Soils and Foundations 2015;55(1):17–34

HOSTED BY

ELSEVIER

CrossMark

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf

Review of existing design methods for geosynthetic-reinforced pile-supported embankments

Priyanath Ariyarathne[1], D.S. Liyanapathirana[2,*]

School of Computing, Engineering and Mathematics, University of Western Sydney, Sydney, NSW 2747, Australia

Received 29 January 2014; received in revised form 2 October 2014; accepted 18 October 2014
Available online 2 January 2015

Abstract

Embankment construction over soft foundation soils is a challenging task for geotechnical engineers due to the undesirable characteristics of soft soils, such as excessive settlements and low bearing capacity. Among the various ground-improvement methods available for overcoming these undesirable characteristics, geosynthetic-reinforced pile-supported (GRPS) embankments are considered to be a reliable solution suitable for time-bound construction projects and difficult ground conditions. Various researchers have introduced methods to design GRPS embankments based on different load transfer mechanisms. However, among design engineers, there is uncertainty regarding the applicability of these design methods. This paper investigates the load transfer mechanism of GRPS embankments using two-dimensional and three-dimensional finite element analyses, and currently available design methods are compared with the results of the finite element modelling. A comparison of the design methods was carried out using the stress reduction ratio, the geosynthetic tension and pile efficacy, considering different pile diameters and spacing, and embankment heights, which govern the currently available design methods. Based on these model results, the inconsistencies in the currently available design methods are identified and discussed in detail.

Keywords: Pile-supported embankment; Geosynthetic reinforcement; Finite element modeling; Load transfer mechanism; Pile efficacy; Stress reduction ratio

1. Introduction

Embankments are widely used in infrastructure development projects to elevate the platform of roads, railways and runways. With the rapid world population growth over the past few decades, infrastructure development activities have increased considerably over marginal lands, which were previously considered unsuitable, such as around river estuaries, low-lying marshy areas and harbour foreshore areas characterising deep soft clay deposits. However, the construction of embankments under these ground conditions is a real challenge for geotechnical engineers due to the undesirable characteristics of soft soils, such as low bearing capacity, insufficient shear strength and high compressibility. Therefore, many complications, like local or global instability and excessive post-construction settlements due to the consolidation of the soft soil, arise when embankments are constructed on soft foundation soils.

A variety of techniques is available for overcoming these issues: (i) preloading or staged construction, (ii) the addition of vertical drains, (iii) the use of lightweight fill materials for the embankment fill, over the excavation of soft soil and replacing it with a suitable fill material, (iv) the reduction of the slope of the

*Corresponding author. Tel.: +61 2 4736 0653; fax: +61 2 4736 0833.
E-mail address: s.liyanapathirana@uws.edu.au (D.S. Liyanapathirana).
[1]Doctoral Student.
[2]Associate Professor (Geotechnical Engineering).
Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2014.12.002
0038-0806/

Nomanclature

a	width of the pile or pile cap
C_c	arching coefficient
c'	effective cohesion
D	depth of the foundation soil
d	pile diameter
E	Young's modulus
E_f	pile efficacy
E_s	equivalent elastic modulus of the foundation soil
e_1	voids ratio at unit pressure
H	embankment height
h_g	arch height
J	tensile stiffness of the geosynthetic
K	earth pressure coefficient at rest
K_p	passive earth pressure coefficient
k	permeability of soil
M	slope of the critical state line
P	total load on the pile
P_c	vertical stress on pile
P_r	vertical stress on the geosynthetic
p_0	uniform vertical pressure on the geosynthetic
q	uniform surcharge on the embankment
R	radius of the circular arc formed by the geosynthetic
S_{3D}	stress reduction ratio
s	pile spacing
s_d	diagonal pile spacing
T	tension in the geosynthetic
t	settlement of the foundation soil at midpoint between piles
t_g	thickness of the geosynthetic layer
W_T	distributed load carried by the reinforcement
β	dimensionless parameter
γ	unit weight of soil
ε	strain in the geosynthetic layer
θ	half angle subtended by geosynthetic circular arc
κ	slope of the swelling line
λ	slope of the virgin consolidation line
λ_1	dimensionless parameter
λ_2	dimensionless parameter
λ_3	dimensionless parameter
ν	Poisson's ratio
σ_s	vertical stress on foundation soil
ϕ'	effective friction angle
χ	dimensionless parameter
ψ	dilation angle

embankment and (v) the addition of column supports (Mitchell, 1981; Magnan, 1994; Shen et al., 2005). Column supports can be hard columns, such as piles (Jenck et al., 2009; Han et al., 2012), semi-hard columns, such as deep cement mixed columns (Huang and Han, 2009) or stone columns (Deb et al., 2007; Deb and Mohapatra, 2013). The first four methods listed above are not suitable for fast-track construction projects as they are all consolidation-based methods and consume time. The use of pile supports is considered as a reliable solution for embankment construction on soft foundation soils as the structure can be built in a single stage without prolonged waiting periods and with a significant reduction in total and differential settlements. Moreover, pile supports are effective in difficult or extremely poor ground conditions, such as landfills, brownfield sites and dumps where the engineering behaviour of the soils is not well known and the extracting of the soil properties by routine laboratory tests is difficult. Since the majority of the embankment load is transferred to the piles, detailed knowledge of the mechanical properties of the ground is not required. Also, in a contaminated ground, it is possible to maintain minimal contact with contaminated water squeezing out of the ground due to consolidation, if pile supports are used instead of consolidation-based methods.

Generally, single or multiple layers of geosynthetic reinforcement are installed in pile-supported embankment systems to increase the load transfer to the piles and to reduce the required area replacement ratio (Lawson, 1992; Kempton et al., 1998). Geosynthetic reinforcement, combined with pile supports, is commonly used for bridge approaches, storage tank supports, the widening of existing roads, retaining walls and embankments to create an efficient load transfer platform, as discussed by many researchers (Han and Gabr, 2002; Collin, 2003; Pham et al., 2004; Qian and Ling, 2009).

A large number of numerical and experimental studies have been conducted over the last few decades on pile-supported embankments with and without geosynthetic, to investigate their behaviour and the load transfer mechanism (Low et al., 1994; Han and Wayne, 2000; Li et al., 2003; Collin, 2004; Han et al., 2004; Chen et al., 2010; Hong et al., 2011; Eskisar et al., 2012). Although various studies have been done and many successful case histories have been presented in the literature over the years, the precise mechanism by which the embankment load is transferred to the piles and the foundation soil is still not clearly understood.

Several methods can be found in the literature for calculating the vertical load distribution in pile-supported embankments. A majority of the currently available design methods assumes that the embankment load is transferred to the piles by the soil arching mechanism introduced by Terzaghi (1943). Guido et al. (1987) proposed a design approach based on model tests performed on sand in a rigid box with multiple layers of geogrid reinforcement. Hewlett and Randolph (1988) presented a semi-spherical arching model to describe the load transfer mechanism based on their three-dimensional model tests. However, the effect of geosynthetic reinforcement on the load transfer mechanism was not considered in this method. Low et al. (1994) investigated a piled embankment system which uses cap beams and geosynthetic reinforcement. They improved the method adopted by Hewlett and Randolph (1988) by incorporating the body force into the plane-strain differential equation of equilibrium. Carlsson (1987)