Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

Consolidation of a High Plasticity Dredged Marine Clay Incorporating Single Drainage Path with Granular Geowastes

Siti Farhanah SM Johan[1], Chan Chee Ming[2,*], Tan Poi Cheong[3], Muhammad Zawawi Rosman[2]

[1] Department of Technical & Project, MTS Fibromat (M) Sdn. Bhd., 574, Jalan Samudra Utara Satu, Taman Samudra, 68100 Batu Caves, Selangor Darul Ehsan, Malaysia
[2] Department of Civil Engineering Technology, Faculty of Engineering Technology (Campus Pagoh), Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, KM 1, Jalan Panchor, 84600 Panchor, Johor Darul Takzim, Malaysia
[3] Reinforce Soil Engineering Sdn. Bhd., No.1, Jalan Seri Austin 1/23, Taman Seri Austin, 81100 Johor Bahru, Malaysia

ARTICLE INFO

Article history:
Received 13 March 2024
Received in revised form 8 May 2024
Accepted 22 May 2024
Available online 30 June 2024

Keywords:
Dredged marine clays; granular geowastes; drainage layer thickness; consolidation

ABSTRACT

The present study simulated a dredged marine clay backfill in standard oedometers, where the examination was carried out on a consolidation process with a single drainage path using pavement milling waste and palm oil clinker. It was found that the dissipation of excess pore water from the soil increased with the thickness of the drainage layer, which facilitated a more effective drainage rate. Also, palm oil clinker was observed to be prone to crushing at higher applied stresses, leading to possible clogging of the pores and diminishing consolidation rate. However, the samples' settlements were not observed to be particularly influenced by the drainage material used. Overall, both by-product wastes could be potentially reused as a drainage layer for field backfilling of dredged marine clay in the preloading stage, simultaneously introducing second lives to the waste materials in beneficial civil engineering applications.

1. Introduction

Conventionally, dredged marine soils (DMS) can be considered geo-waste materials that have been described with high water content, low permeability, and high compressibility. DMS encountered in dredging works for the maintenance of the vessels for the ships as well as to prevent flooding near the riverbanks. Various countries around the globe have been involved with dredging activities such as Asia, Europe, the United States, and Scandinavian countries. These activities create a huge volume of DMS yearly. The common method used in dredging works is dredged and disposed of at certain sites within 10-20 nautical miles from the dredging site. Yet, potentially viewed as harmful to marine ecosystems due to the contamination risk. The ways of handling the DMS indirectly affect the environmental problem such as coastal erosion, and noise generated by dredging machinery and create high turbidity of waters. During the sedimentation, there is a high possibility

* *Corresponding author.*
E-mail address: chan@uthm.edu.my

https://doi.org/10.37934/aram.119.1.8391

for the DMS back to the river mouth due to the wave flow and slow sedimentation [1]. Figure 1 and 2 shows one of the dredging plants used to excavate the DMS in Malaysia.

Despite poor engineering properties and regularly being disposed of back to open waters, DMS can be reused at land reclamation projects. One of the projects in Bremerhaven, Germany used DMS as backfilling and construction material [2]. The project created a land reclamation of about 14 acres and used the sand layer and vacuum drainage system technique to speed up the consolidation time. There were a variety of researchers had reported that DMS can be reused for erosion control, agricultural purposes, shoreline stabilization, and many more [3,4]. Consolidation is the process of soil compression over time by dissipating excess pore pressure. When pressure is 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. Past projects related with accelerate the consolidation of land reclamation such as Manila Bay Reclamation [5], Changi Airport, Singapore [6], Kansai International Airport [7], and Port of Tanjung Pelepas, Malaysia [8].

Malaysia has a lot of agricultural waste that is essentially being thrown away despite the fact that it may be used for civil engineering purposes other than using concrete and pavement. Geo-waste is typically contained in specially constructed bulkheads and landfills due to the poor environmental impact that results from its irresponsible disposal, which results in higher expenses and land utilization with few advantages. Therefore, granular materials such as sand, palm oil clinker, and pavement waste materials were used in this study as single drainage to hasten the consolidation.

