Environmental Research & Technology, Vol. 3 (4), pp. 157-165, 2020

Environmental Research & Technology

http://dergipark.gov.tr/ert

RESEARCH ARTICLE

Experimental evaluation of compressibility parameters of lime and silica fume stabilized dredged soil

Inci Develioglu[1], Hasan Fırat Pulat[1,*]

[1] Izmir Katip Celebi University, Civil Engineering Department, Balatcik No:33/2, 35620, Izmir, TURKIYE

ABSTRACT

The use of alternative materials in civil engineering applications contributes to sustainable development and the economy. Large amounts of sediment are produced as waste material regarding to dredging activities in canals and ports. Storage or disposal of this material may cause some environmental and economic problems. To overcome these problems, dredged soils can be used for various civil engineering applications such as filling materials of road, foundation, and embankment. However, dredged soils generally have low bearing capacity, shear strength, and high compressibility due to their organic matter content. Therefore, these soils need to be improved with various additives before using as fillers. In this study, the index and compressibility parameters of a dredged soil were examined. The dredged soils were obtained from İzmir Bay. In the first part, Atterberg's limit test, sieve analysis, specific gravity, pH determination, scanning electron microscope analysis, Fourier transform infrared spectroscopy and consolidation test has been conducted for dredged samples which have various organic matter content (0, 4, 7 and 11%). In the next part, natural dredged soil samples were mixed with lime and silica fume in various proportions (5, 10, 15, and 20%), and compressibility performance was compared with the natural samples. It has been obtained that liquid and plastic limit, compression index, and void ratio change of natural dredged samples increased when organic matter content increased. While the silica fume has a negative effect on the compressibility behavior of dredged soil, the lime has a positive effect.

Keywords: *Compressibility, dredged soil, lime, silica fume*

1. INTRODUCTION

Advances in the industrial, urban, and tourism sectors cause the emergence of landmarks and high-rise buildings. As the number of lands becomes scarce, land reclamation has become more important. Therefore, more land is needed to expand this development.

Dredging is the operation of removing material from one part of the water environment such as rivers, lakes, seas, oceans and harbors, and relocating it to another. Dredging is carried out for many different purposes and in many different locations [1], [2], [3]. Dredged soil can be used in land reclamation applications such as wildlife habitat development, construction and filling materials, road and foundation embankments [4], [5], [6]. These types of soils have been known to have high compressibility and low shear strength because of their organic matter content (OM) [7], [8], [9]. Therefore, the geotechnical properties and compressibility behavior of this dredged material should be examined in detail before using it in these applications.

When the literature is examined, there are many studies conducted to determine the geotechnical index properties of the dredged soils. Shahri and Chan [3] examined the geotechnical index parameters of dredged materials taken from three sites (Lumut, Marina Melaka, Tok Bali) in Malaysia. The obtained test results of dredged materials were compared with the sediment sample from the Pasir Gudang region. The liquid limits of the dredged and sediment materials were determined 37 and 95% and the plastic limits were 26 and 36%, respectively. The specific gravity values also were designated as 2.41 and 2.68 [3]. Yu et al. [10] investigated the physicochemical properties of dredged soil treated with self-cementing Class C fly ash. The dredged soil was supplied from Milwaukee Harbor, Wisconsin in the USA. Untreated samples were mixed at a rate of 10, 20, and 30% fly ash, and the

Corresponding Author: hfirat.pulat@ikcu.edu.tr (Hasan F. Pulat)
Received 18 August 2020; Received in revised form 23 September 2020; Accepted 28 September 2020
Available Online 2 November 2020
Doi: https://doi.org/10.35208/ert.782042

curing process was applied 2 hours, 7, and 28 days. The undrained compressive strength (UCS) values stayed constant up to 20% fly ash content then increased. The CBR values increased with an increase in the fly ash content and ranged between 1.5 and 20.0. Average UCS was proportional to the fly ash content and the rate of increase in UCS increased with the increasing curing time [10]. Rosman and Chan [11] attempted to examine the compressibility behavior of dredged marine sediment admixed with waste granular materials (coal bottom ash and palm oil clinker) and cement. Samples of 10, 15, and 20% cement and 50, 100, and 150% waste granular material were mixed with the dredged marine sediment and subjected to an oedometer experiment. The test results showed that compression index values decreased where the cement and waste granular materials ratio were increasing. Cement was found to be more effective than the waste granular materials. Compression index values were obtained between 0.009 and 0.3. The minimum compression index was obtained in 10% cement and 100% palm oil clinker added sample. Hence, the authors reported that reusing of coal bottom ash and palm oil clinker could provide better waste management for dredged marine sediment and be suitable as auxiliary materials to cement [11].

