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Research paper

Investigation on shear strength of stabilised clay using cement, sodium silicate and slag

Mohammad Vali Vakili, Amin Chegenizadeh, Hamid Nikraz, Mahdi Keramatikerman *

Department of Civil Engineering, Curtin University of Technology, Kent Street, Bentley, Perth, Western Australia 6102, Australia

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ABSTRACT

A total number of 84 direct shear tests (DST) were performed on slag, sodium silicate, and cemented clay compositions to determine how these materials affect the engineering properties of cemented clay. A constant 2% percentage (by weight) of cement in clay with three different ratios of sodium silicate (1%, 1.5% and 2.5% by weight of dry soil) were mixed with three different percentages of slag (3%, 4% and 5% by weight of dry soil) and tested based on curing times of 7, 14 and 28 days under three types of vertical load, being 50 kPa, 150 kPa and 250 kPa respectively. The results indicated that the shear resistance of cured cemented clay soil was improved by adding percentages of slag and sodium silicate, and this improvement was almost three times stronger for the third sample (1% sodium silicate and 5% slag) under a 250 kPa normal load compared with untreated soil, however sodium silicate generally showed a reverse effect on the improvement of soil shear resistance properties. Observing the visual characteristics using micrographs and X-ray diffraction patterns from the ultimate composition and each component by SEM/EDS and XRD phase analysis techniques, confirmed this improvement in shear resistance.

1. Introduction

Existence of soft clay in any geotechnical structure can be harmful due to its unpredictable changes during time and potential sudden collapses and failures (Moayedi et al., 2011).

In an attempt to remedy the weak strength of soft clay a study was conducted by Ahmed and Issa (2014). They used recycled gypsum to stabilise the soft clay. The results of their study showed that the mixture of soft clay with gypsum had a positive effect on the durability, stability, and strength of the samples. In another study by Vichan and Rachan (2013), Bangkok soft clay was mixed with a blend of calcium carbide residue (CCR) and biomass ash (BA), with results showing that stabilisation of soft clay in terms of its strength can be affected by different factors such as including the interrelationship between the ratio of clay water to binder content, and curing time. Soft clay issue stabilisation was again studied by O'Kelly (2011) with an attempt to determine whether dilute polyelectrolyte with aluminium sulphate could stabilise organic clay, with results confirming an increase in strength of the clayey mixture. In another study by Cong et al. (2014), soft clay stabilisation was sought by using a cemented base stabiliser. The results were derived by UCS tests and the results proved the positive effect of cemented stabiliser on clay. In another case by Modarres and Nosoudy (2015), the effect of coal waste on the clay showed increases in both CBR and the compressive strength of the clay. Ground granulated blast furnace slag (GGBFS) – or simply slag – is a well-known by-product that recently has drawn attention of many researchers. Yi et al. (2015) investigated the effect of lime slag in comparison with Portland cement, and found out that lime-slag acted better in improving UCS strength compared to cement by itself.

Recently, the effects on dispersive soil stabilisation of granulated blast furnace slag (GBFS) and basic oxygen furnace slag (BOFS) were investigated by Goodarzi and Salimi (2015). They concluded that the application of slag and BOFS could solve associated problems with dispersive soils (Goodarzi and Salimi, 2015).

Moreover, the effects of cement as a traditional additive have been studied in various studies. In 2015, it was also noted that the addition of cement improved the strengths of a water-soluble epoxy resins mixed in different ratios with a silty clay soil (Anagnostopoulos, 2015). Horpibulsuk et al. (2012) studied the strength characteristics of weightless cemented clays while considering swelling rates. A mixing design technique to achieve targeted strength and unit weight was proposed (Horpibulsuk et al., 2012).

Verástegui-Flores and Di Emidio (2014) also considered the impact of the sodium sulphate on characteristics of a cement stabilised clay soil, determining that sulphates deteriorated small-strain shear modulus of cement-treated clay (Verástegui-Flores and Di Emidio, 2014). Also cemented low plasticity clay was investigated in field testing. A series of laterally-loaded pile tests were conducted on cement-treated soil, and resulted in increasing lateral load resistance due to addition of cement (Faro et al., 2015). As can be seen from the literature, soft clays play an important role in construction and other industrial

* Corresponding author.
E-mail address: mahdi.keramatikerman@postgrad.curtin.edu.au (M. Keramatikerman).

