International Journal of Engineering & Technology, 7 (4.14) (2018) 434-439

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

The Influence of Water Content on the Settlement Behaviour of Polypropylene Fibre-Reinforced Dredged Marine Soil (DMS)

M. Z. Rosman[1], C-M. Chan[2*]

Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Malaysia
**Corresponding author E-mail: chan@uthm.edu.my*

Abstract

The use of fiber as soil reinforcement is not new in civil engineering field. In the earlier times, rice straw was mixed together with mud or clay to produce construction materials such as brick and concrete. Conventional concrete mix without fiber tends to exhibit brittleness behaviour. Hence, there is a growing attention on using current reinforcement materials such as steel, polypropylene and glass fibers. It is reported that fiber in concrete provide bridging effect, which transfer and distribute load evenly, thus increasing ductility. Now, similar concept of fiber inclusion in concrete can be applied to the case of problematic soil. The addition of chemical additives such as cement in soil resulted with stiffness and brittleness. As solution, numerous studies have shown that the fiber inclusion in soil have increased strength, permeability and ductility. Due to the many studies of fibre-reinforced soil related to its shear strength, the present study will investigate the compressibility behaviour of the fibre-reinforced soil through oedometer test. In this study, the dredged marine soil (DMS) was mixed together with 0.25, 0.5, 0.75 and 1 % of polypropylene (PP) fiber. Two conditions of soil, namely high water content (1.40LL) and low water content (0.90LL) were tested. Samples with 0.90LL water content show great reduction of settlement than samples with 1.40LL water content. The outcome of this study will suggest the beneficial reuse of DMS for engineering application such as backfill material, land reclamation or clay liner for landfills.

Keywords: *Compressibility; Dredged Marine Soil; Polypropylene Fiber*.

1. Introduction

Maintenance dredging is necessary to be carried out constantly due to the reoccurring siltation which may affect the waterways for ships to the jetty. This type of dredging has the most volume of dredged marine soil (DMS) as compared to the other types of dredging projects, namely capital and remedial dredging. In Malaysia, dumping DMS in the open sea is a common practice. This activity has caused short and long terms of negative impacts, such as turbidity and disruption of marine habitats respectively [1,2]. Numerous researchers have extensively studied the beneficial reuse of DMS mainly in construction industry such as capping material for landfill, paving block, blended cement, construction brick and pavement base material [3-8]. By reusing DMS, it will provide an alternate management of DMS and act as preventive measure to resolve the aforementioned negative impacts.

However as reported by many researchers, DMS has high water content, high compressibility, low permeability, low bearing capacity and susceptible to significant consolidation settlement [5, 9-12]. Hence, soil improvement is required to enhance the poor soil properties of DMS. Among the soil improvement technologies outlined by [13] are soil replacement, densification, reinforcement, admixture stabilization and thermal stabilization. Soil reinforcement by using fiber is gaining attention nowadays, although the use of fiber in engineering application is not new. Over the years, natural organic fiber such as rice straw was mixed together in mud or clay brick for reinforcement [14]. As the technology advances, synthetic fibers such as steel, polypropylene and glass fibers were regularly used in concrete mixture [15-17]. It is reported that the application of fiber in concrete has provided the bridging effect which distribute the load evenly and increase the ductility of the concrete. The similar concept of fiber inclusion in concrete can also be apply to the case of problematic soil. Many studies have proven the increment of strength, permeability, bearing capacity, and reduction of crack and settlement of fiber-reinforced soil [18-23]. Despite the various types of material and experimental procedure used in these studies, polypropylene fiber (PP) was most favored in soil reinforcement. According to [24-27], reinforcing soil using PP fiber is an effective approach in term of cost reduction, whereby only small amount of PP fiber is required in the soil mixture (less than 5 % by dry weight of soil).

Most of the currently published and available literature deals with soil with water content below its liquid limit [28-32]. However, only a limited number of studies have been carried out on soil with high water content that exceed its liquid limit, particularly DMS [33, 34]. It should also be pointed out that there has not been a general explanation on the influence of water content on the consolidation settlement behavior of the PP fiber-reinforced soil through oedometer test. Hence, the objective of the current study was to observe the behavior of fiber-reinforced DMS with various water content in terms of consolidation settlement.

