Journal of Cleaner Production 95 (2015) 89–100

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Performance evaluation of the soft soil reinforced ground palm oil fuel ash layer composite

Donovan Mujah [a,*], Muhammad Ekhlasur Rahman [a], Nor Hashimah Mohamad Zain [b]

[a] Department of Civil and Construction Engineering, Curtin University Sarawak, Malaysia
[b] Department of Science and Foundation, Curtin University Sarawak, Malaysia

ARTICLE INFO

Article history:
Received 13 August 2014
Received in revised form
23 December 2014
Accepted 23 February 2015
Available online 28 February 2015

Keywords:
Ground POFA
Soil improvement
Deformation analysis
Consolidation test
Filler effect

ABSTRACT

This study seeks to validate the possible reuse of the ground palm oil fuel ash (POFA) in soft soil improvement. POFA used in the present study was derived from the abundantly available palm oil waste residues from the nearby palm oil mill. Once the POFA is dried, it is further grounded to two different particle sizes i.e. 30 μm (large particle) and 12 μm sieve (small particle) in order to determine the effect of the POFA fineness in soft soil improvement. Furthermore, a one dimensional deformation analysis was carried out using the oedometer apparatus to investigate the effect of water saturation in soft soil samples incorporating both the original unground POFA. The result showed that the improvement factor portrayed by the smaller particle size of the ground POFA was much more pronounced as compared to the larger particle size. Similar trend was found in the consolidation results especially when the soft soil sample was fully saturated. Also, the shear strength parameters of the reinforced soft soil with ground POFA increased significantly at about 50%–60% for both the internal friction angle and the cohesion values.

1. Introduction

Soft soils can be categorized as either soft clay, organic soil and peaty soil. The main difference of these type of soils is their organic content. Peaty soil can contain 75% or more organic matters (Huat, 2004). Peaty soil has low shear strength, low bearing capacity and high compressibility, which leads to excessive settlement (Huat et al., 2009).The main problem for peaty soil is its high water retention characteristic. High water content in soft soils causes lower density and ultimately low resistance towards bearing loads compared to other soil types. In addition, the shear strength of peaty soil is exceptionally low due to the lack of cohesiveness between soil particles in the presence of excessive water as a lubricant. These deficiencies present especially in peaty soil are the primary obstructions for building on soft soil in most part of the world. In previous years, most of the construction projects in the world involving soft soil were done after soil replacement had been carried out. The top layer of the soil is removed by bulldozers and loaded into a dump truck similar to the method explained by Humphries (2000). Soil replacement methods are at times associated with high costs such as transportation of the 'good' soil to the construction site. It may therefore not be economical to use that technique to stabilize the soil. Even when moderate loads are applied, peaty soil will undergo primary and secondary consolidation settlements.

Currently, numerous techniques have been used to improve soft soil in various parts of the world. In the USA, Black et al. (2007) and Gniel and Bouazza (2009) have demonstrated the use of stone column to improve sandy soil. They found that the final strength of the improved soil can be enhanced about 15%–40% of the initial strength. In Thailand, Horpibulsuk et al. (2012) showed that the final strength of the reinforced Bangkok soft clay was significantly improved by imposing the method of both sand and stone columns reinforcement. They attributed this as mainly due to the suction of the unsatutared condition of the partially filled clay voids in the sand-stone-clay soil column matrix. Similar results were observed by Lo et al. (2010) and Kim et al. (2013) dealing with Korean clayey sand. This gap suggests that in much finer soil i.e. organic soil such as peaty soil, more realistic approach in dealing with the soil interparticle voids must be addressed.

To tackle the effect of suction, researchers like Chu et al. (2006); Sinha et al. (2009) and Saowapakpiboon et al. (2010) introduced the

* Corresponding author. Department of Civil and Construction Engineering, School of Engineering and Science, Curtin University Sarawak, CDT 250, 98009, Miri, Sarawak, Malaysia. Tel.: +60 85 443 939; fax: +60 85 443 837.
E-mail address: dmujah@curtin.edu.my (D. Mujah).

http://dx.doi.org/10.1016/j.jclepro.2015.02.058
0959-6526/

use of the pre-vabricated vertical drains (PVD) mainly for soft Bangkok clay. Their findings suggest that though the effect of suction is fully dismissed by fully saturating the soil samples with water but the repeated water flushings into the PVD might have cause extrusion problems thus, affecting the stress history of the sample. Similar findings were observed by Saowapakpiboon et al. (2011) and Abuel-Naga et al. (2012) with clayey Bangkok sand.

