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Accelerated Consolidation of Dredged Marine Soils With Incorporation of Granular Wastes as Drainage Layers

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Abstract. Dredging activities for nearshore marine facilities maintenance and development have long been known to bring adverse effects to the environment potentially. It is particularly so because of the disposal of unwanted dredged materials (DMS) at sea, which disrupts the balance of the marine ecosystem. On the other hand, industrial by-products and construction wastes such as palm oil clinker (POC) and recycled pavement materials (RPM) respectively have posed dangerous menace too on land with poorly managed dispossessing these waste materials as substitutes for virgin materials in the construction industry significantly loosened their negative impact on the surrounding. This paper presents the experimental program of a series of oedometer tests simulating the reuse of DMS as reclaimed backfills, incorporated with granular drainage layers of POC and RPM to expedite the consolidation process. The dissipation of excess pore water from the soil and resulting settlement was observed at a shorter time in the sample with the POC drainage layer than the one with RPM. The subsequent reduction of compressibility and improved stiffness of the DMS enabled it to sustain a more significant load via the pre-loading approach, where subsequent subsidence of the reclaimed ground would be predictable and limited. The findings give a promising notion of reusing the granular waste materials as an incorporated drainage layer for DMS reuse in reclamation works, simultaneously accelerating the consolidation process and giving useful second lives to the otherwise waste materials, with many potential applications in other areas of civil engineering too.

INTRODUCTION

Dredging creates vast piles of marine sediments, also known as dredged marine soils (DMS). The extraction of DMS from the seabed is to maintain the depth of vessels and prevent river stream flooding. DMS is usually soft soil consisting of silt, clay, clay, and small-scale seashell debris. Therefore, DMS can be considered as *geo-waste* materials with low shear strength and permeability as well as high compressibility. Because of the limited space of landfill sites to dispose of DMS, it can be reusable material for geotechnical applications such as land reclamation projects unless contamination is excessive. The adverse environmental effects should be assessed since DMS may contain toxic substances such as heavy metals, especially near the highly industrial coastal area. It may contain lead, mercury, copper, or arsenic from industrial activities. Dredged sediments have been proven (1) to prevent varying degrees of concentration of *Escherichia coli (E. coli)*. Based on the Centres for Disease Control and Prevention (CDC), *E. coli* are bacteria that live in the digestive tracts of humans, animals, the environment, and foods. There are many types of *E-coli*, they are mostly harmless, but some are capable of making humans and animals sick. It can cause bloody diarrhea, severe anemia, or kidney failure.

The usage of natural sources such as gravels (aggregates) or sand in construction has increased., Still, this practice contributes to global warming, which leads to extreme and unpredictable weather conditions. The disposal

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of waste products from different industries is a growing challenge these days(2) reported that most of the waste materials inadvertently contribute to environmental pollution do so because of their non-biodegradable characteristics. Therefore, the ecological consequences of reusing these materials need to be thoroughly investigated to create a sustainable and eco-friendly balance. Increasing economic and environmental considerations have moved the industry towards recycling steel, aluminum, plastic, and other waste materials for various second lives (3).

The palm oil industries produce a massive amount of palm oil wastes, one of which is palm oil clinker (POC). In Malaysia alone, palm oil production has undergine a steady climb because of market demand, and it is targeted to be 100 million tonnes in 2020 (4). POC is a biomass waste material from palm oil shell incineration and can be obtained in large chunks (Fig. 1a). POC is treated as a waste for disposal with little commercial value. Hence it is generally dumped into the wastelands behind the mills (5). Other than POC, recycled pavement m, materials (RPM), as seen in Fig. 1(b), are also produced during milling, where milling machines remove the old paved surface for rehabilitation and repairs. Environmental concerns and regulations have long since forbidden displaced pavement waste materials to be placed or left either on the road shoulder or land surface. This is because the waste could be contributing to land contamination due to the bitumen content present.

Several studies are conducted to investigate the possibilities of using sand in place of cement and lime in seabed stabilization works, which could lead to reduced construction costs and enhanced ‘green’ values. It was generally observed that in these projects where the seafloor is very soft, the deposited sand particles would slowly penetrate the soft layer, hence increasing the amount of sand required for the consolidation works (6) (7) (8) (9)(10). Past projects using sand drains to discharge excess pore water include the Manila Bay Reclamation Area (11)(12) (13) (14).

(a) (b)

FIGURE 1. (a) Palm oil clinker (POC); (b) RPM abandon after road maintenance work.

A project in Bremerhaven, Germany, reported the application of DMS for backfilling with the combination of geotextile and sand layer to expedite consolidation (15)(16)an experimental using oedometer test with silty clay layered with ballotini of glass beads. It was found that settlement increased with ballotini glass beads in the soil during the loading-unloading cycles. This phenomenon was attributed to the rearrangement of the granular materials and parent soil. The time-dependent settlement process was initially delayed by the clay soil's delicate pores, with inherently lower hydraulic conductivity than the filler beads. The introduction and eventual penetration of ballotini beads into the soft clay layer changed the soil fabric and increased the pore size, increasing the consolidation rate. Thus, acceleration of consolidation was facilitated with hydraulic modification, a simple yet effective technique for application in the field (17).

The present study explored the efficacy of incorporating POC and RPM as drainage layers for the soft DMS used as backfills in the pre-loading stage of reclamation. It was aimed to establish the possibilities of using the granular waste materials to speed up consolidation of DMS before external load application. This would ensure the DMS backfill would not undergo excessive settlement under loading due to consolidation, where the excess pore pressure of the water in the soil voids forces pore water to be discharged, leaving empty voids to be filled up by the soil particles, i.e., manifested as overall subsidence of the soft ground.