2. Materials and Methods

The soil used in this study was retrieved from Kuala Mersing, Johor. As displayed in Figure 1, the sample was obtained using a clamshell dredger from a depth of 4 m at sea level and then sealed securely inside air-tight containers to avoid any moisture loss. Based on the standard [35], the DMS was classified as low plasticity silt (ML). The geotechnical properties of DMS are listed in

Table 1. Commercially available fibrillated PP fiber was used in the experiment as seen in Figure 2. Tabulated in Table 2 is the main properties of PP fiber as provided by the manufacturer.

Fig. 1: DMS retrieved by using clamshell dredger.

Fig. 2: Fibrillated PP fiber.

Table 1: Geotechnical properties of DMS.

Properties	DMS
Natural water content, WC (%)	62.51
Liquid limit, LL (%)	44.50
Plastic limit, PL (%)	26.10
WC/LL	1.40
Plasticity index, PI (%)	18.40
Specific gravity, SG	2.10
Soil classification	ML

Table 2: Main properties of PP fiber.

Form	Collated fibrillated fiber
Material	100 % virgin polypropylene
Specific gravity, SG	0.91
Tensile strength (MN/m^2)	310-420
Length (mm)	19
Color	White

The particle size distribution of DMS is given in Figure 3. Based on the distribution, the DMS was composed of 13.12 % of sand, 68.72 % of silt and 18.04 % of clay, by which categorized the DMS as silty clay. As mentioned from the previous studies, the percentage of PP fiber was kept low (< 1 % by dry weight of soil) to ensure better workability, increase effectiveness of pulling resistance, prevent clumping of fiber and disallow the formation of pocket density which would cause reduction of strength [30, 33, 34, 36]. The index value of water content and liquid limit (WC/LL) of DMS in this study is 1.40. By referring to Table 3, most of the soil tested were below 1.00 times its liquid limit (<1.00LL). Only few researchers dealt with soil 1.00 times more than its liquid limit (>1.00LL), which is essential for DMS that is known to contain high amount of water than its liquid limit. Furthermore, an excessive amount of water in soil tends to delay the effectiveness of soil improvement and unable to withstand any significant load [9]. Hence, the soil samples were mixed together with 0.25, 0.50, 0.75 and 1.00 % of fibrillated PP fiber by dry weight of soil in two water content conditions, namely 0.90LL and 1.40LL.

