X-Ray Diffraction Studies Of Some Madhupur Clay Samples Of Savar And Dhaka Of Bangladesh With Especial Emphasis On Clay Minerals

Md. Emdadul Haque, M. Nairuzzaman, M. Hasan Imam

Abstract: The clay and non-clay minerals have been identified by XRD analysis. The non-clay minerals include quartz, crystobalite, orthoclase, microcline, plagioclase, calcite, siderite and dolomite, and the clay minerals include kaolinite (52.39%), illite (36.39%) and illite-smectite mixed layer minerals (11.21%). Kaolinite is the most dominant component in the clay mineral assemblages. The clay minerals e.g. kaolinite, illite and illite-smectite have influences on the liquid limit, plastic limit and plasticity index. The higher amount of illite and illite-smectite will increase the liquid limit, plastic limit and plasticity index in the soil whereas higher amount of kaolinite would decrease the liquid limit, plastic limit and plasticity index. The higher the amount of illite and illite-smectite in the soil, the higher the activity in that soil. The clay minerals like kaolinite, illite and illite-smectite have marked influences on the shrinkage limit of the soil. The higher the illite-smectite in the soil, the higher the co-efficient of volume change (m_V), compression index (C_C), and preconsolidation pressure in the soils. The higher amount of kaolinite and illite decrease the co-efficient of volume change (m_V), compression index (C_C) and preconsolidation pressure. The increase of kaolinite and illite-smectite in the soil decreases coefficient of consolidation. But the increase of illite slightly increases the coefficient of consolidation. Illite influences the coefficient of permeability value less than illite-smectite, but more than kaolinite. Therefore, the clay minerals have significant influences on the geotechnical behaviour of the Madhupur Clay soil of Dhaka and Savar.

Keywords: X-ray diffraction, Madhupur Clay, clay minerals, shrinkage limit, consolidation, Savar and Dhaka.

1 INTRODUCTION

DHAKA, the capital of Bangladesh, is expanding rapidly. Dhaka is characterized by tropical, humid climate conditions. This is marked by cool and short winters, long and wet hot summers with high rainfall. Dhaka and its adjoining area is situated on the Madhupur Clay Formation. The Madhupur Clay Formation consists mainly of silt and clay, which is sticky when wet and shrinks when dry. Due to the special structure of clay minerals, platelets or pockets of platelets are surrounded by water layers [1]. Swelling, shrinkage, consolidation and other geotechnical parameters of clay depend mainly on clay mineralogy. Therefore, it is very important to study the clay minerals of Madhupur Clay soils of Dhaka and its adjoining area (Savar). In the soils, the various physical processes and chemical reactions lead to the formation of different clay minerals which depend on the nature of the reactants and p^H of the weathering environment. Depending upon the environmental conditions, some of the primary minerals, such as feldspar, mica, augite, hornblende and quartz may transform themselves into clay minerals [2].

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Clay mineral formation and transformation in the soil are slow processes and depend upon weathering environment, which in turn is mainly controlled by climate and drainage conditions of the landscape. In this paper an attempt is made to identify the clay minerals from XRD, their semi-quantitative estimation and to find out the relationship between clay minerals and geotechnical behavior of some of the Madhupur Clay samples of Dhaka and Savar. The borehole location of the investigated area is shown in figure 1.

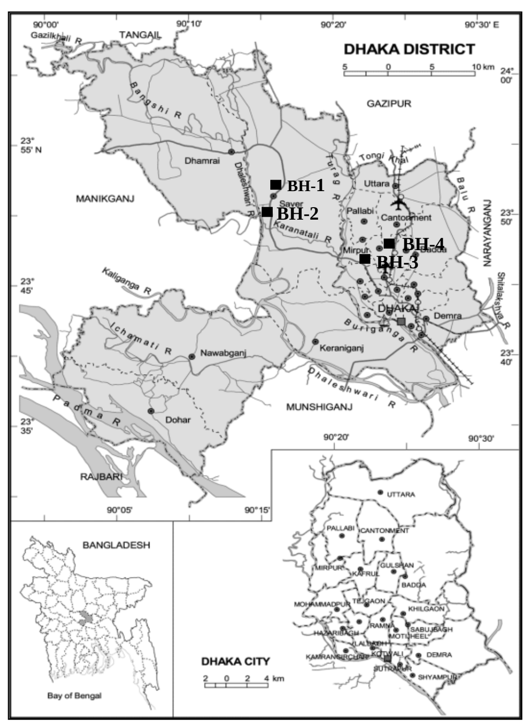


Fig. 1. Location map of the study area [3].

