Influence of Drainage Layer Thickness on the Preconsolidation Rate of Dredged Marine Soils: A Lab Simulation

Siti Farhanah S.M Johan¹ and Chee-Ming Chan¹
¹Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Johor Darul Takzim, Malaysia
E-mail: chan@uthm.edu.my

Abstract. This study conducted to investigate the improved consolidation rate of dredged marine soils used as backfills in land reclamation, with the aim of making the material’s reuse more favourable on site compared to disposal as in the normal practice. In order to quicken the dissipation of excess pore water under loading, efficiency of the drainage layers sandwiching the dredged marine soil plays an important role. With modification of a large oedometer, the present study examines the efficiency of three granular materials, i.e. sand (S), palm oil clinker (POC) and pavement milling waste (PMW) in two different drainage thicknesses for the effective discharge of pore water during consolidation of the dredged marine soils. With sand adopted as Control, it observed that thicker layers (100%) of the granular materials produced higher consolidation rates by 10% compared to 50% of thickness. Settlement reduction also found at POC and PMW as the drainage layers, i.e. 0.6% and 0.5% respectively in comparison with sand. Obviously, the improvement of DMS consolidation about 2% when implantation of granular layer.

1. Introduction
For past decades, dredging project has been an economical solution to the problem related to the siltation of channels, land reclamation and increasing ship sizes. However, this activity gives negative effect on the marine life and social impact on the fishery activities, recreation, and navigation [1]. The retraction of sediments using dredger machine produced higher water content in the range of 200% to 900%, which indicate that dredged sediments are in slurry/ flow state [2]. The dredged sediments known as dredged marine soils (DMS) with poor engineering properties and commonly disposed and not reusable. Numerous researcher identified the beneficial reuse of DMS such as erosion control, shoreline stabilisation and construction purposes unless the contamination found to be excessive [3-4]. There was a lot of benefit from reusing the DMS rather than disposed of it, especially towards the marine ecosystems. Consolidation is the process of soil compression over time by dissipating excess pore pressure. When pressure being applied on saturated consolidating soil, the compression process results in water or air expulsion from void spaces, reduction in water content, deformation and relocation of soil particles. For single drainage, the soil sample rests on an impermeable base with an upward direction.
for the drainage path. The upward and downward flows represent double drainage for a soil sandwiched between permeable boundaries on the top and bottom.

In this case, Berry and Reid [5] stated that the consolidation of the lower half of the soil layer is a mirror image of the upper half. The excess pore water pressure would occur at the centre and bottom of the soil under double and single drainage conditions respectively. The objective of this study to accelerate the consolidation by using the granular materials as drainage layer especially during the land reclamation. Granular materials can be very diverse in terms of its applications and types. The disposal of waste products from different industries is a growing challenge these days. The waste materials could be reuse as backfill materials, road pavements or concrete materials. Yet, the development of advancing the applications by reusing the waste as partial reinforcement in composite materials is still ongoing. Using recycled materials in construction applications will reduce the negative impact on the environment. It also provides an alternative to reduce the usage of natural aggregates, which is one of the key issues in the construction industry [6].

2. Materials and Method
The dredged marine soils were collected from Kuala Perlis during the dredging works by Malaysian Marine Department. The soil samples dredged at a depth of 4 – 6 m from the seabed using backhoe dredger. All the DMS samples retrieved must be handle carefully with double lined the layer of heavy-duty sampling bags, keep it stored inside the white pails and tightly sealed. This to make sure the moisture loss during the transportation back to laboratory at Johor. Materials for the drainage layer i.e. sand, palm oil clinker (POC) and pavement waste materials (PMW) used in this study. POC is a waste material of biomass from the incineration of palm oil shells at the palm oil mill in Kluang, Johor. PMW was collected during the maintenance roadworks at Melaka. All the characterisation of materials were based on BS 1977 [7].

The soil specimen placed in the oedometer ring (100 mm x 100 mm) with porous stones at the top and bottom of the specimen with pressure applied in the vertical direction and deformation occurs. Two configurations as shown in figure 1 including control specimen (DMS). Granular materials such as sand, PMW and POC layer placed on top and bottom according to the thickness required in illustration Figure 1b and 1c. The thickness of drainage layer used in this study was 50% and 100% by dry weight of DMS, which 16 mm and 32 mm (total two layer on top and bottom) respectively. To prevent the penetration of granular into the DMS, a separator of non-woven geotextile are used. Noted that the specimens was the disturbed soil. The oedometer test assumes that the soil sample is fully saturated and the laterally confined to avoid the moisture loss. The sample kept fully submerged in water during the test. Every load increment placed after the sample reached the settlement occurred after t100, i.e. after full dissipation of excess pressures or equilibrium state reached. Each stress was doubled from the previous, i.e. 6.25, 12.5, 25, 50, 100, 200, 400 and 800 kPa.

![Figure 1. Configurations of drainage layer specimens; (a) control; (b) 50%; (c) 100%](image-url)
3. Results and Discussions

3.1. Characterisation of Materials

According to the Unified Soil Classification System (USCS), DMS classified as high plasticity of clay (CH) with 61% clay, 38% silt and only 1% sand. The initial \( w_c \) of DMS is 218% with the ratio \( w_c/LL \) is 2.96. The main chemical compounds detected in the DMS are sodium oxide (Na\(_2\)O) with 46.22% followed by 30.53% of silica oxide (SiO\(_2\)) and 13.38% of alumina (Al\(_2\)O\(_3\)). Na\(_2\)O found to be the highest constituent as the material came from the seabed. Silica oxide traced in the mineralogy as quartz, which can be found in sand or aggregates. The XRD analysis of DMS observed to consist of peaks corresponding to phases of the specimen. As shown in Figure 2a, the plot shows the presence of quartz, halite, illite, montmorillonite, biotite and albite as the main crystalline phases in the DMS. The size of granular materials is in the range of 2.00 – 2.36 mm. Based on USCS, sand and POC were classified as well-graded sand (SW) and well-graded gravel (GW) respectively, while PMW was considered as poor-graded gravel (GP).