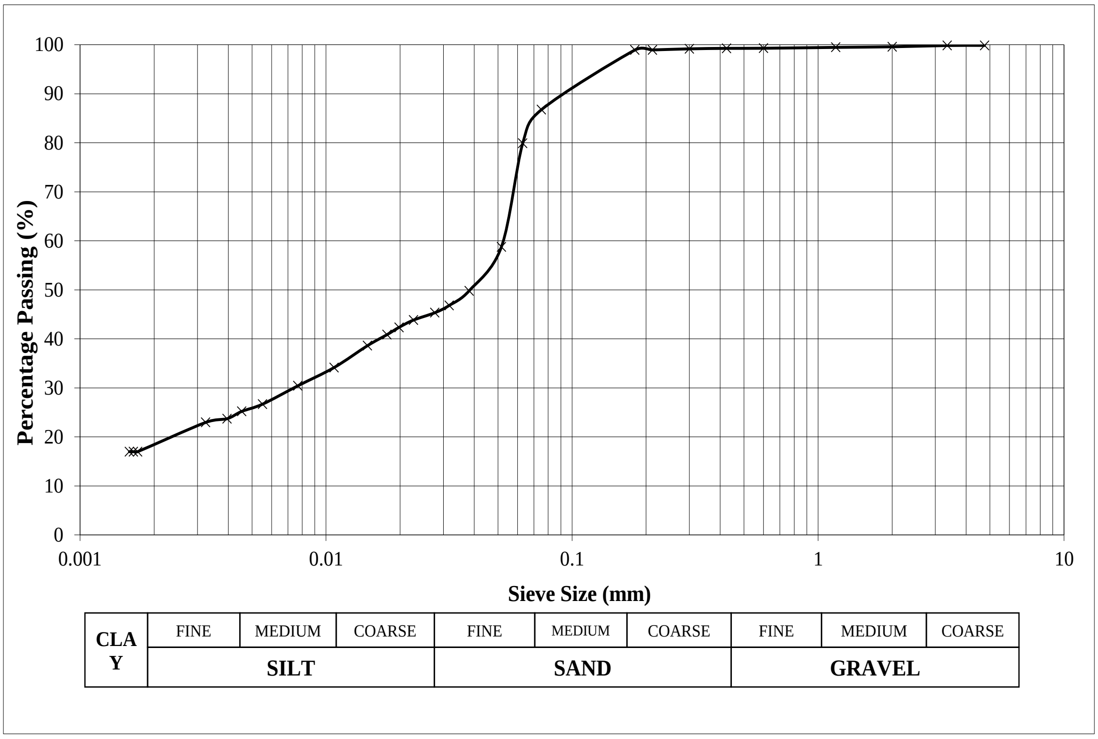


Fig. 3: Particle size distribution of DMS.

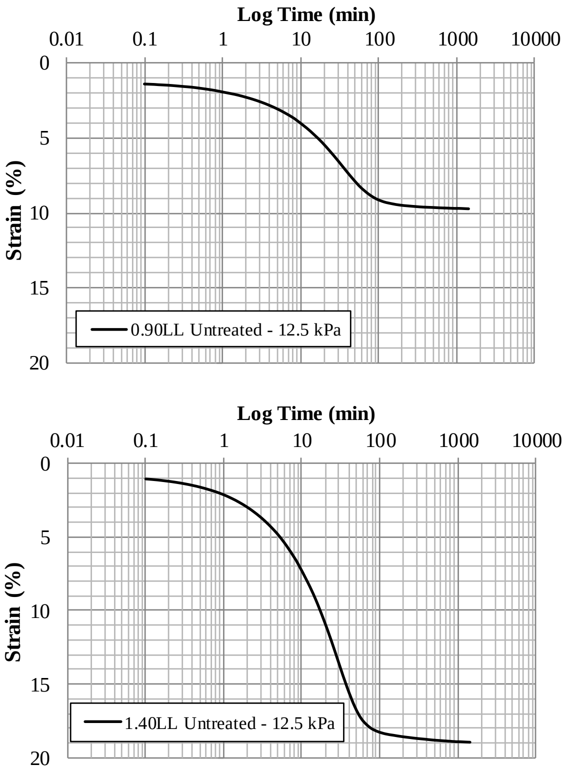
All of the samples were mixed homogeneously using a conventional kitchen mixer for 3-5 minutes. The samples were then placed inside the oedometer cell rings and compacted layer by layer to prevent the fibers to clump together. The experimental procedures of oedometer test were accordance to the standard [38]. The sequential loads were 12.5, 25, 50, 100, 200, 400 and 800 kPa.

Table 3: Literature review of WC/LL from various studies.

Type of soil	Fiber content (%)	WC/LL	Authors
High plasticity clay (CH)	0.25 & 0.50	0.22	[18]
Kaolin clay	0.10, 0.20 & 0.50	1.60	[33]
Clay	0.05, 0.15 & 0.25	0.39-0.44	[25]
Low plasticity silt (ML)	0.05, 0.10, 0.15 & 0.20	0.39-0.55	[24]
High plasticity clay (CH)	0.50, 0.75 & 1.00	0.46	[28]
Silty clay	0.50, 1.00, 1.50 & 2.50	1.13-1.40	[34]
Silty clay	0.30 & 0.60	0.40	[27]
Low plasticity clay (CL)	0.10-0.60	0.22	[30]
Kaolin clay	0.50 & 1.00	0.75	[29]
Low plasticity clay (CL)	0.05, 0.15 & 0.25	0.45	[37]

3. Results Analysis and Discussions

Note that log time-strain plot is the preliminary result from oedometer test. Figure 4 and 5 shows the log time-strain plot for both untreated and 0.50 % of PP-admixed DMS (0.90LL and 1.40LL) under the vertical loading of 12.5 kPa (at minimum stress load). Untreated and 0.50PP samples will represent the natural state of soil and the average content of fiber-admixed soil respectively. The figures displayed apparent inverted S-curve along the log time-strain plots which are similar to the characteristic of natural soft clay [39].



a

Fig. 4: Log time-strain plot of untreated DMS (0.90LL and 1.40LL) under vertical loading of 12.5 kPa.

