Estimation of Consolidation and Settlement Characteristics of Madhupur Clay Formation from Dhaka City and Adjacent Area (Savar), Bangladesh

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ABSTRACT: Pleistocene Madhupur Clay Formation mostly covers Dhaka City and the surrounding areas. Without knowing the consolidation characteristics and settlement of this clay, it is difficult for any construction sites to build infrastructure. In Bangladesh, the research on these parameters is limited. Hence for better understanding the consolidation and settlement behaviors of Madhupur Clay Formation of this area, a detail investigation is carried out by conducting one dimensional consolidation test. The undisturbed samples from Pleistocene Madhupur Clay Formation and the fill materials which are also partly composed of the Madhupur Clay, are collected from 2.4 m to 4.11 m depths of many distinct points. The compression index C_c and coefficient of compressibility, a_v of the samples are range from 0.073 to 0.23 and from 0.059 to 0.14m^2/mn respectively. The values recommend that both types of specimens are medium plastic clay .The Madhupur Clay are stiff consolidated clay and slightly compressible in nature whereas the Madhupur Clay fill samples are less stiff over consolidated and moderately compressible in nature. Fill samples are settled more with time and are not suitable for Shallow foundation of light or heavy infrastructure. However, the Madhupur Clay samples are only appropriate for light infrastructure foundation.

Keywords: Madupur Clay; Settlements; Compressibility; One Dimensional Consolidation Test

INTRODUCTION

It is very important to determine consolidation characteristics and immediate as well as long-term settlement analysis of Clay before designing a foundation structure. It is become a basic part of foundation design before constructing any civil engineering structure on this soil. For that reason, settlement assessment of Clay soil is essential particularly for footings (Foye et al., 2008). An excessive deformation can cause damage to any structure or its safety system. When a structure built on clay soils, settlement can happen due to volume change or consolidation of soil by load over a large period of time or it can take place rapidly. Basically, it occurs in the foundation soils that surround and support the structure. So, in case of design a shallow foundation, prediction of settlement characteristics is important along with calculating the bearing capacity of soil. Otherwise large settlements may occur under load foundation on soft or cohesive soil sites without shear failure of soil after many years of construction. In such case settlement requirement is necessary for shallow foundation and the greatest settlement of cohesive soils will determine the allowable bearing pressure of these soils.

Consolidation characteristics are needed for any design of reclamation that is why carried out a one-dimensional oedometer analysis to calculate the compressibility characteristics of Marine Cay deposit (Suneel et al., 2008). As stated by Prakash and Jain (Prakash and Jain, 2002) the primary goal of this analysis is to predict the percentage and extent of deformation of a structure that is built on soft sediments (clay soil) by collecting the samples. Hence A research on Consolidation characteristics of this type of soil is very crucial in term of finding or forecasting the settlement of subsoil and identifies the causes of the settlement failure below the building foundation. A consolidation test on soft clay has been conducted to find out the compressibility and permeability of clay in order to predict settlement (Tan et al., 1988).

The research area is mostly covered by Madhupur Clay soils which are subjected to consolidate naturally or when any load built on it. It is mandatory to determine its settlement. This is the reason this study only focus on Madhupur Clay sample of this study area as it

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was not fully investigated before. However, Some geotechnical investigations carried out worldwide on highly Plastic Clay in western canada (Fredlund, 1967), very soft Clay in Singapure (Tan et al., 1988), Structured Natural Clay (Chai et al., 2004), Expansive soils of Al-Khobar Palygorskite, eastern Saudi Arabia (Aiban, 2006) compressibility of Clay (Tripathy and Schanz, 2007), Korean marine Clay (Suneel et al., 2008), structured Clay (Suebsuk et al., 2011), natural and reconstituted Clays (Hong et al., 2012), marine soil (Wang, 2016), and Dhaka Clay (Ameen, 1985, Islam et al., 2004) in which Geotechnical characteristics such as consolidation parameters were interpreted. Particularly, consolidation parameter of Madhupur Clay of Dhaka District is not studied properly earlier.

The research area, Dhaka city and its adjoining area (savar), especially Dhaka city is a highly populated area in Bangladesh. This growth rate of urban population is also higher than many other mega cities of the world. It is expected that the population of Dhaka will be more than 21 million by the year 2020 , where in 2030 may see as many as 27.3 million population (United Nations, 2019). It has been significantly growing with many infrastructures over last few decades. Due to population pressure a lot of new housing, commercial building, and urban infrastructure are built that have shaped up urban process and all of these new structure transferred pressure on clay soils (Bashar, 2000). Since it covers two geological units; Madhupur Clay of Pleistocene age and Alluvial Deposits of Recent age. Alluvial Deposits are beyond scope to study in this research. The high compressibility and low strength nature of the Madhupur Clay is sometimes become challenging for engineering site (Banglapedia, 2014). Therefore, the settlement failure has become a common phenomenon in Dhaka. This becomes mandatory to comprehend the consolidation parameters of the subsurface clay materials of the city to interpret the compressibility behavior of clay.

