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Evaluation of Foundation Difficulties over Soft Organic Soil

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ABSTRACT

Over the past 50 years, Dhaka, the Capital of Bangladesh, has experienced a rapid growth of urban population. This high population increase demands rapid expansion of the city. Unfortunately, most parts of Dhaka having competent subsoil for building construction are already exhausted. As such, new areas are being reclaimed by both government and private agencies using dredged fill from nearby river sources. A very soft organic layer exists below the filling layer that is highly plastic and highly compressible. SPT N-values of filling layer and organic layer vary from 2 to 11 and 1 to 2, respectively. It is observed that settlement of the organic layer varied from about 242 mm to 637 mm in between 1.8 to 12.7 years, respectively, due to overburden pressure of 100 kPa. Moreover, the existing organic layer may cause negative skin friction to the pile foundation and make foundation difficulties.

KEYWORDS: Soft organic clay, Shear strength, Compressibility characteristics, Settlement, Foundation difficulties.

INTRODUCTION

Over the past 50 years, Dhaka, the Capital of Bangladesh, has experienced a rapid growth of urban population which will continue in the future due to several unavoidable reasons. Therefore, most of the areas of Dhaka city competitive for building constructions are already occupied. As a result, different new areas are being reclaimed inside and near Dhaka city by both government and private agencies. General practice for reclaiming such areas is to fill low lands (i.e., ditches, lakes... etc.).

In most cases, the practice for developing new areas is just to fill low land by dredged fill materials. Different filling procedures are in practice to develop such land. One of them is to carry soil by vehicles from remote sources and manually dump it at the filling site. Due to huge traffic congestion, the most widely used method is hydraulic filling procedure. In this procedure, soil is collected from riverbed by cutter-suction dredging into a barge, which is carried to the nearest river site. Soil is then pumped through the pipes in a slurry form and transferred to the point of deposition. In most cases, the dredged material is almost silty sand with high fines content (Ahamed, 2005). The presence of fines in hydraulic fill means greater compressibility and greater difficulty in compaction of the fill. Fines also reduce permeability, and hence the rate of drainage is slow. Therefore, consolidation rate is also slow. Dhaka city exists in the seismic Zone 2 (peak ground acceleration, a_{max} = 0.15g) of Bangladesh (BNBC, 1993). Therefore, this silty sand layer may liquefy if an earthquake of sufficient magnitude occurs (Hossain, 2009).

Since the filling material is dumped directly upon the marshy low land, after a certain time, the organic materials beneath the previous filling material are decomposed, and a very soft organic clay layer is

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produced. This organic clay layer may cause excessive settlement problem to the structures having shallow foundation on the top filling layer. In addition, it may cause other geotechnical problems such as negative skin friction to the pile foundation. Negative skin friction produces a drag load that can be very large for long piles. Johannessen and Bjerrum (1965) and Bozozuk (1972) reported measurements of drag loads that exceed the allowable loads which ordinarily would have been applied to the piles in case of marine clay.

It is clear that the presence of this very soft clay layer in reclaimed areas demands special attention for designing foundation system on or through it. Therefore, it is felt necessary to carry out research to know the characteristics of the soft organic clay layer of such reclaimed areas. However, this paper presents the following:

a) Sub-soil characteristics of soft organic layer of selected reclaimed areas of Dhaka city.
b) Estimation of the probable settlement of organic layers.
c) Evaluation of the foundation difficulties.
d) Suggesting some probable soil improvement techniques.

Investigation Related to Soft Soil

Rahman (2008) investigated strength and deformation characteristics of cement and lime-treated soft clay. His studies focused on the effect of cement and lime treatment on different soil properties like compressibility, permeability, shear strength and stiffness behaviour of soft organic clays. For this study, clay samples were collected from Gazipur, Gopalgonj and Khulna districts of Bangladesh. Soils were collected from a depth of 2 m to 3 m from EGL. From the study, it is observed that a significant decrease in compression index (C_c) and swelling index (C_s) was found with the increase in admixture (cement/lime) content and curing time. C_c and C_s values also increased significantly with the increase of mixing clay-water content. The lime-treated clays gained comparatively higher void ratio and volumetric strain and lower yield stress than those of cement-treated clays. Permeability of lime-treated clay was found to be higher than that of cement-treated clays.