Fig. 1. Clamshell dredger (Johor, Malaysia)

Fig. 2. Trailing suction hopper dredger (Kuala Muda, Kedah, Malaysia)

2. Materials and methods

In collaboration with the Malaysian Marine Department, the extraction of DMS was conducted during the dredging project near the coastline of Kuala Perlis. The depth of DMS extraction is in the range of 4 – 6 m from sea level by using a backhoe dredger. All the DMS samples were manually scooped and kept in a storage bin with heavy-duty sampling bags. This sampling method is to control the moisture content of DMS throughout transportation back to the laboratory and stored at a room temperature of 30˚C.

Granular materials can withstand deformation and allows water to flow through the voids. It is commonly used in land reclamation projects where drainage systems are often incorporated in the preloading or sand drain method to accelerate the consolidation rate of the backfill soils. Sand has high permeability and dissipates excess pore water rapidly [9]. Therefore, in this study, sand acted as a control sample to compare the consolidation behaviour of waste materials (POC and PMW). Both POC and PMW are considered by-product waste materials which generally being dumped and have little commercial value. Compared to other renewable energy sources, biomass resources are abundant, giving them a competitive edge. The sector does, however, confront limitations and difficulties, including high disposal costs, high electricity usage, and associated costs [10]. The idea of reusing waste materials can reduce the negative impact on the environment as well.

A large oedometer test with a size of 100 mm diameter and 100 mm height was to evaluate the different thicknesses of the single-drainage layer. The DMS sample was first remoulded by putting the soil in the bowl of a conventional kitchen mixer and maintaining mixing for at least 10 minutes to ensure the soil was uniformly remoulded. The mixer was initially run at a low speed to avoid spilling the sample, followed by a higher speed for 1 minute. Then a plastic spatula was used to gather the mixture into a lump.

The inside and outer parts of the oedometer ring were lubricated with a thin smear of petroleum jelly (Vaseline). In this study, two thicknesses of granular drainage layers were examined, namely thickness no.1 (50% of granular material as per dry mass of soil) and no.2 (100% of granular material as per dry mass of soil), equivalent to 16 and 38 mm respectively (Figure 3). Thus, to create single-granular drainage, the sand, PMW and POC were placed on top of DMS. To separate between DMS and granular, a layer of non-woven geotextile graded MTS 130has been used, to avoid unnecessary penetration of granular materials into the DMS.

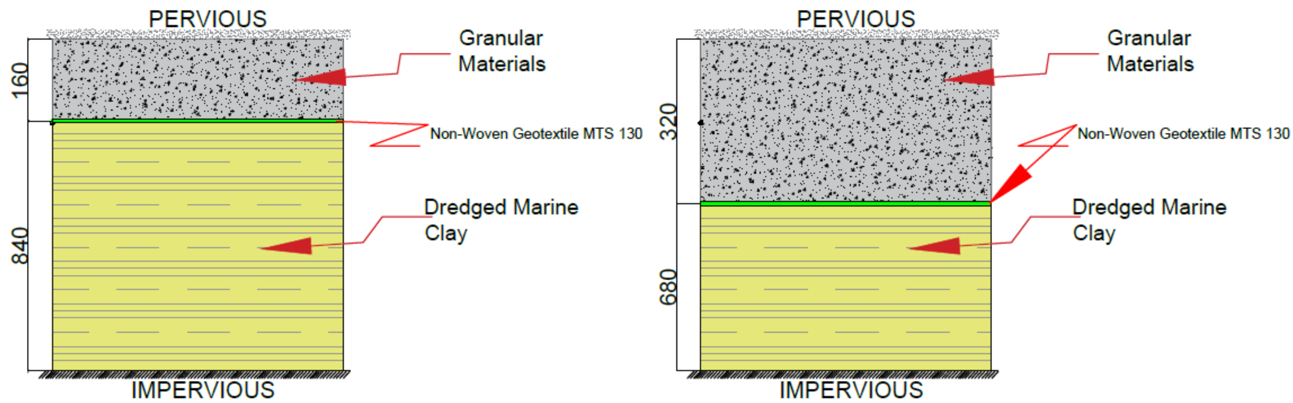

Fig. 3. Configurations of the single-drainage test samples with the different granular material thicknesses (in mm)

