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Review

Predicting geotechnical parameters of fine-grained dredged materials of the gulf of Izmit (NW Turkey) using the slump test method and index property correlations

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In this study, an attempt has been done to figure out the geotechnical properties of physically remolded dredged materials of the Gulf of Izmit located in NW Turkey, by using slump test method. For this aim, slum tests were conducted on dredged material specimens using open-ended polyvinyl chloride (PVC) cylinders of 10 cm diameter and height. Water content of the dredged material specimens was obtained in the laboratory using oven method. Bulk wet density, Atterberg limits and phase relations such as bulk unit weight, % solids by weight, void ratio, and engineering behavior properties such as Vane shear strength, and effective stress were determined. Later, the statistical correlations were conducted by regression analysis to obtain the relationships between water content and slump/cylinder height as well as other parameters such as wet bulk density, % solid by weight, void ratio, Vane shear strength and effective stress.

Key words: Vane shear strength, dredged materials, slump test.

INTRODUCTION

Description of dredged material properties is very necessary for any planned dredging operation, and the fundamental geotechnical parameters need to be determined or predicted. While near shore dredging operations, the dredging process generally involves too much material handling, manipulation, and remolding. The natural previously deposited material has been dredged, transported and re-deposited by the time. Therefore, its geotechnical properties are changed. The most fundamental parameters of the dredged materials are grain size distributions, water content, density, specific gravity and percent solid. Engineering properties include shear strength, permeability, viscosity, consolidation and critical erosion.

The laboratory tests of soil classification and description, grain size analysis and distribution, specific gravity of solid particles, water content, bulk density, shear strength, stress-strain and behavior characteristics provide basic information about the dredged material soil properties. Dredged materials lose their original geotechnical properties while they are being dredged, transported and redeposited. Intergranular bonding and physico-chemical condition affect the materials behavior (Mitchell, 1993; Lee, 2004). As the water content in the dredged material is increased during remoulding and the solid particles become more separated, the material behaves like slurry. If fine-grained particles (silt and clay) composed more than 35% of the total matrix solids, the slurry behaves as viscous material (Spigolon, 1993). High organic content, gas bubbles and fibrous materials affect the shear strength of dredged materials (Klein and Sarsby, 2000; Edil and Wang, 2000). DeMeyer and Mahlerbe (1987) determined the threshold (yield) shear stress σ most clayey slurries less than 10 Pa. Bouziani

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Figure 1. Study area. Stars indicate the dredged material collection points (Google earth).

and Benmounah (2013) conducted v-funnel and mini-slump tests with viscosity of Self-Compacting Mortars (SCM), measured at different rotational speeds and linear relationships were obtained between both v-funnel and mini-slump tests and viscosity. Peila et al. (2009) performed the slump cone test on conditioned material to check the mass behavior. Vinai et al. (2008) used a simple slump test to analyze the global characteristics of the conditioned soils.

The dredged materials are used to improve soil structure for agriculture purposes. Some dredged materials may be very good topsoil according to Francingues et al. (2000) and Nelson and Pullen 1990). They are also used for creating embankments (McLellan et al., 1990; Smith and Gailani, 2005), land improvement (Harrison and Luik, 1980; Perrier et al., 1980; Spaine et al., 1978), land creation (Coastal Zone Resources Division, 1978; capping (Palermo et al., 1998), replacement fill and share protection (Comoss et al., 2002).

The advantage of the slump test is that it allows rapid field estimation of a material's water content (with calculated void ratio, density, or other phase relationships) if a previously developed slump-water content curve is available for the given material. The slump test was originally developed for rapid estimation of mine tailing properties in Australia (University of Melbourne, 1996) by observing the height drop (slump) instead of the spread diameter. In this study, slump tests were conducted on 36 dredge material specimens collected along the coastal areas of the Gulf of Izmit (Gürbüz and Gürer, 2008). Index parameters, phase relationships and engineering behavior of the specimens were determined and some correlations were performed.

Study area

The study was performed at the coastal areas of the Gulf of Izmit, located NW Turkey (Figure 1).

Gulf sediment specimens

The dredged material specimens were collected using a small dredging operation from the study area for the purpose of characterizing their geotechnical properties. The grain size distribution graphic of the dredged material specimen collected from Station #1 is given in Figure 2 and the grain size distribution values of specimens collected from 36 stations are given in Table 1.

The slump test method

The slump test is an operation that consists of filling an upright open-ended cylinder with remolded dredged material, getting rid of the excess material at the top; slowly lifting the cylinder and measuring the variation in height (slump) as the material complete its outward flow. The slump test for concrete (ASTM 2000a) has been used for years to measure the consistency of freshly mixed concrete for quality control purposes. For this test a conical upright open ended cylinder is filled with wet concrete and tamped with a rod. After removing the excess material at the top, the cylinder is slowly lifted and the resulted variation in height (slump) of the concrete is measured. The open-ended cylinder size is 150 mm in height, with a 76 mm inside diameter.