Experimental Program

Field and laboratory investigations were carried out at the selected four locations of Dhaka city. These four areas have been given code names and these code names have been used subsequently in this paper instead of their original name. These are A-1, A-2, A-3 and A-4 instead of Mirpur-12, Dhanmondi, Khilgawn and Gabtali, respectively. These locations have been selected based on past studies and importance of the area. Twenty borings have been conducted at four locations and disturbed and undisturbed soil samples have been collected during boring. Three boreholes at A-1, three boreholes at A-2, four boreholes at A-3 and ten boreholes at A-4 have been carried out at close intervals.

Field investigations have been performed in the form of Standard Penetration Test (SPT) in all the selected areas. SPT N-value was recorded at every 1.5m depth interval up to 20m from EGL. In addition, undisturbed samples have been collected from black soft organic layer. Laboratory tests in terms of sieve analysis, organic content test, Atterberg's limit test, un-confined compression test and one-dimensional consolidation test have been conducted in order to know the index properties, strength properties and compressibility properties of organic soil layer.

RESULTS AND DISCUSSIONS

Characteristics of Organic Soil

The dredged material is generally silty sand with high fines content. It is seen that the depth of filling layer varies from 1.5 m to 5.5 m from Existing Ground Level (EGL). The uncorrected SPT N-value of filling layer varies from 2 to 11. Just below this sandy layer, a very soft layer of a thickness from 0.5 m to 8.5 m exists. This soft soil is dark black in colour with organic content. Uncorrected SPT N-value of this layer varies from 1 to 2. Variation of uncorrected SPT N-value with depth is presented in Figure 1(a). Typical borelogs of the study areas are presented in Figure 1(b).