It is known that the OM of the dredged materials has many effects on the geotechnical and strength parameters of the soil. Thiyyakkandi and Annex [8] explored the effect of OM (7 to 11%) on geotechnical index properties of the Kuttanad clay. As a result of laboratory experiments, the consistency limits linearly increased with increasing OM. While the optimum moisture content was proportional to the OM, not much variation was observed in maximum dry density. As the OM increased, the angle of friction and undrained shear strength decreased. The compression index (C_c), initial void ratio, and rate of secondary compression (C_α) increased, the coefficient of primary consolidation (c_v) decreased with an increase in OM [8]. Malasavage et al. [7] used steel slag fines (SSF) as a stabilizer material. The dredged soil and SSF were mixed 80/20, 60/40, 50/50, 40/60, and 20/80 ratios, and laboratory tests were performed. The plastic limits and liquid limits varied between 37 and 49%, 74 and 140%, respectively. The clay fraction of samples was in the range of 21.7 and 98.8%. The internal friction angle of natural dredged soil was 27.3º, which increased to a peak value of 45º for the mixture of 50/50 ratio [7].

Increasing its resistance by mixing various additives to dredged materials is a popular method of soil improvement among researchers. Nguyen et al. [9] studied on the geotechnical index properties of untreated and treated clayey dredged material. Quicklime, hydrated lime, Portland cement, and Class F fly ash were used as a stabilizer material. These materials were mixed with the dry soil sample at a rate of 12, 6, 6, and 7.5%, respectively. Consistency limits, optimum moisture content, and UCS of both untreated and treated samples were determined. According to test results, liquid limit, plasticity index, and optimum moisture content values decreased with the quick lime, hydrated lime, fly ash increasing and Portland cement decreasing. The quick lime was the additive that increases the optimum water content the most. The UCS values increased with the addition of stabilizers. While the Portland cement showed the most significant improvement, the fly ash had the least effect [9]. Lei et al. [12] focused on the effect of the polyacrylamide (PAM) addition on the compressibility behavior of the dredged clay. One dimensional consolidation tests were conducted with both normally consolidated (NC) and overconsolidated clay (OC) specimens. The PAM in certain proportions (0, 12.5, 25, 50, 75, and 120 mg L^{-1}) was first mixed with deionized water, and then this suspension was mixed with the dry sample so that the water content of the sample was 200%. Finally, the same consolidation tests were carried out with cement added samples (0, 2, 5, 8, and 10%) to compare the effects of PAM and cement. The test results showed that in the NC state, the structural yield stress, and the coefficient of consolidation increased, the coefficient of secondary compression decreased with the PAM content increasing. In the OC state minimum consolidation settlement and coefficient of secondary compression were obtained in the 50 mg L^{-1} PAM suspension. The effects of PAM and cement on the consolidation behavior of dredged clay were found to be approximately similar [12]. Jaditager and Sivakugan [13] examined the compressibility behavior of dredged soil obtained from the Port of Townsville, Australia. The improvement application was made using a fly ash-based geopolymer binder. The samples were mixed with 6, 12, and 18% fly ash-based geopolymers by weight. The coefficient of volume compressibility (m_v) increased with the fly ash-based geopolymer decreasing and was ranged between 0.634 x 10^{-3} and 1.13 x 10^{-3} kPa^{-1}. The permeability values were proportional to the fly ash-based geopolymer and were ranged between 2.17 x 10^{-10} and 3.65 x 10^{-10} m s^{-1} [13].

The effect of OM on the geotechnical and compressibility properties of dredged soil has been investigated within the scope of this study. In addition, it was aimed to improve the compressibility behavior of the dredged soil by using various additives (lime, silica fume). Scanning electron microscope (SEM) and Fourier transform infrared spectroscopy (FTIR) analyzes were performed to determine the internal structure of dredged soil. Geotechnical index properties were obtained from various laboratory tests such as sieve analysis, specific gravity, consistency limits, and pH tests. One dimensional consolidation test was conducted to determine the compressibility parameters of natural and stabilized dredged soil samples. The additives were mixed at 5, 10, 15, and 20% by dry weight of soil sample.

2. MATERIALS AND METHODS

Dredged soils used in the study were obtained from İzmir Bay. Turkish State Railways and İzmir Metropolitan Municipality carried out a project whose name is “Project of İzmir Bay and Harbor Rehabilitation”. Circulation channel projected for the construction was 13 km and dredging has been made up to 8 m. At the end of the project, approximately 22.000.000 m^3 of organic dredged materials have been obtained [14]. The general view of İzmir Bay is shown in Fig 1.

Fig 1. General view of İzmir Bay

The OM of dredged soil was defined by ignition at 440^{0}C in a furnace according to ASTM D2974 [15]. Firstly, natural OM was determined (11%) then samples were ignited at 440^{0}C for predefined times (1440, 70, and 20 minutes) to obtain different OM samples (0, 4, 7 and 11%) (Fig 2).

