The Fundamental Compressibility Characteristics of Solidified Dredged Marine Soil

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Abstract

Yearly large amount of dredged soils is produced during construction of marine structures in Malaysian waters. Dredged soils are generally dumped or deposited in open water, upland or hydraulic fills. As dredged soils consist mainly of clay, some sand and other minerals, they generally display high compressibility, low yield stresses and low permeability. In order to improve the material‟ s properties for possible reuse as sound geo-materials, the addition of solidifying agents, such as ordinary Portland cement (OPC) and fly ash is necessary. This study was aimed to determine the one-dimensional compressibility the treated soil, with relation to the solidifying agent dosage and curing period. Standard oedometer tests were carried out on the untreated and treated dredged soils for comparison purposes. The dredged soils were collected from Sungai Dinding, Lumut, Perak. The solidification was carried out with addition of 10 % solidifying agents by dry weight of the soil, with OPC and fly ash mixed at different proportions. The untreated and mixed samples were lightly kneaded and pressed into individual consolidation rings, measuring 75 mm in diameter and 20 mm in height. The specimens were then cured in a dry condition for 3 and 7 days. The oedometer test results showed encouraging solidification effect of the originally soft, weak dredged soil, where compressibility reduction exceeding 60 % was attained with the OPC-fly ash mixture. The enhanced stiffness also indicates decreased permeability of the treated material, an engineering property desirable in load-bearing geo-materials.

Keywords: Dredged soils, cement, fly ash, oedometer, compressibility

1.0 Introduction

Dredging can be defined as underwater excavation of soils. It is a necessary activity to maintain existing waterways, ports and water channels. The requirement of increased waterway depths may be due to the increased demand for transportation of people, equipment, materials and commodities by water. Besides that, dredging process is also used in flood control measures to maintain or improve the flow capacities of the river or channels. The soil excavated from the waterways, whether in the sea, river or port is known as dredged soil. Generally, such dredged materials consist of sands, silts, clay and other material from underwater. In Malaysia, the dredged soils have yet to be recycled and reused, but mainly disposed of in designated open water, upland or hydraulic fills onshore. However, for soils which contain contaminants, the placement options should be considered in terms of environmental sensitivity and responsibility (IADA & IAPH, 2010).

The dredged soils are very similar to soft clay soils on land, with typical low load-bearing capacity, high compressibility and low permeability. These properties make the soil unfavourable for construction purposes. On the other hand, continuous disposal of the material, whether offshore on inland, does not constitute sustainable practice, considering that the material could be reused, and that the dumping procedures almost always incur one or other environmental concerns. Hence, if the dredged material is to be reused as a sound geo- material, the naturally weak and soft characteristics need to be treated. A possible solution is the solidification technique, where hydraulic binders are admixed with the wet soil to dry and stiffen it chemically.

Based on the above, the present study was conducted primarily to examine the fundamental one-dimensional compressibility of the treated dredged soil. The solidifying agents used are ordinary Portland cement (OPC) and fly ash, a byproduct of coal power plant processes. The fly ash, if chemically active, would serve as a substitution of cement for cost-saving. Alternatively, if it is inert, it could function as a filler material to lend structure and stiffness to the originally soft material.

2.0 Background Study

2.1 Solidifying agents

Cement and fly ash are used in this study. Ordinary Portland cement (OPC) is defined as "hydraulic cement produced by pulverizing clinker consisting essentially of hydraulic calcium silicates". OPC is commonly characterized as being low cost due to the widespread availability of the raw materials, i.e. limestone, shales, etc. The most common type of OPC used in solidified soil is Type I Portland cement. This is due to its availability and lowest cost price compared with other types of cement (Ho, 2008). The fly ash used was retrieved from coal power plant in the local area. Fly ash mostly consists of silt-sized glassy spheres which are calcium oxide, silica and alumina (Rifal et al., 2009). Class C fly ash is self-cementing, with cementitous products similar to those observed in the hydration of OPC (ASCE, 1993). Nonetheless, the properties of fly ash are greatly dependent on the parent material (i.e. coal formation processes) and subsequent combustion conditions, making it highly non-homogeneous and inconsistent in terms of basic characteristics. As such, the function of fly ash, whether as a cementitious material or inert filler, is also investigated in the present study, as mentioned in *1.0*.