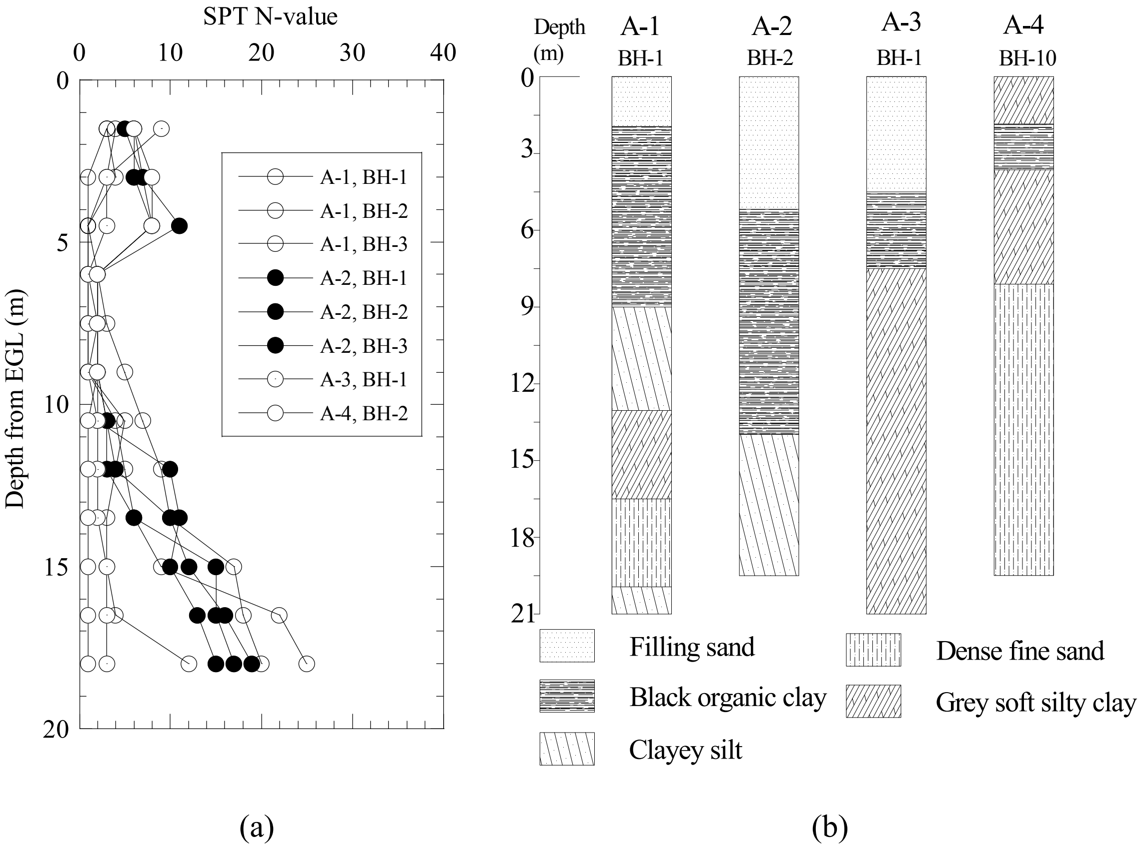

Figure 1:

(a) Variation of SPT N-value with depth; and

(b) Typical borelogs of different study areas

Physical and Index Properties

It has been found that specific gravity of the organic soil varies from 2.29 to 2.59. Mean grain size (D_{50}) and fines content (F_c) of organic soil layer show constant values of 0.010 mm and 100%, respectively. The physical and index properties of organic clay are summarized in Table 1. It has been found that natural moisture content and dry unit weight of the soft organic layer vary from 32% to 84% and from 4.6 to 9.3 kN/m^3, respectively.

This result indicates that moisture content is very high and varies in a large range. Moreover, dry unit weight of this soft organic soil is very low. It has been found that Organic Content (OC) of the soft organic clay at A-1, A-3 and A-4 varies from 11.9 to 28.7%, from 4.7 to 13.2% and from 11.0 to 14.3%, respectively.

Atterberg's Limit test has been performed on organic soil samples at A-1, A-3 and A-4 to determine liquid limit, plastic limit and liquidity index. These are presented in Table 1. It has been found that top filling layer is non-plastic sand. Liquid limit, plastic limit and plasticity index of organic layer vary from 42 to 193%, from 25 to 125% and from 14 to 68%, respectively, showing a highly plastic nature. These properties are similar to the properties of Khulna soft organic soil (Ferdous, 2007). Liquid limit, plastic limit and plasticity index of grey clay layer vary from 40 to 55%, from 26 to 31% and from 13 to 29%, respectively. Soft organic layer has been classified by Unified Soil Classification System (USCS). Figure 2 represents the position of the soft organic clay samples on Casagrande plasticity chart. It is seen that soils are varying from OL (medium compressibility and organic silt) to OH (high compressibility and organic clay).

Table 1. Physical properties of soft organic clay

Location	BH No./Sample No./Depth(m)	w_n (%)	OC (%)	γ_d (kN/m^3)	LL (%)	PL (%)	PI (%)	Classification (USCS)
Mirpur-12 (A-1)	BH-1/UD-1/4.5	57	28.7	4.6~8.8	141	94	47	OH
	BH-2/UD-1/3.0	32	14.3	4.7~6.1	193	125	68	OH
	BH-2/UD-1/4.5	53	14.6	8.2	80	53	27	OH
	BH-2/UD-2/6.5	59~78	11.9	8.6	70	44	26	OH
	BH-3/UD-1/5.0	77	17.1	9.2	66	32	34	OH
	BH-3/UD-2/6.0	78~84	16.3	9.3	80	55	25	OH
Khilgaon (A-3)	BH-1/UD-1/4.5	44~70	8.2	6.3	50	25	25	OL
	BH-1/UD-2/6.0	70	13.2	7.8	58	33	25	OL
	BH-2/UD-1/5.5	39	12.9	4.5	57	27	30	OH
	BH-2/UD-2/6.0	36~43	4.7	5.7	42	28	14	OL
	BH-3/UD-1/5.0	45	9.1	8.8	55	31	24	OH
	BH-3/UD-2/7.0	57~68	11.9	6.0	59	28	31	OH
Gabtali (A-4)	BH-1/UD-1/4.0	43	14.2	7.5	83	50	30	OH
	BH-2/UD-2/5.5	60	11.0	8.5	72	41	31	OH
	BH-3/UD-1/2.5	62	11.3	8.3	75	47	28	OH
	BH-4/UD-2/3.5	67	14.3	5.7	122	72	50	OH
	BH-5/UD-1/4.0	57	13.7	5.4	115	67	48	OH
	BH-6/UD-2/3.5	55	11.2	7.9	67	42	25	OH