STUDY AREA

This investigation region is covers the area of Dhaka city and adjoining area (Savar), Bangladesh. Dhaka is situated in the central part of the country. This city extends from 23° 43□N to 23° 49□ N latitude and 90° 22□ E to 90° 27□30” E longitude (Fig. 1). Savar is one of the Upazila of Dhaka district. This upazila is located around 24 km north-west of Dhaka and having an area of about 280.13 sq.km (Wikipedia_Savar_Upazila).

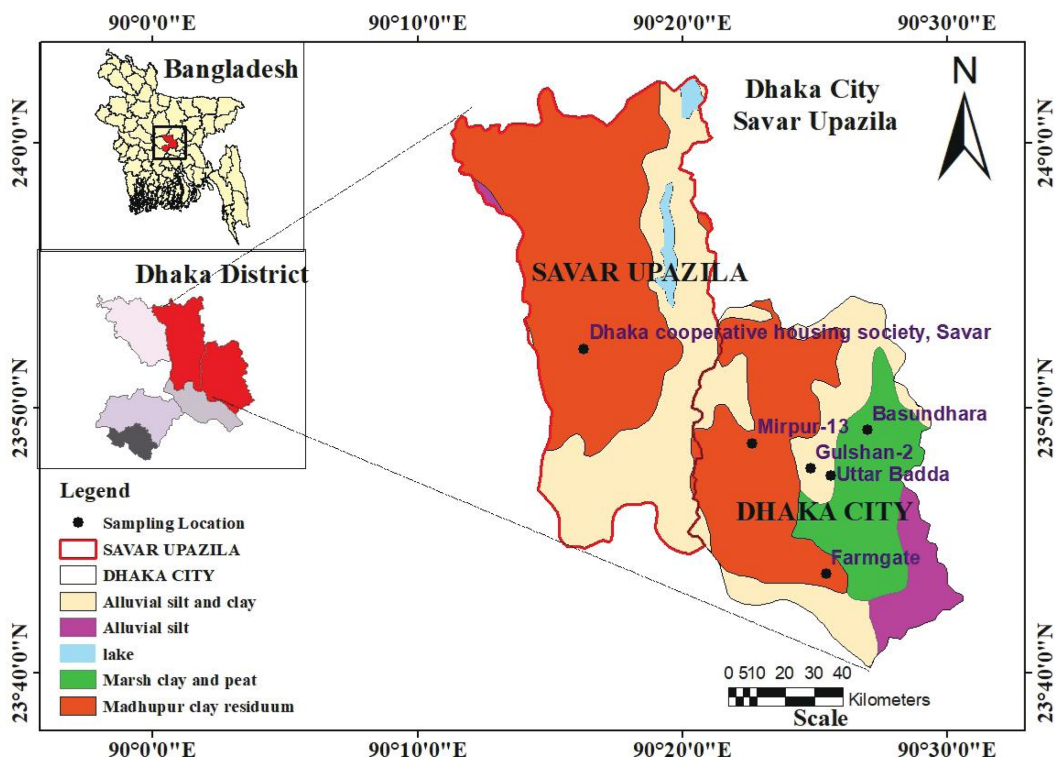


Figure 1: Geological Map (Location Map) Shows the Investigation Area (Dhaka and Adjoining Area, Savar) (Courtesy: ArcGIS)

Dhaka, Bangladesh's capital city is fastest expanding cities in the world. This capital city is positioned on the Buriganga river bank which is in the central region of the country. The elevated Pleistocene terrace (Madhupur Terrace) and the surrounding low-lying alluvium deposits primarily cover the Dhaka. The Pleistocene terrace is made up of silty sand (medium dense to dense) and yellowish brown color silty (medium stiff to extremely stiff) clay. According to Monsur and paepe (Monsur and paepe, 1994), the uncovering Pleistocene terrace deposits can be subdivided into two Formations: 1) lower unit that composed of Madhupur Clay and Sand Formation 2) upper unit that are Bashabo silty clay formation (Monsur and Paepe, 1994). The Madhupur Clay Formation is exposed on all of those north-south trending extended flat landmasses uplifted from surrounding flood plains and covers surface exposure of more than half of Dhaka city, where the thickness varies from 12 to 15 meters (Monsur, 1995).

METHODOLOGY

The undisturbed cohesive soils (clay) are usually used for consolidation test. The undisturbed clay samples from different parts of Dhaka City have been collected using Sellby Tube sampler during the execution of Standard Penetration Test for subsurface investigation to know the bearing capacity of the subsurface geological materials to construct residential and commercial buildings. The sample collected from distinctive locations of Dhaka city at depth approximately from 2.4 m to 4.11 m. Sampling locations are given in table 1.The samples collected from Gulshan-2, Uttar Badda, Farmgate, and the Dhaka cooperative housing societyare Madhupur Clay and other samples from Mirpur-13,Basundharaare fill material which partly composed of Madhupur Clay. Then a Consolidometer (fixed ring type) is utilized to execute the experiment work of clay soils where only saturated soil is suitable for this. The laboratory test is one dimensional test in which all water flow and soil move in a one direction that is upright and no lateral movement is occurred because a metal ring enclosing the sample. Equipment require for this researches are Consolidometer (fixed ring type), Dial gage reading to 0.002mm and Loading device. One-dimensional consolidation test is performed in accord with standard test method ASTM-D2435. A smaller representative sample of soils was properly cut and fitted onto a consolidation ring for this experiment. The soil sample is set on a porous stone base, and another porous stone is set on top to allow the water that is draining out of the sample to flow properly at the top and bottom. The initial height H_i and weight of the sample should be computed precisely before giving load. So that the initial void ratio, e_0 can be determined.

