Effect of cement dosage and early curing towards Kuala Perlis dredged marine sediments: a $\varepsilon_v - \sigma_v$ and SEM-EDX approach

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Abstract. Cement is the primary material used in solidifying the soft soils. This material was applied in solidifying Kuala Perlis dredged marine sediments (DMS). These unwanted sediments are classified as high plasticity silt, MH with 3.36 $LL$ of $w_c/LL$ value. At dosage 10 and 20 % of cemented-DMS and 3 days curing time, compression curve results show the settlement criteria were enhanced than the natural DMS. Unfortunately, the settlement criteria are not complies with the permissible settlement limit and applicable pressure. The formation of cementing compounds appears in the SEM micrograph for 10 and 20 % of cemented-DMS. EDX analysis shows the Ca:Si ratio were increased for cemented-DMS due to the formation of C-S-H gel.

1. Introduction

It is noted that water will increasingly shallow over time due to the sedimentation and accumulation of fine particle. Hence dredging works in offshore area are required to maintain the water depth in shipping ports. The other purpose of dredging works are to allow the maintenance of waterways and construction works in harbour, reclamation of foreshores, and purification of water by the removal of contaminated sediment [1-2]. A large amount of sediments or known as DMS are generated due to the dredging works. The DMS are not appropriate to be used in construction activities because of its poor geophysical properties such as high water content, low shear strength, high compressibility and presence of organic matter and salt [3].

The way to manage DMS is either by disposed it offshore in designated dumping sites or by treating it with an adequate pre-treatment [4]. The offshore dumping of the DMS aggravate the situation with leave a negative impact to the marine ecosystem and environment. Furthermore, it causes the long term damaging pollution due to the contamination of heavy metals [3] and it is now prohibited by the international covenants [1]. While, the treated DMS can be reuse as a geomaterial in various civil engineering applications and it has also become a specific new environmental issue recently. For example, it can be reuse as a backfill material by create a new land bases or rehabilitate the eroded land in near-shore areas [4]. Thus, those applications of treated DMS could meet client demand and moreover it could reduce the construction cost by using the recycle material.

Solidification is the process of utilizing the chemically reactive formulation together with water, other components in sludge and other aqueous hazardous waste to form a stable solids. The material used also insolubilizes, immobilizes, encapsulates, destroys, sorbs or otherwise interacts with selected components. These interactions form a solids which are non-hazardous or less hazardous than the...
original soil. The effectiveness of solidified products are often investigate through their strength, settlement and leach resistance [5]. Solidification technique towards the soft soil will alter in primarily its physical properties to produce a solidified soil hence it will no longer contain free liquids and also improved the strength. The treated soil are much easier to handle and more easily transported to the environment. The higher strength, lower settlement and lower porosity of treated soil are caused by the hydration reactions. The binder will bind together with the pozzolanic material to reduce the rate of hydration kinetics as well as the effect of carbonation. Where the carbonated solidified product develops higher strength material [5-6]. A major factor that will affecting the solidification is the mix design of additive material (binder) and waste (soil/sediment). It will effect on its strength, settlement, hydration, carbonation, pore structure, pore volume, and environmental factors [5].

2. Experimental work

2.1 Materials
The studied materials was dredged from Kuala Perlis Jetty, Perlis of Peninsular Malaysia in year 2016 (figure 1). Selection of dredging site was made based on Malaysian Marine Department (Jabatan Laut Malaysia, JLM) dredging schedule. The sediments was dredged at depth 4 to 6 m from sea level using backhoe dredger (figure 2). The properties results of the DMS are reported in table 1. The natural water content is about 240.74 % (3.36 LL), dried in an oven at 100 °C (BS 1377-2:1990:3.2). The particle density value of DMS is 2.36 Mg/m³, measured using a small pyknometer method (BS 1377-2:1990:8.3). The liquid limit value is 71.70 % by using a cone penetrometer method (BS 1377-2:1990:4.3). The plastic limit and plastic index value for DMS are 40.06 % and 31.64 %, respectively (BS 1377-2:1990:5). The DMS consist of 2.5 % of sand, 80.5 % of silt and 17 % of clay (figure 3). The DMS was classified in high plasticity silt, MH for its soil classification (Unified Soil Classification System).

Figure 1. Location of dredging site at Kuala Perlis Jetty, Perlis, Malaysia.  
Figure 2. Backhoe dredger.
Table 1. Properties of dredged marine sediments.

| Property                        | Value       |
|---------------------------------|-------------|
| Natural water content (%)       | 240.74      |
| Liquid limit (%)                | 71.70       |
| Plastic limit (%)               | 40.06       |
| Plastic index (%)               | 31.64       |
| WC/LL                           | 3.36 LL     |
| Specific gravity                | 2.36        |
| Particle size distribution (%)  | Sand: 2.5   |
|                                 | Silt: 80.5  |
|                                 | Clay: 17    |
| Soil classification             | High plasticity silt, MH |

Figure 3. Particle size distribution of Kuala Perlis DMS.