3. Results and Discussions

3.1 Physical and Chemical Properties

Table 1 and 2 shows the physical and chemical properties of DMS. DMS sample consists of 61% clay, 38% silt, and 1% sand and is categorized by USCS as CH (high plasticity of clay) with w_c (218.00 %). The anthropogenic activities around the dredging area are the main reason the DMS sample contained clay and silt as contributed because the dredging location near Kuala Perlis Jetty and ongoing construction also influence the sediments surrounding it.

The chemical composition of the Kuala Perlis DMS was compared with previous reports as summarized in Table 2. The main chemical compounds detected in the DMS were sodium oxide (Na_2O) with 46.20 % followed by 30.50 % of silica oxide (SiO_2) and 13.40 % of alumina (Al_2O_3). Na_2O was found to be the highest constituent as the material came from the seabed. Silica oxide was traced in the mineralogy as quartz, which can be found in sand or aggregates. The factors such as depth, location, and economic activities could be influencing the oxide compounds either directly or indirectly. Figure 4 shows the FESEM image at 7500x magnification of the DMS sample, with a variety of morphology, including pseudo-hexagonal sharp-edged plates and vermicular stacks. The soil seems to be dominated by face-to-face contact, and the presence of debris or mineral fraction was detected from the image (in the circle).

Table 1
Physical Characteristics of DMS

Parameters	Values
Initial water content, w_c	218%
Specific gravity, Gs	2.57
Liquid limit, LL	73.8%
Plastic limit, PL	32.2%
Plasticity index, PI	41.6
W_c/LL	2.96
Loss on ignition, LOI	4.0%
pH	8.0
Hydraulic conductivity, k	1.05 x 10^{-11} m/s

Soil Classification (USCS)	CH (high plasticity of clay)
Sand	1%
Silt	38%
Clay	61%

Table 2
Chemical Compound of DMS

Elements	Al_2O_3	CaO	K_2O	MgO	SiO_2	SO_3	TiO_2	Na_2O	Fe_2O_3	Cl	P_2O_3
Concentrations (%)	13.4	0.3	0.8	2.2	30.5	0.5	0.3	46.2	2.3	3.4	0.1

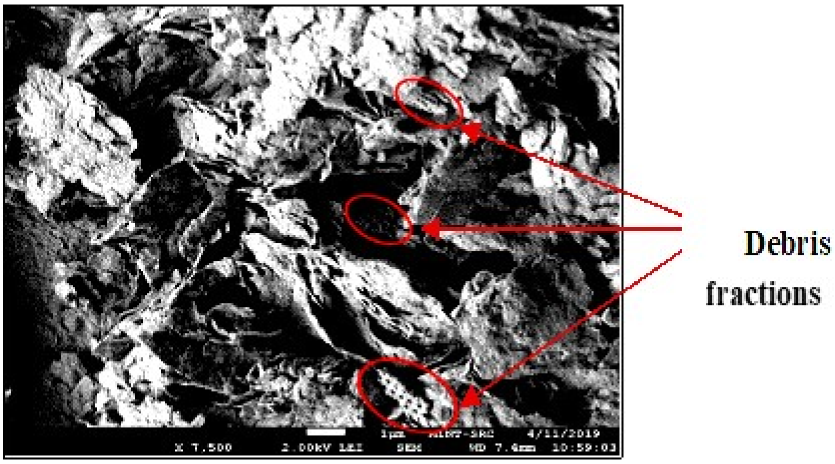

Fig. 4. Morphology of DMS at 7500x magnification

Referring to Tables 3 and 4, the physical and chemical properties of granular materials are determined. Both waste materials have a higher compound of SiO_2 which shows that the mineral quartz was detected and have a hygroscopic substance to absorb the water from the surrounding. The morphology picture of POC and PMW is shown in Figure 5.

