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Swell-consolidation characteristics of fibre-reinforced expansive soils

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Abstract

Many innovative foundation techniques have been devised to counteract the swell-shrink problems posed by expansive soils. Some of these techniques include physical alteration, sand cushioning, cohesive non-swelling soil (CNS) layers, belled piers, under-reamed piers, granular pile anchors and chemical stabilisation. Reinforcing expansive soils with randomly oriented geo-fibres is also an effective technique for controlling the volumetric changes in expansive soils. This paper presents the swell-consolidation characteristics of fibre-reinforced expansive soils. Nylon fibre was used to reinforce expansive soil specimens. One-dimensional swell-consolidation tests were conducted to study the swell-consolidation characteristics of fibre-reinforced clay specimens. The fibre content (f_c) was varied at 0%, 0.05%, 0.10%, 0.15%, 0.20%, 0.25% and 0.30% by the dry weight of the soil. The length (l) of the fibres was varied at 15 mm and 20 mm. The swell potential and the vertical swelling pressure decreased up to f_c=0.25% for both fibre lengths, but increased mildly when f_c was increased to 0.30%. The swell potential and the vertical swelling pressure decreased with an increasing fibre length (l) for all the fibre contents (f_c). The rate of heave for the samples was also found to be in accordance with the above observations. The secondary consolidation characteristics of the fibre-reinforced samples were also studied and compared with those of an unreinforced specimen. It was found that the secondary consolidation characteristics of the fibre-reinforced specimens improved compared to those of the unreinforced specimen.

Keywords: Expansive soils; Fibre-reinforcement; Swell potential; Vertical swelling pressure; Rate of heave; Secondary consolidation

1. Introduction

Expansive soils swell when they absorb water and shrink when water evaporates from them (Chen, 1988; Nelson and Miller, 1992). Due to this alternating swelling and shrinkage, lightly loaded civil engineering structures founded in these soils are severely distressed. The annual cost of damage is estimated at £150 million in the UK, $1000 million in the USA and many billions of pounds worldwide (Gourley et al., 1993). Many innovative techniques have been devised in order to counteract the problems posed by expansive soils. Physical alteration (Phanikumar et al., 2012), belled piers (Chen, 1988) and granular pile-anchors (Phanikumar, 1997; Phanikumar et al., 2004) are some of the innovative foundation techniques adopted for expansive soils. The chemical stabilisation of expansive soils, using lime and fly ash, has also been found quite effective in controlling the volumetric changes in expansive soils (Chen, 1988; Cokca, 2001; Phanikumar and Sharma, 2004). Fly ash columns are a recently developed foundation technique (Phanikumar et al., 2009), which has yielded promising results.

Apart from the above techniques, geosynthetic inclusions as a technique of random reinforcement have also been found

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quite effective in controlling swell and shrinkage (Vessely and Wu, 2002; Viswanadham et al., 2009a', 2009b).

Compacted expansive soils, reinforced with polypropylene fibres, have exhibited reduced tension cracking and controlled volumetric changes due to swelling and shrinkage (Al-Wahab and El-Kedrah, 1995). Ziegler et al. (1998) and Babu et al. (2008) observed that fibre inclusions increased the tensile strength. A combination of fly ash and polypropylene fibres has also been found to reduce the swelling and shrinkage characteristics of expansive soils (Puppala and Musenda, 2000; Punthutaecha et al., 2006; Tang et al., 2007). It has been reported that fibre reinforcement enhanced the unconfined compressive strength and reduced the swelling potential of expansive clays. Cai et al. (2006) observed that an increase in fibre content led to a reduction in the swelling potential of lime-stabilized clayey soil.

The consolidation settlement and swelling of fibre-reinforced samples decreased, whereas the hydraulic conductivity and shrinkage limit increased slightly, when the fibre content and length were increased (Abdi et al., 2008). Ikizler et al. (2008) reported a potential decrease in swelling pressure as a result of the inclusion of expanded polystyrene geofoam placed between an expansive soil and a rigid wall.