2 Materials and Methods

Samples were collected from four different boreholes in the field with the technical assistance of "Metro Geotechnical Engineers" at different depths. Four boreholes were selected of which two in Savar (BH-1 at Jahangirnagar University and BH-2 at Cornopara) and two in Dhaka (BH-3 at Bangladesh Institute of Health Science, Mirpur and BH-4 at Banani Housing Complex). The samples were recovered by manual Hydraulic Rotary Drilling method at disturbed and undisturbed state. Disturbed soil samples were collected by using split spoon sampler with Standard Penetration Test (SPT) method and undisturbed samples were collected with the help of thin open Shelby tubes (U76). Samples both in the disturbed and undisturbed state were collected continuously. In some selected samples, the XRD analysis has been done in the Pet-min laboratory of GSB for the identification and estimation of clay minerals. The bulk samples were run in the air dried state between 2° 2θ to 66° 2θ. For clay mineral analysis, oriented mount was prepared. Four different treatments were applied to the oriented mount for clay minerals. The clay samples were run in the air dried state (2° to 32° 2θ), then with ethylene glycol treatment (2° to 24° 2θ), then heated with 400° C (2° to 24° 2θ) and 600° C (2° to 24° 2θ). The XRD of a few selected samples are shown in fig. 2-fig. 6.

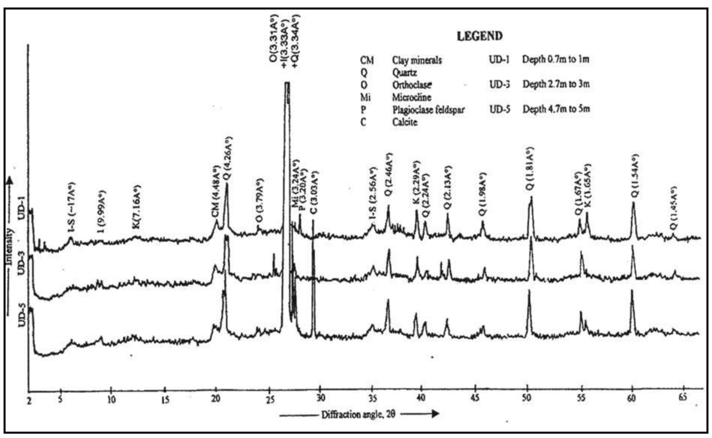


Fig. 2. X-ray Diffractogram of the bulk samples of Banani Houshing Complex (BHC) area.

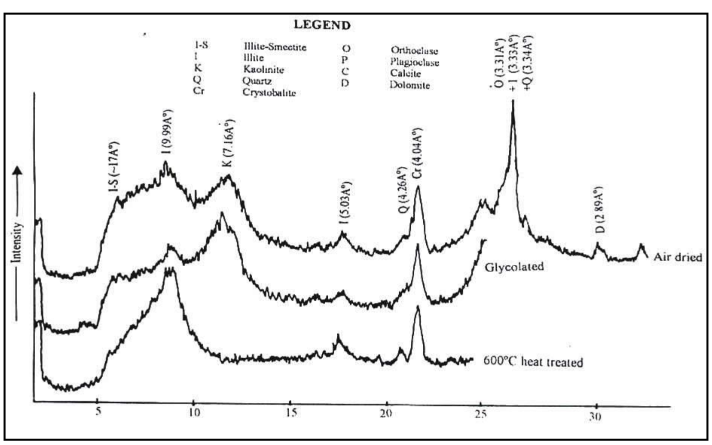


Fig. 3. X-ray Diffractogram of clay fraction at the depth 0.7m to 1.0m of JU area.

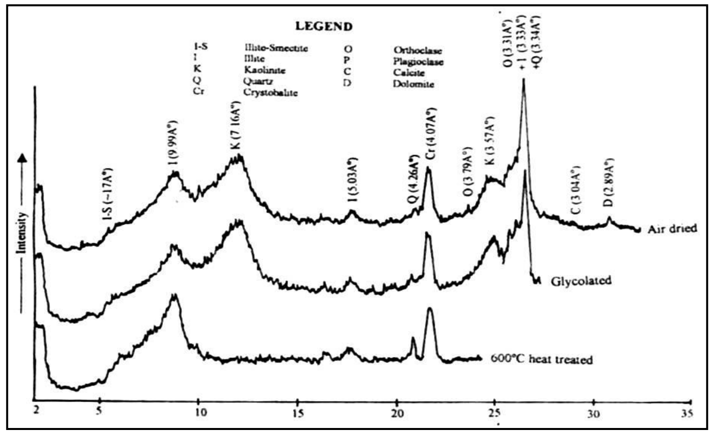


Fig. 4. X-ray Diffractogram of clay fraction at thr depth 4.7m to 5m of CP area.

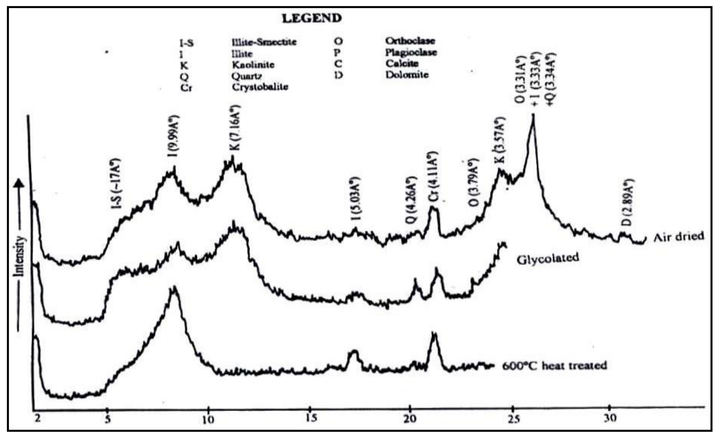


Fig. 5. X-ray Diffractogram of clay fraction at the depth 0.7m to 1.0m of BIHS area.