[40] has studied the influence of water content on dredged soil which contained high water content at low effective stress. In his study, he stated that soil has its own and unique structure. The differences of soil structure were affected by initial water content. Hence, each soil was able to sustain certain extent of external load. If the external load is less than the maximum load of soil, the soil will still maintain its original structure. However, if the external load is greater than the maximum load, the structure will deconstruct and the water content decreases as the water will dissipate out from the soil under acting pressure. From the figures, soil samples with high water content have high strain values. A possible explanation for this is that high water content soil contains high void ratio. There is similarity between the influence of water content on void ratio in this study and that described by [41]. As for low-void soil samples, the strain values are less than the high-void samples. This is due to the formation of soil structure as the induced stress begin to compressed the soil. The addition of fiber in the soil fabric provide more structure in soil. Hence, the reduction of settlement in fiber-reinforced soil samples. Figure 6 shows a simple diagram of 0.90LL and 1.40LL soil samples with and without 0.50 PP fiber. However, further research should be done to investigate the microstructure of the soil samples.

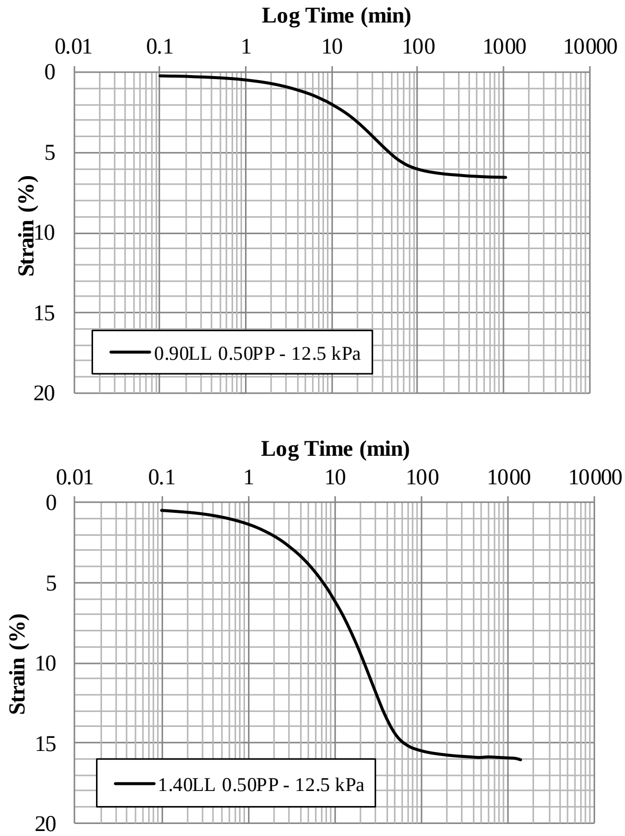


Fig. 5: Log time-strain plot of DMS admixed with 0.5PP (0.90LL and 1.40LL) under vertical loading of 12.5 kPa.

There are two types of compression curves plot, namely log stress (σ'_v)-void ratio (e) and log stress (σ'_v)-strain (ε) plots. The most preferable method is the log stress-strain plot since the purpose of this plot is to determine the stress-strain properties of the soil [42]. By referring to the compression curves in Figure 7, all of the soil samples exhibited direct normal consolidation line (NCL) which is normal for alluvial soil deposit particularly silt and clay sized particles soil. The present findings seem to be consistent with other research which found that clay or silt with high water content tend to produce direct NCL [43,44]. It is also possible that the direct NCL of the soil samples were influenced by the initial load (12.5 kPa), which was too heavy for soil samples to support. A further study using lower initial load (5 kPa) for all soil samples is therefore suggested. The pre-consolidation pressure (σ_p) can be determine if the initial curve line is visible by using lower initial load of 5 kPa.

What is interesting in this data is that most of the compression curves are almost linear with each other. This finding indicates that all of the soil samples has similar value of compression index (c_c). The only difference in this data is the magnitude of settlement. It is encouraging to compare this figure with that found by [44-46] who reported that the compression curves (highlighted at NCL) were parallel to the untreated soil. It can therefore be assumed that the addition of PP fiber in DMS has yet to form a firm soil structure, unlike chemically-treated soils that can develop firm soil structure once the soil and chemical reacted. Hence, future work by adding chemical additive such as cement in fiber-reinforced DMS is suggested.

