International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:11, No:2, 2017

Geotechnical Properties and Compressibility Behavior of Organic Dredged Soils

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***Abstract*—**Sustainable development is one of the most important topics in today's world, and it is also an important research topic for geoenvironmental engineering. Dredging process is performed to expand the river and port channel, flood control and accessing harbors. Every year large amount of sediment are dredged for these purposes. Dredged marine soils can be reused as filling materials, road and foundation embankments, construction materials and wildlife habitat developments. In this study, geotechnical engineering properties and compressibility behavior of dredged soil obtained from the Izmir Bay were investigated. The samples with four different organic matter contents were obtained and particle size distributions, consistency limits, pH and specific gravity tests were performed. The consolidation tests were conducted to examine organic matter content (OMC) effects on compressibility behavior of dredged soil. This study has shown that the OMC has an important effect on the engineering properties of dredged soils. The liquid and plastic limits increased with increasing OMC. The lowest specific gravity belonged to sample which has the maximum OMC. The specific gravity values ranged between 2.76 and 2.52. The maximum void ratio difference belongs to sample with the highest OMC ($\Delta e_{11\%}$ = 0.38). As the organic matter content of the samples increases, the change in the void ratio has also increased. The compression index increases with increasing OMC.

***Keywords*—**Compressibility, consolidation, geotechnical properties, organic matter content, organic soils.

I. Introduction

ALTERNATIVE construction materials have always been an attractive topic for researchers [1]-[3]. All over the world, large amount of dredged mud is excavated for land reclamation and port expanding projects, and this material is one of the alternative sustainable materials used in various civil engineering applications, such as; road and foundation embankments, construction of recreation areas, and production of ready-mixed concrete. However, engineering properties must be defined comprehensively, because of its OMC [4]-[7]. There are many studies summarized below conducted to define the engineering properties of dredged materials.

Geotechnical engineering properties of dredged samples, taken from Port of Brisbane, Queensland, Australia, were investigated. Index properties of dredged soil, such as particle size distribution, consistency limits and specific gravity were determined. The oedometer tests were conducted to determine the consolidation parameters of dredged soil. The test results showed that liquid and plastic limits of the dredged material are 80% and 34%, respectively. The specific gravity was found as 2.65. As a result of the oedometer test, maximum and minimum m_v values were determined as 1.95 x 10^{-2} and 4 x 10^{-4}, respectively. Researchers reported that the coefficients of permeability varied from 3 x 10^{-10} and 0.5 x 10^{-10} (m/s) under the effective stress range of 12 to 150 kPa [8].

Engineering properties of soft organic soil below the dredged fill area was determined. Index properties, OMC, shear strength properties and compressibility characteristics were obtained. The specific gravities ranged between 2.25 and 2.55. The OMCs vary between 4.7 and 9.4%. Liquid limit, plastic limit and plasticity index were between 45 and 192%, 20 and 129%, 18 and 63%. Samples classified as OH and OL according to USCS. Unconfined compressive strength and failure strain varied from 6 to 58 kPa and 9 to 15%. The consolidation test results show that initial void ratio (e_0), compression index (C_c) and recompression index (C_r) were in between 1.5 and 3.88, 0.44 and 1.25, 0.05 and 0.44, respectively. The coefficient of consolidation (c_v) varied from 0.20 to 10.9 m^2/yr [9].

The engineering properties of Malaysian dredged soils, which belonged to three different sites were investigated (Lumut, Marina Melaka, Tok Bali). In addition to this, test results were compared with sediment sample from Pasir Gudang region. The clay contents of Lumut, Melaka, Tok Bali and Pasir Gudang samples were found as 78%, 68%, 60% and 26%. The specific gravities were obtained as 2.60, 2.63, 2.68 and 2.41 from small pycnometer test. The liquid limits of the dredged and sediment materials were found as 95%, 58%, 37% and 46% from fall cone test. The plastic limits were found as 34.5%, 30.7%, 25.8% and 35.6%, respectively [10].

The shear strength properties of Germany East harbor mud were examined with large scale oedometer test (D=22 cm). At the end of the test, the peak friction angle was found 14° and residual friction angle was found 3°. The cohesion of harbor mud was almost 0 (c' = 0.22 kPa). Researchers reported that measured values for both undrained peak and residual shear strengths increase linearly with increasing consolidation stress [11].