Slump test application

Slump tests were conducted on 36 dredged material specimens using an open-ended polyvinyl chloride (PVC) cylinder of 10 cm height and diameter. *In situ* each dredge material specimen was placed into the slump cylinder, leveled off, and allow to flow outward as the cylinder was slowly lifted upward with minimum disturbance to the specimen. After the outward flow has visually stopped, the change in height (slump) as material

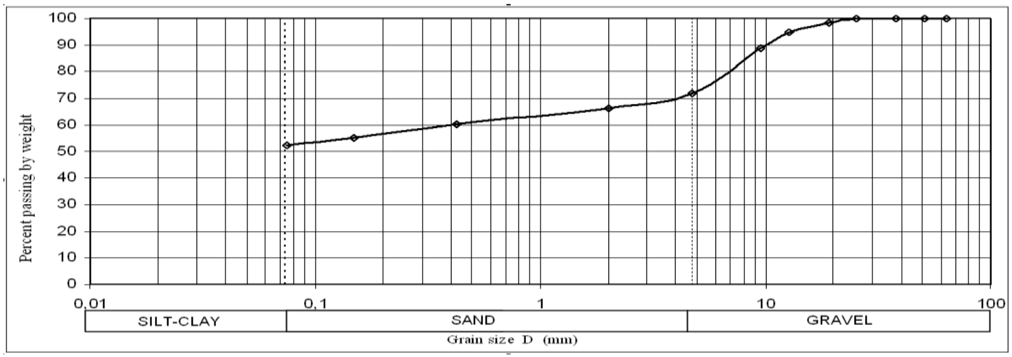

Figure 2. Grain size distribution of dredged specimen collected from Station #1.

Table 1. Grain size distribution of specimens collected from 36 stations.

Station No	Gravel	Sand	Silt+Clay
1	28.31	19.32	52.36
2	30.12	19.61	50.27
3	25.63	21.10	53.27
4	26.58	23.17	20.26
5	29.15	17.94	52.91
6	30.81	17.43	51.76
7	25.94	22.78	51.28
8	28.91	20.45	50.64
9	28.64	15.13	56.23
10	29.48	19.65	50.87
11	29.11	17.39	53.47
12	31.92	15.11	52.98
13	25.48	21.89	52.63
14	26.45	23.15	50.32
15	25.31	20.87	53.82
16	27.96	21.69	50.36
17	21.93	23.76	54.31
18	23.81	23.84	52.36
19	16.34	20.47	63.19
20	21.59	19.52	58.49
21	19.78	25.49	54.73
22	23.62	25.02	51.36
23	12.56	25.11	62.34
24	23.58	25.45	50.96
25	21.36	25.74	52.63
26	22.54	26.79	50.67
27	22.45	22.07	55.48
28	24.51	24.06	51.43
29	24.73	20.59	54.68
30	25.31	24.45	50.23
31	26.94	18.70	54.36
32	38.14	11.74	50.12
33	29.57	19.00	51.43
34	31.96	17.36	50.68
35	19.74	26.47	53.79
36	21.65	28.06	50.29

completes its outward flow is measured. The slump was divided by cylinder height to find normalized slump which is the best predictor (DOER, 2004), (Figure 3). The slump test was performed as quickly as possible to prevent thixotropic effects. The cylinder walls were pre-wetting to prevent material sticking to the walls while lifting the cylinder. The cylinder was removed in less than *7* s after leveling off the top.

Determination of water content (Wn) and bulk wet density (γ)

The water content is the ratio of the weight of water to weight of solids obtained by weighing a specimen in its natural wet state and then again upon drying at 105°C for 24 h. Bulk wet density was obtained using Equation 1.

$$Wn(\%) = 2.10^{11}\gamma^{-4.7128} \quad (1)$$

The relationship between *Wn (%)* and normalized slump (slump/cyl ht) is given in Figure 4. The water content and normalized slump data show scattering since the coarser-grained soils have less water content variability. The relationship between water content and bulk wet density is illustrated in Figure 5.

Determination of Atterberg limits

The Atterberg limits are a basic measure of a fine-grained soil consisting of the liquid limit (water content at which the soil passes from the liquid to plastic state), the plastic limit (water content at which the soil passes from the plastic to semi-solid state) and the shrinkage limit (water content at which the soil passes from the semi-solid to the solid state). Laboratory testing (ASTM, 2000b) is required to determine the Atterberg limits. A suitable prediction method using water content percent and normalized slump is given by the Equation 2 (DOER-D1, 2004).