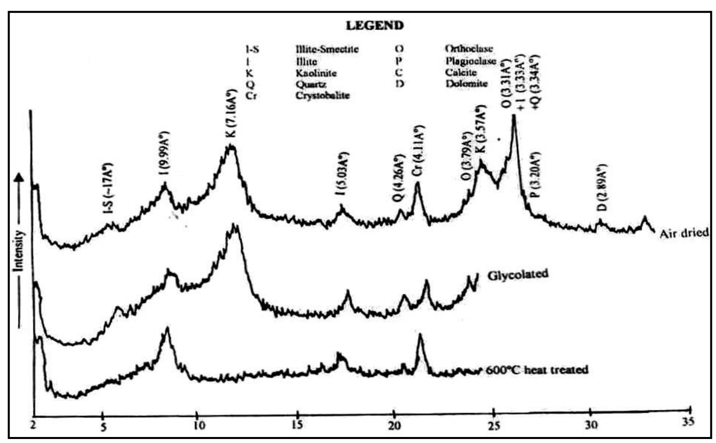


Fig. 6. X-ray Diffractogram of clay fraction at depth 4.7m to 5.0m of BHC area.

The mineralogical composition of the samples were identified after Carver (1971) [4], Brindley and Brown (1980) [5], JCPDS (1986) [6] and Moore and Reynolds (1997) [7]. Semi-quantitative estimation of the minerals was made after Galan (1975) [8] and Klages and Hopper (1982) [9]. The quantification of the clay minerals was made by considering the peak area by taking the height above the background for each diagnostic reflections at 2.0 mm intervals across the peak. The peak area has been divided by a correction factor, such as 1 for illite, 2.5 for kaolinite and 10 for smectite [9]. This technique is less time consuming and a good compromise between the two methods peak height and peak area. In the case of chlorite and kaolinite, the intensity at 7Å has been splitted by taking the intensity relation at 3.52 Å for chlorite and at 3.57 Å for kaolinite.

3 RESULTS

3.1 Nonclay minerals

The nonclay minerals identified in the samples are shown in table-1. Quartz is present as a common constituent of clays. Quartz is identified by distinctive reflections at 4.26 Å, 3.34 Å, 2.46 Å, 2.28 Å, 2.24 Å, 2.13 Å, 1.98 Å, 1.81 Å, 1.67 Å, 1.54 Å and 1.45 Å (fig. 2). It gives a strong diffraction pattern with sharp reflections. The strongest reflection observed at 3.34 Å (I01), which is several times more intense than the (100) peak at 4.26 Å. A strong reflection is observed in oriented clay samples of 4.07 Å to 4.11 Å, which is identified as crystobalite, a variety of quartz. In oriented clay samples, quartz and crystobalite occur as a major non-clay component.

TABLE 1
NON CLAY MINERALS OF THE MADHUPUR CLAY OF SAVAR AND DHAKA (FROM BULK SAMPLES AND ORIENTED MOUNTS)

Location	Sample No.	Depth (m)	Identified minerals
JU (BH-1)	UD-1	0.7-1.0	Quartz, Crystobalite, Microcline, Orthoclase, Piagioclase Feldspar, Dolomite.
	UD-3	2.7-3.0	Quartz, Crystobalite, Orthoclase, Calcite, hematite, Siderite, Dolomite.
	UD-5	4.7-5.0	Quartz, Crystobalite, Orthoclase, Plagioclase.
CP (BH-2)	UD-1	0.7-1.0	Quartz, Crystobalite, Orthoclase, Microcline, Calcite, Dolomite.
	UD-3	2.7-3.0	Quartz, Crystobalite, Orthoclase, Microcline, Plagioclase, Calcite, Dolomite.
	UD-5	4.7-5.0	Quartz, Crystobalite, Orthoclase, Microcline, Plagioclase, Calcite, Dolomite.
BIHS (BH-3)	UD-1	0.7-1.0	Quartz, Crystobalite, Orthoclase, Microcline, Calcite, Dolomite.
	UD-3	2.7-3.0	Quartz, Orthoclase, Microcline, Calcite, Plagioclase.
	UD-5	4.7-5.0	Quartz, Orthoclase, Microcline, Plagioclase feldspar, Calcite, Dolomite.
BHC (BH-4)	UD-1	0.7-1.0	Quartz, Crystobalite, Orthoclase, Plagioclase feldspar, Dolomite.
	UD-3	2.7-3.0	Quartz, Crystobalite, Orthoclase, Microcline, Plagioclase, Dolomite.
	UD-5	4.7-5.0	Quartz, Crystobalite, Orthoclase, Microcline, Plagioclase, Calcite, Dolomite.