w_n=Natural moisture content; OC=Organic content; γ_d=Dry density; LL=Liquid limit; PL=Plastic limit; PI=Plasticity index; OH=High compressibility and organic clay; OL=Medium compressibility and organic silt.

Strength Properties

Unconfined compression tests have been conducted on undisturbed soil samples from different study areas. Table 2 shows the summary of unconfined compression test results. Unconfined compressive strength and failure strain of the organic clay vary from 6 to 66 kPa and from 7 to 15%, respectively.

In some locations, a grey silty clay layer has been found beneath this soft organic layer. This layer is soft in nature (Terzaghi and Peck, 1967). Natural moisture content of the soft grey layer varies from 34.9 to 66.1%. Unconfined compressive strength and failure strain of this layer have been found to vary from 5.7 to 66 kPa and from 9 to 15%, respectively.

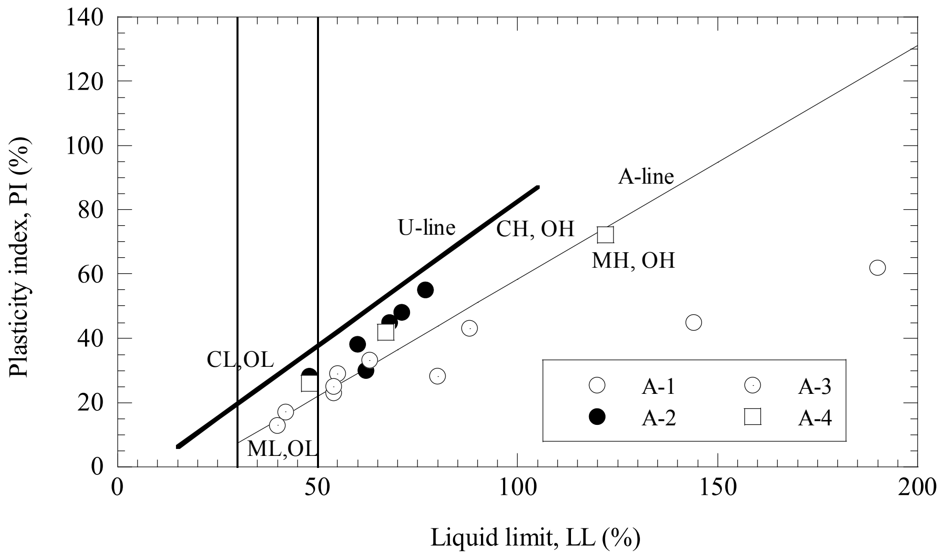

Figure 2: Position of the organic soil samples on Casagrande plasticity chart

Table 2. Strength properties of soft organic clay

Location	BH No./Sample No./Depth (m)	w_n (%)	γ_d (kN/m^3)	q_u (kPa)	s_u (kPa)	ε_f (%)	Consis-tency
Mirpur-12 (A-1)	BH-1/UD-1/4.5	57	4.6~8.8	16	8	15	Very soft
	BH-2/UD-1/3.0	32	4.7~6.1	50	25	13	
Dhanmondi (A-2)	BH-1/UD-1/5.5	81~82	8.8	10~11	5~5.5	7~14	Very soft
	BH-1/UD-2/7.0	44	12.1	42	21	15	
	BH-2/UD-1/5.5	84	8.0	13	6.5	15	
	BH-2/UD-2/7.0	50	8.4	39	19.5	10	
	BH-3/UD-1/5.5	64~81	9.0	13~62	6.5~31	15	
	BH-3/UD-2/7.0	69	8.8	50	25	7	
Khilgaon (A-3)	BH-1/UD-1/4.5	44~70	6.3	10~33	5~16.5	13	Very soft
	BH-1/UD-2/6.0	70	7.8	6	3	13	
	BH-2/UD-1/5.5	39	4.5	66	33	9	
	BH-2/UD-2/6.0	36~43	5.7	12~58	6-29	14~15	
	BH-3/UD-1/5.0	45	8.8	36	18	12	
	BH-3/UD-2/7.0	57~68	6.0	11	5.5	9~12	
Gabtali (A-4)	BH-1/UD-1/4.0	43	7.5	30	15	13	Very soft
	BH-2/UD-2/5.5	60	8.5	24	12	15	
	BH-3/UD-1/2.5	62	8.3	36	18	15	
	BH-4/UD-2/3.5	67	5.7	22	11	14	
	BH-5/UD-1/4.0	57	5.4	16	8	15	
	BH-6/UD-2/3.5	55	7.9	34	17	12	

w_n = Natural moisture content; q_u = Un-confined compressive strength; s_u = Un-drained shear strength; ε_f = Failure strain.