$$LL = 52.74 + 0.526Wn - 59.97\ N \quad (2)$$

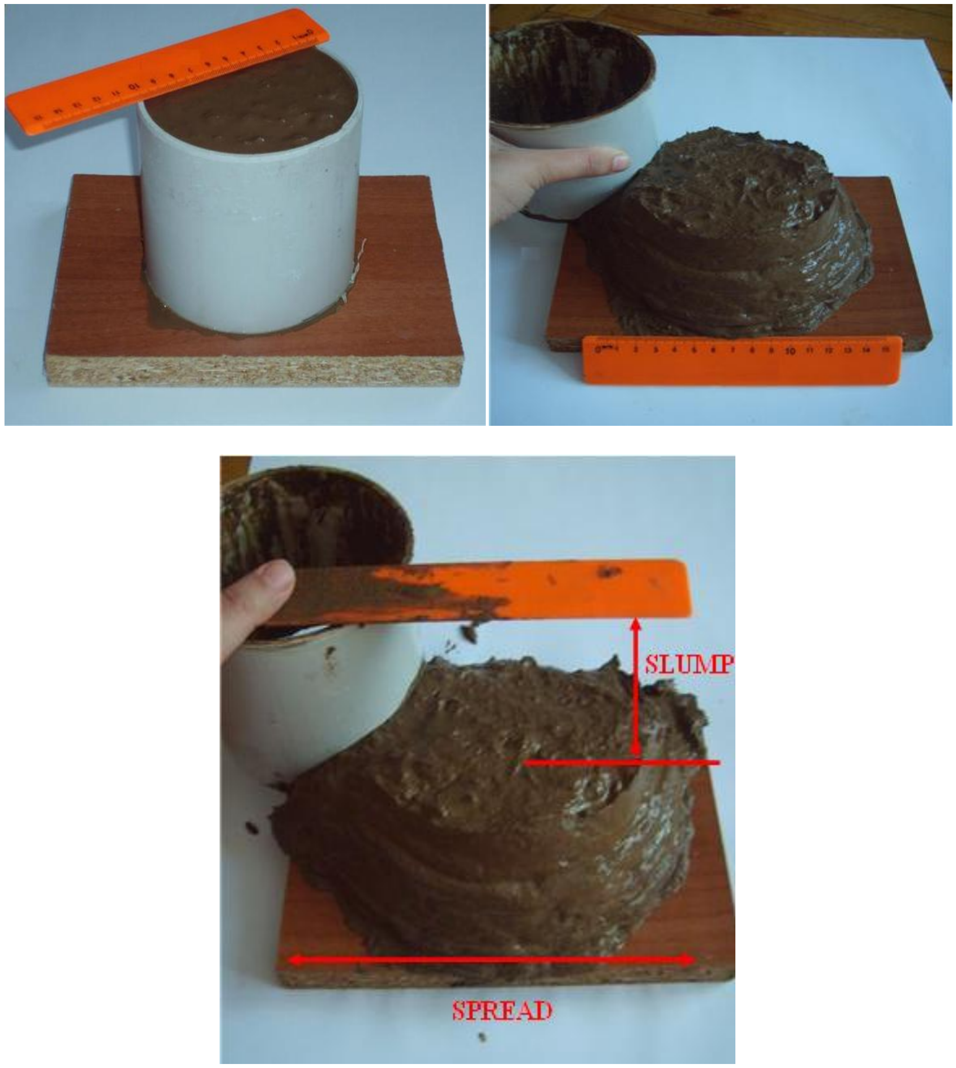

Figure 3. Sequences of slump test application.

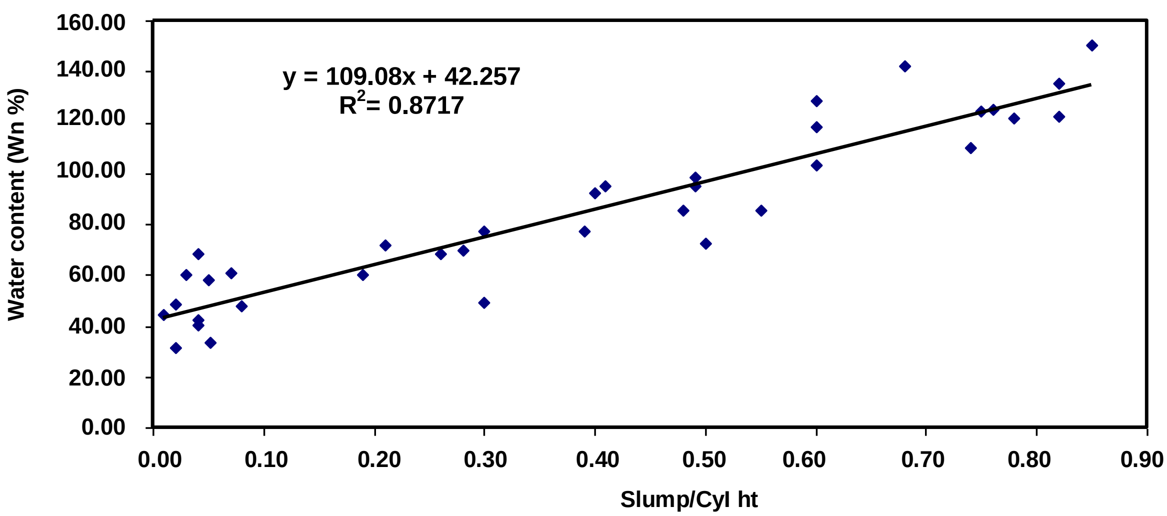

Figure 4. Relationship between water content and normalized slump.