Table 3
Physical Characteristics of Granular Materials

Parameters	Sand	PMW	POC
Moisture Content, w_c (%)	0.59	0.32	0.43
Specific gravity, Gs	2.65	2.58	2.28
Water absorption (%)	0.66	1.04	3.85
Bulk density, ρ_{bulk} (kg/m^3)	1570	1267	915
Particle density, $\rho_{particle}$(kg/m^3)	2735	2580	2278
Porosity, η (%)	40.75	44.43	64.54
pH	7.1	7.5	8.2
Hydraulic conductivity, k (m/s)	26.2 x 10^{-3}	27.5 x 10^{-4}	30.3 x 10^{-3}
Soil Classification (USCS)	SW	GP	GW

Table 4
Chemical Compound of Granular Materials

Elements		Al_2O_3	CaO	K_2O	MgO	SiO_2	SO_3	TiO_2	Na_2O	Fe_2O_3	Cl	P_2O_3
Concentrations (%)	PMW	15.6	1.1	3.5	0.9	68.3	1.9	0.2	5.9	2.2	0.04	0.2
	POC	7.9	2.9	7.7	3.1	73.0	0.4	0.2	0.4	2.5	0.1	1.8

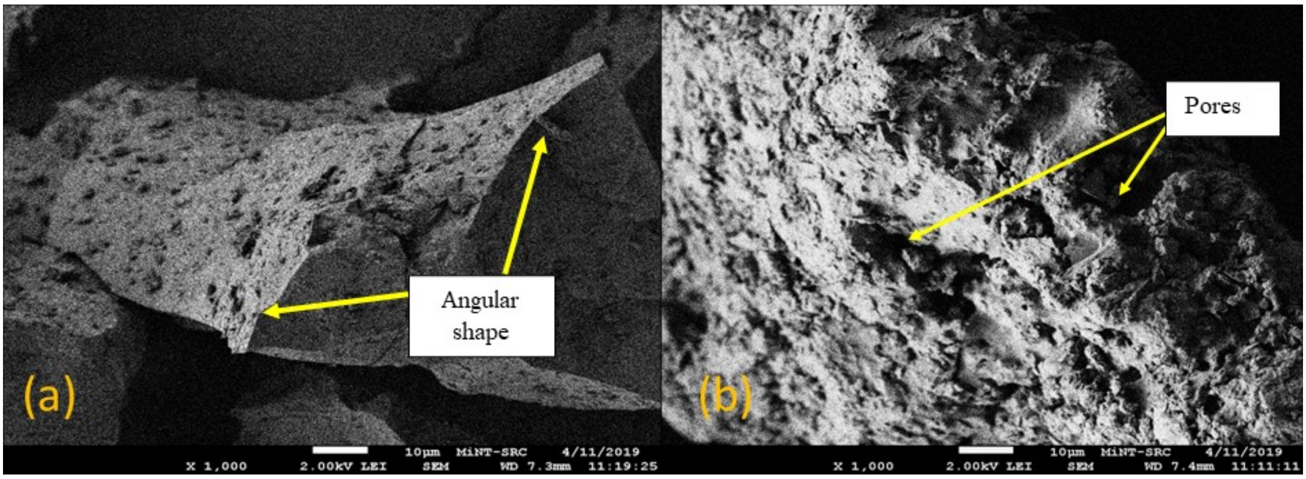

Fig. 5. Morphology of waste materials; (a) PMW; (b) POC

3.2 Consolidation

Figure 6 shows void ratio-effective vertical stress (e-σ_v') on both thickness drainage with different waste materials. The sand was adopted as the benchmark (Control) material to compare against both recycled materials used in the study, POC and PMW. Note that the use of both recycled materials is to promote the use of sustainable materials as well as a greener approach for the construction industry, especially in reclamation works. A reduction in settlement can be found in the PMW-1 and PMW-2 compared to Control and POC. However, the settlement plots between Control and PMW vary slightly at 1- 2% only. Similar observations can be made of POC and control. Also, POC settled a little more than PMW, i.e., about 4%. This is attributed to the rather porous nature of POC, making it susceptible to crushing under load as well as the soft clay material squeezing into the voids and losing overall volume. This was further verified with post-test sieving of the granular material, which showed evidence of some particle crushing in the loading process.

