Consolidation Behaviour of Dredged Marine Soils Considering the Incorporation of Granular Drainage Layer

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Abstract. The extraction of DMS from seabed along the Malaysian coastal generate millions cubic meters every year. Dredge-transport-dump the DMS at the specified open waters are unfavourable in context of environmental and geotechnical engineering. This paper describes consolidation behaviour of DMS using a modified large-öedometer with a layer of recycled granular materials such as palm oil clinker and recycled pavement materials. DMS were obtained to have high ratio of Wc with 3.27LL and considered as silty clay. A layer of drainage materials accelerates the rate of consolidation and changes in hydraulic conductivity, k of DMS. At the end of consolidation, both RPM and POC layer expediate the water from DMS and it becomes stiffer and structured.

1. Introduction

The maintenance of sea bottom near the harbours is necessary for maritime activities. It is to prevent any of the vessels in or out of the ports from stranded due to the soil sedimentation. The sedimentation rapidly happens because of the current wave. Therefore, dredging works play a vital role in this case. Prevalently, Malaysia’s practice by dredge and dump the sediments from the dredging site to the designated pond or open water within 10 nautical miles. Considering the disposal of unwanted sediments without any proper treatment, causes an environmental effect on the marine life either short or long term [1]. For examples, impacts on the contamination of sediments into the water, change in seabed surface and exposure of contamination to benthic organisms and fishes. Excavation near urbanized areas have high contamination with organic matter, high water content and low shear strength [2]. Wang et al. [3] supported that the dredging not only creates or produces huge amounts of sediment, but also brings others type of contamination to the surrounding waters. According to Bortone and Palumbo [4], mostly of the sediments that settle down at the seabed are consists of sand, silt and clay. Rocks and gravels are also considered types of dredged sediments [5]. Dredged marine soils (DMS) are generally classified as waste materials in civil engineering applications or known as geo-waste because of poor engineering properties such as low in shear strength, permeability and high compressibility. Hence, DMS are generally classified as waste materials (geo waste). The beneficial uses of DMS depend on the properties, dredging location and dredging method. DMS can be considered as a resource and reusable material for construction purpose unless contamination is found to be excessive. Other benefits by reusing the DMS such as mitigation control, stabilisation of coastal near the shoreline or any construction purposes [6-7]. Satoh and Kitazume [8] and Ganesalingam et al. [9] had successfully proven their works on land reclamation projects for Central Japan International Airport and Port Brisbane, Australia. Additionally, DMS been used as a backfilling and construction material at the Bremerhaven, Germany [10]. Another application to reuse the dredged sediment by filled-in-place the
sediments into geotextile tubes for variety of functions such as dewatering, tube walls, embankment and land restoration. This practice provides a lot of benefits toward the environmental and economic near the coastal [11].

The idea of reusing waste materials in civil structures is not a new concept to be applied these days. The waste materials could be reused as backfill materials, road pavements or concrete materials. Yet, the development to advancing the applications by reusing the waste as partial reinforcement in composite materials is still on going. Using recycled materials in construction applications will reduce the negative impact the environment. It also provides an alternative to reduce the usage of aggregates that often been used in construction industry [12]. Palm oil clinker (POC) are waste by-products after the incineration of oil palm shell and fibre to produce steam for palm oil mill. POC generally have large porosity and high-water absorption. Recycled pavement materials (RPM) usually comes from the milling work during the maintenance roadworks that reach the end of design life. RPM consists of aggregates that still coated with bitumen binder. This study attempts to investigate the consolidation behaviour of DMS by using the POC and RPM as a layer in single drainage.