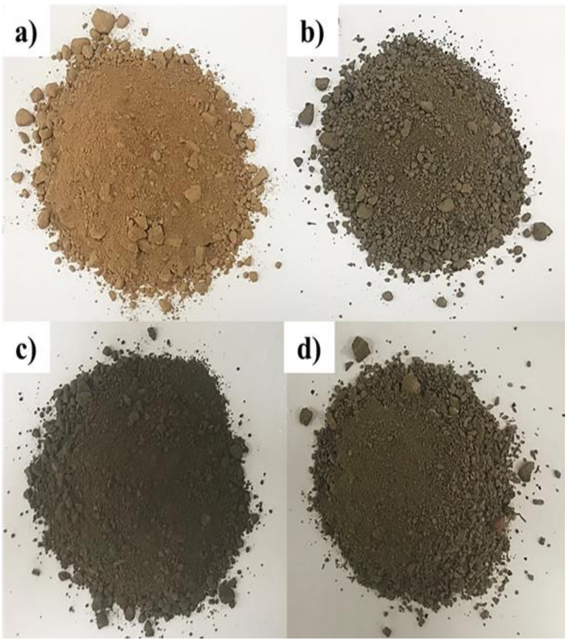

Fig 2. Dredged soil samples a) 0% OM, b) 4% OM, c) 7% OM, d) 11% OM

The specific gravity of samples was determined according to ASTM D854 with the pycnometer method [16]. The pH values of samples were obtained from a digital pH meter. The suspension was prepared by mixing 50 g sample and 125 ml distilled water. pH measurement was performed after 24 hours of preparation [17]. The particle size distributions for four dredged samples with different OM were defined using wet sieve analysis in accordance with ASTM D422 and ASTM D6913 [18], [19]. The liquid limit was determined by the fall cone method [20]. The plastic limit test was carried out according to ASTM D4318 [21]. The dredged soil samples were classified using Atterberg's limits and particle size analyses according to ASTM D2487 [22].

The FTIR analysis was conducted to obtain a molecular bond characterization of natural and stabilized samples in the mid-infrared region (4000 – 400 cm^{-1}). The analysis was performed at Izmir Katip Celebi University Central Research Laboratory with the dry sample passing from No.40 sieve (0.425 mm). The specimen was placed on the sample plate and the head was brought into contact with the sample after that the analysis was carried out with the Thermo iS50 FT-IR model device.

SEM analysis was performed to determine the internal structure of the dredged soil sieved from No. 40 (0.425 mm). The analysis was conducted at Izmir Katip Celebi University Central Research Laboratory with the Zeiss brand Sigma 300 VP model device. In this analysis, both microscopic image scanning and elemental analysis results were obtained.

The 1D consolidation test was turned out to obtain compressibility parameters of dredged soil according to ASTM D2435 [23]. Each test sample was prepared at their liquid limit to obtain uniform samples. The seating pressure of 5 kPa was applied before the experiment started. The specimen was loaded with 24.5, 49, 98, 196, 392, and 784 kPa of vertical stresses. Then the same specimen was unloaded with 196 and 49 kPa vertical stresses to determine the swelling behavior. The consolidation tests were repeated two times for each sample to check the repeatability.

Following the consolidation experiments with natural samples, consolidation experiments were carried out on additive samples (lime, silica fume). The specific gravities of lime and silica fume are 2.48 and 2.21, respectively. The dredged soil was mixed with the additive of 5, 10, 15, and 20% (dry weight additive by dry weight dredged soil) for one-dimensional consolidation test. The samples were prepared again at their liquid limits. The samples, mixture ratios, and abbreviations are listed in Table 1.

Table 1. Sample, abbreviations and mixture ratios

Dredged soil	Additive content (%)			
	Lime			
	5	10	15	20
0% OM	0OM5L	0OM10L	0OM15L	0OM20L
4% OM	4OM5L	4OM10L	4OM15L	4OM20L
7% OM	7OM5L	7OM10L	7OM15L	7OM20L
11% OM	11OM5L	11OM10L	11OM15L	11OM20L
	Silica fume			
0% OM	0OM5S	0OM10S	0OM15S	0OM20S
4% OM	4OM5S	4OM10S	4OM15S	4OM20S
7% OM	7OM5S	7OM10S	7OM15S	7OM20S
11% OM	11OM5S	11OM10S	11OM15S	11OM20S

3. RESULTS AND DISCUSSION

3.1. Index and compressibility properties of natural dredged soil

The particle size distributions of dredged soil samples that have various OM have been shown in Fig 3. The particle size distribution curves of all samples were very similar to each other. The maximum particle size of the dredged soil sample is about 4.75 mm, it was also observed that more than half of the sample passed through No. 200 sieve.