JU=Jahangirnagar University, CP= Cornopara, BIHS= Bangladesh Institute of Health Science, BHC= Banani Housing Complex.

Feldspar forms a minor component of clays and usually occurs in the coarser, 1-2µm and larger size fractions. The studied samples contain both alkali feldspars (orthoclase and microcline) and plagioclase feldspars. Alkali feldspars are identified by their principal-reflections of 3.79 Å for orthoclase and microcline by its and highest reflections at 3.24 Å. The 1st principal reflection for orthoclase at 3.31 Å could not be determined as because of the principal reflection of quartz (3.34 Å) and illite (3.33 Å) of about the same position. For plagioclase, the presence of distinct and prominent peak at 3.20 Å is considered. In the studied bulk samples, the orthoclase, microcline and plagioclase are prominent feldspars, whereas in oriented clay samples (<2 µm) microcline is absent, and orthoclase and plagioclase are present. In the bulk samples, calcite and dolomite are found as carbonate minerals. Calcite and dolomite are identified by weak reflections at 3.03 Å and 2.88 Å respectively. The sample at the depth 2.7m to 3.0m at JU area shows trace of siderite and hematite by weak reflection at 2.79 Å and 2.69 Å respectively. No secondary peak for calcite and dolomite appear in the XRD indicating trace amount of these minerals. In oriented clay sample (<2 µm) siderite and hematite are absent whereas calcite is present. It is observed that dolomite is found only one sample at the depth 4.7m to 5.0m, but it is present in ten samples in oriented clay samples and opposite case is observed in calcite.

3.2 Clay Minerals

The clay minerals identified in the Madhupur Clay of Dhaka and Savar are listed in table 2. The results revealed that the clay minerals present in the soil are kaolinite (52.39%), illite (36.39%) and small amount of illite-smectite (11.21%). Illite is characterized by a 10 Å (9.93 Å -10.1 Å) basal reflection (001) and its 002 reflections at 4.48 Å-5.03 Å (fig.3-fig.6). It is also identified at 3.32 Å to 3.35 Å. On glycolation, illite is essentially non-expanding. On heating to 600°C the (001) peak of illite may show slight collapse, although if this is well marked it suggests that expandable layers are present. The sharp peaks of illite indicate that illite of all the samples are well crystallized. Illite is present in all the samples ranging from 24.1% to 44.25% with an average of 36.39% among the clay minerals. The average amount of illite is comparatively lower at Banani Housing Complex area (28.12%) than that of the other three locations where the range of illite percentages are very closer (table-2). Kaolinite is the major component in all the samples. It is identified from 7 Å (7.1 Å to 7.17 Å), 3.57 Å, 2.29 Å and 1.65 Å peak (fig. 3-fig. 6). All the kaolinites are found to be unaffected on glycolation and 400°C heat treatment. On heating to 600°C, kaolinite tends to lose its crystalline character whereas chlorite at this temperature is partially dehydrated, causing increased intensity at the 14 Å reflection (Grim, 1968) and this confirm the identification of the kaolinite and chlorite. The kaolinite ranges from 41.67% to 67.69% and the average is 52.39% in the analyzed samples. The average amount of kaolinite is comparatively lower at Jahangirnagar University area (42.91%) than that of the other three locations where the range of kaolinite percentages are very closer (table-2).

TABLE 2
CLAY MINERALS OF THE MADHUPUR CLAY SAMPLES OF SAVAR AND DHAKA

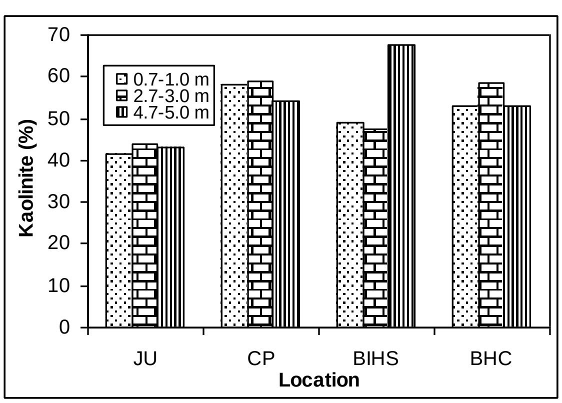
Location	Sample No.	Depth (m)	Clay mineral (%)		
			Illite- Smectite	Illite	Kaolinite
JU (BH-1)	UD-1	0.7 – 1.0	13.89	44.25	41.67
	UD-3	2.7 – 3.0	19.7	36.5	43.8
	UD-5	4.7 – 5.0	16.21	40.53	43.26
	Average		16.6	40.43	42.91
CP	UD-1	0.7 – 1.0	3.22	38.71	58.07