2. Methodology
DMS were retrieved from Kuala Perlis during the dredging works along the Peninsular of Malaysia in 2015. The backhoe dredger machine on top of barge (figure 1) was used to dredge the DMS from seabed at depth 4-6 m. The disturbed samples of DMS (figure 2a) were sealed with sampling bags and all the samples were kept inside the storage bin to avoid the loss of moisture content along way back to laboratory at Johor. The waste granular materials used in this study were palm oil clinker and recycled pavement materials. Palm oil clinker (POC) samples were collected from the palm oil mill in Kluang, Johor and RPM from the stockpile of bitumen pavement in Melaka. Both materials were kept in an open air to dry. The origin shape of POC and RPM as shown in figure 2 (b) and (c) respectively. Therefore, both need to be ground using grinder machine in low speed and sieve the particle within range of 2.00-2.36 mm. The XRD and X-ray fluorescence (XRF) were carried out for DMS, POC and RPM to determine the mineralogy and chemical composition. Preparation on DMS samples must be in homogenous state and uniformly remoulded by mixing using the conventional mixer at least 10 minutes in same speed. At the oedometer specimen mould, the outer and inner part need to be lubricated with petroleum jelly to avoid any skin friction of specimen. In this case, the modified large mould been used with dimension of 100 x 100 mm height. The configuration of specimens was conducted as shown in the illustration figure 3. Noted that 50 % of granular waste materials from the dry unit weight were used in this study. All the setup and apparatus of oedometer test was adopted from BS 1377:1990 Part 5 Clause 3 [13].

Figure 1. Backhoe Dredger machine during dredging work at Kuala Perlis
Figure 2. Raw materials; (a) DMS; (b) RPM; (c) POC

Figure 3. Schematic cross-section of test configuration on the large oedometer (100 x 100 mm); (a) Control (DMS); (b) Single layer drainage of 50% granular (RPM or POC)
3. Results and discussions

3.1 Characterisation of materials

The physical characteristics of DMS are reported in Table 1. The initial water content of DMS is about 218%, which considered as typical for dredged sediments. By using wet sieving and hydrometer method, confirmed that the DMS in Kuala Perlis mainly clay with little bit of silt (silty clay). The proportion of clay about 61%, silt is 38% and fine sand only 1%. The ratio of liquid limit of DMS (wc/LL) is 3.27, higher than previous study at the same dredging site but different time. This indicate that space of time of sedimentation influenced the properties of DMS. The specific gravity, Gs of DMS is 2.68. According to Unified Soil Classification System (USCS), POC and RPM are classified as well-graded gravel and RPM is considered a poorly graded gravel. The Gs of POC are significantly lower than RPM with 2.23 and 2.39 respectively. In this case, it much lower than the typical Gs of virgin aggregates that within in the range of 2.65-2.70. However, the content of bitumen that still coated on the aggregates do influence the density of RPM. Same goes to POC, where the incineration process at the final stage change the physical structure and properties.

As summarised in Table2, it shows the chemical composition of DMS, POC and RPM from the X-ray fluorescence (XRF). The results indicated that all materials contained several kinds of oxides such as $\text{Al}_2\text{O}_3$, $\text{SiO}_2$, $\text{Na}_2\text{O}$, $\text{MgO}$, $\text{CaO}$ and so on. Among all these oxides compound, sodium oxide ($\text{Na}_2\text{O}$) occupies the dominant portion of DMS with the percentage of 46.22% and proven to have higher salt content. Followed by silica oxide ($\text{SiO}_2$) and alumina ($\text{Al}_2\text{O}_3$) with 30.53% and 13.8% respectively. Chemical compounds in Kuala Perlis reportedly to have similar results where sodium oxide much higher but lower percentage of alumina (8.7%) [15]. On the other hand, Wan Salim [16] reported to have lower in sodium oxide (1.44%). This suggests the activity of dredging change the chemical compound of seabed. POC indeed to have higher silica oxide than RPM with 73% and 68.3% respectively. Figure 4 shows the peaks obtained from analysis of DMS, POC and RPM through the X-ray diffraction (XRD) test. Aforementioned earlier, all 3 materials majorly to have higher quartz components, which a type of silica oxide that found to be prominent.

