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A simplified model to analyze the reinforced piled embankments

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ABSTRACT

It is an economic way to use the piled embankment for the construction of embankment over soft soil. The combination of piles and reinforcement can effectively reduce the differential settlement at the surface of embankment. The paper presents a simplified model for analysis of an embankment of granular fill on soft ground supported by reinforcement and piles. This model is based on consideration of the arching effect in granular material proposed by Hewlett & Randolph. The vertical equilibrium of the unit body at the center of pile caps immediately below the reinforcement is established. The refinements of the model are that the failure mechanisms of the arch both at the crown and at the pile cap were considered, three-dimensional situation was taken into account for reinforced piled embankment, calculation of the vertical stress carried by the subsoil due to arching effect and reinforcement for multi-layered soil was proposed. Using the simplified model, the influence of embankment height, one-dimensional compression modulus of subsoil, tensile stiffness of reinforcement on stress reduction ratio (SRR) and tensile force of reinforcement is investigated. It is found that the model can be used to assess the relative contribution of the reinforcement and subsoil. The results show that subsoil gives a major contribution to overall vertical equilibrium, while the reinforcement gives obvious contribution at relatively large settlement. The inclusion of the reinforcement can reduce the vertical stress acting on the subsoil. The simplified model is then evaluated by three case studies. The results of this model show good consistence with these cases.

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1. Introduction

Construction of embankments on soft soil is very challenging task for geotechnical engineering due to the possible bearing failure, intolerable settlement and slope instability. Piled embankments provide an economic and effective solution to settle these problems compared to the traditional soft foundation improvement methods, such as preloading (Magnan, 1994). The inclusion of tensile reinforcement enhances the load transfer mechanism and considerably minimizes the maximum as well as differential settlements (Gangakhedkar, 2004). The reinforced piled embankment system combines vertical piles and reinforcement placed at the base of embankment horizontally to transfer the embankment load to a stiff layer.

The logical starting point for assessment of performance of a piled embankment is the effect of 'arching' in the embankment itself. A number of authors (e.g. Naughton and Kempton, 2005; Stewart and Filz, 2005) have concluded that various analytical methods give different results in specific situations, but without commenting on systematic differences. A more recent review which attempts to rationalize the generic outcome of various methods is given by Ellis and Aslam (2009a).

There are relatively well-established methods to account for the load that sagging tensile reinforcement (e.g. a geotextile or geogrid) can carry in a two-dimensional situation. Russell et al. (2003) proposed a design method for piled embankments, including equations to account for the effect of sagging tensile reinforcement. Ellis and Aslam (2009b) proposed an alternative combination of the equations for the reinforcement, allowing sag to be expressed directly in terms of the load. This approach is considered further below.

Han and Gabr (2002) performed a numerical study of reinforced piled embankments, including underlying subsoil. However, an axisymmetric analysis was used, an approach whose validity had previously been questioned by Russell and Pierpoint (1997). Stewart and Filz (2005) considered the effect of the compressibility of the subsoil underlying a piled embankment using 3-dimensional

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numerical analysis. It was concluded that this should be a factor in the design of piled embankments, but the authors did not propose how this could be done analytically.

Three dimensional calculation methods to assess the influence of geosynthetics are included in the analytical methods proposed by Kempfert et al. (2004) and Filz and Smith (2007). Kempfert et al. (2004) considered geosynthetic behavior as an elastic cable. Thus, differential equations are defined for the loading system of the geosynthetic reinforcement that includes the foundation-soil effect. Filz and Smith's (2007) methodology to assess geosynthetic tension and strain is based on calculation of the deflection of a geosynthetic material under linear elastic conditions. The deflection calculation also includes the influence of soft soil; thus, the foundation soil contributes to the support of the embankment's residual load.

Naughton et al. (2008) considered the historical development of analysis of piled embankments. It was concluded that the design of piled embankments was complex and not yet fully understood, particularly with respect to 3-dimensional effects and support from the subsoil. BS8006-1 (2010) mentions the potential role of subsoil support, but suggests that it should not be used in design (e.g. due to seasonal fluctuations in ground water level).

Abusharar et al. (2009) and Van Eekelen et al. (2012a,b) both consider analytical approaches for piled embankments including the effect of tensile reinforcement and subsoil support. However, both approaches are conceptually and mathematically quite complex.

Deb (2010) developed a mathematical model to study the soil arching effect in stone column-supported embankment resting on soft foundation soil. Consolidation effect of soft soil due to inclusion of stone columns was also been included in the model. However, the effect of the soft soil depth and stiffness of the geosynthetic reinforcement on the soil arching was not considered. Indraratna et al. (2012) also investigated the consolidation effect of the soft soil by developing a finite-difference solution for stone column-reinforced soft ground. However, the study was concentrated on unreinforced embankments, thus the effect of tensile reinforcement was not considered.