Al-Akhras et al. (2008) investigated the effect of two types of fibres (natural and synthetic) on the swelling properties of clayey soils. Nylon and palmyra fibres with different aspect ratios (*l/d*) were mixed with three types of expansive soils that had different physical properties. Four aspect ratios ($l/d=25$, 50, 75 and 100) and five different fibre contents ($f_c=1\%$, 2%, 3%, 4% and 5%) were used in the study, and both the vertical swelling pressure and the swell potential were evaluated for each combination. The results of the study showed that an increase in the percentage of both types of fibre reduced the vertical swelling pressure and the swell potential of the clayey soils significantly.

This paper presents the swell-consolidation characteristics of remoulded expansive clay specimens reinforced with randomly distributed nylon fibre. The secondary consolidation characteristics of both unreinforced and fibre-reinforced specimens were also studied. It should be mentioned here that there are quite a few differences between the work done by Al-Akhras et al. (2005) and the work presented in this paper. The fibre contents presented in this paper ranged from 0% to 0.3%, whereas those presented in Al-Akhras et al. (2005) ranged from 0% to 5%. The l/d ratios or the aspect ratios considered in this paper were only 15 and 20, whereas those considered by Al-Akhras et al. (2005) ranged from 25 to 100. Furthermore, in addition to nylon fibre, Al-Akhras et al. (2005) studied palmyra fibre; however, only nylon fibre is considered in this paper.

2. Experimental investigation

2.1. Test materials

Expansive soil of a high free swell index (FSI) was used in the experimental study. Nylon fibre was used to reinforce the expansive soil specimens. Expansive soil was collected at a depth of 1 m from the ground level from the town of Amalapuram, AP, India. The FSI of the soil was 200%. Based on its liquid limit and plasticity index, the soil was classified as CH (high plasticity). Table 1 shows the index properties of the expansive soil. The nylon fibre used to reinforce the soil specimens was randomly oriented as reinforcement. The fibres were twisted monofilament fibres with a diameter of 1 mm.

Table 1
Index properties of the expansive soil.

Specific gravity of soil solids, G_s	2.73
Liquid limit (%)	79
Plastic limit (%)	26
Plasticity index (%)	53
Sand (%)	14
Fraction passing 0.075 mm sieve (%)	86
Free swell index (%)	200
USCS classification	CH

2.2. Test Variables

The dry unit weight (γ_d) of the expansive soil was kept constant at 12 kN/m^3. Oven-dried expansive soil, passing through a 4.75-mm sieve, was used to prepare the test specimens. Hence, the initial water content (w_i) of the specimens was 0%. Oven-dried specimens were used in order to ensure measurable values of the heave and the swell potential. In the case of nylon fibre, the length of the fibre (l) was varied at 15 mm and 20 mm. As the diameter of the fibres was 1 mm, the aspect ratio of the fibres used was equal to 15 and 20, respectively. The fibre content (f_c) used in the testing programme was varied at 0%, 0.05%, 0.1%, 0.15%, 0.2%, 0.25% and 0.3% by the dry weight of the soil.

2.3. Tests conducted and quantities determined

One-dimensional swell-consolidation tests were performed in an oedometer on remoulded expansive clay specimens under both unreinforced and geofibre-reinforced conditions to study the effect of fibre reinforcement on the heave, the swell potential and the swelling pressure. The secondary consolidation behaviour of the fibre-reinforced and unreinforced specimens was also studied and compared. The effect of the fibre content (f_c) and the aspect ratio (*l/d*) on the above quantities was studied. One-dimensional swell-consolidation tests were conducted by employing the free swell method, wherein the sample is allowed to absorb water freely and undergo heave. In this method, heave is allowed up to saturation or equilibrium heave.

The swell potential ($S\%$) of the samples was determined as the ratio of the increase in thickness (ΔH) to the original thickness (H) expressed as a percentage, as shown below:

$$S\% = \left(\Delta H/H\right) \times 100 \quad (1)$$

The swelling pressure (σ_{vs}) is defined as the vertical pressure required to recompress a fully swollen soil sample to its initial void ratio (e_0). It is determined from one-dimensional

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