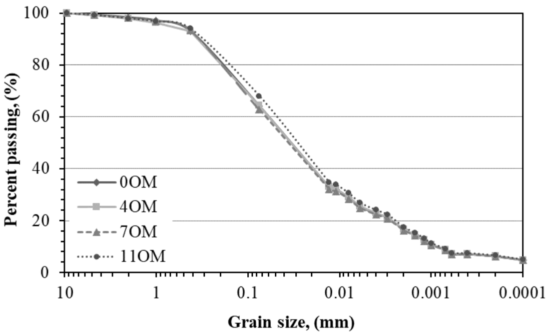

Fig 3. Particle size distributions of dredged soils

The natural dredged soil contains fine particles such as algae, branches, and bones that are much larger than the other two dimensions. Therefore, two-dimensional sieve analysis was insufficient for the particle size distribution of the dredged soil. For this reason, it is aimed to support the sieve analysis results with SEM analyzes. SEM analyzes were carried out with 0OM and 11OM samples to see the OM effect on particle size in detail. The SEM analyzes results have been shown in Fig 4. While the natural dredged sample contains organic materials (Fig 4b), there isn't any organic matter in the 0OM sample (Fig 4a).

According to FTIR analyzes, the peak positions (cm^{-1}) of the spectra were obtained as 711 – 713, 777 – 797, 872 – 874, 999 – 1005, 1409 – 1428 and 3391 – 3641. These spectra have been obtained very similarly to each other for samples with different OM. The boundary conditions which represent a chemical bond and a functional group were adaptable with the studies in the literature [24], [25], [26].

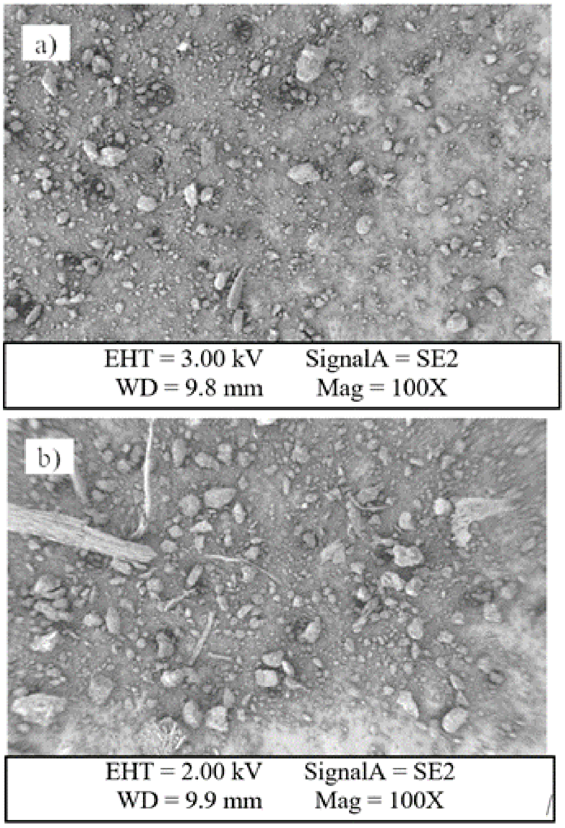

Fig 4. SEM analysis of a) 0OM sample, b) 11OM sample

The graph showing the change of specific gravity with respect to the OM has been given in Fig 5. As a result of specific gravity experiments, it was determined that there is an inverse relationship between OM and specific gravity. This situation can be explained by the increase in the amount of carbon content and the weakening of the internal structure with the increase of OM [7], [27], [28], [29], [30].

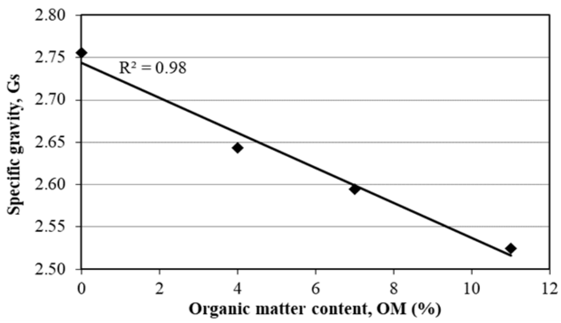

Fig 5. The relation between specific gravity and OM

The graph showing the change of liquid and plastic limit with respect to the OM has been given in Fig 6. As a result of the fall cone and plastic limit experiments, it was determined that there is a proportional relation between OM and liquid and plastic limit. This situation can be explained by the fact that the water covers the particles after the hydration of the organic materials is completed. As a result, an increase in liquid and plastic limits occurs [8], [31].

The pH values of the dredged soil samples were obtained in the range of 7.2 and 8.9, which are defined from slightly alkaline (7-8) to moderately alkaline (8-9). The classification of the dredged soil sample was made using consistency limits and particle size distribution curves according to USCS [22]. In the plasticity chart, the place of 0OM sample was above the A-line, other samples were under the A-line and liquid limits were in the range of 32.6 and 39.5%, indicated as OL (low plasticity organic soil) group for all samples.