Compressibility and Swelling Properties

One-dimensional consolidation tests have been conducted on undisturbed soil samples from different study areas. Typical e-logP curves have been presented in Figure 3. It is seen the elastic rebound is very low. Table 3 presents the one-dimensional consolidation test results. It has been found that the initial void ratio (e_o) and compression index (C_c) of soft clay layer vary from 0.88 to 3.00 and from 0.26 to 1.10, respectively. It is also seen that e_o and C_c are very high which is similar to the properties of organic soil. This indicates that excessive settlement may occur to the structures on it. Again, from Table 3 it is seen that in most of the cases compression index varies from 0.5 to 1.0. In addition, recompression index (C_r) increases with the increase of compression index and varies from 0.04 to 0.14.

Table 3. Compressibility and permeability properties of soft organic layer

Loca-tion	BH No./Sample No./Depth (m)	e_o	C_c	C_r	c_v (m^2/yr)	m_v (*10^{-3} kN/m^2)
Mirpur-12 (A-1)	BH-1/UD-1/4.5	1.45~3.60	0.40~1.22	0.18~0.43	0.36~3.76	0.14~5.93
	BH-2/UD-1/3.0	2.71~3.90	0.74~1.10	0.27~0.33	0.34~4.99	0.14~4.010
	BH-2/UD-2/6.0	1.99	0.71	0.14	0.27~4.22	0.20~2.40
Dhanmondi (A-2)	BH-1/UD-1/5.5	1.86	0.70	0.07	0.39~1.65	0.16~1.32
	BH-1/UD-2/7.0	0.88	0.35	0.04	3.30~7.10	0.14~1.27
	BH-2/UD-1/5.5	1.89	0.85	0.06	1.15~16.85	0.19~.99
	BH-2/UD-2/7.0	1.77	0.56	0.07	0.51~3.99	0.10~2.87
	BH-3/UD-1/5.5	1.63	0.63	0.05	0.9~10.15	0.11~1.16
	BH-3/UD-2/7.0	1.67	0.77	0.07	0.72~1.39	0.18~1.10
Khilgaon (A-3)	BH-1/UD-1/4.5	3.00	1.01	0.11	1.30~2.10	0.17~1.23
	BH-1/UD-2/6.0	1.70	0.62	0.08	0.55~1.10	0.20~1.00
	BH-2/UD-1/5.5	2.45	1.10	0.13	0.22~9.89	0.23~1.20
	BH-2/UD-2/6.0	1.60	0.55	0.05	1.05~3.78	0.16~1.39
Gabtali (A-4)	BH-1/UD-1/4.0	1.21	0.26	0.05	1.00~11.02	0.08~0.44
	BH-2/UD-2/5.5	1.13	0.36	0.08	1.82~10.90	0.12~0.71
	BH-3/UD-1/2.5	1.11	0.34	0.04	4.50~14.00	0.13~0.67
	BH-4/UD-2/3.5	1.63	0.52	0.05	0.45~1.82	0.15~2.99
	BH-5/UD-1/4.0	2.61	0.95	0.08	0.37~6.33	0.15~11.4
	BH-6/UD-2/3.5	1.65	0.51	0.07	0.55~6.10	0.16~3.16