| Table 1. Properties of DMS |
|---------------------------|
| Initial water content, $w_c$ | 218.07% |
| Specific gravity, $G_s$ | 2.68 |
| Liquid limit, LL | 66.5% |
| Plastic limit, PL | 55.8% |
| Plasticity index, PI | 10.69 |
| pH | 8.0 |
| $W_c/LL$ | 3.27LL |
| Soil classification (USCS) | MH (high plasticity silt) |
| Sand | 1% |
| Silt | 38% |
| Clay | 61% |
Table 2. Chemical composition of DMS and granular materials

| Minerals composition (%) | DMS | RPM | POC |
|--------------------------|-----|-----|-----|
| Alumina                  | Al₂O₃| 13.376 | 15.626 | 7.895 |
| Calcium oxide            | CaO | 0.296 | 1.144 | 2.907 |
| Potassium oxide          | K₂O | 0.778 | 3.529 | 7.667 |
| Magnesium oxide          | MgO | 2.199 | 0.873 | 3.063 |
| Silicon oxide            | SiO₂| 30.533 | 68.274 | 73.042 |
| Sulphur trioxide         | SO₃ | 0.496 | 1.914 | 0.402 |
| Titanium dioxide         | TiO₂| 0.274 | 0.222 | 0.177 |
| Sodium oxide             | Na₂O| 46.221 | 5.902 | 0.436 |
| Iron oxide               | Fe₂O₃| 2.246 | 2.157 | 2.455 |
| Chlorine                 | Cl  | 3.411 | 0.041 | 0.076 |
| Phosphorus pentoxide     | P₂O₅| 0.103 | 0.208 | 1.794 |

Figure 4. XRD patterns; (a) DMS; (b) RPM; (c) POC
3.2 Consolidation behaviour

A large-modified oedometer test setup was used to consolidate the DMS samples with 50% of granular materials (RPM and POC) in single drainage condition. The compression curves, coefficient of consolidation \(c_v\), volume of compressibility \(m_v\) and permeability \(k\) were estimated at the incremental of vertical stresses as the variation of effective vertical stress \(\sigma'_v\) in kPa was plotted in figure 5, 6 and 7. The compression curves proven that DMS significantly change with the \(\sigma'_v\), where, the DMS more settle than RPM and POC layering. The water in soil dissipate much faster than DMS only because of the thickness of granular materials influence DMS to consolidate when the increment of \(\sigma'_v\) at each stage. As seen in the figure 6a, \(m_v\) of both materials at early stage shows the gap about 5%. However, an overlapping happens at \(\sigma'_v = 12.5\) kPa to 800 kPa which means that both granular have large voids to let the water in DMS dissipate rapidly. Same goes to figure 7, where the trend in the same condition as \(m_v\). It is noticeable that the \(k\) curves of RPM and POC have high \(k\) value than the DMS specimens with a \(k\) value < 10\(^{-9}\) m/s as impermeable in practice. As a result, the excess pore pressure of dissipation become more slowly because of low permeability of DMS and this will take a long period of time for the DMS to fully consolidate. Overall, the reduction of settlement happens largely with a layer of RPM and POC. This could be stiffening the DMS much faster than DMS alone.

![Figure 5. Compression curves](image)

![Figure 6. (a) Volume of compressibility, \(m_v\); (b) Coefficient of consolidation, \(c_v\)](image)
Figure 7. Coefficient of permeability

4. Conclusion
Dredged marine soils (DMS) are generally classified as waste materials in civil engineering applications or known as geo-waste because of poor engineering properties such as low in shear strength, permeability and high compressibility. DMS can be considered as a resource and reusable material for construction purpose unless contamination is found to be excessive. This study investigated the physical and chemical properties of DMS and recycled granular materials (RPM and POC). DMS in Kuala Perlis mainly clay with little bit of silt (silty clay). The proportion of clay about 61%, silt is 38% and fine sand only 1%. The ratio of liquid limit of DMS (wc/LL) is 3.27, higher than previous study at the same dredging site but different time. This indicate that space of time of sedimentation influenced the properties of DMS. all 3 materials majorly to have higher quartz components, which a type of silica oxide that found to be prominent. The water in layer RPM and POC dissipate much faster than DMS only because of the thickness of granular materials influence DMS to consolidate when the increment of $\sigma^v$ at each stage. The reduction of settlement happens which can be reuse as backfill materials in civil applications for future works. On other hand, the consumption usage of natural aggregates can be less and it became more sustainable for the environment.

