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Influence of stress anisotropy on small-strain stiffness of reinforced sand with polypropylene fibres

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Abstract

This paper reports on the small-strain stiffness (G_{max}) of a well graded crushed rock reinforced with polypropylene fibres. The experimental study was conducted on twenty-five fully saturated samples subjected to bender element tests. The contents of fibre used were equal to 0%, 0.5%, 1.0%, 1.5% and 2.0%. The bender elements were inserted in a resonant column and a stress path triaxial apparatus accommodating samples of 70 and 50 mm in diameter, respectively, with a ratio of length to diameter equal to 2:1. The samples were initially consolidated isotropically to pressures of 50, 100, 400 and 700 kPa. At a given isotropic pressure, G_{max} measurements were conducted increasing the deviatoric compressive stress (q) and keeping a constant mean effective confining pressure (p'). This allowed the study of the effect of stress anisotropy, expressed with the ratio (q/p'), and the role of fibre inclusion and content on G_{max} of the reinforced samples under variable mean effective confining pressures. The data were analysed by means of the normalized shear modulus, $G_{max,normalized}$, against the stress ratio, where $G_{max,normalized}$ expressed the increase of the small-strain shear modulus under an anisotropic stress state with respect to the corresponding modulus under an isotropic stress state. For a given confining pressure, the results showed a clear increase of $G_{max,normalized}$ with increased content of fibres which implied that the sensitivity of modulus to the stress anisotropy became more pronounced for greater contents of fibres. However, this influence of fibre inclusion and content on the small-strain stiffness of the samples was found weaker at greater magnitudes of p'.

1. Introduction

Reinforcing of soil with synthetics fibres is a popular approach in ground improvement with applications, for example, in foundation engineering, retailing walls, slope stabilization and improvement of the liquefaction resistance of soils. Particular focus of previous researches has been paid on the medium to large deformation behavior under monotonic or cyclic loading of fibre reinforced soils, for example the studies by Gray and Ohashi (1983), Maher and Gray (1990), Al-Refeai and Al-Suhaibani (1998), Consoli et al. (2005, 2009), Casagrande et al., 2006; Dos Santos et al. (2010), and Miranda Pino and Baudet (2015), among others. Most available data show that the inclusion of fibres increases the shear strength of soils which may be desirable in the study of large deformation problems and limit analysis of geo-structures, even though the compressibility of fibre reinforced soils may not be affected by means of an alteration of the slope of the critical state or normal compression lines when fibres are added to the host soil.

However, works examining the role of fibre inclusion and content on the small-strain behavior of reinforced soils are relatively limited. With respect to polypropylene fibres, for which type of synthetic fibres there have been previously numerous notable works in the literature associated

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with their large deformation behavior, Heineck et al. (2005) noticed that the inclusion of fibres did not affect the small-strain stiffness, G_{max}, of their reinforced specimens. That work was limited in that the content of fibres examined was equal to 0.5% and the specimens were subjected to an isotropic stress path. For pure sands (unreinforced sands), a recent study by Payan et al. (2016a) showed that G_{max} of sands may be strongly affected by the stress ratio concluding that for sands of better grading and more irregular in shape grains, there is a notable increase of G_{max} when the soil is subjected to an anisotropic stress state in comparison to an isotropic stress state, whereas for uniform and of regular in shape grains, the role of the stress ratio on G_{max} is fairly negligible.

The present work reports on the small-strain behavior of polypropylene fibre reinforced sand using a well graded soil of fractal grading and irregular in shape grains with focus on the role of fibre content and stress ratio on G_{max}. This sand, due to the grain size distribution and irregular shape of grains, may be characterised as highly sensitive to the stress ratio. The stress ratio is expressed herein with respect to the applied deviatoric stress (q) over the mean effective confining pressure (p') as (q/p').