e_o = Initial void ratio; γ_d = Dry density; C_c = Compression index; C_r = Recompression index; c_v = Coefficient of consolidation; m_v= Coefficient of volume compressibility; k = Coefficient of permeability.

Coefficient of volume compressibility (m_v) varies from 8.0 x 10^{-5} to 3.16 x10^{-3} kN/m^2. Figure 4 shows the variation of m_v with effective vertical stress. It is seen that m_v decreases with the increase of vertical effective stress. The coefficient of consolidation (c_v) of samples have been computed using Eq. 1 (Das, 1983).

$$c_v = \frac{0.848\, d^2}{t_{50}} \quad (1)$$

where, c_v = coefficient of consolidation; d = length of the maximum drainage path and t_{50}=time required for 50% consolidation.

The coefficient of consolidation (c_v) varies from 0.20 to 16.85 m^2/yr. Figure 5 presents the variation of c_v with effective stress. It is seen that c_v also decreases with the increase of vertical effective stress.

Estimation of Settlement

Settlement of soft organic layer for different soil pressures with variable time is estimated. Figure 6 shows the variation of settlement corresponding to 100 kPa soil pressure due to structural load with variable time. From Figure 6, it is observed that settlement of the organic layer varies from about 242 mm to 637 mm (considering double drainage) in between 1.8 to 12.7 years, respectively due to overburden pressure of 100 kPa. It is seen that consolidation settlement for this applied pressure is much higher than the allowable limit of 63.5 mm as per Bangladesh National Building Code (BNBC, 1993). This excessive settlement may cause serious structural damage.