Numerous researchers investigated the effects of OMC on engineering properties of different type soils. The engineering and physical properties of peat soils were inspected provided from six different locations of Sarawak (Malaysia). Researchers reported that organic contents ranged between 43% and 85%, liquid limits varied from 69 to 79, fibre contents were found between 32% and 67%. The test results showed that specific gravities of peat soil samples ranged

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between 1.5 and 1.8. The maximum dry densities of the six samples were found between 7 kN/m^3 to 8.70 kN/m^3. The optimum moisture contents were between 54% and 63%. The values of liquid limit, fibre content and optimum moisture content increased, maximum dry density and specific gravity decreased with an increasing in organic content [12].

The influence of OMC on the engineering and physical properties of the Kuttanad clay was determined. The laboratory tests were performed with clay samples with various organic matter contents. The particle size distribution analysis, liquid limit, triaxial compression (CU) and one dimensional consolidation tests were conducted to determine engineering properties of soils. The liquid limit and plastic limit were in the range of 83-90% and 54-58%. Both plastic and liquid limit linearly increased with increasing organic content. Increasing the OMC increased the optimum moisture content whereas no much variation in maximum dry density was observed. Increasing the OMC decreased the undrained shear strength and angle of friction. The initial void ratio, compression index (C_c) and rate of secondary compression (C_α) increased, coefficient of primary consolidation (c_v) decreased with an increasing in OMC [13].

The mechanical engineering properties of the dredged material (DM), such as drainage capacity, settlement behavior and shear strength characteristics were examined. Steel slag fines (SSF) were used as a soil improvement material. The samples were prepared with DM and SSF in various compositions (DM: 80% / SSF: 20%, 60/40, 50/50, 40/60 and 20/80). The highway embankments were constructed with 100% DM, 100% SSF, 80/20, 50/50 and 20/80 ratios for field application. The internal friction angle of 100% DM was 27.3º, which increased to a peak value of 45º for the mixture of 50/50 ratio. The hydraulic conductivity of 100% DM was 10^{-8} cm/s which reached to a peak value of 10^{-5} cm/s for 20/80 ratio. The average cone penetration test (CPT) tip resistances were found 1.3 and 57.3 MPa for 100% DM and 100% SSF whereas the average CPT tip resistances were found as 2.9, 6.2 and 11.6 for 80/20, 50/50 and 20/80 ratios [14].

In this study, geotechnical engineering properties and compressibility behavior of Izmir Bay's organic soils were investigated. Index properties were defined with particle size distributions, consistency limits, specific gravities, pH tests for samples with four different OMCs (0%, 4%, 7% and 11%). In order to determine OMC effects on compressibility behavior, one dimensional consolidation tests were conducted and consolidation parameters were defined.

II. Materials and Methods

Projects related to deepening works were generated to improved sea transport in Izmir Bay as from 1990s. Aside, storage, dumping area and effect of these process on the ecosystem connected dredged material were investigated. Izmir Metropolitan Municipality and Turkish State Railways conducted the Izmir Bay and Harbor Rehabilitation project. For this channel, dredging was conducted up to 8 m and 22.000.000 m³ of dredged material was excavated [15]. General view of Izmir Bay is shown in Fig. 1.

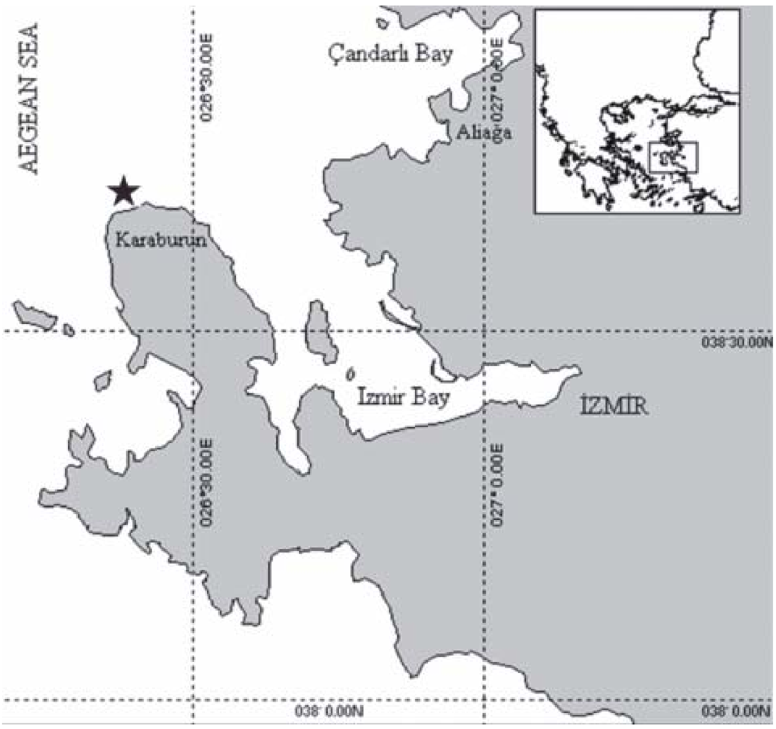

Fig. 1 General view of İzmir Bay

Geotechnical engineering properties of the İzmir Bay's organic soils obtained from previous studies are summarized in Table I [16].