2. Materials and methods

As host soil in the study, a well-graded sand was used which material is composed of a crushed rock of irregurally shaped quartz grains (typical of a wide range of soils from fill-backfill material to tailing soils with respect to its grain characteristics). The grading curve and a scanning electron microscope (SEM) image of the sand are given in Fig. 1. The mean grain size (d_{50}), coefficient of uniformity (C_u) and specific gravity of solids of the sand are equal to 1.00 mm, 6.1 and 2.65, respectively. The authors quantified the shape descriptors of sphericity (S) and roundness (R) by visually observing representative grains and using an empirical chart proposed in the literature by Krumbein and Sloss (1963). Based on a similar procedure to the one described by Cho et al. (2006) and Payan et al. (2016a, 2016b), the authors quantified the arithmetic mean of S and R, named the regularity, ρ (after Cho et al., 2006) which was found equal to 0.41 for the sand. This empirical chart is given in Fig. 2. Particularly, the authors randomly selected a total number of thirty grains and quantified, for each grain, the parameters S and R by visually matching the shape of each grain to a reference shape from Fig. 2. This gave average values of the particle shape descriptors for the total set of grains examined, which showed that the host sand is composed of fairly angular and low sphericity grains.

$$\rho = \frac{S+R}{2} \tag{1}$$

The well-graded sand was mixed with polyprolypene fibres using percentages of the fibres by sand dry mass equal to 0%, 0.5%, 1.0%, 1.5% and 2.0%. These fibres have an average length of 12 mm and an average thickness of 0.03 mm, with a specific gravity of 0.9. During the preparation of the samples, a small amount of water of about 2% by dry mass of fibre-sand mixtures was added and the moist samples were mixed in a way that the fibres were distributed relatively uniformly within the mixture. Thereafter, specimens were prepared in two different apparatus: a resonant column which can accommodate samples of 70 mm in diameter and 140 mm in length and a stress path triaxial apparatus which can accommodate samples of 50 mm in diameter and 100 mm in length. The samples were prepared into split molds of appropriate dimensions and were compacted in order to achieve relatively high relative density. Thereafter, typical procesures of saturation and consolidation of the samples were followed. Note that the previously described method of moist compaction was

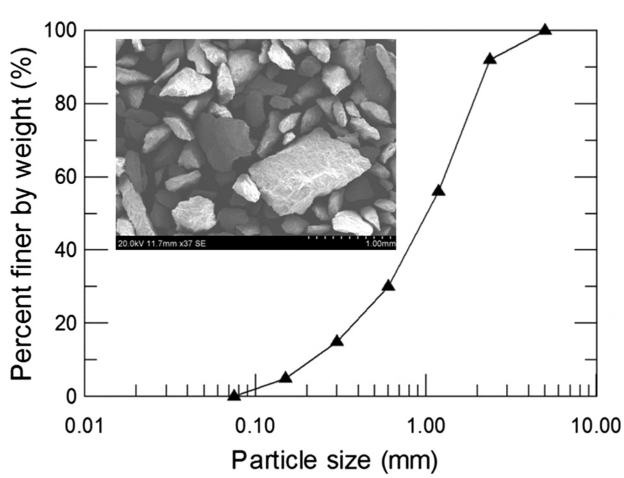

Fig. 1. Grading curve and scanning electron microscope (SEM) image of the sand used in the study.

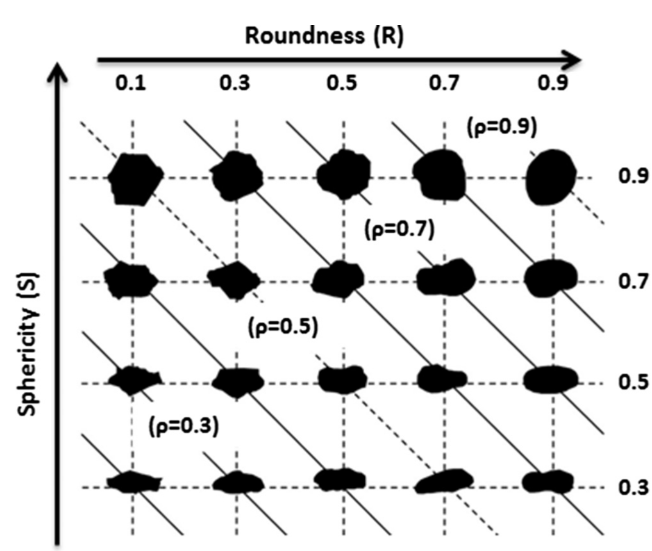

Fig. 2. Empirical chart for the quantification of particle shape descriptors of sphericity (S), roundness (R) and regularity (ρ = (S + R)/2) from Krumbein and Sloss (1963) (modified by the authors).