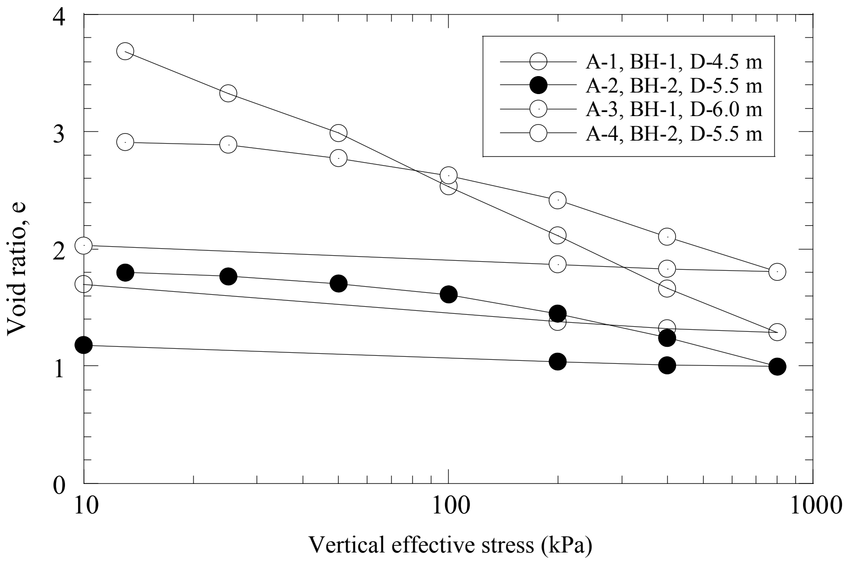

Figure 3: Typical e-logP curves of organic clay samples

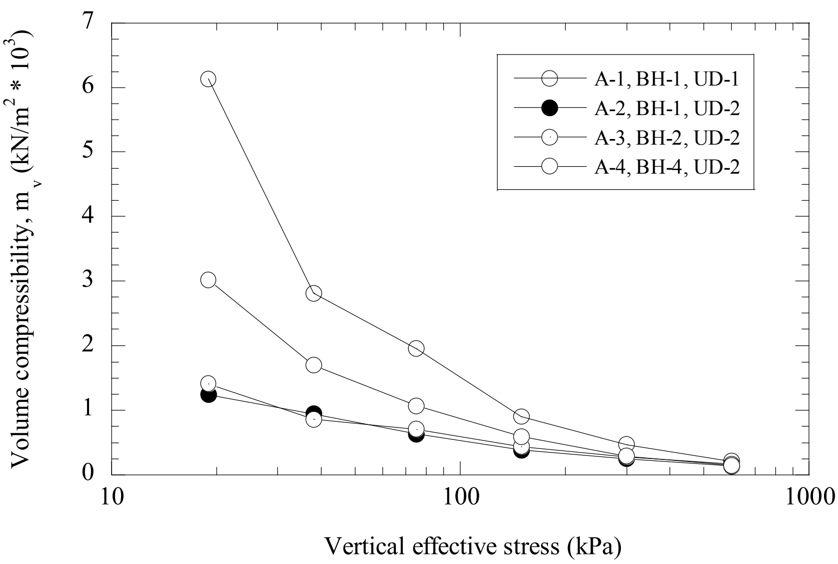

Figure 4: Coefficient of volume compressibility (m_v) *vs.* vertical effective stress

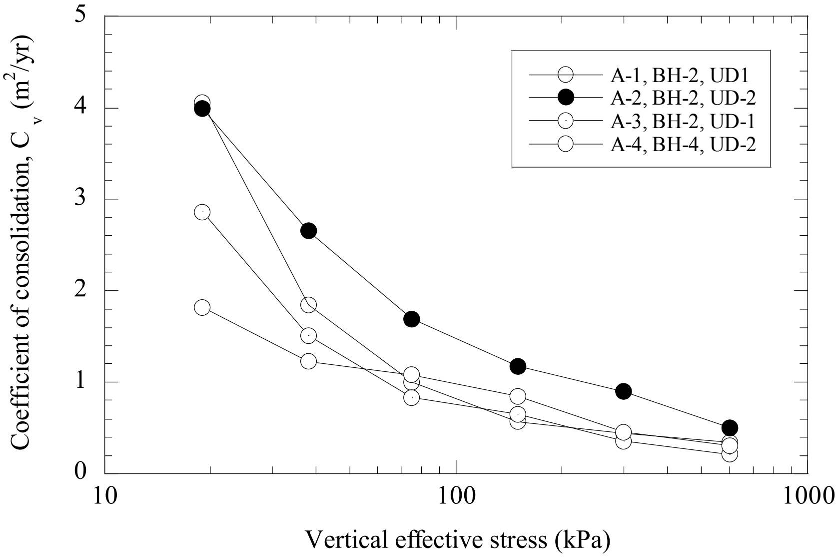

Figure 5:Coefficient of consolidation (c_v) *vs.* vertical effective stress

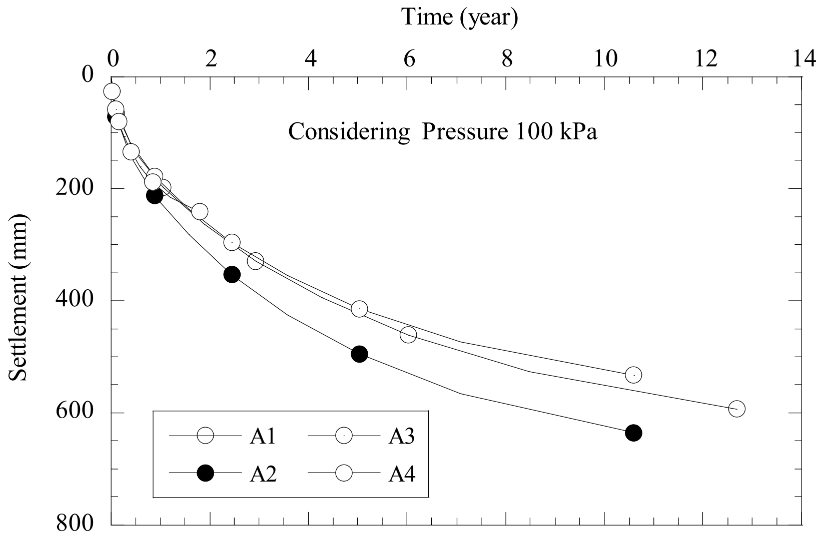

Figure 6: Time *vs.* settlement curve for different study areas soil at overburden pressure of 100 kPa