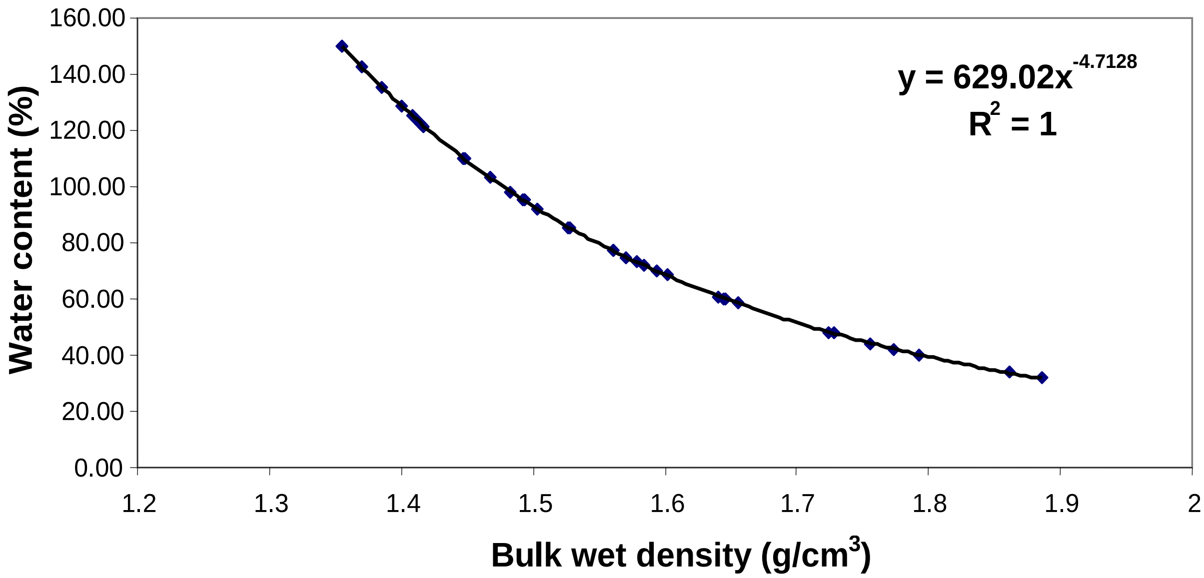

Figure 5. The relationship between water content and bulk wet density.

Where, LL: Liquid limit percent, W: Water content percent, N: Normalized slump = (slump / cylinder height). Liquidity index (LI) and Plastic limit percent (PL) are given by Equations 3 and 4.

$$LI = 1.601(Wn/LL) - 0.612 \tag{3}$$

$$PL = [(LI)(LL) - Wn]/[(LI) - 1] \tag{4}$$

Plasticity index (PI) is obtained from the difference of LL and PL Equation 5.

$$PI = LL - PL \tag{5}$$

The Atterberg limits of the dredged material specimens were figured out using Equations (2 to 5). The results are given in Table 2.

Determination of bulk unit weight (saturated wet bulk density), (γ)

The Equation (6) is used to determine the bulk unit weight of the dredged material when only the water content is known (DOER-D1, 2004).

$$\gamma = 233.21\omega^{-0.2051} \tag{6}$$

Where, γ: Bulk unit weight (N/m^3), *Wn*: Water content percent .

The result of bulk unit weight of dredged material specimens determined using Equation (6) is given in Table 2.

Determination of void ratio *(e)*

Void ratio *(e)* is defined as the ratio of the volume of voids to the volume of solids. If only water content is known, the void ratio can be easily determined conducting a single slump test and using Equation 7.

$$e = 0.028\ Wn - 0.055N - 0.065 \tag{7}$$

Where, *e*: Void ratio, *Wn*: Water content percent, *N:* slump / cylinder height.

The void ratio data of dredged material specimens determined using Equation (7) is given in Table 2.

Determination of percent solids

General equation for percent solids by weight is given by Equation (8) (DOER-D1, 2004).

$$\%\ solids\ by\ weight = 10000/(Wn + 100) \tag{8}$$

Where, *Wn*: Water content percent.

The percent solids by weight obtained using Equation (8) are given in Table 2. The relation between % solids by weight and water content is shown in Figure 6.

Determination of specific gravity

Specific gravity is the ratio of density of a substance compared to the density of fresh water at 4°C (39°F). Specific gravity compares the mass of a given volume of material to the mass of the same volume of water and

Table 2. Physical properties of dredged material specimens collected from the coastal areas of the Gulf of Izmit.