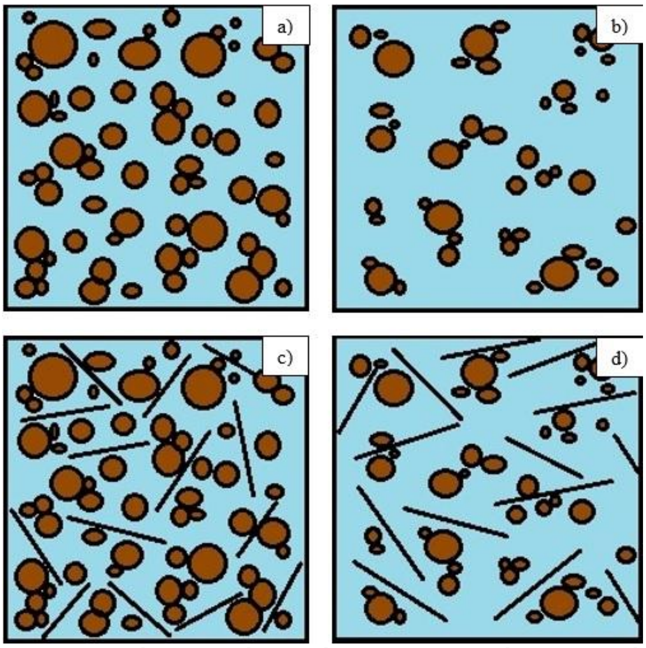


Fig.6: a) Sample 0.90LL, b) Sample 1.40LL, c) Sample 0.90LL with 0.50 % PP fiber, d) Sample 1.40LL with 0.50 % PP fiber.

At water content of 0.90LL, fiber-reinforced DMS has reduced the settlement effectively than untreated DMS. Samples 0.25PP and 0.75PP at water content of 1.40LL show increasing settlements. The observed increase in settlement could be attributed by the high water content in the admixed soil. This theory is also depicted in Figure 6. It can thus be suggested that high water content in DMS tend to lubricate the interfacial shear strength of the materials and also decrease the effectiveness of the bridging effect between fiber and soil. This result is consistent with [24], whereby high water content has affected the tensile strength of reinforced DMS. Moreover, samples of 0.25PP, 0.75PP and 1.00LL are less effective than 0.50LL regardless of the water content conditions. This result may be explained by the fact that the fiber content is too low and too high to produce homogeneous mixtures. Without the right consistency and homogeneity, the bridging effect between fiber and soil could not be initiated [33, 36].

Interestingly, sample 0.50PP provided the lowest settlement than the other percentages of PP fiber in 0.90LL and 1.40LL water content conditions. A possible explanation for this might be that 0.50 % of PP fiber is the threshold content for DMS in this study. This finding corroborates the results of [29, 31, 33, 34], by which 0.50 % of PP fiber in soil (in the range of 0.70LL-1.60LL water content) has improved the unconfined compressive strength (UCS) effectively. These researchers also agreed that 0.50 % of PP is the optimum fiber content and soil samples with PP fiber more than 0.50 % would reduce the effectiveness of compressive strength.

As mentioned, the compression curves of all samples in both water content conditions display immediate NCL. It is possible that the initial loading of 12.5 kPa is too much for the DMS to sustain and to obtain the pre-yield curve, thus incapable to estimate the effective yield stress (σ_y'). It can be suggested the use of load below 12.5 kPa for high water content DMS in the future study.

Constraint modulus (D) is an inverted value of volume of compressibility (m_v), which measures the soil stiffness and provides simple estimation of soil settlement [47]. Figure 8 shows the log stress (σ'_v)–constraint modulus (D) plot. This plot is located in the elastic region. Elastic is a condition when the load is released, the soil will be back in its origin form. The plot also shows a strain-hardening feature which may be due to the loosely packed soil begin to move closer together as the stress applied. The trend of D value is increasing along with the incremental stress. The higher the D value, the stiffer the soil samples. From the plot, soil sample with 0.50 % of PP fiber at water content of 0.90LL is stiffer than the other samples. This result corresponds well with the compressibility results. Therefore, it is plausible to remark that 0.50 % of PP fiber is the fitting percentage for this type of soil in both 0.90LL and 1.40LL water content conditions.