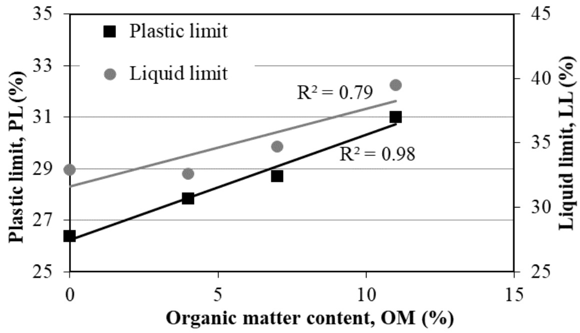

Fig 6. The relation between liquid limit, plastic limit, and OM

The results obtained from the literature studies investigating the index and compressibility properties of the dredged soils and the current study have been summarized in Table 2.

Table 2. Index and compressibility properties of dredged soils from different studies

Reference	G_s	OM (%)	LL (%)	PL (%)	C_c
Present study	2.76	0	32.9	26.4	0.097
	2.64	4	32.6	27.9	0.134
	2.60	7	34.7	28.7	0.189
	2.52	11	39.5	31.0	0.318
[2]	-	7.00	104	38	0.74
[7]	2.58	11.76	140	38	0.28
[32]	2.67	-	55.0	26.0	0.048
[3]	2.60	-	95.8	34.5	-
	2.63	-	58.5	30.72	
	2.38	-	36.8	25.83	
	2.41	-	46.1	35.6	
[37]	2.53	6.27	76.1	35.3	-
[33]	2.71	-	78.8	28.3	-
	2.70	-	54.7	24.3	
	2.65	-	39.8	21.0	
[34]	2.45	-	56.5	16.92	-
	2.56	6.33	95.8	34.4	
[35]	2.76	6.60	65.3	15.5	-
	2.75	4.20	61.2	20.7	
	2.70	8.30	89.5	72.2	
[13]	2.67	-	74	32	-
[36]	2.64	10.20	107.6	35.4	-
[11]	2.57	-	47.7	31.5	0.3
[10]	2.59	9.8	62	42	-
[12]	2.74	-	63.8	29.2	-
[9]	2.68	2.85	80	28	-

The specific gravity values were between 2.76 and 2.38 as shown in Table 2. Also, the plasticity indices were in the range of 5 and 102%. The geotechnical index properties' results of the current study were compatible with the results of the literature studies. This table also proves that the studies on the compressibility behavior of the dredged soil are very limited.

The void ratio (e) – effective vertical stress (σ') curves have been shown in Fig 7. The highest change in void ratio ($\Delta e = e_0 - e_1$) was obtained on the 11OM sample (Δe_{11OM} = 0.38). The change in void ratio were proportional with the OM (Δe_{7OM} = 0.23, Δe_{4OM} = 0.20, Δe_{0OM} = 0.11).

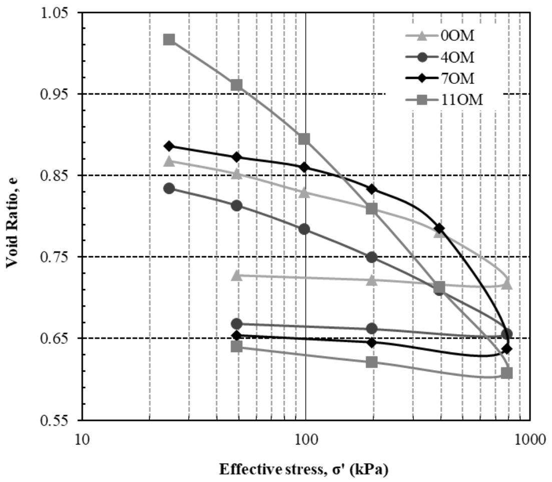

Fig 7. The compressibility curves of dredged soils

It was determined that the ignited dredged soil samples (0OM, 4OM, 7OM) did not have a breakpoint (the maximum curvature of the curve [the point where the slope of the curve increases sharply]) on the e - σ 'curve, whereas the natural dredged material (11OM) had a breakpoint. The steepest slope of the swelling curve and the maximum swelling potential belong to a natural dredged soil sample containing the highest OM. The graphs showing the change of the compression (C_c) and swelling index (C_s) depending on the OM obtained from one-dimensional consolidation tests has been given in Fig 8.

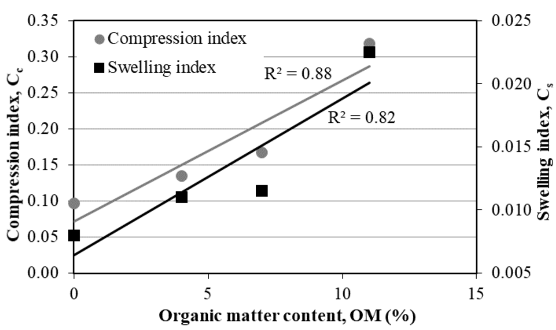

Fig 8. The relation between C_c, C_s, and OM

According to test results, it was determined that C_c and C_s were proportional to the OM. This can be explained by the fact that organic particles are more deformable than solid particles and have high void ratios. Consequently, as OM increases, the change in void ratio increases.