Referring to Figure 7 and 8, the e - σ_v' plot for Controls recorded a 6.00 % difference between Control-1 and Control-2. Thickness no-2 (36 mm), regardless of the granular material, underwent less settlement compared to no-1 (18 mm). Apparently, the increased thickness of granular materials could act as a surcharge to hasten the excess pore water dissipation under load. This phenomenon can be seen for specimens-1, where PMW-1 recorded a longer consolidation process compared to POC-1 and Control-1. Contrary to specimen 2 showed slightly slower dissipation of excess pore water under the same load compared to the others. Note too that during primary consolidation, PMW-2 seemed to expedite the consolidation process by 10 minutes more than Control-2. From $\varepsilon_v > 20\%$, the consolidation time difference between the two materials diminished and the plots folded into one. This is suggestive of the breaking down of the soil structure along the normal compression line post-yield stress.

As further shown in the plots, Control and PMW have similar time evolution patterns throughout the incremental stress stages. This indicates that PMW reacted similarly to Control, although the surface of the aggregates of PMW was coated with bitumen. Despite the possibility of POC discharging water less efficiently due to the lower water affinity, it has shown satisfactory performance as a drainage media for the DMS. This corroborates with the past report that the bituminous coating of the milling waste partially seals off the voids within the granular material, leading to lower porosity and permeability [11].