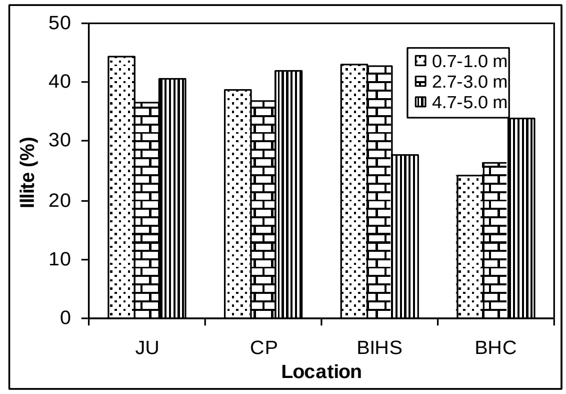
(BH-2)	UD-3	2.7 – 3.0	4.16	36.86	58.99
	UD-5	4.7 – 5.0	4.0	42.0	53.99
	Average		3.79	39.19	57.02
BIHS (BH-3)	UD-1	0.7 – 1.0	8.04	42.91	49.04
	UD-3	2.7 – 3.0	9.53	42.85	47.62
	UD-5	4.7 – 5.0	4.62	27.69	67.69
	Average		7.4	37.82	54.78
BHC (BH-4)	UD-1	0.7 – 1.0	22.72	24.1	53.18
	UD-3	2.7 – 3.0	15.18	26.3	58.52
	UD-5	4.7 – 5.0	13.23	33.96	52.81
	Average		17.04	28.12	54.84

The X-ray diffraction of all the samples of the Madhupur Clay of Dhaka and Savar show a minor amount of illite-smectite mixed layer minerals. Without illite-smectite mixed layer minerals, no pure or discrete smectite was identified. The illite-smectite mixed layer minerals are identified by distinctive reflections at 16 Å to 18 Å and 2.56 Å. The peaks of illite-smectite mixed layer minerals were wide and shifted to 17 Å after glycol treatment and after 400°C heat treatment, the peaks were also shifted to 10 Å and increased the illite intensity. These facts indicate the presence of illite-smectite mixed layer minerals. Illite-smectite ranges from 3.22 % to 22.72 % and the average is 11.21% in the analyzed samples (table-2). The highest amount of illite-smectite (22.72 %) is found in Banani Housing Complex area, at the depth 0.7m to 1.0m. The lowest amount of illite-smectite (3.22%) is found in Cornopara area, at depth 0.7m to 1.0m. The illite-smectite ranges from 4.62% to 9.53% and the average is 7.4 % in Bangladesh Institute of Health Science (Mirpur) area (Table-2). At Banani Housing Complex area the illite-smectite ranges from 13.23% to 22.72% and the average is 17.04%. In the Jahangirnagar University campus (Savar) the illite-smectite ranges from 13.89% to 19.7% and the average is 16.6% whereas at the Cornopara (Savar) the illite-smectite ranges from 3.22% to 4.16% and the average is 3.79 %. The results indicate that the Madhupur Clay of Jahangirnagar University and Banani Housing Complex areas have more expandable minerals than the other two locations of the studied area (table-2). The variation of clay minerals in different borehole locations are shown in Figure 7.

4 Discussion

The analyzed Madhupur Clay soils of Savar and Dhaka consists of kaolinite, illite and illite-smectite mixed layer minerals. Haque and Hossain (2002) [10] studied the clay minerals and shrinkage behaviour of Dhaka and mentioned that the Madhupur Clay of JU, Curzon Hall and Mirpur area contains several clay and non-clay minerals.





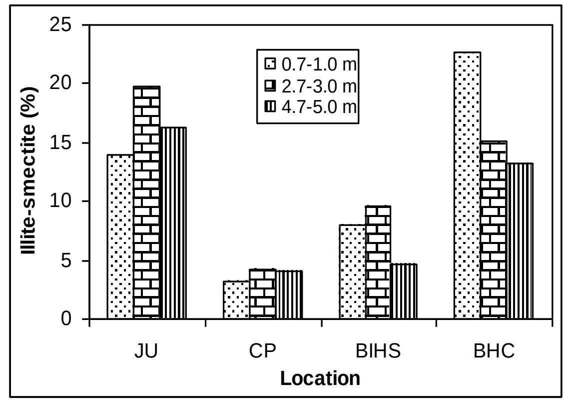


Fig. 7: Variations of kaolinite, illite and illite-smectite at different boreholes.