2.2 Preparation of specimens
Distilled water was added to the DMS to achieve the consistency of 3.36 $LL$ for each sample to achieve the same as natural water content of the DMS [7]. Cement was added to the DMS at a dosage of 10 and 20 %, corresponding to the $w/c$ ratio as shown in Table 2. DMS and cement was thoroughly mixed by using kitchen mixer at a lower speed. The mixture was then transferred into a consolidation ring (H: 20 mm, $\phi$: 75 mm) and left to cure for 3 days before a 1-dimensional compressibility test were performed. The sample was then dried in the oven and materials passing 63 $\mu$m are used in performing the SEM-EDX analysis.
Table 2. Specimen list and mix ratio.

| Specimen | Natural Water Content | Wet Soil (g) | Dry Soil (g) | Water, W (g) | Cement, C (g) | Cement Dosage (%) | w/c |
|----------|-----------------------|--------------|--------------|--------------|--------------|-------------------|-----|
| 10C      | 240.74                | 250          | 73.37        | 176.63       | 7.34         | 10                | 24.06 |
| 20C      |                       |              |              |              | 14.67        | 20                | 12.04 |

3. Results & Discussion

3.1 $\varepsilon_v - \sigma_v$ curves

The compression curves of natural Kuala Perlis DMS, 10 (10C3D) and 20 (20C3D) % cemented-solidified DMS are tabulated in figure 4. The natural Kuala Perlis DMS was used as the control sample and for comparison purpose. Sample 10C3D displayed slightly lower settlement reduction than the 20C3D. But both dosages displays a quite similar trend of compressibility.

The 6% of axial strain value denoted as the permissible settlement limit of embankment. Where it was simulated in a 1-dimensional compressibility test with maximum settlement of 1.2 mm from 20 mm specimen’s height. National Cooperative Highway Research Program (1975), specified the allowable maximum settlement of 4.5 m height embankments are between 300 to 600 mm. Thus the 300 mm was taken as the permissible settlement limit. The 300 mm settlement from 4.5 m height of embankment are equal to the 1.2 mm from 20 mm of compressibility test. It shows, both cemented-solidified DMS start yielding after 6% of axial strain. The applicable pressure for 4.5 m height embankment are 100 kPa. Those pressure were used and applied as the applicable pressure in compressibility test [8]. From the results, 10C3D and 20C3D shows both compression curves are not complies with the settlement criteria and applicable pressure.

![Figure 4. $\varepsilon_v - \sigma_v$ curves of DMS and cemented-DMS.](image-url)
3.2 SEM-EDX

Figure 5, 6 and 7 represents the SEM micrographs and EDX spectra of natural Kuala Perlis DMS, 10 and 20 % cement-solidified DMS, respectively. The microstructure of cemented DMS are quite different compare to natural DMS. Specimens with 10 and 20 % of cement illustrates the flocculated nature of the fabric and the formation of new cementing compounds in the matrix. The flocculated nature occurred due to the cation-exchange process. Hence, resulting in replacement of calcium ions with readily exchangeable ions during cement hydration. For specimen with 20 % of cement, it demonstrate a transform of soil fabric from a particle-based form to an integrated composition. Moreover, the existence of plate-shaped crystals of hydroxide calcium (cementing compounds) are clearly seen in 20 % cemented DMS [9-11].

Table 3 presents the Ca:Si ratio for natural Kuala Perlis DMS, 10 and 20 % cement-solidified DMS. It shows the Ca:Si ratio increased upon the cement application towards the DMS. The further increase in Ca:Si ratio of cemented DMS are probably due to the formation of C-S-H gel. Where the depositing of higher C-S-H gel on the surface of the particles lead to the increment in Ca:Si ratio [9,12].

Figure 5. SEM image and EDX spectra of Kuala Perlis DMS.
Figure 6. SEM image and EDX spectra of 10 % cemented-DMS.

Figure 7. SEM image and EDX spectra of 20 % cemented-DMS.

Table 3. Ca:Si ratio from EDX analysis.

| Specimen         | Kuala Perlis DMS | 10C DMS | 20C DMS |
|------------------|------------------|---------|---------|
| Ca:Si (%)        | 1.63             | 17.78   | 26.48   |

4. Conclusions
From the compression curves, it can be conclude that in order to enhance the settlement criteria of cement-solidified DMS, a further studies are required in decrease the w/c ratio and increase curing time [7]. The prolonged curing are believe could enhance the settlement criteria of cemented-DMS even though at 10 and 20 % of cement dosage. Otherwise, the cement dosage need to be increase if the specimen will be left cured at a short times (ie. 3 days). SEM micrograph proves the formation of the
cementing compounds in cement treated specimens. EDX results revealed the increment of Ca:Si ratio towards the specimens. The specimen’s final leachate pH observations are recommended to support the explanation of the C-S-H gel formation. Where, the lower pH of specimens may imply the more cementing reactions. Hence, depositing higher C-S-H gel on the particles and increased the Ca:Si ratio.

5. References

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