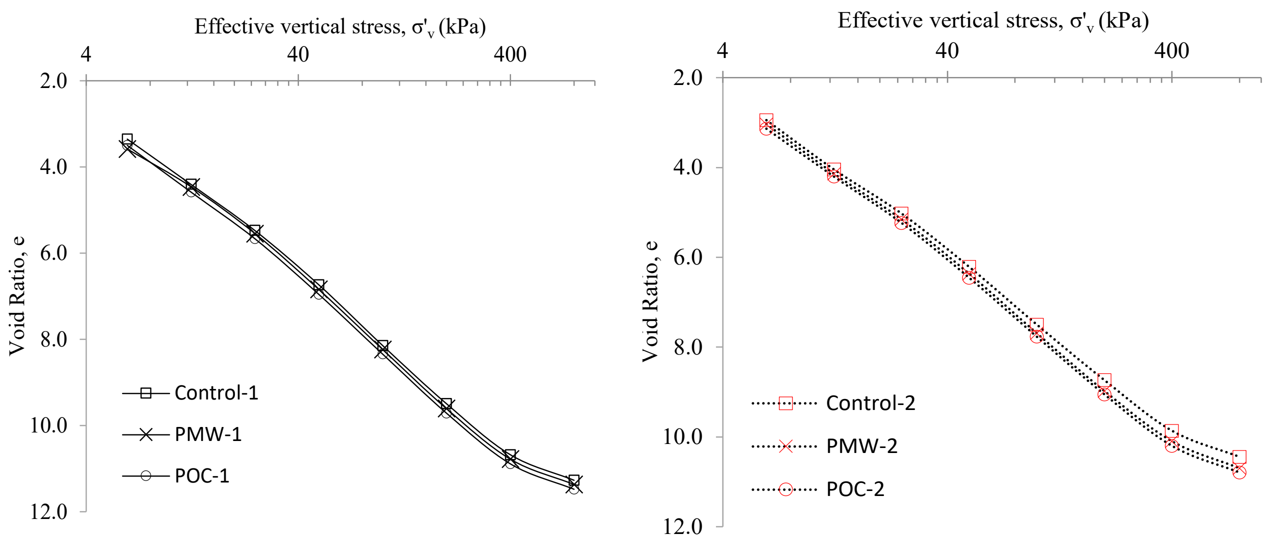

Fig. 6. Plot graph of e - σ_v' for specimens with thicknesses no-1 and 2

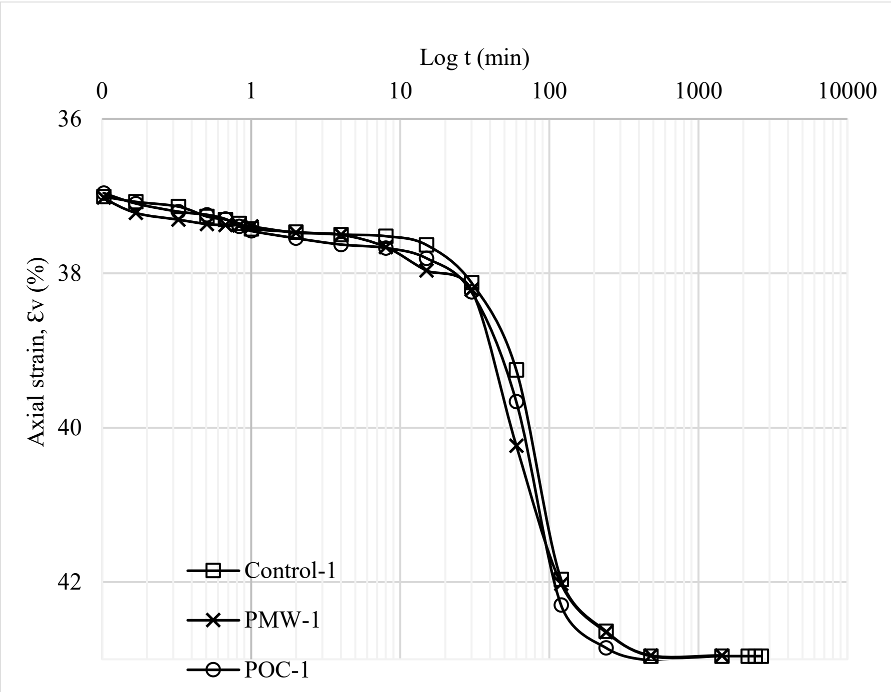

Fig. 7. Plot graph of e - σ_v' for specimens with thicknesses no-1

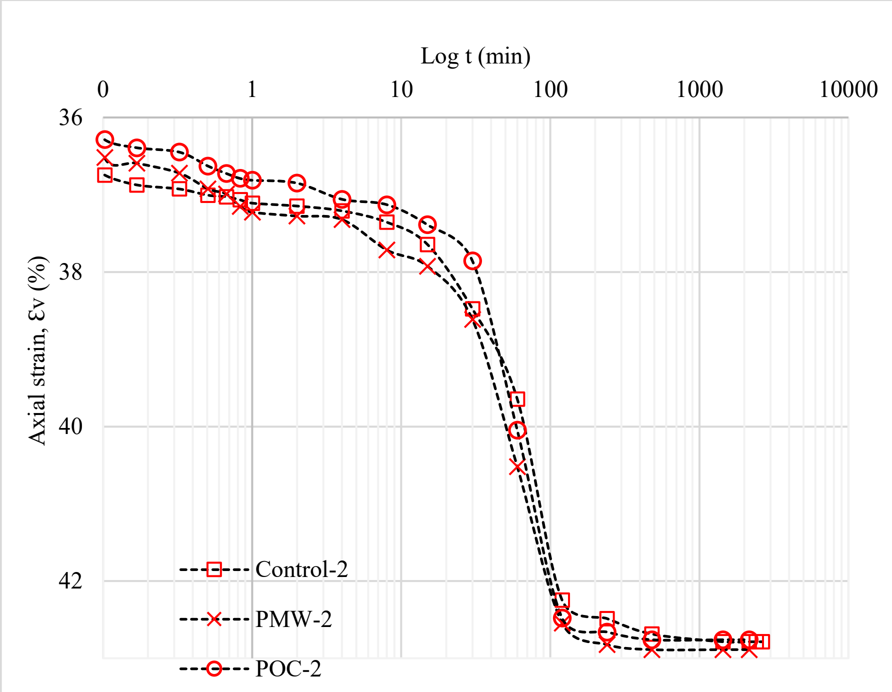

Fig. 8. Plot graph of e - σ_v' for specimens with thicknesses no- 2

4. Conclusion

The study revealed the influence of drainage layer thickness on the rate of consolidation of DMS. The granular drainage layer of the no-2 thickness sample propagated excess pore water at a higher rate by 10 % compared to the no-1 thickness sample at the early stage of consolidation. The thicker the granular layer, the faster water was observed to dissipate from the DMS, consequently accompanied by a reduction of compressibility. As such, this study proved that the waste granular materials can be effectively reused as drainage layers for accelerated excess pore water discharge in embankments or reclaimed land with DMS as backfills.

Acknowledgment
The research was supported by Universiti Tun Hussein Onn Malaysia (UTHM), Industrial Research Grant (M030), and Reinforce Soil Engineering Sdn. Bhd.

References
[1] Salim, Wan Safizah Wan, Siti Fatimah Sadikon, Samsuri Mohd Salleh, Nur Asmaliza Mohd Noor, Mohd Fadzil Arshad, and Norlizan Wahid. "Assessment of physical properties and chemical composition of Kuala Perlis dredged marine sediment as a potential brick material." In *2012 IEEE Symposium on Business, Engineering and Industrial Applications*, pp. 509-512. IEEE, 2012. https://doi.org/10.1109/ISBEIA.2012.6422937
[2] Schlue, Benjamin Friedrich, Stefan Kreiter, and Tobias Moerz. "Time-dependent deformation of dredged harbor mud used as backfilling material." *Journal of waterway, port, coastal, and ocean engineering* 135, no. 4 (2009): 154-163.https://doi.org/10.1061/(ASCE)0733-950X(2009)135:4(154)