In this study, the OMC of dredged soil was determined [17]. After the initial OMC was determined as 11%, the dredged soil samples were burned at 440 ºC for various time periods to obtain samples with different organic contents (0%, 4%, 7% and 11%) (Fig. 2).

TABLE I
SOME PROPERTIES OF ORGANIC SOIL [16]

Parameters	Unit	Filibeli, 1994	Alyanak, 1986	DEU, 1986
Specific gravity	-	2.0	-	-
Water content	%	64	64.2	56.2
OMC	%	11.8	20.3	11.9

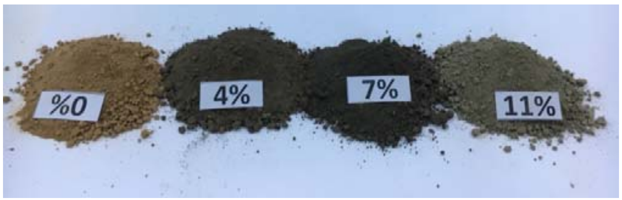

Fig. 2 Dredged materials with different OMCs

The particle size distributions of the four dredge soil samples with different OMCs were determined in soil mechanics laboratory [17]. The sample was dried in oven and then washed through No.200 (0.075 mm) sieve. The material retained on the sieve was dried and dry sieve analysis was performed. The plastic and liquid limits also known as consistency limits were determined [17]. The fall cone test method was used to determine liquid limits of samples. The dredged soil samples were classified using consistency limits and particle size distribution [17]. The specific gravities of samples were defined [17]. This method was performed using vacuum pump, pycnometer, air-free distilled water and dredged soil sample (50 g).

pH values of samples were determined [18]. Suspension was prepared by mixing 125 ml distilled water and 50 g sample. It was waited 24 h and then pH measurement was made with digital pH meter, each measurement was performed two times to check repeatability (Fig. 3).

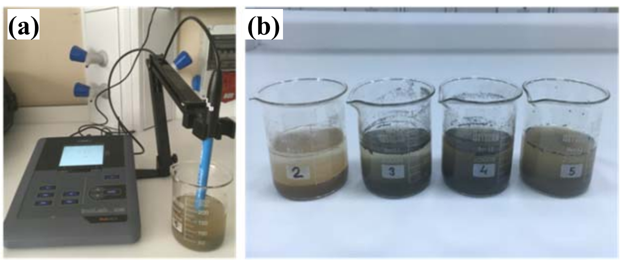

Fig. 3 pH test equipment (a) and samples (b)

The one-dimensional consolidation test was performed to obtain compressibility behavior of dredged soil [17]. In order to obtain uniform samples, each consolidation test sample was prepared at liquid limit. Before the loading period was started, the seating pressure of 5 kPa was applied.

The specimen was loaded with 24.5 kPa, 49 kPa, 98 kPa, 196 kPa, 392 kPa and 784 kPa of vertical stresses, respectively. Then same specimen was unloaded with 196 kPa and 49 kPa vertical stresses to determine the swelling characteristics. After the measurements were completed, the specimen was extruded from the sample ring and weighed. The consolidation tests were repeated two times for each sample to check the repeatability. Taylor's square root of time method (t_{90}) was used to determine coefficient of consolidation c_v. The consolidation test samples are shown in Fig. 4.

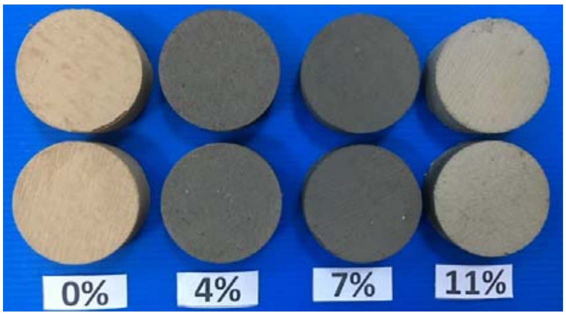

Fig. 4 Consolidation test samples

III. RESULTS AND DISCUSSION

The grain size distributions of samples which have various OMCs are shown in Fig. 5. The samples with different OMCs have similar particle size distributions. The maximum particle size of dredged soil sample is approximately 4.75 mm and more than half of the sample is smaller than 0.075 mm.

