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Evaluation of effect of basal geotextile reinforcement under embankment loading on soft marine deposits

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ABSTRACT

This paper presents a case history on the performance of a coastal embankment reinforced by a layer of geotextile at the bottom of the embankment on soft marine deposits. The coastal embankment is the sea wall of the Qinshan nuclear power station on the northern side of Hangzhou bay near Shanghai, China. Monitoring of settlement and excess pore water pressure were carried out during and after embankment construction. The finite element method (FEM) was used to analyse the performance of the geotextile reinforcement and its effect on soil behaviour under the embankment loading, based on the field monitored results. Stability analyses were conducted using two approaches: c-ϕ reduction in FEM, and limit equilibrium analysis. Both field and simulation results indicate that the geotextile has an effect on reducing the vertical displacements of subsoil. However, the results show basal reinforcement cannot increase the overall factor of safety, but the factor of safety at the local position, under reinforcement, can be increased during the construction procedure, and this is due to the confinement of the soil element by the reinforcing fabric. Thus, in these circumstances, one layer of basal geotextile reinforcement can prevent sudden failure of subsoil during embankment construction.

1. Introduction

China has a very long coastline running from north to south along the Bohai Sea, Yellow Sea, Eastern China Sea, and South China Sea, and the total length is over 18,000 km (Liu, 1998; Xu et al., 2009). The coastal regions have the densest population and the most developed economy in China, taking up 8% of the total land area, 40% of the gross population, 35% of the cultivated area and 70% of gross industrial product. However, the coastline and the security and finance of citizens living along the shore are threatened by coastal erosion in these regions. Statistical data show that almost all of the exposed mud coastline and 70% of the sandy coastline in China are subjected to erosion (Sheng and Zhu, 2002; Xu et al., 2009). Geotextiles are often used to protect the coastline from erosion (Bao, 1999; Chu et al., 2012; Du et al., 2009; Fowze et al., 2012; Lee and Douglas, 2012; Yasuhara et al., 2012).

With the economic boom in recent years, many reclamation projects have been conducted in the eastern coastal region of China. Many embankments have been constructed to provide new land for both industrial and urban infrastructure. However, since the reclaimed coast area is soft marine deposit with highly compressibity (Yin et al., 2010, 2011a,b, 2013), embankments can easily fail during construction. In order to accelerate the consolidation of subsoil and to maintain safety during embankment construction, geosynthetics (Horpibulsuk and Niramitkornburee, 2010; Horpibulsuk et al., 2011; Ma et al., 2011), prefabricated vertical drains (PVD) (Chai et al., 2001; Shen et al., 2005; Chai and Carter, 2009; Wu et al., 2015), deep mixing (Shen et al., 2003a,b, 2008), and jet grouting (Shen et al., 2013a, b, c; Wang et al., 2013, 2014) are applied in the construction of embankments on soft deposits. Geosynthetics have been used to protect coastal and river bank embankments in China since 1978 (Bao, 1999). So far more than thousands of embankment projects reinforced by

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Nomenclature

c	cohesion (M/L·T^2)
c_r	reduced cohesion (M/L·T^2)
C_u	undrained shear strength (M/L·T^2)
e	void ratio
e_0	initial void ratio
E	elastic modulus (M/L·T^2)
F	factor of safety
F_r	reduced factor
k	permeability coefficient (L/T)
k_h	horizontal hydraulic conductivity (L/T)
k_v	vertical hydraulic conductivity (L/T)
K	stiffness of geotextile (ML^2/T^2)
K_0	lateral earth pressure coefficient
M_R	anti-slip moment (ML^2/T^2)
M_S	slip moment of soil (ML^2/T^2)
p'	effective mean stress (M/L·T^2)
q	deviator stress (M/L·T^2)
w	water content
γ_t	unit weight (M/L^{2}T^2)
$\Delta\varepsilon$	shear strain increment
$\Delta\tau$	shear stress increment (M/L·T^2)
η	stress ratio q/p'
κ	reloading/unloading slope in e-ln(p′) plot
λ	virgin loading slope in e-ln(p′) plot
Λ	1-κ/λ
M	slope of failure line in (q, p′) plot
ν	Poisson's ratio
σ	principal stress (M/L·T^2)
τ	shear stress (M/L·T^2)
τ_r	reduced shear stress (M/L·T^2)
τ_R	factual maximum shear stress of soil (M/L·T^2)
φ	internal friction angle
φ'	effective internal friction angle
φ_r	reduced internal frictional angle
ϕ'	effective internal friction angle
ϕ_r	reduced internal frictional angle

geosynthetics have been constructed in China. The functions of geosynthetics under embankments in these cases are: (1) load filtration, (2) accelerating drainage in subsoil, (3) separation between different geomaterials, (4) protection from erosion, or scouring due to natural or human activity, and (5) reinforcing the embankment.

This paper presents a case history of the performance of a full-scale test embankment constructed on a very soft clay deposit improved by one layer of basal geotextile reinforcement. The objectives of this paper are as follows: (1) to investigate the performance of basal geotextile reinforcement under embankment loading through numerical analysis; (2) to reveal the reinforcing mechanism of basal geotextile reinforcement on the stability of an embankment; and (3) to verify the effectiveness of the current design method for basal reinforced embankments.

2. Project background

2.1. Embankment construction

The Qinshan nuclear power station is the second oldest nuclear power plant in China. It is located on the soft marine deposit of Hangzhou Bay, as shown in Fig. 1. To provide the nuclear power station with primary protection from the erosion of waves and

Fig. 1. Location of Qinshan nuclear power station.

tides, an embankment was constructed. The total length of the embankment was 1871 m and its height was up to 8.0 m Fig. 2 illustrates a typical sectional structure of the embankment. A staged construction method was undertaken to reduce settlement and to accelerate the construction process, as shown in Fig. 3. The stages of construction and consolidation are given in Fig. 4 and Table 1. In this case, construction was divided into four stages. The first stage took 85 days for construction of a 3 m platform and 37 days for consolidation; the second stage took 53 days for construction of a 4 m platform and 45 days for consolidation; the third stage was 49 days for construction of a 5.5 m platform and 153 days for consolidation; and the fourth stage was 17 days for construction of an 8 m platform. The fill material for the embankment was stone rip-rap and clay. The unit weight of the stone rip-rap was 20.5 kN/m^3 and the clay was 18.3 kN/m^3. Initially, one layer of geotextile was placed over the soft soil, and then stone rip-rap was heaped and compacted over the geotextile layer. In addition, the clay liner which was protected by the geotextile, was back-filled and compacted in the middle of the embankment filter.

The geotextile used in this case was woven polypropylene. It has a strength of 22 kN/m, and stiffness (K) of 200 kN/m, with a failure strain reaching 11% and permeability at 2.7 × 10^{-5} m/s. The functions of reinforcing geotextiles are as follows: (1) separating the filled materials of the embankment and the soft subsoil; (2) providing a drainage path for the pore water from soft subsoil driven by the excess pore pressure and thereby speeding up the consolidation; (3) providing tensile basal reinforcement, which contributes to the stability of the embankment; and (4) providing a confinement to the embankment fill and foundation soil adjacent to the reinforcement. This confining effect can reduce the lateral distortion of the subsoil due to the embankment load, and therefore, the shear stress level in the soft subsoil.

2.2. Geotechnical profile and soil properties

The soft ground at the site was deposited under a marine environment and has a very high compressibility and low bearing capacity. The groundwater level was about 1 m below the ground surface. The physical and mechanical properties of the soil clay deposit within a depth of 30 m are shown in Fig. 5. The soils under the embankment are in six different layers: the top layer is a thin