Specimen No.	Slump/Cylht	Solid weight (%)	Water content (%)	Wet bulk density (N/m³)	Liquid limit (%)	Liquidity index	Plastic limit (%)	Plasticity index
1	0.02	75.94744	31.67	1.885489	68.19902	0.131466	26.14076	42.05826
2	0.04	70.28395	42.28	1.773361	72.58048	0.320624	27.98004	44.60044
3	0.07	62.14268	60.92	1.641114	80.58602	0.598296	31.62955	48.95647
4	0.08	67.71398	47.68	1.728704	73.02208	0.433378	28.29723	44.72485
5	0.40	52.04267	92.15	1.503146	77.2229	1.298472	27.21109	50.01181
6	0.41	51.25051	95.12	1.493062	78.18542	1.335769	27.75018	50.43524
7	0.49	50.45154	98.21	1.482968	75.01316	1.484088	27.09455	47.91861
8	0.30	56.43978	77.18	1.560765	75.34568	1.027977	9.780324	65.56536
9	0.60	43.73305	128.66	1.400376	84.43316	1.827618	30.99445	53.43871
10	0.03	62.41808	60.21	1.645201	82.61136	0.554864	32.28662	50.32474
11	0.01	69.30487	44.29	1.75597	75.43684	0.327969	29.08951	46.34733
12	0.02	67.43998	48.28	1.724123	76.93588	0.392684	29.75138	47.1845
13	0.55	53.8648	85.65	1.526658	64.8084	1.503862	23.44472	41.36368
14	0.49	51.18755	95.36	1.492264	73.51406	1.464764	26.5097	47.00436
15	0.50	50.47701	72.48	1.483289	62.205	1.500322	50.95218	11.25282
16	0.60	47.62585	118.45	1.447803	74.60222	1.74801	15.98296	58.61926
17	0.04	57.72339	68.38	1.578215	88.86544	0.707492	18.83166	70.03378
18	0.05	63.15125	58.35	1.656192	80.4336	0.549434	31.42054	49.01306
19	0.04	71.33685	40.18	1.792635	71.47588	0.287998	27.52109	43.95479
20	0.052	74.8111	33.67	1.861147	67.33198	0.188595	25.84592	41.48606
21	0.60	49.20049	103.25	1.467304	71.0675	1.714003	25.99419	45.07331
22	0.68	41.26093	142.36	1.37063	85.04266	2.068047	31.37712	53.66554
23	0.82	42.50436	135.27	1.385568	74.71662	2.286515	27.64887	47.06775
24	0.85	39.96483	150.22	1.355089	80.78122	2.365205	29.91794	50.86328
25	0.26	62.0232	68.35	1.639348	76.6981	0.814741	31.63624	45.06186
26	0.21	59.98081	48.22	1.609749	89.4126	0.677214	35.46784	53.94476
27	0.30	55.16328	82.33	1.543717	57.8769	15.58019	23.31408	34.56282
28	0.39	54.77951	77.12	1.538647	69.91682	1.153943	23.12561	46.79121
29	0.28	60.09254	56.32	1.61134	72.7684	0.928092	34.26943	38.49897
30	0.19	62.3558	48.33	1.644275	72.9057	0.705592	29.06953	43.83617
31	0.82	44.98021	122.32	1.415473	67.90492	2.271949	25.12405	42.78087
32	0.74	46.41233	110.29	1.432914	66.37474	2.048263	24.48139	41.89335
33	0.75	45.41739	124.12	1.420784	73.04962	2.10829	26.96926	46.08036
34	0.78	45.14061	121.53	1.41742	69.88818	2.172012	25.82564	44.06254
35	0.76	44.38132	125.32	1.408214	73.08112	2.133406	26.99093	46.09019
36	0.48	53.95489	85.34	1.527833	68.84324	1.372644	24.57378	44.26946

Specimen No	Void radio	Specific gravity	Water content / Liquid limit	Vane shear (kPa)	Effective stress (kPa)	Undrained Shear strength (Cu) kN/m2	Compression index Cc	Permeability m/sec
1	0.82066	2.591285	0.464376	0.332503	230.2969	92.86217	0.523791	0.003877
2	1.11664	2.64106	0.582526	0.251262	79.27978	38.90342	0.563224	0.012674
3	1.63691	2.686983	0.755962	0.166543	23.26455	10.84738	0.635274	0.053101
4	1.26564	2.654446	0.652953	0.212619	46.34254	23.16091	0.567199	0.020351
5	2.4932	2.705589	1.193299	0.059043	2.716764	0.433202	0.605006	0.247325
6	2.57581	2.707958	1.216595	0.05587	2.48056	0.364911	0.613669	0.277925
7	2.65793	2.706374	1.309237	0.044851	1.756347	0.184464	0.585118	0.310768
8	2.07954	2.694403	1.024345	0.088135	5.571432	1.503198	0.588111	0.131322
9	3.50448	2.72383	1.523809	0.026966	0.860068	0.037992	0.669898	0.828806
10	1.61923	2.689304	0.728834	0.177608	27.62866	13.24592	0.653502	0.051026
11	1.17457	2.651998	0.587114	0.248544	76.4072	37.61104	0.588932	0.015356
12	1.28574	2.66309	0.627536	0.225828	55.86003	27.92821	0.602423	0.0216
13	2.30295	2.688792	1.321588	0.043557	1.680454	0.168427	0.493276	0.18565
14	2.57813	2.703576	1.297167	0.046154	1.834566	0.20161	0.571627	0.27865
15	2.0075	2.676667	1.577204	0.063114	2.587881	0.395421	0.469845	0.11052

Table 2. Contd.