2.2 Solidification with cement

The cement solidification technique has been widely used for the past years to improve the performance of poor quality soils, in terms of the physical, chemical and engineering properties. The improved engineering properties of cement-treated soils are mainly attributed to the cement hardening effect. It is due to hydration, where the moisture of the soil reacts with cement, as well as the lapsed time between admixing and load-bearing, i.e. curing period. The addition of small amounts of cement, as little as 2 %, can effectively modify the properties of a soil. The suitable range of cement contents for clay may range from 3 to 16 % by dry weight of soil (Lee & Ali, 2004), though this is a conservative estimation, taking into account the high variability of soil properties which dominates the solidification outcomes.

2.3 Solidification with fly ash

Fly ash used for soil improvement has the advantage of being environmental-friendly and sustainable to a certain extent, as it is but an industrial waste from the coal power plants. As a solidifying agent, there are two primary mechanisms by which fly ash could alter the soil to form a stronger and more stable matrix, i.e. (i) increase in particle size by cementation leading to higher internal friction resistance, resulting in overall greater shear strength with reduced plasticity and shrink/swell potential; (ii) absorption and chemical binding of moisture to enable more efficacious compaction, hence better strength and load-bearing capacity (Rifal et al., 2009).

2.4 Effect of curing time and solidifying agent dosage

Due to pozzolanic reaction with time, it is generally accepted that the longer the curing period, the better the strength development. As reported by Kamaruzzaman et al. (1998), cement-treated Singaporean marine clay showed significant curing effect in the physical properties, unconfined compressive strength and compressibility characteristics, such as the decrease of compression index (C_C) with longer curing period.

Rekik & Boutouil (2009) experimented with two different groups of cement contents on a dredged marine soil sample, i.e. (i) dry cement content between 2-10 % by wet weight of soil, cured for 7 and 28 days; (ii) dry cement content of 10 % by wet weight of soil, cured for 3 and 58 days. It was found that the effective curing period for determining the maximum value of pre-consolidation pressure (or yield stress for solidified soils) was 28 days, where the maximum yield stress for specimens with 10 % cement addition tested at 7 and 28 days was 120 kPa and 210 kPa respectively. The authors also observed that the compressive index (C_C) increased during the first 3 days of curing but did not change significantly after that up to the curing period of 58 days.

3.0 Materials and Methodology

3.1 Preparation of Specimens

The dredged soils were oven-dried for 24 hours at 105°C and sieved with a standard No. 16 (1.18 mm) sieve, where only particles smaller than the aperture was collected for mixing and formation of test specimens. The total dosage of cement-fly ash added to the soil was kept at 10 % by the dry soil mass, and prepared at different pre-determined fly ash : cement (FA:C) proportions, as shown in Table 3.1. The sieved dried soil sample was mixed with measured quantities of fly ash and/or cement at 1.75 times the optimum moisture content (OMC = 24 %), as obtained from the compaction test. The additional water used for admixing was necessary to avoid prematurely dried out or crumbly mixtures, which could result in non-uniform distribution of the solidifying agents.

Table 3.1: Summary of test specimens.

Mix Proportion (FA:C)	Fly Ash Content (%)	Cement Content (%)	Curing Period (days)	Specimen
100:0	10	0	3, 7	0C10FA
70:30	7	3	3, 7	3C7FA
50:50	5	5	3, 7	5C5FA
-	0	0	-	0C0FA

* FA = Fly Ash, C = Cement

The mixture was stirred mechanically in a conventional kitchen mixer for approximately 10 minutes till a homogenized paste was formed. The mixture was then placed in the oedometer ring of 75 mm in diameter and 20 mm in height in two layers. Each layer was lightly tamped with a steel cylindrical rod (diameter 10 mm) for 40 times. Before placing the second layer, the top of the first compacted layer was scratched to allow better fusion of the two layers. The tamping method was chosen to deliver a light kneading and pressing motion to the mixture instead of the commonly used static compaction technique, because the latter could risk producing ‘bottom-heavy’ specimens (i.e. non-uniformly compacted specimens with density variation over the height within the mould). The ends of the specimens were carefully trimmed flat to avoid poor contact with the porous stones during tests. The specimens were finally wrapped in cling film and left to cure on raised platforms in buckets filled with water and bleach for 3 and 7 days prior to testing. The bleach solution was for fungal growth prevention during the curing period.

