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Research paper

Treatment of highly dispersive clay by lignosulfonate addition and electroosmosis application

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ABSTRACT

Dispersive soils are clayey, high in sodium content, and washed easily when subjected to water with low salt concentrations. The works of stabilizing dispersive soils using chemical additives from throughout the world are well documented. In the current study, a highly dispersive clay was treated with various proportions of lignosulfonate, an environmentally friendly stabilizer. A 58% reduction in dispersivity of the soil was achieved by addition of 1.5% lignosulfonate by dry mass. Meanwhile, the electroosmosis technique is known as an effective and modern soil improvement method. In the subsequent stage of the study, the effects of electroosmosis treatment on the dispersive clay were investigated by using different potentials. The dispersivity of soils taken from around the anodes was found decreased by 52% after 7 days of electroosmosis application under 48 V potential. The above two methods were capable of reducing dispersivity however, when used alone, insufficient in bringing the treated soils into the non-dispersive category. Consequently, the simultaneous treatment by lignosulfonate addition and electroosmosis application was successful in reducing the dispersivity of the initially highly dispersive clay by 65% and qualifying it for the non-dispersive designation.

1. Introduction

When exposed to water, the dispersive clay transforms into individual colloidal particles before getting washed. A dispersive clay is one with large amount of sodium ions in its pore water (Zorluer et al., 2010). The dispersivity characteristics in soils have led to catastrophic and irreversible failures of earthen structures such as dams and embankments. The conventional method of improving a dispersive clay is by chemical addition such as using lime, cement, and pozzolanic materials (Goodarzi and Salimi, 2015; Vyas et al., 2011). Numerous experiments have been carried out by researchers in studying the effects of treatment by additives to the resulting properties of the dispersive clays which were in the forms of decreased dispersivity and plasticity index, and increased strength, among others (Vakili et al., 2017; Savaş, 2016; Zhang et al., 2016; Vakili et al., 2013a, 2013b, 2013c, 2015a; Ouhadi and Goodarzi, 2006). However, certain draw backs of treatment with traditional stabilizers have been identified such as the harms brought to the environment and health risk endured by humans who are exposed to the substances, besides the limited improvements realized by the procedure (Shi et al., 2012; Vinod et al., 2010a). Thus new and environmentally friendly soil improvement methods are very much sought after (Goodarzi and Salimi, 2015; Kim and Park, 2013; Vinod et al., 2010a). Using the lignosulfonate additive and employing the electroosmosis technique which are both environmentally friendly, when used independently or together, can be considered advantageous in overcoming the limitations associated with treatment with traditional additives.

The lignosulfonate is a new stabilizer and considered modern in terms of its environmental friendly, inflammable, non-hazardous, nontoxic, and non-corrosive properties (Zhang et al., 2016; Sezer et al., 2016; Koohpeyma et al., 2013; Indraratna et al., 2012a). The lignosulfonate is the by-product of wood and paper processing industry, categorized under lignin based organic polymers, and normally considered a waste. It was found that, with increasing lignosulfonate content, the critical hydraulic shear stress of the treated dispersive soil samples increased, and the coefficient of soil erosion decreased (Athukorala et al., 2013; Indraratna et al., 2012a, 2012b; Vinod et al., 2010a, 2010b). The strength of low plasticity clay also significantly

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improved by treatment with the lignosulfonate (Tingle and Santoni, 2003). In comparison with the untreated dispersive clay, the one treated with the lignosulfonate achieved higher resistance when subjected to the erosion test (Indraratna et al., 2015). The main cause of the erosion resistance enhancement in the chemically treated soil was attributed to the increase in cohesion due to cementation mechanisms (Indraratna et al., 2008). In a research on a silty sand with high erodible character and treated with the lignosulfonate, the shear strength and initial stiffness moderately increased with increasing additive content (Indraratna et al., 2012a).

Electroosmosis, electro migration, and electrophoresis are the three different electrokinetic processes which are considered among the most powerful techniques in treating problematic soils (Jayasekera, 2015; Abdullah and Al-Abadi, 2010). The electroosmosis phenomenon refers to the migration of the pore water from the positive electrode - the anode - towards the negative electrode – the cathode - due to the hydraulic forces generated by the direct current applied in the process (Estabragh et al., 2014; Lima et al., 2012; Abdullah and Al-Abadi, 2010). The electroosmosis method could be employed in various treatment cases however its advantage in the rehabilitation of foundation materials under an existing structure is especially noteworthy. From this point of view, the method is considered as the most rapid and cost effective as the usual underpinning technique is known to be very complicated and costly. In addition, the electroosmosis application is most effective for dewatering purposes when used in soils with microporous structures (Xin et al., 2016). Unlike coarse-grained soils, clay behaviour adheres to interactive electrochemical forces instead of gravity forces due to the small size particles and thus the narrow channels running through them (Gingine and Cardoso, 2016), and the nature of the exchangeable cations and the polarization of water molecules. Hence, the low hydraulic conductivity of the clays as compared to the granular soils can be enhanced by an external electric field such as applied in the electroosmosis treatment (Xin et al., 2016).