16	2.98116	2.710885	1.474085	0.023172	1.005341	0.054792	0.58142	0.473262
17	1.98352	2.708247	0.824167	0.16129	15.49562	6.564475	0.709789	0.109923
18	1.56605	2.68389	0.725443	0.179042	28.24155	13.58087	0.633902	0.045089
19	1.05784	2.632753	0.562148	0.263701	93.73778	45.20208	0.553283	0.010314
20	0.8749	2.598456	0.50006	0.305527	162.5673	71.40371	0.515988	0.004971
21	2.793	2.705085	1.452844	0.031907	1.076385	0.064069	0.549608	0.370797
22	3.88203	2.726911	1.673983	0.018887	0.552708	0.012573	0.675384	1.187243
23	3.67746	2.718607	1.810441	0.013666	0.382288	0.004603	0.58245	0.981706
24	4.09441	2.725609	1.859591	0.012163	0.337026	0.003205	0.637031	1.430452
25	1.8378	2.688808	0.891156	0.120866	10.72872	4.008339	0.600283	0.081043
26	1.93835	2.692153	0.805256	0.148171	17.28368	7.545382	0.714713	0.098779
27	4.1185	2.745667	0.850426	0.133122	0.070703	1.46E-05	0.430892	2.391568
28	2.07291	2.687902	1.103025	0.073135	3.933439	0.842157	0.539251	0.127336
29	1.8796	2.685143	0.961956	0.102187	7.487823	2.379808	0.564916	0.086991
30	1.60455	2.67425	0.822981	0.142073	15.60096	6.622081	0.566151	0.049257
31	3.31486	2.70999	1.801342	0.013964	0.391457	0.004922	0.521144	0.680927
32	2.98242	2.704162	1.661626	0.019449	0.572314	0.01377	0.507373	0.468257
33	3.36911	2.714397	1.699119	0.017794	0.515283	0.010448	0.567447	0.721164
34	3.29494	2.711215	1.738921	0.016192	0.462103	0.007794	0.538994	0.666602
35	3.40216	2.714778	1.714807	0.017145	0.493479	0.009308	0.56773	0.746438
36	2.29812	2.692899	1.239628	0.0529	2.271074	0.307983	0.529589	0.184358

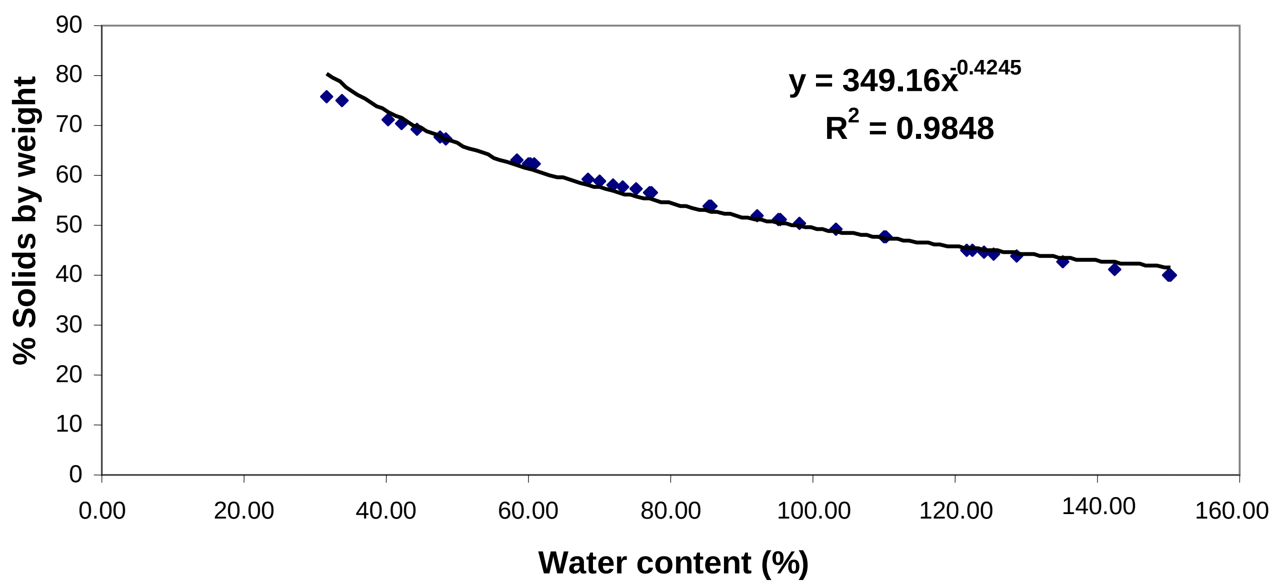

Figure 6. Relationship between % solids by weight and water content.

helps determine types of the minerals. Specific gravity is calculated from Equation 9.

$$Gs = 2.8 - 5.5\ N/W - 6.5/W \quad (9)$$

Where, *Gs*: Specific gravity of solids, *W*: Water content percent, *N*: Normalized slump=slump/cylinder height. The specific gravity values are given in Figure 2.