Foundation Problems

It is found that top layer soil is generally silty sand. Therefore, this layer may liquefy if an earthquake of sufficient magnitude occurs (Hossain, 2009). Besides this, filling material is dumped directly upon the marshy low land. After a certain time, the organic materials beneath the previous surface water are decomposed and a soft organic clay layer is produced. This soft organic clay layer may cause excessive settlement problem to the structures having shallow foundation on the top filling layer. In addition, it may cause other geotechnical problems such as negative skin friction to the pile foundation. Negative skin friction produces a drag load that can be very large for long piles. Johannessen and Bjerrum (1965) and Bozozuk (1972) reported measurements of drag loads that exceed the allowable loads which ordinarily would have been applied to the piles in case of marine clay.

Probable Solutions

Further studies are required for probable suitable solutions. For shallow depth, replacement of soft organic layer may be a solution. Again, for larger depth, the following solutions might be used:

a) Pre-loading with sand drains.
b) In-place densification by vibrofloatation, compaction piles, stone columns and blasting.
c) Soil stabilization by lime piles and calcinations.
d) Grouting and injection method by lime or cement slury.

CONCLUSIONS

Dhaka city has experienced a rapid growth of urban population which will continue in the future due to people demand and several unavoidable reasons. Unfortunately, most parts of Dhaka city having competent subsoil for building construction are already exhausted. As a result, different new areas are being developing by filling low land.

In most cases, the practice for developing such areas is just to fill lowlands (1.5 m to 5.5 m) by dredged soils collected from nearby riverbank and riverbed. It is found that the dredged soil is almost silty sand. Mean grain size and fines content of the fill materials for developing such areas vary from 0.148 mm to 0.200 mm and from 17.4 to 27.6%, respectively. The SPT N-value of the filling depth varies from 2 to 11. It is found that some parts of the reclaimed areas are susceptible to earthquake induced liquefaction (Hossain, 2009).

Filling soil is directly dumped on the marshy low land just upon the vegetation and other organic materials. After a certain time, these organic materials beneath the filling soil are decomposed and produce a soft organic layer. It has been found that the thickness of the soft layer varies in the range from 0.5m to 8.5m. The SPT N-value of this soft organic layer varies from 1 to 2.

Moisture content of organic layer varies from 32 to 84%. Liquid limit and plasticity index vary from 42 to 193% and from 14 to 68%, respectively. It is seen that this organic soil (OL to OH) is very soft in nature and shows high moisture content and highly plastic behavior. Organic content of the soft soil varies from 4.7 to 28.7%.

Unconfined compressive strength and failure strain vary from 6 to 66 kPa and from 7 to 15%, respectively. In addition, initial void ratio, compression index and coefficient of consolidation vary from 0.88 to 3.90, from 0.26 to 1.10 and from 0.22 to 16.85 m^2/yr, respectively. This soil is highly compressible with very low shear strength.

It is observed that settlement of the organic layer varies from about 242 mm to 637 mm in between 1.8 to 12.7 years, respectively due to overburden pressure of 100 kPa.

From the characteristics of the soil, it is seen that the filling soil is liquefiable in some places. The properties of the soft organic layer indicate that this soft layer will undergo large settlement due to the weight of the filling layer and the load that will come from the super-structures. In addition, this may cause other geotechnical problems such as negative skin friction to the pile foundation. Negative skin friction produces a drag load that can be very large for long piles. Further studies are being conducted to develop or design desired suitable ground improvement techniques or alternative foundation systems for such sub-soil condition.

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