviour of reinforcement piled embankments has also been studied for these configurations by Blanc et al. (2013, 2014) and Girout et al. (2014).

The aim of this paper is to analyse the influence of different types of geometries and geosynthetic stiffnesses on the load transfer mechanisms and deformations for higher embankments H (1.0–7.2 m) with higher area ratios α (up to 20%), not analysed in previous studies. With this propose, a series of centrifuge test are performed, combining two pile diameters d, three pile spacings s, and five embankment heights H and two geosynthetic stiffness J, for which modifications in the IFSTTAR apparatus for piled embankment simulation had to be introduced. The experimental results were compared with the values computed according to the British "Code of practice for strengthened/reinforced soils and other fills" (BS8006, 2010) and its corrigendum (BS8006, 2012). The present study follows the paper of Fagundes et al. (2015) in which results of the piled embankments without geosynthetic were presented.

2. Centrifuge modelling of piled embankments

2.1. Materials and methods

The reduce-scaled models were tested in the IFSTTAR centrifuge at a g-level N equal to 20, obeying the centrifuge tests scaling laws (Schofield, 1980; Garnier et al., 2007). Model parameters values are indicated by the subscript letter "m" and without the subscript for the prototype values.

The granular soil representing the embankment material is placed on a perforated steel mobile tray, as shown in Fig. 2. The