3.2 Oedometer Test

Oedometer test was carried out by following the procedure prescribed in BS 1377: 1990: Part 5. The ring containing the cured specimen was placed between the two porous stones, one at the top of the specimen and another at the bottom. Incremental vertical stress was applied as follows: 12.5, 25, 50, 100, 200, 400 and 800 kPa, with each load being maintained for 24 hours.

4.0 Results and Discussion

4.1 Physical properties of dredged soil

The relevant soil data required for computations of the oedometer test results, i.e. specific gravity of the soil grain, moisture content and other soil properties are as shown in Table 4.1. Note that the dredged material was mainly fine-grained silt and clay particles.

Table 4.1: Physical properties of dredged soil.

Parameter	Value
Moisture Content	166%
Specific Gravity, G_S	2.56
Plastic Limit	34.4%
Liquid Limit	95.8%
Sand	22% 78%
Silt and Clay	

4.2 Compressibility

Figure 4.1 shows the settlement curves for all specimens, as recorded in the oedometer tests. Referring to the low-lying plot for the original soil (0C0FA), the treated specimens recorded an average of approximately 68 % settlement reduction. This suggests stiffening of the soil mass, either by cementation alone or with the filler effect mentioned earlier (see *2.1*). The solidification process also transformed the soft soil into a structured mass, as demonstrated by the curvature of the treated specimens’ plots. The initial part of the curve with a gentler slope shows the pre-yield state, while the second part with a steeper plot represents the yield state. The intersection of the two parts gives the yield stress (σ_y’), a parameter commonly used in the study of solidified soils to indicate the maximum vertical stress bearable by the soil before failure, i.e. excessive compressibility. Also, it is apparent that the extended curing period of 7 days did not contribute significantly to the improved compressibility, where the compression curves for all the pairs of 3d and 7d treated specimens did not differ much. Nonetheless the longer curing time did result in slightly lower compressibility, i.e. the 7d curve lies above that of

3d.

Figure 4.2 illustrates an example of the possible function of fly ash in a cement-fly ash blend. Incorporated in the same figure is the data from Chan (2006) on the cement-treated soft clay (MC: water content = 74 %, G_S = 2.66), cured for 7 days, as well as the data from the present study with the same cement content, i.e. 3C7FA. With a much higher mixing water content, 3 % cement produced marginal reduction to MC's compressibility. On the other hand, a 3C7FA blend reduced settlement of the present dredged soil by almost 70 %, besides giving structure to the initially weak mass. As such, it can be concluded that with low cement dosages, prolonged curing cannot ensure meaningful stiffness gain in solidified soils, and that the mixing water content plays an important role too for effective solidification.