[3] Siham, Kamali, Bernard Fabrice, Abriak Nor Edine, and Degrugilliers Patrick. "Marine dredged sediments as new materials resource for road construction." *Waste management* 28, no. 5 (2008): 919-928. https://doi.org/10.1016/j.wasman.2007.03.027
[4] Shahri, Zarina, and Chee-Ming Chan. "On the characterization of dredged marine soils from Malaysian waters: Physical properties." *Environment and Pollution* 4, no. 3 (2015): 1. https://doi.org/10.5539/ep.v4n3p1
[5] Tominaga, M. M., T. Sakaki, M. Hashimoto, and C. C. Paulino. "Embankment tests in reclamation area, Manila Bay." In *Proc., 6th Asian Reg. Conf. Soil Mech. and Found. Eng*, pp. 195-198. 1979.

[6] Choa, V., A. Vijiratnam, G. P. Karunaratne, S. D. Ramaswamy, and S. L. Lee. "Consolidation of Changi marine clay of Singapore using flexible drains." In *Proc. European conference on Soil Mechanics and Foundation Engineering*, pp. 29-36. 1979.

[7] Suzuki, S. and Yamada, M. Construction of an artificial island for the Kansai International Airport. *Proceedings 1989 Seminar on Coastal Development, IEM and Kosai Club, Malaysia*, (1990):511-520.

[8] Lam, Yoon C., Dennis Ganendra, and Krishna Prasad. "Land reclamation & soil improvement works for a coal-fired power plant in Malaysia." *Japanese Geotechnical Society Special Publication* 2, no. 51 (2016): 1767-1772.

[9] Paikowsky, S. G. "Short & Long Term Settlement Analysis Of Shallow Foundations." (2013).

[10] Yow, Hui Ming, Amir Abdul Razak, and Adel Aboulqasim Alheemar. "Current energy recycling technology for agricultural waste in Malaysia." *Progress in Energy and Environment* (2024): 11-22. https://doi.org/10.37934/progee.27.1.1122

[11] Soleimanbeigi, Ali, and Tuncer B. Edil. "Compressibility of recycled materials for use as highway embankment fill." *Journal of Geotechnical and Geoenvironmental Engineering* 141, no. 5 (2015): 04015011.https://doi.org/10.1061/(ASCE)GT.1943-5606.0001285