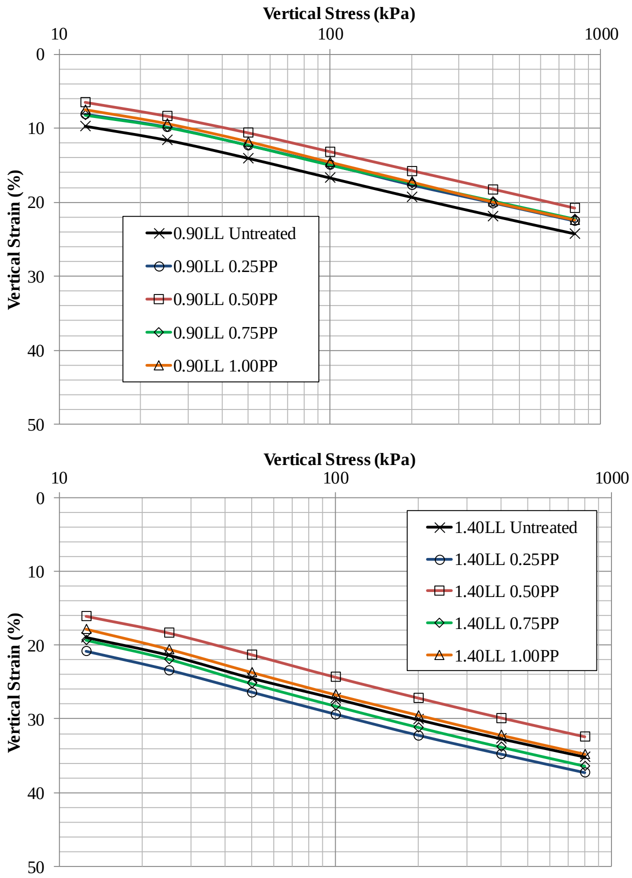


Fig. 7: Compression curves of PP-reinforced DMS (0.90LL and 1.40LL).

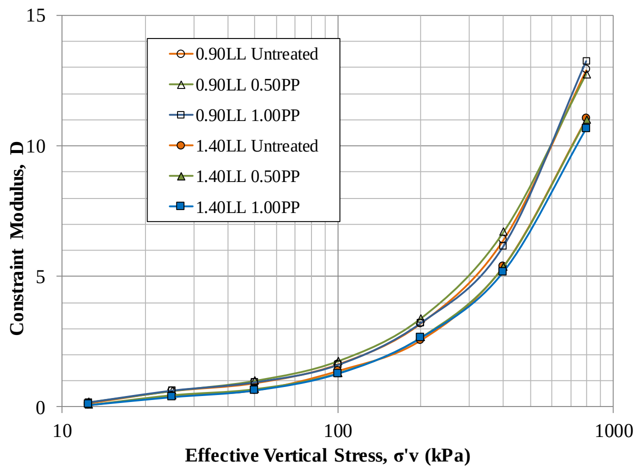


Fig. 8: Constraint modulus (D) of PP-reinforced DMS (0.90LL and 1.40LL).

4. Conclusions

This study has investigated the influence of water content on the settlement behavior of fiber-reinforced DMS with various fiber contents. Series of samples were tested using oedometer test and the following conclusions can be drawn.

Fiber-reinforced DMS with 1.40LL of water content shows higher settlement as compared to fiber-reinforced DMS with 0.90LL of water content.

High water content in DMS tend to lubricate the interfacial surface of the materials and reduce the effectiveness of bridging effect between DMS and fiber.

The optimum PP fiber in DMS is 0.50 %, regardless of the water content conditions (0.90LL and 1.40LL).

DMS admixed with 0.25, 0.75 and 1.00 % of PP fibers in both water content conditions have resulted with less effective settlement reduction than admixed DMS with 0.50 % PP which probably affected by the homogeneity of the soil samples.

The constraint modulus (D) or soil stiffness is observable to the soil sample with water content of 0.90LL.

Acknowledgement

The technical support provided by RECESS and Faculty of Engineering Technology laboratories are dully acknowledged.

References

[1] Bray RN, *Environmental aspects of dredging*, Taylor & Francis, (2008).

[2] Balchand AN & Rasheed K,"Assessment of short environmental impact on dredging in a tropical estuary", *Terra et aqua*, Vol.79, (2000), pp.16-26.

[3] El-Shinawi A & Kramarenko V,"Assessment of stabilized dredged marine sediments using portland cement for geotechnical engineering applications along Hurghada Coast, Red Sea Egypt", *Asian journal of applied sciences*, Vol.3, (2015), pp.819-830.

[4] Said L, Missaoui A & Lafhaj Z,"Reuse of Tunisian marine sediments in paving blocks: Factory scale experiment", *Journal of cleaner production*, Vol.102, (2015), pp.66-77.