5.0 References

[1] Manap N and Voulvoulis N 2015 Environmental management for dredging sediments- The requirement of developing nations Journal of Environmental Management 147 338-348
[2] Berilgen S A, Kilic, H and Ozaydin, I K 2007 Determination of undrained shear strength for dredged golden horn marine clay with laboratory tests Proceedings of the Sri Lankan Geotechnical Society’s First International Conference on Soil and Rock Engineering pp. 5-11.
[3] Wang D X, Abriak N E, Zentar R and Xu W 2012 Solidification/stabilization of dredged marine sediments for road construction Journal of Environmental Technology 33(1) 95-101
[4] Bortone G and Palumbo L 2007 Sustainable Management of Sediment Resources 1st Ed. Elsevier.
[5] International Association of Dredging Companies (IADC) 2009 Dredging Materials as A Resource. Netherlands
[6] Siham K, Bernard F, Abriak NE 2008 Marine dredged sediments as new materials resource for road construction Journal of Waste Management 28(5) 918-928
[7] Shahri Z and Chan C-M 2015 On the Characterization of Dredged Marine Soils from Malaysian Waters: Physical Properties, Journal of Environment and Pollution, Canadian Center of Science and Education 4 (3)
[8] Satoh T and Kitazume M 2003 Sea Reclamation with Dredged Soft Soil for Central Japan International Airport *Proceedings of Nakase Memorial Symposium, Yokosuka (Japan)* pp 311-318

[9] Ganesalingam D, Arulrajah A, Ameratunga J, Boyle P and Sivakugan N 2011 Geotechnical Properties of Reconstituted Dredged Mud, *Proceedings from the Pan-AM CGS Geotechnical Conference* pp 1-7

[10] Schlue B F, Kreiter S and Moerz, T 2009 Time-dependent deformation of dredged harbor mud used as backfilling material *Journal of Waterway, Port, Coastal, and Ocean Engineering* 135(4) 154–163.

[11] Howard I L, Vahedifard F, Williams J M and Timpson C 2017 Geotextile tubes and beneficial reuse of dredged soil: applications near ports and harbours *Ground Improvement, Proceedings of the Institution of Civil Engineers (ICE)* pp. 1-14

[12] Kanadasan J and Razak H A 2014 Mix design for self-compacting palm oil clinker concrete based on particle packing *Materials Design* 56 9-19.

[13] British Standard Institution (BSI) 1990 BS1377:1990 Methods of test for soils for civil engineering purposes (United Kingdom: British Standard Institution)

[14] Grubb D G, Wazne M, Jagupilla S C and Malasavage N E 2011 Beneficial use of steel slag fines to immobilize arsenite and arsenate: slag characterization and metal thresholding studies *Journal of Hazardous, Toxic and Radioactive Waste* 15 130-150

[15] Salim W S W, Sadikon, S F, Mohd Salleh S, Mohd Noor NA, Arshad M F and Wahid N 2012 Assessment of physical properties and chemical composition of Kuala Perlis dredged marine sediment as a potential brick material 2012 *IEEE Symposium on Business, Engineering and Industrial Applications* (Bandung, Indonesia) pp 188-191

[16] Kaliannan S 2016 *Light solidification of Kuala Perlis dredged marine soil via admixtures of GGBS-cement and sand: 1D compressibility study* Master Thesis (UTHM)

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