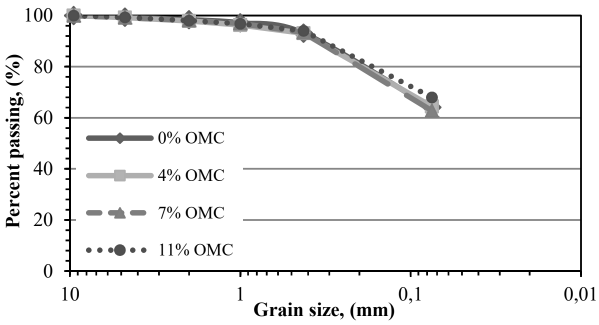

Fig. 5 Grain size distributions of dredged material samples

The geotechnical engineering properties of the dredged soils with different OMCs were summarized in Table II. The consistency limits experiments have shown that liquid and plastic limit values increase with the OMC increasing. The natural dredged sample has 20% higher liquid limit value, compared to sample with 0% OMC ($LL_{11\%}$ = 39.5 and $LL_{0\%}$ = 32.9). As a result of the conducted laboratory tests, the specific gravity values of 0%, 4%, 7% and 11% OMC samples were found as 2.76, 2.64, 2.60 and 2.52, respectively. When the specific gravity results were compared to literature studies, similar values were observed [8]-[10].

The test results have presented that the specific gravity increases with the OMC decreasing. The pH values of the dredged soil materials ranged between 7.2 and 8.9.

TABLE II
GEOTECHNICAL ENGINEERING PROPERTIES OF DREDGED SOIL

Name	0% OMC	4% OMC	7% OMC	11% OMC
Liquid limit, w_L (%)	32.9	32.6	34.7	39.5
Plastic limit, w_P (%)	26.4	27.9	28.7	31.0
Specific gravity, G_s	2.76	2.64	2.60	2.52
pH	8.9	7.5	7.2	7.4
USCS	OL	OL	OL	OL

The dredged soil samples were classified using particle size distribution curve and consistency limits according to USCS. The dredged soil samples were classified as low plasticity organic soil symbolized with OL.

For each vertical stress increment, the coefficient of consolidation (c_v), coefficient of volume compressibility (m_v) and coefficient of permeability (k) were specified and their variation with effective stress ($\boldsymbol{\sigma'_v}$) were plotted as in Figs. 6-8.

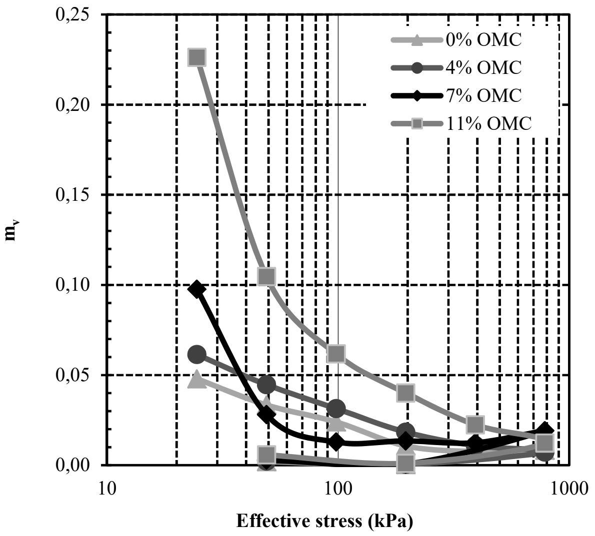

Fig. 6 Volume compressibility (m_v) - effective vertical stress (σ'_v)

Fig. 6 has shown that, the maximum m_v value of 0.23 was observed at 24.5 kPa (at loading stage) for specimen 11% OMC, and the minimum was 6.73 x 10^{-4} at 196 kPa (at unloading stage) for specimen 7% OMC. The permeability coefficients of specimens were 1.24 x 10^{-7} to 6.11 x 10^{-7} at 24.5 kPa, and decrease sharply at the next load increment (Fig. 7). During the loading and unloading stages, the coefficients of permeability of specimens were similar and below 10^{-7} except 24.5 kPa and 49 kPa load increments.