[5] Smolar J, Mladenovic A & Petkovsek A,"Stabilization of soft marine sediments from the Port of Koper (Slovenia)", *5th International Young Geotechnical Engineers Conference*, (2013), pp.1-4.

[6] Dang TA, Siham KB & William AP,"Design of new blended cement based on marine dredged sediment", *Construction and building materials*, Vol.41, pp.602-611.

[7] Salim WSW, Sadikon SF, Salleh SM, Noor NAM, Arshad MF & Wahid N,"Assessment of physical properties and chemical composition of Kuala Perlis dredged marine sediment as a potential brick material", *IEEES Symposium on business, engineering and industrial applications*, Vol.23-26, (2012), pp.509-512.

[8] Dubois V, Abriak NE, Zentar R & Ballivy G,"The use of marine sediments as a pavement base material", *Waste management*, Vol.29, (2009), pp.774-782.

[9] Chan CM & Yusof MNM,"Remoulded strength of high plasticity marine silt retrieved from maintenance dredging", *Modern applied science*, Vol.9, No.6, (2015), pp.13-19.

[10] Rahman ZA, Yaacob WZW, Rahim SA, Lihan T, Idris WMR & Sani WNFM,"Geotechnical characterisation of marine clay as a potential liner material", *Sains malaysiana*, Vol.42, No.8, (2013), pp.1081-1089.

[11] Sasanian S & Newson TA,"Basic parameters governing the behaviour of cement-treated clays", *The Japanese geotechnical society*, Vol.54, No.2, (2014), pp.209-224.

[12] Bushra L & Robinson RG,"Strength behaviour of cement stabilised marine clay cured under stress", *Indian Geotechnical Conference*, (2010), pp.601-604.

[13] Kitazume M & Terashi M, *The deep mixing method*, Taylor & Francis, (2013).

[14] Maidi BR, *Steel-fibre reinforced concrete*, Ernst & Sohn, (2013).

[15] Domski J, Katzer J, Zakrewski M & Ponikiewski T,"Comparison of the mechanical characteristics of engineered and waste steel fiber used as reinforcement for concrete", Vol.158, (2017), pp.18-28.

[16] Festugato L, Menger E, Benezera F, Kipperm EA & Consoli NC,"Fibre-reinforced cemented soils compressive and tensile strength assessment as a function of filament length", *Geotextiles and geomembranes*, Vol.45, (2017), pp.77-82.

[17] Ahmad F, Mujah D, Hazarika H & Safari A,"Assessing the potential reuse of recycled glass fibre in problematic soil applications", *Journal of Cleaner Production*, Vol.35, (2012), pp. 102-107.

[18] Mirzababaei M, Arulrajah A, Horpibulsuk S & Aldava M,"Shear strength of a fibre-reinforced clay at large shear displacement when subjected to different stress histories", *Geotextiles and geomembranes*, Vol.45, (2017), pp.422-429.

[19] Sharma V, Vinayak HK & Marwaha BM,"Enhancing compressive strength of soil using natural fibers", *Construction and building materials*, (2015), pp.1-7.

[20] Zaimoglu AS & Yetimoglu T,"Strength behavior of fine grained soil reinforced with randomly distributed polypropylene fibers", *Geotechnical geology engineering*, Vol.30, (2012), pp.197-203.

[21] Miller CJ & Rifai S,"Fiber reinforcement for waste containment soil liners, *Journal of environmental engineering*, Vol.130, No.8, (2004), pp. 981-985.

[22] Michalowski R & Cermak J,"Triaxial compression of sand reinforced with fibers, *Journal of geotechnical and geoenvironmental engineering*, Vol.129, No.2, (2003), pp. 125-136.

[23] Prabakar J & Sridhar RS,"Effect of random inclusion of sisal fiber on strength behaviour of soil, *Construction and building materials*, Vol.16, No.2, (2002), pp. 123-131.

[24] Tang CS, Wang DY, Cui YJ, Shi B & Li J,"Tensile strength of fiber-reinforced soil", *Journal of material and civil engineering*, (2016), pp.1-13.

[25] Teja MS,"Soil stabilization using polypropylene fiber materials, *Engineering and Technology*, Vol.5, No.9, (2016), pp. 18906-18912.