The consolidometer must be properly set and positioned inside the loading device. The dial gauge is subsequently fixed into place to measure the relative displacement between the loading cap and the consolidation cell's base. After that water is put into the consolidometer in order to saturate the clay sample. At a convenient starting time, the initial load increment is inserted and after that, writes down the readings (strain) from reading scale at a definite period of times such as 0.1, 0.25, 0.50, 1, 2, 4, 8, 15, 30, 60,120 min; then say, 24 hours. Applied Loads are increased in a manner that the consecutive load strength, σ, is twice the preceding one; the magnitude of load that are generally used being 50,150, 250, 500, 1000 and 2000kPa. Each load is permitted to stand until main consolidation has all but stopped. The weight is started to withdraw from the soil sample when the largest load necessary for the test has been applied to it. The data observed from dial reading are used to calculate height, change in height of samples, void ratio and later determine consolidation parameters.

RESULTS AND DISCUSSION

Physical Properties

The physical properties are significant supplement in consolidation test. Test is performed to determine this and these values are summarized below (Table 1);

Table 1: Sampling Location and Values of Water Content and Void Ratio of Undisturbed Clay Specimens

location	Latitude longitude	Depth (meters)	Lithologic description.	Initial water content (%) w_i	Final water content(%) w_t	Initial void ratio, e_i	Final void ratio, e_f
Mirpur-13,	N23˚48'38.4" E90˚22'38.4"	3.6576 to 4.1148	Light grey to yellowish brown silty clay (filling).	26.680	24.961	1.0478	0.8340
BasundharaResidential area.	N23˚43'42.2" E90˚25'27.1"	2.438 to 2.9	Yellowish brown to grey coloured clay with silt and brick chips (filling)	29.863	26.023	1.1516	0.8708
Gulshan-2.	N 23˚47'41.36" E 90˚24'51.24"	2.438 to 2.8956	Dark brown to bluish grey coloured silty clay.	23.839	19.449	0.7120	0.5534
Uttar Badda.	N 23°47'25.31" E 90°25'37.73"	2.4384 to 2.7432	Reddish brown to grey coloured silty clay.	20.038	18.522	0.6678	0.5510
Farmgate,	N 23˚43'42.2" E 90˚25'27.1"	2.4384 to 2.7432	Reddish brown colourd silty clay	26.551	23.086	0.8779	0.7151
Dhaka cooperative housing society, Savar.	23°52'12.48"N 90°16'17.02"E	2.4384 to 2.7432	Reddish brown to grey coloured silty clay.	22.552	18.864	0.700	0.5635

A graphical plot between initial void ratio and natural moisture content is illustrated in Fig. 2. From the table1, it shows that the range of water content of soils are between 20.038% and 29.863%, on the other hand the initial void ratio is in the range from 0.6678 to 0.870. It points out a clear trend that natural moisture content of any deposit or soil has a good linear correlation with initial void ratio. The sample of Basundhara Residential area has higher initial water content with higher initial void ratio compare to other samples from six different areas in the study zone.

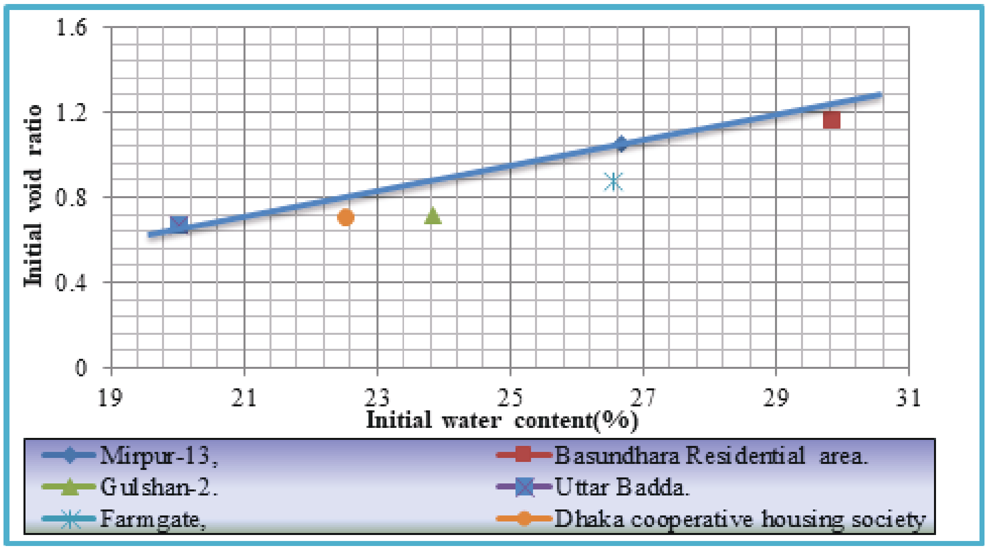


Figure 2: Initial Void Ratio vs. Intial Water Content Diagram for Six Samples

Consolidation Characteristics

Consolidation characteristics (compression index, Coefficient of compressibility, and preconsolidation stress) of examined soil specimen are discussed in this section. Based on the consolidation data analysis, a comparison between the Madhupur Clay samples and fill materials, mostly composed of madhupur clay are revealed. The samples of Gulshan2, Uttar Badda, Farmgate and Dhaka cooperative society, Savar are Madhupur Clay regard to be Pleistocene Age. The samples at location of Mirpur13 and Basundhara Residential Area are fill material (partly composed of Madhupur Clay).