The non-clay minerals include quartz, orthoclase, microcline and plagioclase whereas the clay minerals include kaolinite (30%), illite (46%), illite-smectite (11%), and small amount of chlorite, Na-smectite and exandable smectite. The present investigation is different from Haque and Hossain (2002) [10] that no chlorite and smectite is found in this research work. Hossain (1997) [2] analyzed the Madhupur Clay of Shripur at Gazipur district and mentioned that the soil consists of kaolinite (30-35%), illite (45-55%) and mixed layer mineral (13-20%). He mentioned that vermiculite, montmorillonite and chlorite has not been identified in any horizon of the soil profile. The present investigation is well agreement with Hossain (1997) [2]. Habibullah et al. (1971) [11] mentioned that the Madhupur Clay contains kaolinite and illite as the main minerals. They also observed minor quantities of quartz, vermiculite, goethite and hematite. Habibullah et al. (1971) [11] also mentioned that one of the Madhupur Clay samples showed the presence of large amount of amorphous material, which they estimated as about 12.5%. The present investigation is consistent with Habibullah et al (1971) [11]. Hossain (1983) [12] studied the mineralogy of Bangladeshi soils and reported that illite, kaolinite, vermiculite, chlorite, feldspar and quartz are the main minerals of the alluvial soils. Aftabuzzaman et al. (2013) [13] studied the Pleistocene Madhupur Clay of Barind tract and mentioned that it contains kaolinite and illite clay minerals. The present investigation is consistent with Hossain (1983) [12] but inconsistent with Aftabuzzaman et al. (2013) [13]. The earlier researchers [11], [12] mentioned that smectite is not present in the Madhupur Clay. The authors view point is somewhat different from that of others. The present study suggests that the Madhupur Clay contains illite-smectite mixed layer mineral (11.21%) which is consistent with Hossain (1997) [2] and Haque and Hossain (2002) [10]. The present investigation suggests that kaolinite is the dominant mineral in the Madhupur Clay which is consistent with Habibullah et al. (1971) [11]. Clay minerals have been ranked by relative resistance to weathering and assigned a number to each mineral indicating weathering stage or mineral stability. Higher value indicates greater stability of the mineral [14]. According to Jackson (1964) [14], illite with stage 7 weathers to vermiculite (stage 8), then vermiculite transforms into montmorillonite (stage 9) and montmorillonite alters to kaolinite (stage 10) under favourable conditions. No trace of vermiculite and montmorillonite has been found in the analyzed samples. This may be due to the weathering of these two minerals. Hossain (1997) [2] mentioned that strongly developed red Madhupur soils form only on the edges or margins of dissected valleys or blocks where well drained leaching environment does not allow vermiculite or montmorillonite to be stable and if present, they get transformed into kaolinite through desilication. The vertical sequence of clay minerals and higher percentages of mixed layer minerals in the analyzed samples indicate that transformation of clay minerals is probably incomplete and an equilibrium weathering stage has not yet been achieved. The specific gravity of all clay minerals are similar with values in the range from about 2.0 to 3.0 [15]. He poined out that the specific gravity of different clay minerals: kaolinite, 2.6-2.68; illite, 2.64-3.0; and montmorillonite, 2.2-2.75. The iron rich clay mierals and the titaniferous materials show higher specific gravity values. Clays composed largely of attapulgite and montmorillonite have low bulk density [16]. The specific gravity of the Madhupur Clay soils of Savar and Dhaka ranges from 2.44 to 2.71 and the average value is 2.59 [17]. The analyzed samples of the Madhupur Clay consists of kaolinite, illite and illite-smectite mixed layer minerals and the specific gravity of the Madhupur Clay soil is closer to the recommended values of Gidigasu (1976) [15] for different clay minerals like illite, kaolinite and illite-smectite. Grim (1962) [16] pointed out that there is no single liquid limit, plastic limit and plasticity index that is characteristic of a particular clay mineral. The range of liquid limits for a particular group of clay mineral is much greater than the range for the plastic limits. After Hough (1957) [18] the liquid limit of montmorillonite ranges from 140%-710%, of illite from 78%-120% and of kaolinite from 38%-59%. Nairuzzaman (2000) [17] determined the liquid limits of the Madhupur clay of Savar and Dhaka and mentioned that the liquid limit ranges from 28.5% to 59% and the average value is 45.72%. The results also suggest that the clay minerals e.g. kaolinite, illite and illite-smectite have influences on the liquid limit of the Madhupur Clay of Savar and Dhaka. The higher amount of illite and illite-smectite will increase the liquid limit in the soil whereas higher amount of kaolinite would decrease the liquid limit in the Madhupur Clay samples. Samuels (1950) [19] mentioned that the plastic limit of montmorillonite ranges from 41%-51%, of kaolinite from 41%-44%, of nontronite from 19%-27%. Nairuzzaman (2000) [17] determined the plastic limits of the Madhupur Clay of Savar and Dhaka and mentioned that the plastic limit ranges from 18.3% to 34.77% and the average value is 25.57%. Therefore, the plastic limit is consistent with clay mineralogy of the Madhupur Clay according to Samuels (1950) [19]. The results also suggest that the clay minerals e.g. kaolinite, illite and illite-smectite have influences on the plastic limit of the Madhupur Clay of Savar and Dhaka [17]. The higher amount of illite and illite-smectite will increase the plastic limit in the soil whereas higher amount of kaolinite would decrease the plastic limit in the Madhupur Clay of Savar and Dhaka. According to Grim (1962) [16], the plasticity indices of the clay minerals range from higher than 600% for some Na-montmorillonites to 1 for Na-kaolinites in about the following decreasing order: montmorillonite; illite; kaolinite. Grim (1962) [16] also pointed out that the plasticity index of montmorillonite ranges from 75% to 600%, of illite from 23% to 50% and of kaolinite from 1% to 40%. But Hough (1957) [18] mentioned that the plasticity indices for montmorillonites range from 70% to 650%, for illite ranges from 31% to 63% and for kaolinite the value ranges from 11% to 28%. The presence of montmorillonite in illite substantially increases the plasticity index [16]. Nairuzzaman (2000) [17] determined the plasticity index of the Madhupur Clay of Savar and Dhaka and mentioned that the plasticity index ranges from 10.2% to 27.4%. Therefore, the plasticity index is consistent with clay mineralogy of the Madhupur Clay according to Hough (1957) [18] and Grim (1962) [16]. The results also suggest that the clay minerals like kaolinite, illite and illite-smectite have influences on the plasticity index of the Madhupur Clay of Savar and Dhaka. The higher the amount of illite and illite-smectite in the soil, the higher the plasticity index in the soil whereas the higher the kaolinite in the soil, the lower the plasticity index in the soil. Dumbleton and Newill (1962) [20] mentioned that there is no single shrinkage limit value that is characteristic of a particular clay mineral and the shrinkage limit varies with the type of clay minerals present in the soil. The range of shrinkage limit for a particular clay mineral is lower than the liquid and plastic limits. The decreasing order of shrinkage limit