[26] Shahrokhabadi S & Nazeryadeh N,"Efficacy of resinous polypropylene (PP) fibers on strength behavior of reinforced soils", *Advanced materials research*, Vo.787, (2013), pp.75-80.

[27] Ple O, Le TNC & AbuAisha MS,"Landfill clay barrier: Fibre reinforcement technique", *Advanced materials research*, Vol.378-379, (2012), pp.780-784.

[28] Soganci A,"The effect of polypropylene fiber in the stabilization of expansive soils, *International. journal of environmental, chemical, ecological and geophysical engineering*, Vol.9, No.8, (2015), pp. 956-959.

[29] Fatahi B, Khabbaz H & Fatahi B,"Mechanical characteristics of soft clay treated with fibre and cement, *Geosynthetics international*, Vol.19, No.13, (2012), pp. 252-262.

[30] Pradhan PK, Kar RK & Naik A,"Effect of random inclusion of polypropylene fibers on strength characteristics of cohesive soil", *Geotechnical geology engineering*, Vol.30, (2012), pp. 15-25.

[31] Falocra IMCFG & Pinto MIM," Effect of short, randomly distributed polypropylene microfibers on shear strength behaviour of soils", *Geosynthetics international*, Vol.18, No.1, (2011), pp. 2-11.

[32] Abdi MR, Parsapajouh A & Arjomand MA,"Effects of random fiber inclusion on consolidation, hydraulic conductivity, swelling, shrinkage limit and dessication cracking of clays", *International journal of civil engineering*, Vol.6, No.4, (2008), pp. 284-292.

[33] Ayeldeen M & Kitazume M,"Using fiber and liquid polymer to improve the behaviour of cement stabilized soft clay", *Geotextiles and geomembranes*, Vol.45, (2017), 592-602.

[34] Chen M, Shen SL, Arulrajah A, Wu HN, Hou DW & Xu YS,"Laboratory evaluation on the effectiveness of polypropylene fibers on the strength of fiber-reinforced and cement-stabilized Shanghai soft clay", *Geotextiles and geomembranes*, Vol.43, (2015), pp. 515-523.

[35] ASTM D2487-11, *Unified soil classification system*, American society for testing and materials (ASTM), (2011).

[36] Anagnostopoulos CA, Tzetzis D & Berketis K,"Shear strength behaviour of polypropylene fibre reinforced cohesive soils", *Geomechanics and geoengineering: An international journal*, (2013), pp.1-12.

[37] Tang C, Shi B, Gao W, Chen F & Cai Y,"Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil", *Geotextiles and geomembranes*, Vol.25, (2007), pp.194-202.

[38] BS1377-Part 5, *Compressibility, permeability and durability test*, British standard institution (BS), (1990).

[39] Hong ZS, Yin J & Cui YJ," Compression behaviour of reconstituted soils at high initial water contents", *Geotechnique*, Vol. 60, No. 9, (2010), pp. 691-700.

[40] Imai G," Experimental studies of sedimentation mechanism and sediment formulation of clay materials", *Soils and foundations*, Vol. 21, No. 1, (1981), pp. 7-20.

[41] Burland JB," On the compressibility and shear strength of natural clays", *Geotechnique*, Vol. 40, No. 3, (1990), pp. 329-378.

[42] Coduto DP, Young MR & Kitch WA, *Geotechncial engineering principles and practices,* Pearson Prentice Hall, (2011).

[43] Xu GZ & Yin J," Compression behavior of secondary clay minerals at high initial water contents", *Marine georesources & geotechnology*, (2015), pp.1-31.

[44] Frederico A, Vitone C & Murianni A," On the mechanical behaviour of dredged submarine clayey sediments", *Canadian Geotechncial Journal*, (2015), pp. 1-42.

[45] Moghal AAB, Chitoori BCS, Basha BM & Al-Mahbashi AM," Effect of polypropylene fibre reinforcement on the consolidation, swell and shrinkage behaviour of lime-blended expansive soil," *International journal of geotechnical engineering*, Vol. 12, No. 5, (2017), pp. 462-471.

[46] Starcher RD," Impact of curing time and curing stress in the mechanical behavior of the cement-improved and cement-fiber-improved soft soil," *Master Thesis*, (2013).

[47] Duncan JM & Bursey A,"Soil modulus correlations", *Foundation engineering in the face of uncertainty*, (2013), pp.321-336.