The chemical compound from the XRF analysis found that PMW has 68.27% SiO\(_2\), 15.63% Al\(_2\)O\(_3\), 5.9% Na\(_2\)O and 3.53% K\(_2\)O. Other components traced but lower than 2% only. Other impurities such as bitumen found on the aggregates. As well as POC, the major element compound detected consist of 73.04% SiO\(_2\), 7.895% Al\(_2\)O\(_3\), 7.667% K\(_2\)O, 3.1% MgO, 2.9% CaO and 2.2% Fe\(_2\)O\(_3\). The morphology of PMW from FESEM (Figure 2b) shows the smooth, sharp-edged and flat shaped particles. XRD diffraction analysis used to trace the mineralogical properties of PMW. The peaks of the main trace phases, including quartz, albite, dolomite and mullite detected in the region of 22 - 68° 2θ. Figure 2c shows the XRD and FESEM of POC. POC categorized as generally angular and irregular in various sizes and diameters. Irregularities clearly seen the flaky while some had with sharp edges and semi hexagonal type of pores on its surface. It shows micro pores of small, medium and extra-large sizes.

3.2. Comparison of Drainage Layer Thickness During the Consolidation

Void ratio-effective vertical stress (\( e-\log \sigma' \)) curves in figure 3 and figure 4 were measured by the modified large oedometer test as mentioned in section materials and method. A clear bending point corresponding to yield consolidation observed at 25 kPa. At the first stage of compression (6.25 – 12.5 kPa), all the granular materials seem enveloped or overlapping with each other especially for 32 mm (100%) of drainage layer thickness. Contrary to the 16 mm (50%), where the PMW-50 and S-50 were the only overlapping but happens at 12.5 kPa until 50 kPa. At certain point, the behaviour of both drainage thickness regardless of the granular materials, the line curves show the workability of materials as good drainage used in this study. PMW-100 shows the less settlement followed by S-100 and POC-100 respectively. Even though PMW-100 is a waste material, does not mean that it has poor drainage ability compared to S-100 (clean sand).

The bitumen coating at the PMW could be the reason because of the slippery surface of PMW make the water flow through the voids without any problem. However, the different gap between PMW and sand about 0.5% only. Therefore, both materials considered the best drainage materials compared to POC. From the morphology imaging, POC seem to have lot of voids on the surface and can absorb the water effectively during the incremental stress. Eventually, the voids of POC entrapped the water and the unintentional clogging happens due to the crushing of POC particles when the higher stress applied. DMS can be permeable when there have large voids within the soil, such as for gravels and sand, while fine soils such as clay have smaller voids resulting in lower permeability. Thus, the properties and characteristics of DMS influence the rate of consolidation. For example, when soft clay is subjected to incremental stress, it causes water to disperse from the soil slowly. This is because of the low permeability of clay soils as shown in figure 5. The plotted graph shows DMS as control without any additional granular materials took a longer time to finish the consolidation. Obviously, the 100% of granular materials propagated faster than the dissipation of the surcharge load induced excess pore pressure at early stage of consolidation by 10% compared to 50% layer thickness.
Figure 2. FESEM-XRD of waste materials; (a) DMS; (b) PMW; (c) POC.
Figure 3. e-log $\sigma'_v$ relationship of drainage thickness; (a) sand; (b) PMW.

Figure 4. e-log $\sigma'_v$, of POC.

Figure 5. Deformation-time of drainage layer thickness.
4. Conclusions
Based on the results, the oedometer test on DMS with two different drainage layer thickness that influenced the acceleration of consolidation rate of DMS, which is 50% and 100% by dry weight. DMS as control without any additional granular materials took a longer time to finish the consolidation. Thickness at 100% of granular materials propagated faster than the dissipation of the surcharge load induced excess pore pressure at early stage of consolidation by 10% compared to 50% layer thickness. The thicker of granular layer, the faster water to dissipate from the DMS and consequently accompanied with gradual reduction of compressibility. Thus, this lab simulation shows that the waste granular materials effectively used as drainage layers for accelerated excess pore water discharge for a backfilled embankment or reclaimed land.

Acknowledgement
The authors would like to acknowledge the Universiti Tun Hussein Onn Malaysia (UTHM) for technical assistance and fund support. This support is gratefully acknowledged.

References
[1] Neville B T and Fletcher C A 1997 Terra et Aqua. Number 6
[2] Wang L, Zhu W, Xie J, Li L and Zhang C 2015 Marine Geosources and Geotechnolog. 33(6) 556-566
[3] Siham K, Bernard F, Abriak N E 2008 Journal of Waste Management. 28(5) 918-928
[4] Shahri Z and Chan C-M 2015 Journal of Environment and Pollution 4 (3)
[5] Berry P L and Reid D 1987 An Introduction to soil mechanics, Mc Graw Hill 100-137
[6] Kanadasan J and Razak H A 2014 Materials Design 56 9-19
[7] British Standard Institution (BSI) BS1377 1990 British Standard Institution