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Triaxial behavior of sand–mica mixtures using genetic programming

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ABSTRACT

This study investigates an application of genetic programming (GP) for modeling of coarse rotund sand–mica mixtures. An empirical model equation is developed by means of GP technique. The experimental database used for GP modeling is based on a laboratory study of the properties of saturated coarse rotund sand and mica mixtures with various mix ratios under a 100 kPa effective stresses, because of its unusual behavior. In the tests, deviatoric stress, and pore pressure generation, and strain have been measured in a 100 mm diameter conventional triaxial testing apparatus. The input variables in the developed GP models are the mica content, and strain, and the outputs are deviatoric stress, pore water pressure generation. The performance of accuracies of proposed GP based equations is observed to be quite satisfactory.

1. Introduction

The presence of platy mica particles in coarse rotund sands alters the mechanical behavior of sandy soils. The mechanical response of micaceous sands has been subject to intensive research in soil mechanics (Gilboy, 1928; Hight, Georgiannou, Martin, & Mundegar, 1998; McCarthy & Leonard, 1963; Mundegar, 1997; Olson & Mesri, 1970; Terzaghi, 1925). As early as 1925, Terzaghi stated that much more experimental works were required for the foundation settlements prediction, as particle size alone was not enough to estimate a reasonable indication for the foundation settlements prediction. Gilboy (1928) studied the influence of mica content on the compressibility of sand, and concluded that an increase in mica content resulted in an increase in the void ratio of the uncompressed material as well as an increase in compressibility. The observations, first made by Gilboy (1928), that any system of analysis or classification of soil which neglects the presence and effect of the flat-grained constituents will be incomplete and erroneous. Olson and Mesri (1970) concluded that for all apart from the most active of reconstituted clays, mechanical properties were the governing factors in determining compressibility. A recent experimental study by Theron (2004) was conducted on mixtures of mica and sand, and demonstrated the enormous impact of particle shape on the mechanical properties.

Most current basic soil mechanics text show that mica particles; (i) cause undrained strength anisotropy from a brittle response in triaxial extension tests to a ductile behavior in triaxial compression tests (Hight et al., 1998), (ii) decreases strength (Harris, Parker, & Zelazny, 1984), (iii) alters internal shear mechanism (Lupini, Skinner, & Vaughan, 1981) and (iv) increase compressibility (Clayton, Theron, & Vermeulen, 2004). Micaceous sands are deemed unacceptable for earthworks because of these reasons. Actually, a number of slope failures have been attributed to the presence of mica (Harris et al., 1984). The behavior of micaceous sands was studied in connection with flow slides that occurred during construction of river training for the Jamura Bridge in Bangladesh (Hight et al., 1998), and Merriespruit gold tailings dam in South Africa which failed in such a catastrophic fashion in 1994 (Fourie, Blight, & Papageorgiou, 2001; Fourie & Papageorgiou, 2001). Interestingly the behavior of mica is clay-like, but particle size analyses and the origins of the geomaterial provide that they contain little clay-sized material, and do not have colloidally-active minerals.

Material models describe the stress-strain relationship at element level. The Cam-Clay and the modified Cam-Clay models are the early models commonly used in geomechanics to describe clay behavior (Roscoe & Burland, 1968). Soil models in geotechnical engineering were developed by multiple yield surfaces and bounding surface plasticity (Dafalias, 1986; Li, 2002; Whittle & Kavadas, 1994). The field of relationships has recently been developed particularly because of the computer inspired methods of information processing known as soft computing techniques. For example, a different way of using artificially neural network (ANN) was employed to model the material behavior from the experimental results. Due to the ability to learn and generalize interactions among many variables, the ANN technique has a potential in the modeling problems (Ellis, Yao, & Zhao, 1992; Ghaboussi, Garret, & Wu, 1991; Ghaboussi & Sidarta, 1998; Hashash, Ghaboussi, Jung, & Marulanda, 2002; Pande & Shin, 2002). ANNs have been used successfully in, for example; pile capacity prediction, modeling soil behavior, site characterization, earth retaining structures, settlement of structures, slope stability, design of tunnels and underground openings, liquefaction, soil permeability and hydraulic

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conductivity, soil compaction, soil swelling, classification of soils and geotechnical earthquake engineering (Ali & Najjar, 1998; Basheer, Reddi, & Najjar, 1996; Ellis, Yao, Zhao, & Penumadu, 1995; Goh, 1994; Goh, Wong, & Broms, 1995; Hashash, Jung, & Ghaboussi, 2004; Nawari, Liang, & Nusairat, 1999; Panakkat & Adeli, 2007; Sivakugan, Eckersly, & Li, 1998).

This study presents an alternative model, genetic programming (GP), as a robust tool for the development of empirical model equation for coarse rotund sand–mica mixtures, due to its pattern of behavior suggesting that the high compressibility and other 'clay like' behavior. Although genetic programming techniques have been widely used in engineering applications, they have not been applied for the development of model equations of granular materials to our knowledge. The advantage of GP is that it can discover a pattern from a set of fitness cases without being explicitly programmed for them (Koza, 1992). When we define set of functions and terminals, select a target fitness function, provide a finite set of fitness cases, GP can find a solution in the search space defined by these functions and terminals provided to the problem (Liu, 2001). The proposed GP based equation here in this study is actually a realistic empirical model based on a wide range of experimental results consisting of 5237 test records (individual points along given stress paths). The predictions of GP based equation developed to predict relationship of the mixtures is found to be quite accurate.