values for various clay minerals: illite; kaolinite; montmorillinite. They mentioned that the shrinkage limit values of illite range from 14% to 22%, kaolinite has 18%, and of montmorillonite from 11% to 15%. Hough (1957) [18] pointed out that the shrinkage limit considerably influenced by the nature of exchangeable cations of clay minerals. Based on the type of exchangeable ions the shrinkage limit of montmorillonite varies from 9% to 14.7%, illite from 14.7% to 17.5% and kaolinite from 24.5% to 29.2% [18]. The analyzed samples of the Madhupur Clay consist of kaolinite, illite and illite-smectite mixed layer minerals. Nairuzzaman (2000) [17] determined the shrinkage limit of the Madhupur clay of Savar and Dhaka and mentioned that the shrinkage limit ranges from 7.4% to 17.7% and the average value is 12.86%. The shrinkage limit is consistent with clay mineralogy of the Madhupur Clay according to Hough (1957) [18], Dumbleton and Newill (1962) [20] and Grim (1962) [16]. The results also suggest that the clay minerals like kaolinite, illite and illite-smectite have influences on the shrinkage limit of the Madhupur Clay of Savar and Dhaka. The higher the amount of illite in the soil, the higher the shrinkage limit in the soil. The higher the kaolinite in the soil, the lower the shrinkage limit in the soil. The presence of illite-smectite might have some influences in the soil samples. Therefore, the illite, kaolinite and illite-smectite clay minerals have some influences on shrinkage limit of the soil samples of Savar and Dhaka. The different clay minerals show variable activity of soil. Skempton (1953) [21] mentioned that the activity of different clay minerals is as follows: Na-montmorillonite, 7.2; Ca-montmorillonite, 1.5; illite, 0.9 and kaolinite, 0.33-0.46. Mitchell (1976) [22] pointed out that the approximate activity of different clay mineral: smectite, from 1.0-7.0; illite, from 0.5-1.0 and kaolinite, 0.5. The activity value of natural clay and soil is higher than values for pure clay minerals [16]. Nairuzzaman (2000) [17] determined the activity of the Madhupur clay soils of Savar and Dhaka and mentioned that the activity ranges from 0.89 to 2.86 and the soil is normal to active in nature. The activity is consistent with clay mineralogy of the Madhupur Clay according to Skempton (1953) [21], Mitchell (1976) [22] and Grim (1962) [16]. The results also suggest that the clay minerals like kaolinite, illite and illite-smectite have influences on the activity of the Madhupur Clay of Savar and Dhaka. The higher the amount of illite and illite-smectite in the soil, the higher the activity in the soil. The higher the kaolinite in the soil, the lower the activity in the soil. The presence of illite-smectite might have a significant influence on activity in the soil samples. In case of unconfined compressive strength, Grim (1962) [16] mentioned that the montmorillonite yields lower strength than kaolinite when not mixed with sand but yields higher strength than kaolinite when mixed with sands. For clay minerals, the strength would increase with increasing percentages of clay minerals in the following order: montmorillonite; illite; kaolinite [16]. The Madhupur Clay is mainly kaolinitic and Illitic in composition with illite-smectite mixed layer minerals. So, its strengths should lie closer to the strength for kaolinite and illite [23]. Grim (1962) [16] mentioned that there is no clear cut relationship between clay mineral composition and shear strength, but variations in the clay mineral composition do cause substantial differences in the shear strength of a soil. Grim (1962) [16] also mentioned that the shear strength increases rapidly with depth in montmorillonite clays. The Madhupur Clay is mainly kaolinitic and Illitic in composition with illite-smectite mixed layer minerals. So, its strengths should lie closer to the strength for kaolinite and illite and not increases with depth [23]. Grim (1962) [16] again mentioned that the value of angle of internal friction (ϕ) for kaolinite is 20°, for illite from 10° to 15°, and for montmorillonite it approaches to 0°. As the Madhupur Clay mainly consists of illite and kaolinite with small amount of mixed layer minerals so the value of 'ϕ' should lie between 10° and 20° according to Grim (1962) [16] and Hossain and Haque (1995) [23]. The clay minerals have significant influences on the consolidation behaviour of the Madhupur Clay of Savar and Dhaka [17]. Mitchell (1976) [22] pointed out that different clay minerals have variable compression index (C_C) values and the values range from 0.5 to 1.10 for illite, from 0.19 to 0.28 for kaolinite and 1.0 to 2.6 for montmorillonite in different ionic forms. Nairuzzaman (2000) [17] studied the Madhupur Clay of Savar and Dhaka and mentioned that the compression index value increases with higher amount of illite-smectite mixed layer minerals and decreases with increase amount of illite and with the higher amount of kaolinite. So, it is clear that there is a relationship between illite-smectite and compression index (C_C) values [17]. They also mentioned that the higher the illite-smectite in the sample, the higher the compression index (C_C) in the formation. The higher amount of kaolinite and illite decrease the compression index of the clay formation [17]. Nairuzzaman (2000) [17] again mentioned that the co-efficient of compressibility (a_V) value increases with higher amount of illite-smectite mixed layer minerals and slightly decreases with higher amount of illite and with the higher amount of kaolinite. Therefore, the higher the illite-smectite in the sample, the higher the co-efficient of compressibility (a_V) in the formation. The higher amount of kaolinite and illite decrease the compression index of the Madhupur Clay of Savar and Dhaka [17]. Nairuzzaman (2000) [17] also mentioned that the co-efficient of volume change (m_V) value increases with higher amount of illite-smectite mixed layer minerals and slightly decreases with higher amount of illite and kaolinite. Therefore, the higher the illite-smectite in the soil, the higher the co-efficient of volume change (m_V) in the Madhupur Clay of Savar and Dhaka. The higher amount of kaolinite and illite decrease the co-efficient of volume change (m_V) [17]. The co-efficient of consolidation (C_V) value decreases with higher amount of illite-smectite in the Madhupur Clay [17]. They also mentioned that the increase of kaolinite in the soil decreases coefficient of consolidation. But the increase of illite slightly increases the coefficient of consolidation of the Madhupur Clay of Dhaka and Savar. The co-efficient of permeability (k) value slightly increases with higher amount of illite-smectite mixed layer minerals, more or less similar with higher amount of illite and decreases with higher amount of kaolinite in the Madhupur Clay [17]. Nairuzzaman (2000) [17] stated that the presence of illite-smectite influences the co-efficient of permeability of the samples. The higher coefficient of permeability value is related with higher amount of illite-smectite mixed layer clay minerals. Among the clay minerals present in the Madhupur Clay, illite influences the coefficient of permeability value less than illite-smectite, but more than kaolinite [17]. According to Nairuzzaman (2000) [17], the preconsolidation pressure slightly decreases with higher amount of illite-smectite mixed layer clay minerals in the soil. It decreases with increase of illite in the samples, and increases with abundance of kaolinite. Therefore, the clay minerals have significant influence on preconsolidation pressure.