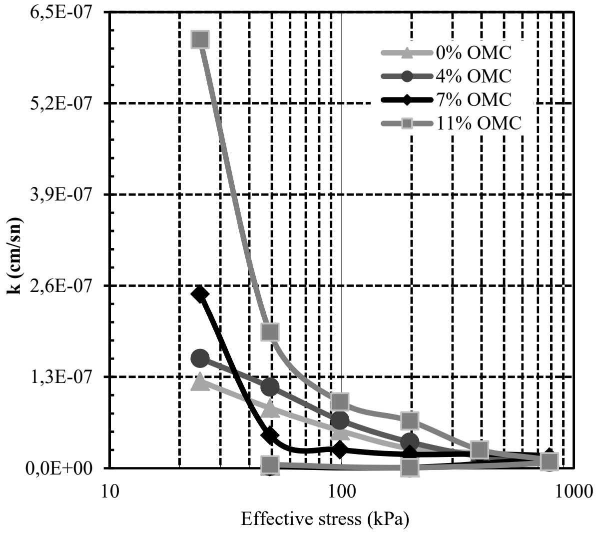

Fig. 7 Coefficient of permeability (k) - Effective vertical stress (σ'_v)

The relation of effective stress with void ratio (e) at the end of the consolidation was plotted during the loading and unloading stages (Fig. 8).

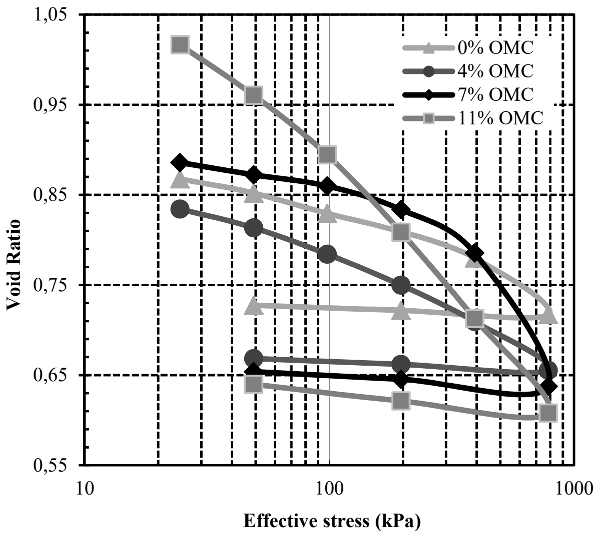

Fig. 8 Void ratio (e) - effective vertical stress (σ'_v)

The void ratio - effective stress curves have shown that the maximum void ratio difference ($\Delta e = e_0 - e_1$) belongs to sample with the highest OMC ($\Delta e_{11\%} = 0.38$). As the OMC decreases, the void ratio difference decreases too ($\Delta e_{7\%} = 0.23$, $\Delta e_{4\%} = 0.20$, $\Delta e_{0\%} = 0.11$).

The compression index C_c was determined over an approximate stress range of 196 – 392 kPa. The results are given in Fig. 9.

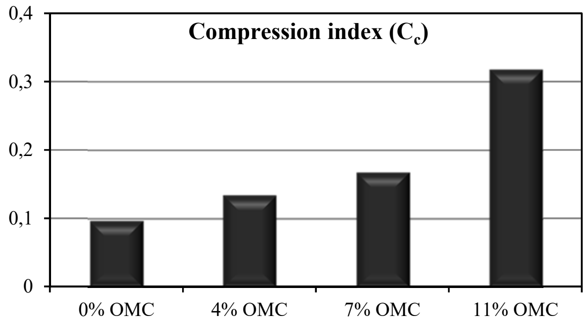

Fig. 9 Compression index values of specimens

The compression indexes of dredged materials ranged between 0.32 and 0.10. Fig. 9 has shown that compression index increases with the OMC increasing. The consolidation coefficients of samples with four different OMC were ranged between 7.75 x 10^{-4} and 2.9 x 10^{-3} cm^2/s.

IV. Conclusion

In this study, the geotechnical properties and compressibility behavior of İzmir Bay's organic soil were examined. First of all, geotechnical index properties, such as particle size distribution, consistency limits, pH and specific gravity tests were conducted for samples with different OMCs (0%, 4%, 7% and 11%). Furthermore, one dimensional consolidation tests were conducted and consolidation parameters were defined. The test results show that liquid and plastic limit values increase with increasing OMC. The natural dredged sample has 20% higher liquid limit value, compared to sample with 0% OMC ($LL_{11\%}$ = 39.5 and $LL_{0\%}$ = 32.9). The specific gravity increases with decreasing OMC. The consolidation test results show that the consolidation coefficient of specimens decreases with effective vertical stress in loading. There is no significant change in unloading for coefficient of consolidations. The maximum void ratio difference ($\Delta e = e_0 - e_1$) belongs to sample with the highest OMC ($\Delta e_{11\%}$ = 0.38). As the OMC decreases, the void ratio difference decreases too. The compression indexes of dredged materials are ranged between 0.32 and 0.10. The compression index increases with the OMC increasing.

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