Determination of undrained shear strength (c_u)

If only the water content and liquid limit of the dredged material are known, the undrained shear strength is obtained using the approximate Equation 10, (DOER-D1, 2004).

$$LI = \log(170/c_u)/2 \quad (10)$$

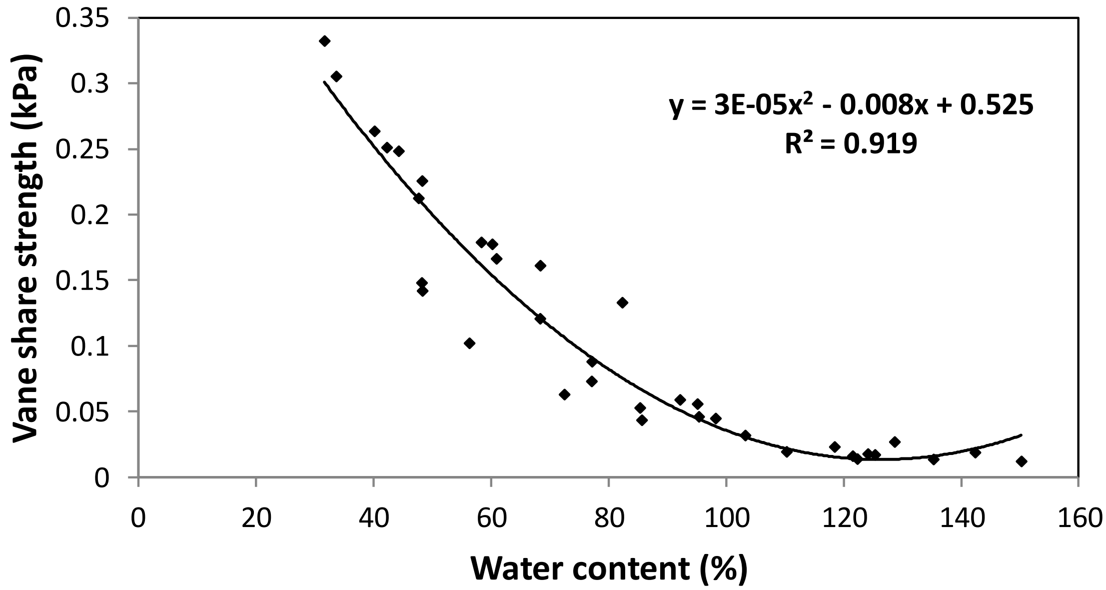

Figure 7. Relation between Vane shear strength and water content (%) / LL.

$$C_u = 170e^{-4.6LI} \quad (11)$$

Where *LI*: Liquidity bindex, c_u: Undrained shear strength

$$e = 2.178$$

The soil compression index Cc is given by Equation 12 (Terzaghi and Pack, 1967).

$$Cc = 0.009(LL - 10) \quad (12)$$

Where *Cc*= Compression index, *LL*= Liquid limit percent.

Determination of Vane shear strength

The Vane test is one of the most widely used techniques to estimate the undrained strength of soft clays. It provides an indication of *in-situ* undrained shear strength of fine - grained clays and silts or other fine geomaterials such as mine tailings, organic muck, and substances where undrained strength determination is required. It is a cheaper and quicker method. Vane shear strength is given by Equation 13.

$$Vane\ shear\ strength = 183e^{-2.3714(Wn/LL)} \quad (13)$$

Where, *e:* 2.718, Wn/LL: Water content percent / Liquid limit percent.

The Vane shear strength values determined are given in Table 2, and the relation between Vane shear strength and water content (%) / *LL* is demonstrated in Figure 7.

As depicted in Figure 7, the correlation between Vane shear strength and water content (%) / *LL* is very good.

Determination of effective stress (σ')

The effective stress is a combination of both the externally applied stresses and the internal pressure of fluid phase(s) and enables the conversion of a multiphase porous medium into mechanically equivalent single-phase continuum. Soil settlement models are developed base on effective stress concept where settlement is always associated with effective stress increase (Terzaghi, 1943; Janbu et al., 1956; Schertmann et al., 1978). If only the water content percent and liquid limit are known, then the effective stress is calculated by Equation 14 (DOER-D1, 2004).

$$\sigma' = 129.77(Wn/LL)^{-4.7044} \quad (14)$$

Where, σ': Effective stress (kPa), *Wn /LL*: Water content percent / liquid limit percent.
The calculated effective stress values are given in Table 2, and the relation between effective stress and water content / liquid limit is shown in Figure 8.