5 CONCLUSION

The clay and non-clay minerals have been identified by XRD analysis from the Madhupur Clay soil samples of Savar and Dhaka. The non-clay minerals include quartz, crystobalite, orthoclase, microcline, plagioclase, calcite, siderite and dolomite, and the clay minerals include kaolinite (52.39%), illite (36.39%) and illite-smectite mixed layer minerals (11.21%). Kaolinite is the most dominant component in the clay mineral assemblages. Transformation of clay minerals is probably incomplete and an equilibrium weathering stage has not yet been achieved in the soils. The clay minerals e.g. kaolinite, illite and illite-smectite have influences on the liquid limit, plasic limit and plasticity index. The higher amount of illite and illite-smectite will increase the liquid limit, plastic limit and plasticity index in the soil whereas higher amount of kaolinite would decrease the liquid limit, plastic limit and plasticity index in the Madhupur Clay soils. The activity is consistent with clay mineralogy of the Madhupur Clay according to different authors. The clay minerals also have influences on the activity of the soils. The higher the amount of illite and illite-smectite in the soil, the higher the activity in the soil. The clay minerals like kaolinite, illite and illite-smectite have marked influences on the shrinkage limit of the soil. The higher the illite-smectite in the soil, the higher the co-efficient of volume change (m_V), compression index (C_C) and preconsolidation pressure in the soils. The higher amount of kaolinite and illite decrease the co-efficient of volume change (m_V), compression index (C_C) and preconsolidation pressure. The increase of kaolinite and illite-smectite in the soil decreases coefficient of consolidation. But the increase of illite slightly increases the coefficient of consolidation. The co-efficient of permeability (k) value slightly increases with higher amount of illite-smectite mixed layer minerals, more or less similar with higher amount of illite and decreases with higher amount of kaolinite. Among the clay minerals present in the Madhupur Clay, illite influences the coefficient of permeability value less than illite-smectite, but more than kaolinite. Therefore, the clay minerals have significant influences on the geotechnical behaviour of the Madhupur Clay soils of Dhaka and Savar.

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