3.2. Compressibility properties of lime stabilized dredged soil

The graph showing the change of the compression index depending on the lime content (LC) has been given in Fig 9 for all samples. The C_c values were inversely proportional to the LC and took values between 0.043 and 0.247.

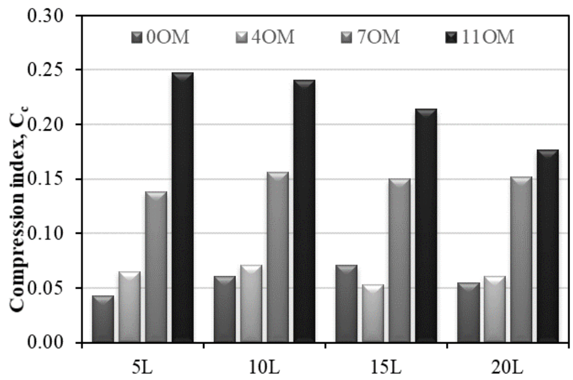

Fig 9. The relation between C_c and LC

3.3. Compressibility properties of silica fume stabilized dredged soil

The graph showing the change of the compression index depending on the silica fume content (SFC) has been given in Fig 10 for all samples. The C_c values were proportional to the SFC except for 11 OM samples and had values between 0.156 and 0.426.

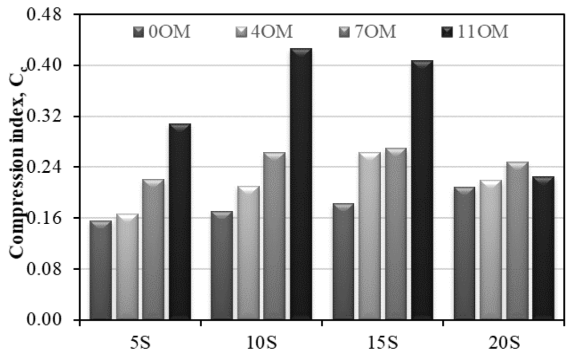

Fig 10. The relation between C_c with SFC

The axial strain values of lime and silica fume stabilized dredged soil samples have been listed in Table 3. The axial strains of the natural dredged soil samples were also as follows; 0.085, 0.102, 0.153, and 0.213, respectively.

Table 3. Axial strains of lime and silica fume stabilized dredged soil samples

OM (%)	Axial strain (ε)			
	LC (%)			
	5	10	15	20
0	0.030	0.035	0.048	0.064
4	0.031	0.043	0.047	0.053
7	0.075	0.077	0.142	0.091
11	0.121	0.139	0.133	0.087
	SFC (%)			
	5	10	15	20
0	0.094	0.094	0.103	0.121
4	0.123	0.144	0.157	0.152
7	0.164	0.191	0.191	0.193
11	0.228	0.205	0.216	0.218

For lime added samples, in three out of four samples, the minimum axial strain was obtained in 5% lime stabilized sample except for 11OM. It was observed that the axial strain of the lime stabilized sample was lower than the axial strain of the natural sample for all samples. These results prove that the addition of lime positively affects the compressibility properties. However, it has been determined that the most effective contribution rate, in general, is 5%. The previous studies which are Önal [38] and Önal and Sarıavcı [39] were also suggested 4% lime for improvement strength properties. For silica fume added samples, it was determined that the axial strain values increased with the SFC increasing. Also, it was observed that the axial strain of the silica fume stabilized sample was higher than the axial strain of the natural sample. These results prove that the addition of silica fume negatively affects the compressibility properties. This situation can be explained by the fact that the silica fume contains more fine-grained compared to the dredged soil, and therefore the silica fume has a higher void ratio.

The lime and silica fume were used in various ratios to improve the compressibility parameters of dredged soil. Axial strains and compression indices were measured, and results were compared. As a result of the consolidation experiments, it has been observed that while lime has a positive effect on the compressibility parameters, silica fume has a negative effect.

4. CONCLUSIONS

In the scope of this study, the geotechnical and compressibility properties of dredged soil obtained from İzmir Bay were investigated under different conditions. Initially, the organic matter content effect on both geotechnical and compressibility behavior of dredged soil was examined. Afterwards, the effect of lime and silica fume on the compressibility properties of the dredged soil was determined. For natural samples the test results showed that;

- Specific gravity was inversely proportional to the organic matter content.
- The compression index, swelling index, liquid, and plastic limit were proportional to the organic matter content.
- The change in the void ratio was proportional to the organic matter content.
- The maximum change in the void ratio was obtained from the 11OM sample.