Jones et al. (2010), Halvordson et al. (2010) and Plaut and Filz (2010) analyzed the geosynthetic reinforcement in pile-supported embankments for three-dimensional situation. They utilized a 3D thin-plate model, 3D cable-net model and axisymmetric model of the geosynthetic, respectively. Zhang et al. (2012) and Deb and Mohapatra (2013) both analyzed the geosynthetic-reinforced and pile-supported embankment for a plane strain situation. All the studies above assumed the foundation system (including the pile and subsoil) as elastic springs or linearly deformable homogeneous materials.

Van Eekelen et al. (2011) analyzed and modified the BS8006-1 (2010) in terms of the calculation method of the tensile force in the tensile reinforcement for 3D situation, but the support of the subsoil was not considered. Van Eekelen et al. (2013) presented a new concentric arches model, which is an extension of models of Hewlett and Randolph (1988) and EBGEO (2011). In the model, both full and partial arching were described, and the increasing arching with subsoil consolidation (GR deflection) was also explained. However, the arch failure at the pile cap was not considered.

This paper proposes a simpler analytical model (including tensile reinforcement and subsoil support). The simplified model can be used to estimate the magnitude of tensile stress generated in reinforcement, and can also be applied to calculate the vertical stress acting on subsoil for multi-layered soft soils due to the effect of arching and tensile reinforcement. Finally, the results of the simplified model are compared with three case studies to investigate its validity.

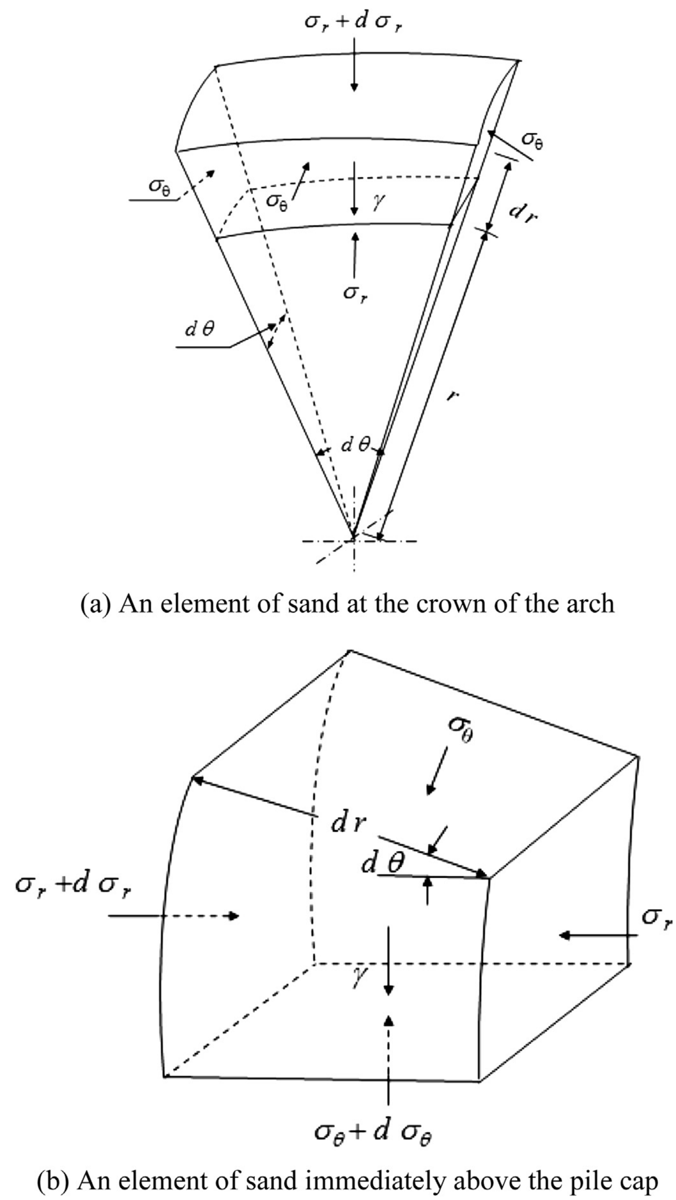

Fig. 1. Stresses applied on the element of soil arching: (a) An element of sand at the crown of the arch; (b) An element of sand immediately above the pile cap. (Source: Hewlett and Randolph, 1988).

2. A simplified model in the reinforced piled embankment

In developing the present method, the following simplifications are used:

(a) The embankment fill is homogeneous, isotropic, and cohesionless.
(b) The soft soil ground is homogeneous, isotropic and linear response for each layer of soil.
(c) The reinforcement is homogeneous, isotropic.
(d) The soft soil and the embankment fill deform only vertically.
(e) Piles are sufficiently rigid and undergo insignificant deformation.
(f) There is no friction between a pile and the surrounding soft soil.
(g) The ratio of the embankment fill height to the center-to-center pile spacing is greater than 0.5.

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