Compression Index, Cc

This predominant value is get from calculating the consolidation data after completing of consolidation examination. It is mainly a slope in the void ratio vs. log pressure plot's linear section (Singh, 2011). The void ratio, e vs log pressure curve diagram for six samples is plotted in fig. 3.a. The soil plasticity characteristics and initial water content are the one on which the e vs. log p depend and might become curved, concave upwards or concave downwards revealed by a research. Therefore, it may not logical to presume that C_C is constant in many cases (Sridharan and Gurtug, 2005). C_c is not only function of both void ratio but also depends on effective overburden pressure (Siddique A, 1986).

The empirical equations available for determinations of C_c (Singh, 2011),

$$C_c = \frac{\Delta e}{\log\left(\sigma'2/\sigma'1\right)} \text{ or } \frac{\Delta e}{\Delta\left(\log \sigma'_v\right)} \quad \text{........(1)}$$

The compressibility of many Clay at higher pressure can be determined by using preliminary results that get from the odometer test (Tripathy and Schanz, 2007). The value of compression index and compression ratio for Undisturbed Clay samples are given in table (Table 2).

The value of C_c and compression ratio for the samples,fill materials , reveal that the samples have moderate compressibility behavior which fall in soil compressibility range (0.10-0.20). And according to compression index range (0.3-0.075), these samples are medium plastic clayas per soil Compressibility classification (Coduto, 2002) and compression index classification (Murthy, 2003)

Similarly, for the case of samples, Madhupur Clay, they are about medium plastic clay (compression index range (0.3-0.075)) (Murthy, 2003) and slightly compressible in nature which fall in soil compressibility range (0.05-0.10) (Coduto, 2002).

Therefore, it can predict that, because of medium plastic nature, the soil will lose it strength when the water content gets high. Apart from this, the samples having filling materials will decrease it volume due mechanical load in a short period of time because of moderate compressible nature. Whereas, the samples which are Madhupur clay will take time to reduce its volume after load due to its slightly compressible nature.

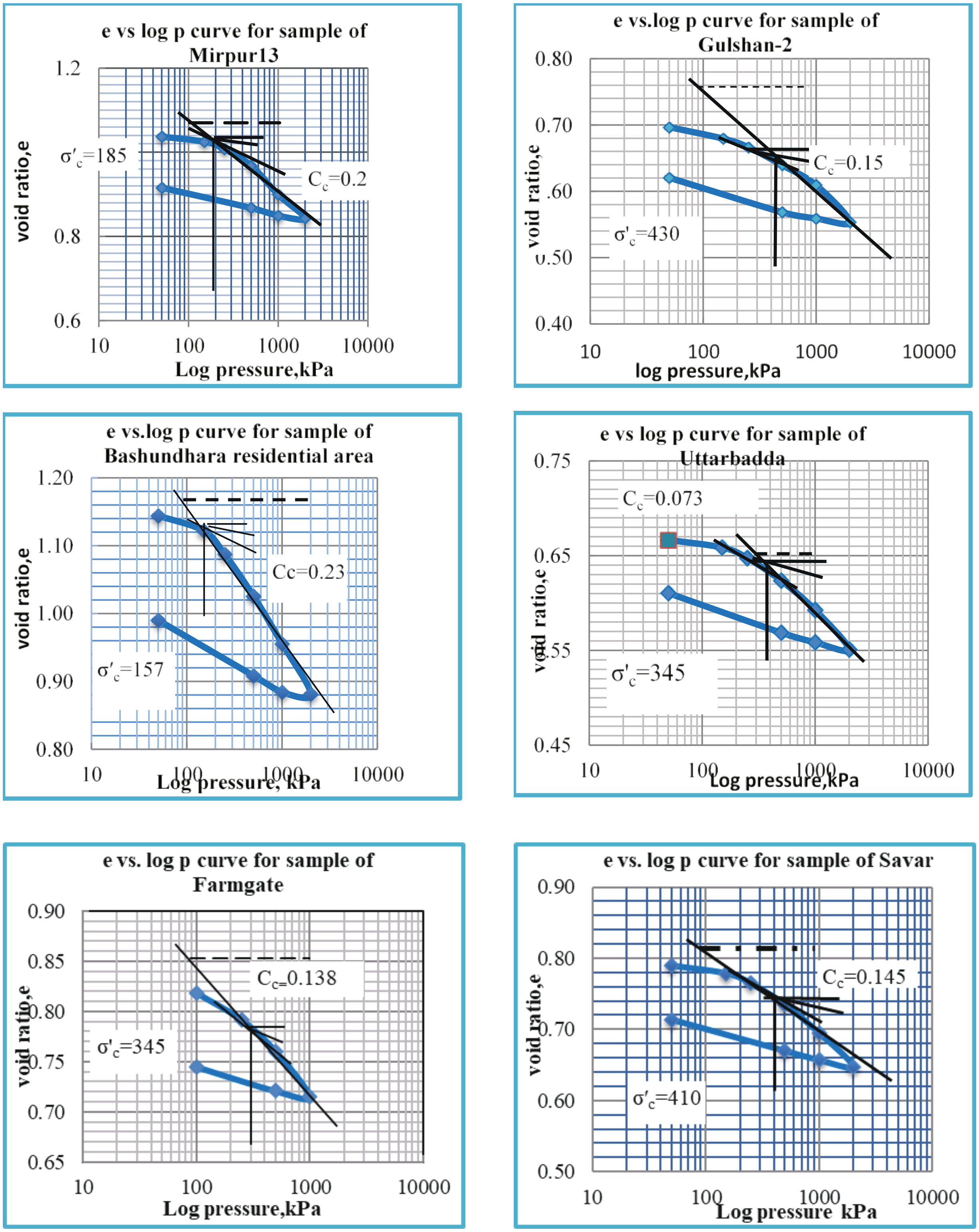
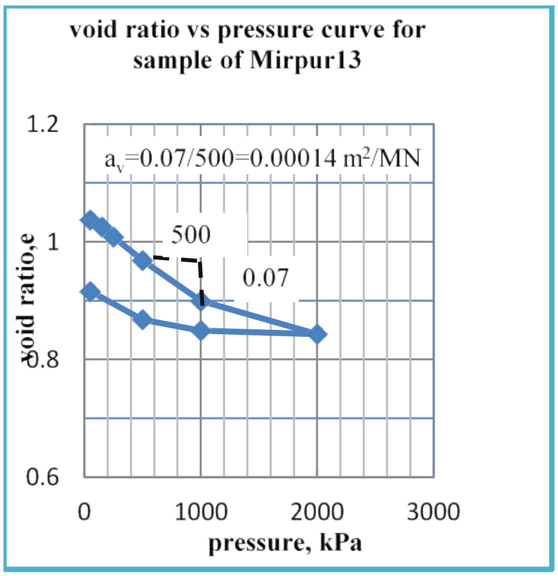