For lime stabilized samples;

- The lime stabilization had a positive effect on the compressibility behavior of dredged soil.
- The compression index values were inversely proportional to the organic matter content.
- Lime contents of 5 – 10 % were more effective than the lime contents of 15 – 20 % on the compressibility performance.

For silica fume stabilized samples;

- The silica fume stabilization had a negative effect on the compressibility behavior of dredged soil.
- The compression index values were proportional to the silica fume content except for the 11OM sample.
- According to these results, this type of stabilizer is not appropriate to improve the compressibility behavior of dredged soil for the 0OM, 4OM, and 7OM samples but it is appropriate for the 11OM sample.

REFERENCES

[1]. https://www.european-dredging.eu/Dredging, The European Dredging Association website. [Online]. Available: (2018).

[2]. B. Rekik and M. Boutouil, "Geotechnical properties of dredged marine sediments treated at high water/cement ratio," *Geo – Marine Letters,* Vol.29, pp. 171 – 179, 2009.

[3]. Z. Shahri and C.M. Chan, "On the characterization of dredged marine soils from Malaysian waters:

physical properties," *Environment and Pollution*, Vol. 4, pp. 1 – 9, 2015.

[4]. J. Limeria, L. Agullo, and M. Etxeberria, "Dredged marine sand as construction material," in *Proc. Journees Nationales Genie Cotier – Genie Civil*, 2010.

[5]. D. Ganesalingam, A. Arulrajah, J. Ameratunga, P. Boyle, and N. Sivakugan, "Geotechnical properties of reconstituted dredged mud," in *Proc. Pan-AM CGS Geotechnical Conference*, pp. 1 – 7, 2011.

[6]. L. Zeng, Z. Hong, and Y. Gao, "Practical estimation of compression behavior of dredged clays with three physical parameters," *Engineering Geology*, Vol. 217, pp. 102 – 109, 2017.

[7]. N.E. Malasavage, S. Jagupilla, D.G. Grubb, M. Wazne, and W.P. Coon, "Geotechnical performance of dredged material – steel slag fines blends: laboratory and field evaluation," *Journal of Geotechnical and Geoenvironmental Engineering,* Vol. 8, pp. 981 – 991, 2012.

[8]. S. Thiyyakkandi and S. Annex, "Effect of organic content on geotechnical properties of Kuttanan clay," *Electronic Journal of Geotechnical Engineering*, Vol. 16, pp. 1653 – 1663, 2011.

[9]. T.T.M. Nguyen, S. Rabbanifar, N.A. Brake, Q. Qian, K. Kibodeaux, H.E. Crochet, S. Oruji, R. Whitt, J. Farrow, B. Belaire, P. Bernazzani, and M. Jao, "Stabilization of silty clayey dredged material," *Journal of Material in Civil Engineering*, Vol. 30 (9), pp. 1 – 11, 2018.

[10]. H. Yu, J. Yin, A. Soleimanbeigi, and W.J. Likos, "Effects of curing time and fly ash content on properties of stabilized dredged material," *Journal of Materials in Civil Engineering*, Vol. 29 (10), pp. 1 – 11, 2017.

[11]. M.Z. Rosman and C. Chan, "Settlement reduction of dredged marine soils (DMS) admixed with cement & waste granular materials (WGM): 1-D compressibility study," *International Journal of GEOMATE*, Vol. 13 (38), pp. 104 – 110, 2017.

[12]. H. Lei, Y. Xu, X. Li, G. Zheng, and G. Liu, "Effects of polyacrylamide on the consolidation behaviour of dredged clay," *Journal of Materials in Civil Engineering*, Vol. 30 (3), pp. 1 – 10, 2018.

[13]. M. Jaditager and N. Sivakugan, "Consolidation behaviour of fly ash-based geopolymer-stabilized dredged mud," *Journal of Waterway, Port, Coastal and Ocean Engineering*, Vol. 144 (4), pp. 1 – 7, 2018.

[14]. B. Ozkırlı and O. Urker, "İzmir Körfezi ve Limanı Rehabilitasyon Projesi kapsamında, Gediz Deltası sulak alanı içerisinde yapılması planlanan tarama malzemesi depolanması ve işlenmesi sürecinin ekolojik ve hukuki olarak incelenmesi," *Doğa Derneği*, 2012.

[15]. ASTM D2974 – 14, "Standard test methods for moisture, ash, and organic matter of peat and other organic soils," *ASTM International*, 2014, www.astm.org.

[16]. ASTM D854-14, "Standard test methods for specific gravity of soil solids by water pycnometer," *ASTM International,* 2014, www.astm.org.

[17]. G. Kocasoy. Atıksu arıtma çamuru ve katı atık ve kompost örneklerinin analiz yöntemleri, 1st ed., *Boğaziçi Üniversitesi Yayınları*, İstanbul, Turkey. 1994.