The early electroosmosis applications were for the purposes of dewatering and consolidation; however, the subsequent uses have helped improve soil bearing capacity, undrained strength, and shear strength, and reduce dispersivity and swell potential (Moayedi et al., 2014; Kaniraj et al., 2011; Jayasekera and Hall, 2007). Nevertheless, literatures on detailed electroosmosis applications in mitigating dispersivity problems, especially those involving large scale apparatuses, are still lacking. The combined effects of stabilization by environmental friendly materials such as the lignosulfonates and new methods such as the electroosmosis have not been well addressed particularly on dispersive clays.

Thus, in addition to treatment with lignosulfonate, this study aimed to investigate the effects of electroosmosis application on the highly dispersive clay involving a fabricated apparatus, before simultaneously combining the two methods. While previous studies showed that the dispersivity problems persisted in around the cathode of an electroosmosis arrangement, this study seeks to improve the results by resorting to the lignosulfonates addition.

2. Materials and methods

2.1. Dispersive clay sample

The samples used in this study were clays dispersed in the laboratory. In order to achieve a high dispersion degree for the clays, the method involving mixing with sodium hexametaphosphate was followed (Vakili et al., 2013a, 2015b). The physical, chemical, and mechanical properties of the dispersed samples are given in Table 1 and the chemical composition of the dispersive clay sample as determined by the X-ray fluorescence (XRF) test are shown in Table 2. The sample was predominated by silica at 47% and alumina at 42%, matching its high clay content. The Na content was significant at 4.30% reflecting the highly dispersive nature of the sample; dispersive soils are clayey soils with sodium ions controlling (Vakili et al., 2017). A view of the sample provided for the pinhole test is shown in Fig. 1a while Fig. 1b illustrates the same sample after completing the test, reflecting its high dispersivity and erodibility properties.

Table 1
physical, mechanical, and chemical properties of the dispersive clay sample.

Soil property	Value
Clay content (%)	46
Silt content (%)	32
Sand content (%)	22
Liquid limit (%)	35
Plastic limit (%)	15
Plasticity index (%)	20
Soil classification	CL
Maximum dry density (g/cm^3)	1.65
Optimum moisture content (%)	19
Pinhole classification	D_2
Dispersion percent (%)	89
Unconfined compressive strength (kg/cm^2)	0.74
PH	9.12
Total dissolves solid $\left(\frac{mg}{l}\right)$	2771
Electrical conductivity $\left(\frac{s}{m}\right)$	4.33×10^3

Table 2
Chemical compositions of the dispersive clay sample.

Formula	Concentration
Al_2O_3	41.66%
SiO_2	46.58%
Fe_2O_3	5.74%
Na_2O	4.30%
TiO_2	0.73%
K_2O	0.46%
SO_3	0.11%
P_2O_5	0.10%
MgO	0.08%
Cl	0.06%
ZrO_2	0.04%
CaO	0.03%
V_2O_5	0.02%

2.2. Lignosulfonate

The stabilizer used in this study was the lignosulfonate, which is a non-toxic and non-corrosive waste material coming from the wood and paper processing industry. In the industrial process, the lignin is separated from the cellulose and since lignin does not have good solubility in water, it is converted into lignosulphonate in a chemical process called sulfonation. This by-product is available in both solid and liquid forms, which contains carbon (C), oxygen (O), sulfur (S), and sodium (Na) (Vinod et al., 2010a; Xie et al., 1991). The lignosulfonate is considered to be an economical material, easy to use, and can rapidly become effective (Vinod et al., 2010b). Note that the lignosulfonate molecular structure consists of functional groups such as OH, benzene ring, C—H stretching group, C—O bond primary alcoholic group, C—O bond secondary alcoholic group, C—O—C stretching —OCH_3 group, and S=O stretching sulfonate group (Vinod et al., 2010a). The structure of the lignosulfonate is shown in Fig. 2a. The brown coloured, pH 4, powdered lignosulfonate used in the study was completely soluble in water. A photo of the lignosulfonate used in the study is shown in Fig. 2b.

2.3. Sample preparation and methodology

2.3.1. Stabilization with the lignosulfonate

Predetermined lignosulfonate contents were respectively added to amounts of water equal to the optimum moisture content as determined