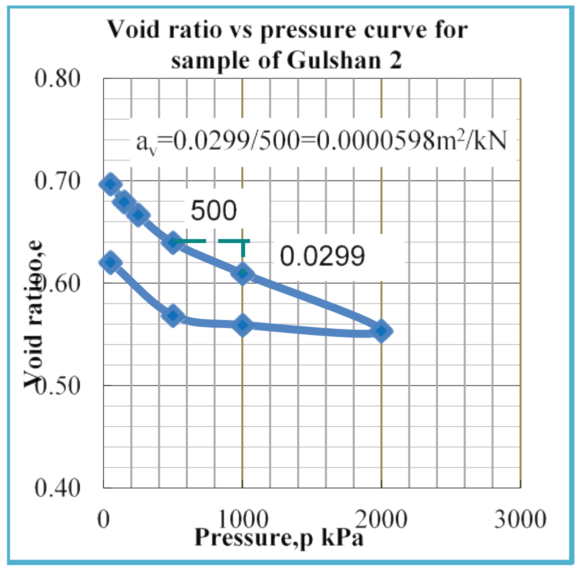
Figure 3.a: The Void Ratio, e v_s Log Pressure Curve Diagram for Six Samples

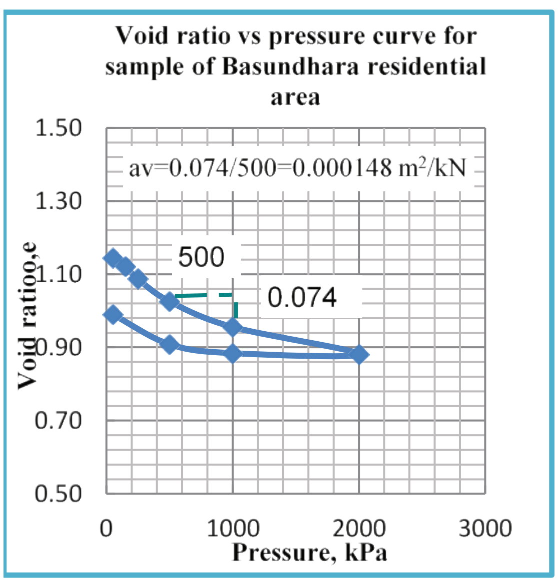
Coefficient of Compressibility, a_v

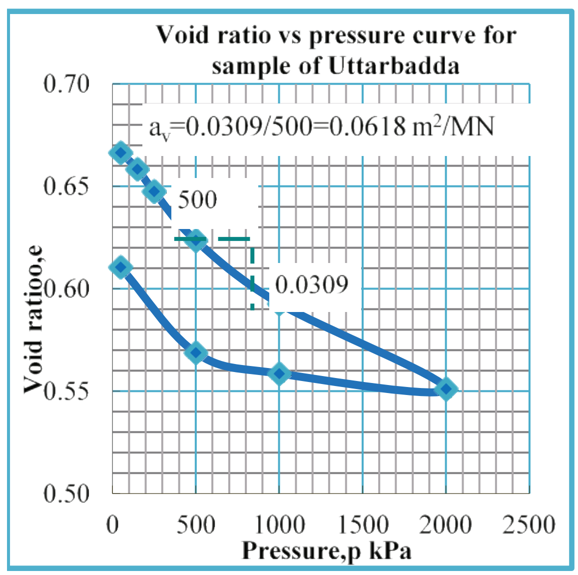
This characteristic is deduced from void ratio, e vs. pressure, σ curve which is plotted in Fig. 3.b for six samples. Coefficient of compressibility, a_v and water content of Clay samples are given in table 1 and 2. Due to soil structure and water content in clay soil, natural and reconstituted (Hong et al., 2012) or structured and remold (Wang et al., 2016) soils shows the difference in compression. A critical state model together with bounding surface theory was used to explain the physical behavior of naturally and artificially structured clay during its over consolidated state as well as it is also appropriate to delineate the compression and shearing behavior of Clay (Suebsuk et al., 2011)