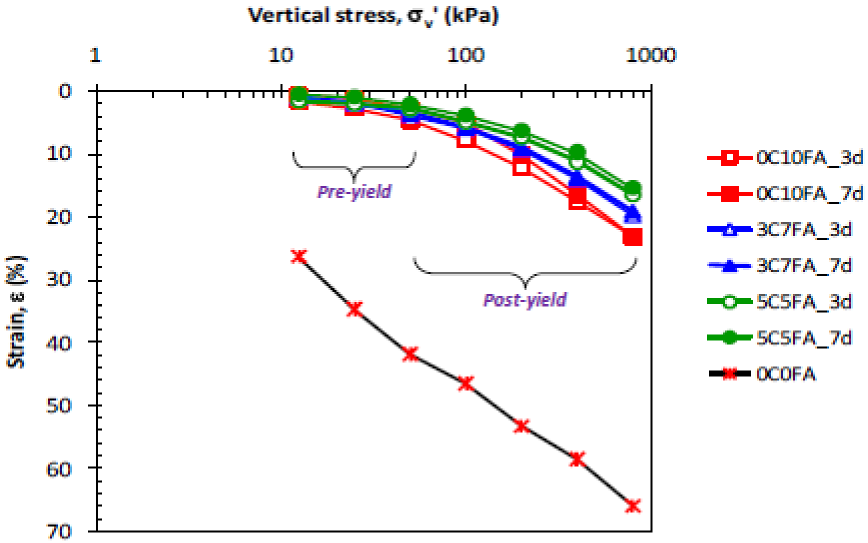

Figure 4.1: Compression curves for all specimens

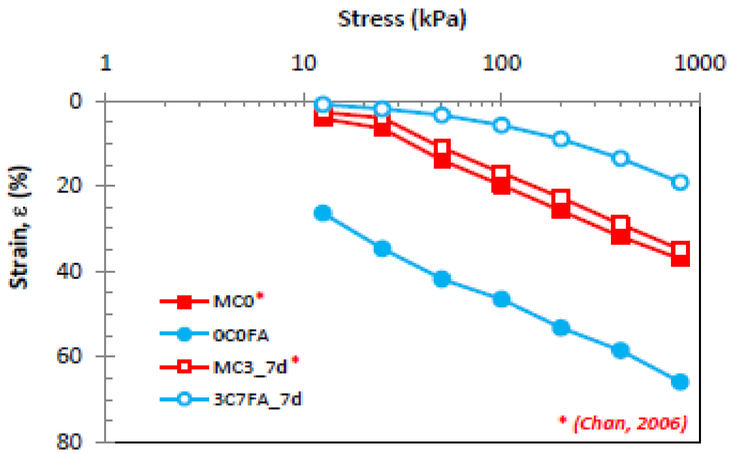

Figure 4.2: Stiffening effect of fly ash in solidified clay soils.

4.3 Yield Stress (σ_y') and Strain (ε f)

Figure 4.3 shows σ_y' plotted against curing period for the solidified specimens. Overall σ_y' increased with cement content (i.e. 5C>3C>0C), but the most significant increment over time was demostrated by 0C10FA, i.e. $\approx$ 53 %. This is indeed contradicting with reports by Kamaruzzaman et al. (1998) that time effect on the yield stress is dependent on the cement content, as the specimens with the least cement dosage (i.e. 0C10FA) showed the highest increment. However, considering the absence of a certain pattern in σ_y'/7y" evolution with time for the same dosages of solidifying agent and a large quantity of data, further work is necessary before any conclusions can be made.

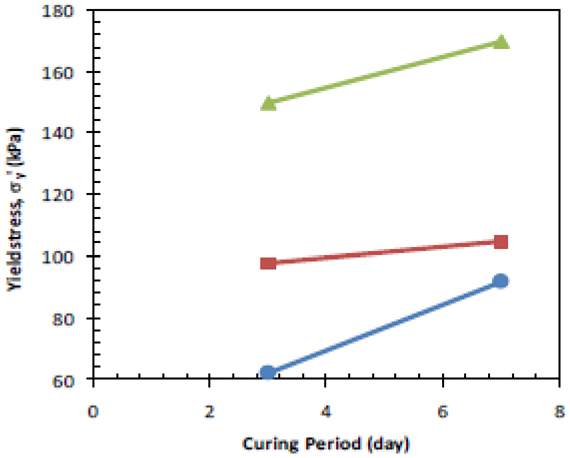

Figure 4.3: σ_y' versus curing period.

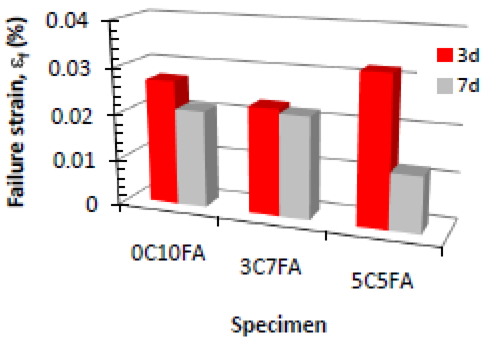

Figure 4.4: Failure strain (ε_f) of treated

Figure 4.4 shows ε f (the strain which corresponds with σ_y' for the solidified specimens. Again there appeared to be no specific relationship between cement and fly ash dosages with ε f, though lower cement content seemed to cause greater deformation pre-yield. The curing period did not show any dramatic changes in ε f, except in 5C5FA which registered approximately 65 % reduction. This suggests stiffness gain, where the solidified specimen became more rigid and yield at lower strain. In fact, this low ε f is in agreement with the highest σ_y' discussed above. It is hypothesized that fly ash takes longer to stiffen the soil compared to cement, and that the threshold for effective stiffness gain in this case is 5 % cement.

5.0 Conclusion

The following are the conclusions that drawn from the study: Curing period of 1 week is insufficient to produce significant stiffness gain in the dredged soil specimens treated with cement-fly ash. The mixing water content affects the resulting compressibility of the treated soil, where wet samples generally require higher dosages of solidifying agents. The yield stress and failure strain - curing period relationship is unclear and requires more study.

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