2. Experimental study

2.1. Materials

Two different geomaterials were used in all the tests, Leighton Buzzard Sand and mica. The Leighton Buzzard Sand used in the experiments was a fraction B supplied by the David Ball Group, Cambridge, UK, confirming to BS 1881-131:1998. Its specific gravity, minimum and maximum dry densities were found to be 2.65, 1.48 g/cm^3 and 1.74 g/cm^3, respectively. As it can be seen from Figs. 1a and 2, more than 90% of the coarse sand particles, which are rounded and mainly quartz, are between (around) 0.6 mm and 1.1 mm.

Mica used in the experiments 52–105 μm muscovite mica supplied by Dean and Tranter Ltd. It's specific gravity, minimum and maximum dry densities were found to be 2.9, 0.725 g/cm^3 and 0.916 g/cm^3 respectively (Theron, 2004). Figs. 1b and 2 show the SEM pictures and size gradation for the mica particles, respectively.

Leighton Buzzard Sand and mica were mixed at various percentage of mica. The percentage of mica meant in this study refers to the dry weight of mica relative to the total dry weight of the mixture. Three mica percentages were considered; namely 5%, 10%, 15% and then the results were compared with the clean Leighton Buzzard Sand.

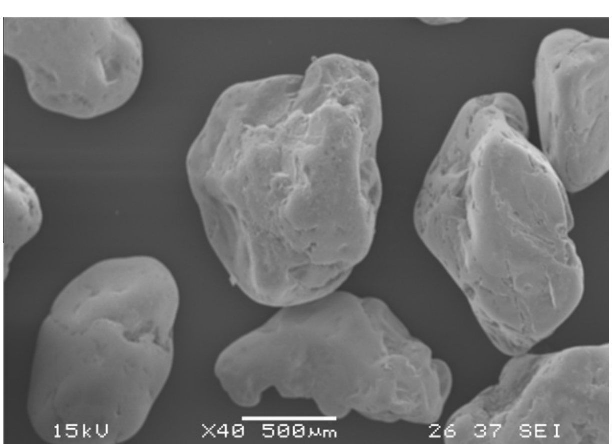

Fig. 1a. SEM picture of the Leighton Buzzard Sand used in the experimental study.

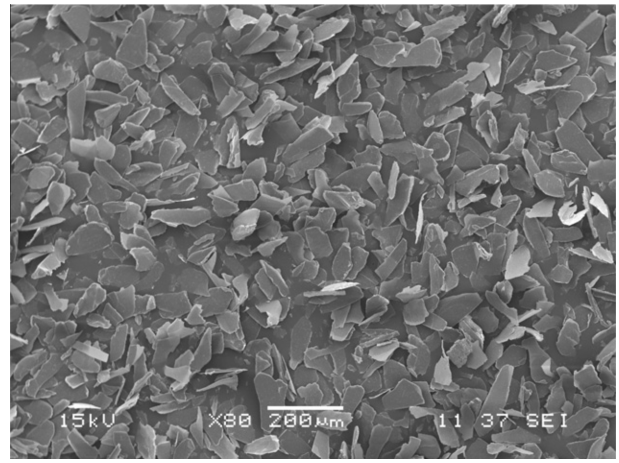

Fig. 1b. SEM picture of mica used in the experimental study.

2.2. Testing apparatus and procedures

The tests were performed in a conventional 100-mm-diameter Wykeham Farrance compression triaxial machine. Strain controlled loading was applied using a digitally controlled STALC 4958 type internal load cell at a constant rate of displacement. In order for the cell and the back pressures to be measured, two pressure transducers, PDCR 810 produced by Druck Limited, were used. Pairs of strain gauges were submersible LVDTs produced by R.D.P. Electronics Ltd., which were employed to measure the axial displacement in the middle third of the specimen in diametrically opposite positions.

Leighton Buzzard Sand fraction B, water and mica were mixed in the desired proportions to produce a uniform paste. A cylindrical membrane was attached to the bottom endplate using two o-rings and the split mold was placed around the endplate. Prepared uniform paste was then gently spooned into the split mold on the pedestal. Great care was taken to ensure that no vibration was employed. When the mold was completely filled, the excess sand particles were removed and the weight of the specimen was recorded. The top end plate was attached with two o-rings and 20 kPa suction was applied to the inside of the specimen. The split mold was carefully split to prevent any disturbance to the specimen. The test cell was then assembled and filled with water to apply cell pressure. After the test cell was completely assembled, the loading frame was placed. The suction inside the specimen was decreased while the gradually increasing the cell pressure by the desired value was achieved.

A series of isotropically consolidated undrained triaxial compression tests were carried out on the specimens at 100 kPa effective consolidation stress. During the consolidation process, the pore-pressure, cell pressure, volume, strain measurements were closely examined and recorded. Following the consolidation, the drainage valve to the specimen was closed, and then compressive load was commenced at a constant displacement rate of 0.015 mm/min.

3. Presentation and discussion of experimental results

The experimental work presented here provides an additional data set to compare the Leighton Buzzard Sand–mica mixtures in a triaxial apparatus. The test results show that the characteristics