Based on the data analysis, it can determine that the Coefficient of compressibility of samples (fill materials) is moderate, which is typical of less stiff over-consolidated clay. Whereas, the value of samples (Madhupur Clay) exhibit the characteristic of stiff over-consolidated clay.









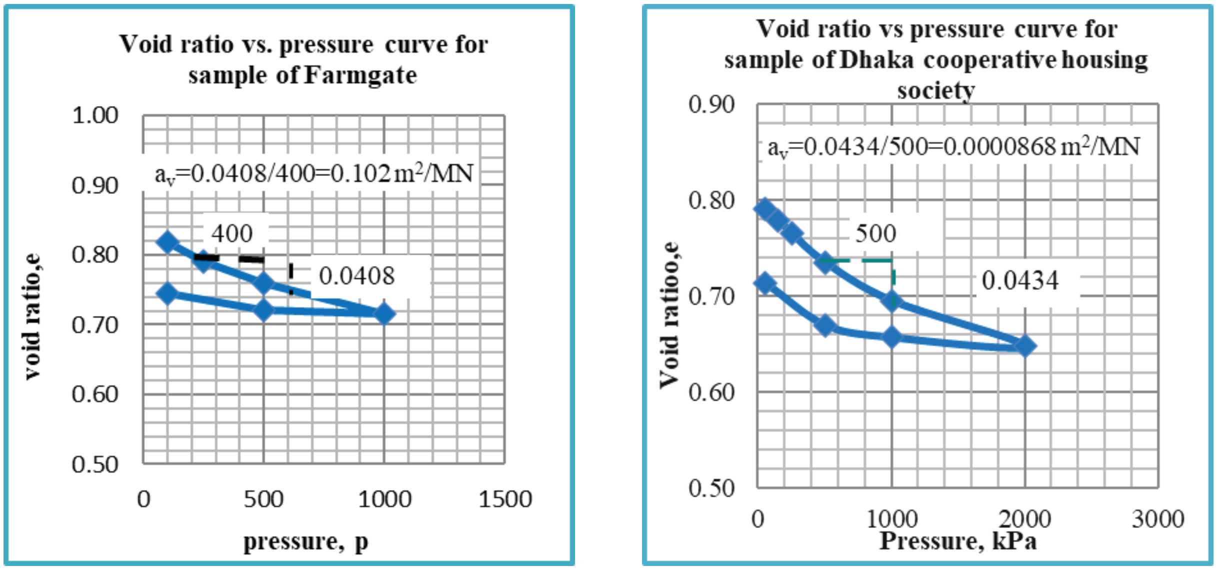


Figure 3.b: Void Ratio, e vs. Pressure, σ of Clay Samples for Six Locations Diagram

Table 2: Summarizes of Value of C_c and a_v, Preconsolidation Stress, σc̄ and Over Consolidation Margin of Clay Samples

location	C_c	$C_c/(1+e_0)$	a_v m²/MN	Depth (m)	Over burden pressure $\bar{\sigma}_0$ kPa	Preconsolidation stress, $\bar{\sigma}_c$ kPa	OCR	Over consolidation margin, σ'_m
Mirpur-13. (filling)	0.21	0.102	0.14	3.6576 to 4.1148	85.27	185	2.169	99.73
Basundhara Residential Area (filling)	0.23	0.12	0.148	2.438 to 2.9	57.55	157	2.728	99.45
Gulshan-2.	0.15	0.088	0.059	2.438 to 2.8956	49.956	430	8.6	380.04
UttarBadda.	0.073	0.043	0.062	2.4384 to 2.7432	54.792	345	6.379	290.21
Farmgate.	0.138	0.073	0.10	2.4384 to 2.7432	54.764	350	6.391	295.24
Dhaka cooperative housing society, Savar.	0.145	0.081	0.086	2.4384 to 2.7432.	55.655	410	7.366	354.35

Preconsolidation Pressure, σ'_c:

This is calculated from the void ratio vs. log pressure curve. The quantity of σ'_c is sometimes greater than that of $\sigma' z_0$ which mean that In the geologic past, soil may remained in a pre-consolidated stage because of the volume of glacier that has disappeared, and other geologic overload, or structural pressures that are no longer present (Coduto, 2002). The assessment value of σ'_c and σ'_m are given in a table 2. Maximum (pre-consolidation) pressure ($\sigma' p$) and stress history are important due to the fact that it impact on the shear strength and compressibility (consolidation parameter) nature of fine grained soils(clay) (Umar and Sadrekarimi, 2017)

The range of over consolidation margin, kpa (0-100) is slightly over-consolidated soil (Coduto, 2002); hence the fill materials fall in this category. Diversely, the Madhupur Clay Samples are moderately over consolidated since this samples fall in between the range 100- 400 kpa (Coduto, 2002)

Settlement Analysis and Prediction of Settlement of Study Area

To establish the consolidation characteristics, laboratory tests on undisturbed clay soil samples are performed. The settlement is calculated using these consolidation properties, specifically the compression index Cc..

There are several methods to predict and calculate settlement. In this study total settlement is calculated by using the modified Terzaghi's equation. That is

$$S = (H/C)*Ln((\Delta\sigma'_v + \Delta P)/\Delta\sigma'_v) \ldots\ldots (2)$$

Where, S= Settlement (m)

H=thickness of the soil layer (m)

C= Constant of consolidation

$\Delta\sigma'_v$ = Initial vertical effective stress

Δp = Increase in vertical effective stress.

Koppejan's settlement formula is used to calculate the settlement of clay samples. The formula is

$$St= H*(1/C_p + 1/C_s \log t/t_o)*Ln(\Delta\sigma'_v + \Delta P)/\Delta\sigma'_v \ldots\ldots (3)$$

Change in volume is $\Delta V=SA$, change in volume is equal to the change in volume of the voids (definition of settlement) and by the definition of the void ratio, $\Delta V=S A=\Delta V_v =\Delta e V_s$

Using the initial void ratio and total volume (e_o and V_o) gives, $V_s= V_o/(1+e_o)=AH/(1+e_o)$

Combining and rearranging gives, $\Delta V=S A=\Delta e V_s= (AH/(1+e_o))* \Delta e$

Therefore, $S/H= \Delta e/ (1+e_o)$ or $S= (H*\Delta e)/ (1+e_o)$

$\Delta e=C_c \Delta[\log \sigma'_v]= C_c [\log(\sigma'+\Delta\sigma')-\log\sigma']= C_c * \log(\Delta\sigma'_v+\Delta\sigma')/\Delta\sigma'$

Hence $S= (C_c H)/(1+e_o) * \log(\Delta\sigma'_v +\Delta p)/ \Delta\sigma'_v \ldots (4)$

When this formula (4) compared to the Terazghi's settlement formula (2) the relation is evident,

$$1/C= Cc/2.3(1+e_0) \ldots\ldots (5)$$

The Terzaghi's equation (2) can rewrite as below,

$$S(cm)=H(Cc/2.3(1+e_0)) \ln(p+\Delta p/p) \ldots\ldots (6)$$

Comparing formula (5) with Koppejan's formula (3), is only possible for long term settlement say for t=10000days (27 years) than log t/to=4 and

$$1/C=(1/C_p + 4/C_s) = C_c /(2.3(1+e_o)) \ldots\ldots (7)$$

and the result are given in below (table 3)

Table 3: Summarizes of the Settlement Calculation of Undisturbed Samples

Locations	Pressure in kPa	Settlement of the samples (cm) total settlement	Settlement of samples in percentage (%) Long term settlement
Mirpur-13.	50	0.043	2.15
	150	0.095	4.75
	250	0.128	6.4
	500	0.180	9.0
	1000	0.238	11.9
	2000	0.299	14.95
Basundhara Residential Area.	50	0.058	2.9
	150	0.119	5.95
	250	0.156	7.8
	500	0.211	10.55
	1000	0.271	13.55
	2000	0.332	16.6
Gulshan-2.	50	0.053	2.65
	150	0.106	5.3
	250	0.137	6.85
	500	0.183	9.15
	1000	0.232	11.6
	2000	0.283	14.15
Uttar Badda.	50	0.024	1.2
	150	0.048	2.4
	250	0.063	3.15
	500	0.085	4.25
	1000	0.108	5.4
	2000	0.133	6.65
Farmgate.	100	0.066	3.3
	250	0.110	5.5
	500	0.148	7.4
	1000	0.189	9.45
Dhaka cooperative housing society, Savar	50	0.045	2.25
	150	0.092	4.6
	250	0.120	6.0
	500	0.162	8.1
	1000	0.207	10.35
	2000	0.254	12.7