[18]. ASTM D422-63(2007)e2, "Standard test method for particle-size analysis of soils (Withdrawn 2016)," *ASTM International*, 2007, www.astm.org.

[19]. ASTM D6913-04(2009)e1, "Standard test methods for particle-size distribution (Gradation) of soils using sieve analysis," *ASTM International*, 2009, www.astm.org.

[20]. BS 1377-1, "Methods of test for soils for civil engineering purposes," *British Standard Institution,* London, 2016.

[21]. ASTM D4318-10e1, "Standard test methods for liquid limit, plastic limit, and plasticity index of soils," *ASTM International*, 2010, www.astm.org.

[22]. ASTM D2487-11, "Standard practice for classification of soils for engineering purposes (Unified Soil Classification System)," *ASTM International*, 2011, www.astm.org.

[23]. ASTM D2435/D2435M-11, "Standard test methods for one-dimensional consolidation properties of soils using incremental loading," *ASTM International,* 2011, www.astm.org.

[24]. C. Huang and P.F. Kerr, "Infrared study of the carbonate minerals," *Am. Mineral*, Vol. 45, pp. 311 – 324, 1960.

[25]. T. Nguyen, L.J. Janik, and M. Raupach, "Diffuse reflectance infrared Fourier transform (DRIFT) spectroscopy in soil studies," *Soil Research*, Vol. 29(1), pp. 49 – 67, 1991.

[26]. R. Ravisankar, A. Chandrasekaran, S. Kalaiarsi, P. Eswaran, C. Rajashekhar, K. Vanasundari, and A. Athavale, "Mineral analysis in beach rocks of Andaman Island, India by spectroscopic techniques," *Archives of Applied Science Research*, Vol. 3(3), pp. 77 – 84, 2011.

[27]. C. Chan, "Geo-parametric study of dredged marine clay with solidification for potential reuse as good engineering soil," *Environmental Earth Sciences*, Vol. 75, pp. 941 – 955, 2016.

[28]. G. Kang, T. Tsuchida, and A.M.R. Athapaththu, "Engineering behaviour of cement-treated marine dredged clay during early and later stages of curing," *Engineering Geology*, Vol. 209, pp. 163 – 174, 2016.

[29]. G. Kang, T. Tsuchida, and Y. Kim, "Strength and stiffness of cement-treated marine dredged clay at various curing stages," *Construction and Building Materials*, Vol. 132, pp. 71 – 84, 2017.

[30]. D. Wang, N.E. Abriak, and R. Zentar, "One-dimensional consolidation of lime-treated dredged harbour sediments," *European Journal of Environmental and Civil Engineering*, Vol. 19, pp. 199 – 218, 2015.

[31]. I. Develioglu, and H.F. Pulat, "Geotechnical Properties and Compressibility Behaviorof Organic Dredged Soils," in *Proc. 19th*

International Conference on Earthquake Geotechnical Engineering, pp. 194 –198, 2017.

[32]. A. Federico, C. Vitone, and A. Murianni, "On the mechanical behaviour of dredged submarine clayey sediments stabilized with lime or cement," *Canadian Geotechnical Journal*, Vol. 52, pp. 2030 – 2040, 2015.

[33]. G. Xu, Y. Gao, J. Yin, R. Yang, and J. Ni, "Compression behaviour of dredged slurries at high water contents," *Marine Georesources & Geotechnology*, Vol. 33, pp. 99 – 108, 2015.

[34]. C. Chan, "Strength improvement characteristic of cement-solidified dredged marine clay with relation to water-cement ratio," *International Journal of GEOMATE*, Vol. 11, pp. 2734 – 2740, 2016.

[35]. G. Kang, T. Tsuchida, and A. M. R. G, Athapaththu, "Engineering behaviour of cement-treated marine dredged clay during early and later stages of curing," *Engineering Geology*, Vol. 209, pp. 163 – 174, 2016.

[36]. G. Kang, T. Tsuchida, and Y. Kim, "Strength and stiffness of cement-treated marine dredged clay at various curing stages," *Construction and Building Materials*, Vol. 132, pp. 71 – 84, 2017.

[37]. D. Wang, N.E. Abriak, and R. Zentar, "One-dimensional consolidation of lime-treated dredged harbour sediments," *European Journal of Enviromental and Civil Engineering*, Vol. 19, pp. 199 – 218, 2015.

[38]. O. Önal, "Lime Stabilization of Soils Underlying a Salt Evaporation Pond: A Laboratory Study," *Marine Georesources and Geotechnology*, Vol. 33(5), pp. 391 – 402, 2015.

[39]. O. Önal, and Ç. Sarıavcı, "Stabilization of Meles Delta soils using cement and lime mixtures," *Geomechanics and Engineering*, Vol. 19(6), pp. 543 – 554, 2019.