More recently, some studies have opted for geotextiles to improve soft soil. Ahmad et al. (2012) and Mwasha (2009a, b) have used natural fibres to strengthen the shear strength parameters of soft soil. They found that the final strength of the reinforced soils were increased about 10%–20% of the initial strength when the natural fibres were coated with resin. Hazarika et al. (2010) and Mujah et al. (2013) studied the possible reuse of recycled glass fibres as ground improving geomaterial. Their results showed that by coating recycled glass fibres with acrylonitrile butadiene styrene (ABS) thermoplastic, they can get an improvement factor of at least 0.3 from the initial sample strength.

Not only in the improvement of the soft soil has the used of natural fibres gained popularity but also in the enhancement of the concrete strength. Studies by Yusoff (2006), Al-Oqla and Sapuan (2014) and Shafigh et al. (2014) have showed that natural fibers such as empty fruit bunches and jutes can be used to improve the strength of concrete. They reported that the final compressive strength of the concrete sample reinforced with natural fibers can be increased to about 30%–50% depending on their particle sizes.

Although previous studies utilizing various techniques have shown the potential improvement towards the shear strength parameters of soft soil and concrete, the present research focuses on the reuse capability of ground POFA derived from the palm oil waste residues to not only strengthen but also improve soft soil condition through its filler effect.

2. Motivations for the reuse capability of the ground POFA

The main motivation of using ground POFA as soft soil improvement material stems from the fact that the small particles of the ground POFA will induce reinforcement towards the soft soil inter-particle. The small particles of ground POFA will fill all the voids inside the soil strata and hence improve the soil's shear strength parameters through the filler effect. Earlier study conducted by Jaturapitakkul et al. (2011) has shown that the ground POFA is able to enhance the compressive strength of mortar by replacing Type I Portland cement at 10%–40% by weight of binder. Their results showed that the compressive strength of mortar due to the filler effect tended to increase slightly with increased cement replacement. (Tangchirapat et al., 2007) had used POFA as pozzolan in concrete. Their results revealed that the compressive strengths of concrete at 90 days for the concrete containing 10%–20% replacement of the fines of POFA; 7.4 μm–15.9 μm, showed higher value than that of concrete made from Portland cement Type I. Similar trend of results were observed in the later research conducted by the same researcher (Tangchirapat and Jaturapitakkul, 2010). Also compared to other pozzolan, ground POFA is a proven reactive pozzolan thus, it will surely help to improve the soft soil condition.

A study by Jaturapitakkul et al. (2011) examined the pozzolanic reaction of ground POFA and found that the compressive strength of mortar due to the pozzolanic reaction increased with increasing particle fineness, replacement rate of cement and age of the mortar. Moreover, POFA is in abundance due to the fact that Malaysia produces about 47% of the world's supply of palm oil (Sumathi et al., 2008). Also, ground POFA used in the present study is derived from the palm oil mill as waste residues which in turn translates to the low procurement cost of such material making it the most viable alternative for soft soil improvement (Muntohar and Rahman, 2014).

(Rahman et al., 2014) developed masonry block using POFA as partial replacement for cement and found out that the compressive strength of the tested blocks incorporating POFA is directly proportional to the percentage replacement by mass. They also reported that the durability of the tested samples satisfy the requirement of ASTM C55-11. In short, their study suggested that POFA based masonry block has a significant potential for application in the construction industry.

Although previous studies had showed the applicability of utilizing ground POFA as filler material in concrete production, none of the study recorded the potentials of using ground POFA in soft soil improvement. Hence, this paper attempts to investigate the possible reuse of ground POFA in soft soil improvement by looking at the soft soil's shear strength parameters (internal friction angle and cohesion value) enhancement as well as the soil's one-dimensional deformation characteristics through consolidation test. To our knowledge, this study is the first of its kind in attempting the use of ground POFA as soft soil improvement agent and the benefits it may bring to the shear strength parameters improvement of the soft soil sample in the current research.

3. Materials and methods

The laboratory work consisted of testing the soft soil sample, assorting the ground POFA to its desired sizes, direct shear and consolidation tests were done in the facilities available in the Curtin University Sarawak, Malaysia. Both direct shear and consolidation tests were carried out using American Society for Testing Material (ASTM) standards to evaluate the laboratory scaled model of soft soil sample reinforced with ground POFA.

3.1. Soil sample

The soil sample used in this study is the Borneo soft soil that was collected at a location along Miri-Marudi road, about 35 km from Miri. Fig. 1 shows the distribution of the soft soil deposits in Malaysia and the location of where the current sample was taken from. The sample used is one of the soft soil types in Malaysia which contains organic matter and peat. The soil sample was oven-dried to ensure that there is no moisture content that will affect the soil compaction test. Before experiment, the wood fibres and plant roots were removed from soil samples as these impurities might also affect the experiment results. The typical particle size distribution curve of the soft soil sample is shown in Fig. 2 while its geotechnical properties are tabulated in Table 1.

Fig. 1. Soil sampling location.