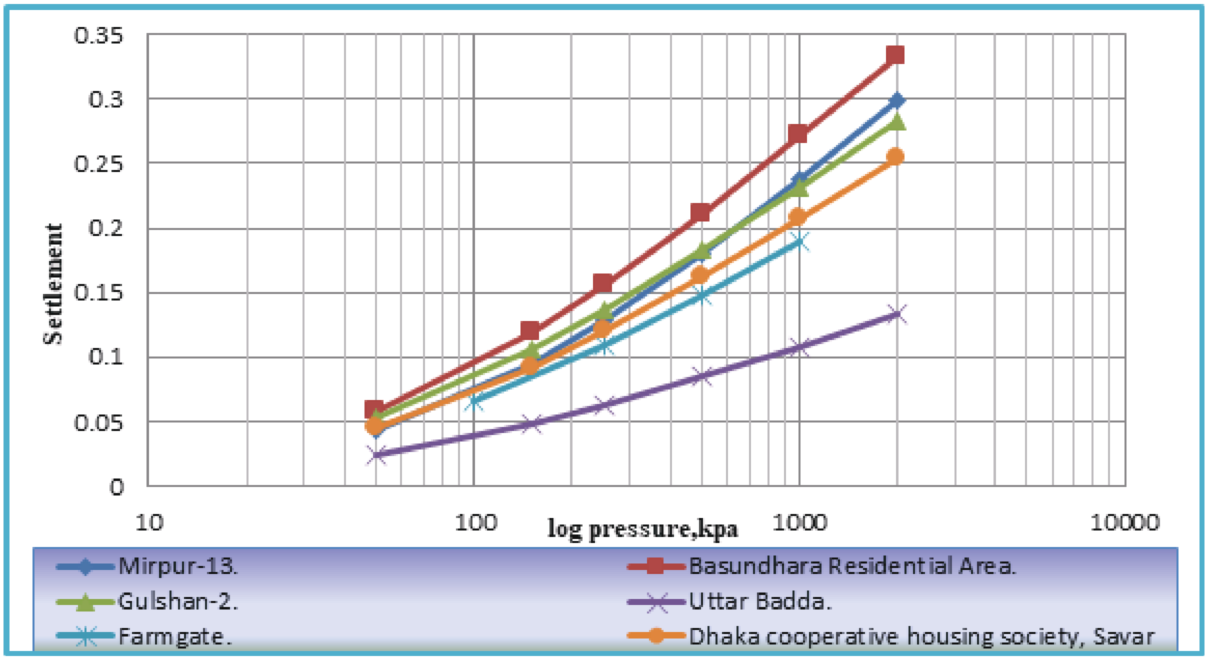


Figure 4: A Plot of Settlement and Pressure of Clay Samples

From the fig. 4, it has been observed that the settlement of all samples is going up with the increasing pressure. Settlement characteristics of sample are altered from the area to area. In some places the greater settlement may occur, in contrast less settlement may occur in other places for applying the similar pressure. The specimen having high water content or void ratio will be more settled by subjected to pressure.

- The settlement of Sample at the location Basundhara Residential Area (Table 3) is high compare to that of other samples. In this situation the change of moisture content with void ratio is high with increasing pressure that lead to more settled or consolidated of the soil sample. This sample has high initial water content and void ratio and this cause the sample settle more with time.

- The settlement of sample (from Table 3 and Fig. 4) at the area of Uttar Badda will not as much of settle with compare to the other investigated samples of the study area. The settlement is resulted from a loss of moisture or decrease of void ratio in the sample. The higher the loss of moisture or decrease of void ratio, the greater settlement of soil will be occurred. Whereas, the change of moisture content in this sample is lower with respect to the other samples causing less settlement in this area.

- The moisture content of clay samples at location of Mirpur13 and Farmgate are almost same but the clay in Mirpur13 will be settled more than the clay at the location of Farmgate by applies the same pressure. As the clay sample in Mirpur13 is found at a greater depth 4.11 m with compare to the clay in Farmgate which occurred at 2.74 m depth, so the overburden stress of clay in Mirpur13 is higher than that of clay in Farmgate. As a result the clay in the Mirpur13 area will be settled more than the sample in farmgate.

- The settlement of Clay in Gulshan-2 will be 2.65% for 50kPa stress and 14.15% for 2000kPa stress after 27 years, and the settlement of Clay in Dhaka cooperative housing society, Savar will be 2.25% for 50kPa stress and 12.7% for 2000kPa stress after 27 year.

CONCLUSION

This study conducted a one-dimensional consolidation test on Madhupur Clay and fill material, to some extent consists of Madhupur clay and analyze the consolidation parameters as well as predict the settlement of the study area. In the study it has found out that, the samples having Madhupur Clay fill materials are slightly stiff, moderately compressible in nature, less stiff over-consolidated soil. While Madhupur Clay samples are stiff, slightly compressible in nature and stiff over consolidated clay. Furthermore, Madhupur clay specimens are moderately over-consolidated soil than fill material of Madhupur Clay. However both types of samples are medium plastic clay. Now the settlement of Madhupur clay samples are to some extent less than that of samples which have fill material. It has also observed that the all specimen will have settled considerably after applying significant amount of load. Particularly, the sample of Basundhara Residential Area (sample having fill materials) is settled more compared to other samples. Moreover, overburden pressure of clay play a role to settle the mirpur sample than farmgate sample. Moreover these samples are medium plastic clay, which show some swelling properties during consolidation and is not good for any infrastructure. Therefore, the characteristics of Madhupur Clay fill samples suggest that it is not suitable for the shallow foundation of heavy or light structures. On the other hand, Madhupur clay soil samples are right for light structure foundation only. For the construction of any civil structures on the Clay soils, the compressibility and settlement characteristics of the clay must be taken account during the subsurface soil investigation.

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