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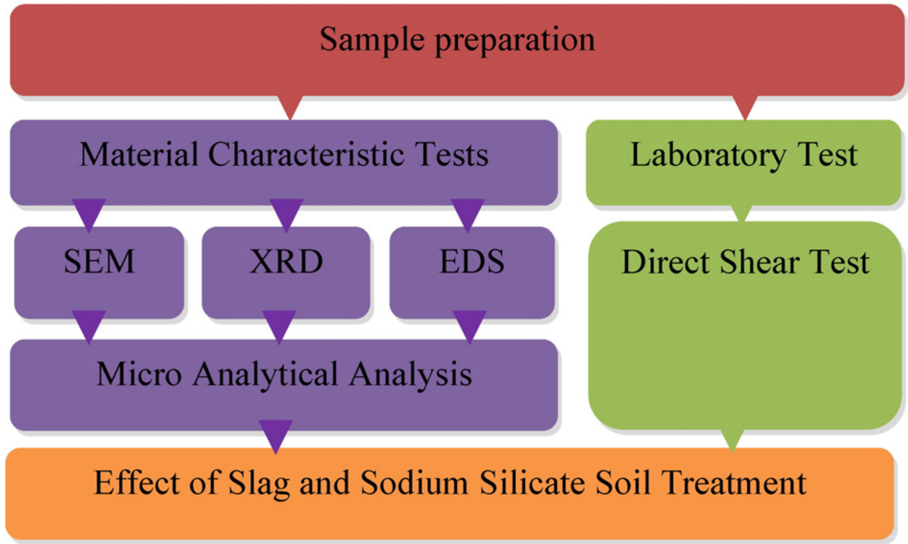

Fig. 1. Flow chart of the study.

projects, however there remains gaps to in research on the effects of chemicals in soft clay stabilisation. The aim of this research is to investigate the shear strength of clay using non-traditional methods, by adding sodium silicate, ground granulated blast furnace slag (GGBFS), and ordinary Portland cement (OPC) as stabilisers. The objective is to investigate the behaviour of sodium silicate and GGBFS, and based on past investigations, to find the best proportion of each stabiliser to use with a cemented clay soil. Throughout this study, the cement content was kept the same for all specimens. This paper is extracted from the first author's thesis at Curtin University and is part of ongoing research into stabilisation (Amiralian et al., 2015a, 2015b; Budihardjo et al., 2015a, 2015b, Hasan et al., submitted for publication). A flow chart of this study can be seen in Fig. 1.

2. Test material

2.1. Sodium silicate

Sodium silicate was used in powder format because it can be completely mixed with soil particles in dry conditions without causing any reaction. This makes simpler to use for making samples, and also in real world applications. Table 1 lists the typical properties of sodium silicate.

2.2. Ground granulated blast furnace slag (GGBFS)

Ground granulated blast furnace slag (GGBFS) used in this research has the chemical specifications described in Table 2. It is an off-white, fine-grained powder which, similar to sodium silicate, can be mixed into soil in dry conditions without causing a reaction.

Table 1
Typical properties of sodium silicate (PQ Australia Pty. Ltd, 2005).

Properties	Limits
Na_2O %	26.20–27.80
SiO_2%	54.0 (typical)
Ratio SiO_2%/Na_2O%	1.90 to 2.10
H_2O%	16.0–20.0
Bulk density kg/m3	672.78–800.92

2.3. Portland cement

Portland cement was another component used for adding to clay specimens. It can be used in the same way as GGBFS and sodium silicate in dry conditions. Table 3 lists the physical properties of the cement.

2.4. Clay

Clay was used in this project as the primary material for admixture evaluation. The clay used in this experiment was sourced in Western Australia. Fig. 2 illustrates the particle size analysis of the clay, and the chemical composition of the clay can be seen in the supplementary materials section as an energy dispersive X-ray spectrometer (EDS) test has been performed for the used clay.

3. Methodology

The mix proportion was adapted from previous research in which a maximum of 2.5% by weight of sodium silicate was used (Huat et al., 2011). A maximum of 5% GGBFS was used in the mixtures as it was assumed that this would be high enough to increase the plasticity index of the soil.

After some trial mixtures, the maximum amount of cement used was set to 2% due to the low amount of other additives used and the objective of using the least amount of cement possible. Moreover, attempts were made to use the lowest quantity of all of the additives, taking into consideration the costs associated with real world projects. Table 4 lists the number of mixing samples based on the number of additives. In this research, a small direct shear device with a 60 $*$ 60 mm box has been employed.

The use of cement in this experiment requires a curing time of 24 h to 28 days for each sample. Therefore, curing times of 7, 14 and 28 days were assigned for the testing of each sample.

Table 2
Ground granulated blast furnace (GGBFS) specification (BGC Cement, 2013).

Ingredient	Formula	Content
Calcium oxide	CaO	30–50%
Silica, amorphous	SiO_2	35–40%
Aluminium oxide	Al_2O_3	5–15%
Sulphur	S	<5%