Determination of permeability (*k*)

Permeability is determined by Equation 15.

$$k = 0.0174\,[e - 0.027\,(PL - 0.242PI)\,/\,PI]^{4.29} / (1 + e) \quad (15)$$

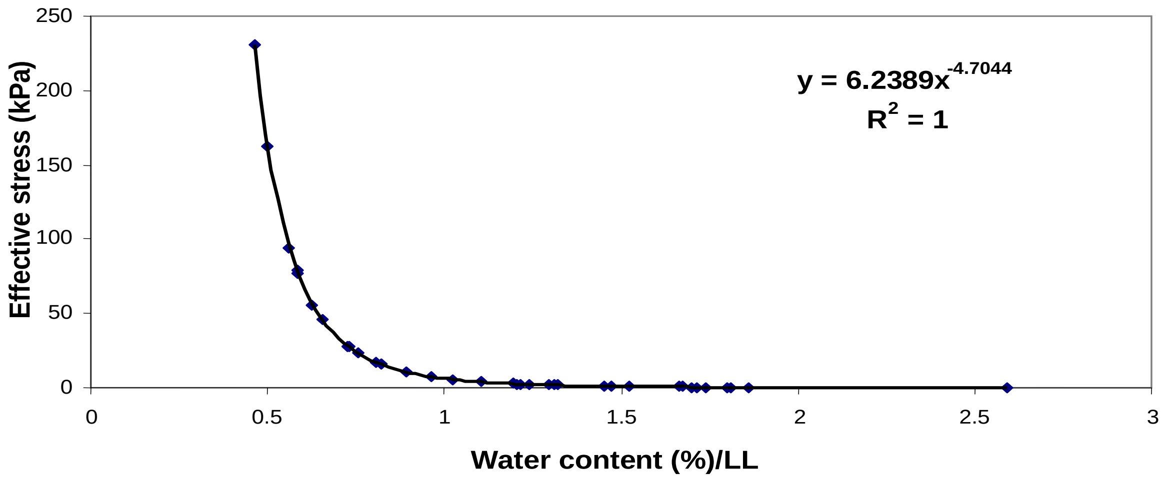

Figure 8. Relation between effective stress and water content / liquid limit.

Where, *k*: permeability, *e*: Void ratio, *PL*: Plastic limit percent, *PI*: Plasticity index.

DISCUSSION

The physical and engineering properties of the dredged materials collected at the coastal areas of the Gulf of Izmit were predicted using correlation equations given by ERDC TN-DOER (2004) in order to figure out their usability in engineering planning and construction aspect. These properties mostly depend upon the site geology. The dredged materials consist of mostly clay and silt which have plasticity index values change in a large range indicating medium to very high plasticity. They have relatively high water content and void ratio but very low shear strength indicating that they are very soft in consistency. These results show similarities with the results obtained by ERDC TN-DOER (2004) and Klein and Sarsby (2000). The water content and bulk wet density obtained by ERDC TN-DOER (2004) are higher than our values. This study is the first study on the marine dredged materials at the coastal areas of the Gulf of Izmit. The results obtained in this study can be utilized by the researchers and the people who are interested in dredged materials.

CONCLUSIONS

In order to determine the physical and geotechnical properties of dredged materials of the Gulf of Izmit, a combination of slump tests were conducted *in-situ* and water content of the dredged material specimens were obtained in the laboratory using the oven method. The other properties such as bulk wet density, Atterberg limits, bulk unit weight, void ratio, percent solids, shear strength and effective stress were calculated using the formulae given by Doer Technical Note (ERDC TN-DOER-D1, 2004).

Sieve analysis indicated that the dredged material had 12.56 to 30.12% gravel, 11.74 to 28.06% sand and 20.26 to 63.19% clay and silt. Atterberg limit tests demonstrated that the dredged material had liquid limit ranging from 57.86 to 89.41, plastic limit varying from 9.78 to 50.95 and plasticity index ranging from 11.25 to 70.03. The specific gravity of the dredge material varied from 2.59 to 2.72. The natural water content ranged from 31.67 to 150.22% with the void ratio changed from 0.82 to 4.11. The Vane shear strength varied from 0.013 to 0.33 kg/cm^2. The effective stress ranged from 0.07 to 230.29 kg/cm^2. The dredged material was very soft in consistency and exhibit very low shear strength.

Good correlations were determined *(R^2 = 0.87)* between water content and normalized slump, % solids by weight and water content *(R^2 = 0.98)* and Vane shear strength and water content/liquid limit *(R^2 = 0.872).* Very good correlations were obtained between water content and bulk density and effective stress and water content/liquid limit *(R^2 = 1).* Water content increases with increasing slum/Cyht, and exponentially decreases with increasing bulk wet density. % solids by weight and Vane shear strength decrease exponentially with increasing water content. Similarly the effective stress also decreases exponentially with increasing water content/LL. The geotechnical parameters using the correlation equations are for the preliminary investigations and do not substitute for standardized laboratory testing requirements.

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