Investigation of Microfabric and Geotechnical Properties of Clay Soils of Kapasia Upazila, Gazipur, Bangladesh

GeoCalgary 2022 October 2-5 Reflection on Resources

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ABSTRACT
This paper describes the results of the microfabric and geo-technical parameters studies of clay soils of Kapasia Upazila, Gazipur district, Bangladesh. The microfabric study of Kapasia soils revealed that the soils consist of silt and clay, intergranular pore spaces with clay coatings and Si, Al, O, K, Fe etc. Based on the grain size distribution, Atterberg limit and British soil classification system, the Kapasia soils can be characterized as intermediate to high plasticity inorganic to organic silty clay and classified as CI to CH. The activity and linear shrinkage results suggest that the Kapasia soils are normal to active and non-critical to critical in nature. The studied soils might be composed of illite, kaolinite or mixture of illite-montmorillonite clay minerals. The ground contains huge amount of organic matter at 5-14 m depths which have very high moisture content (up to 72%) and might be associated with the subsidence occurred in the region.

RÉSUMÉ
Cet article décrit les résultats des études de microfabrication et des paramètres géotechniques des sols argileux de Kapasia Upazila, district de Gazipur, Bangladesh. L'étude des microfabrics des sols de Kapasia a révélé que les sols sont constitués de limon et d'argile, d'espaces poreux intergranulaires avec des revêtements d'argile et de Si, Al, O, K, Fe, etc. Sur la base de la distribution granulométrique, de la limite d'Atterberg et du système britannique de classification des sols, les sols de Kapasia peuvent être caractérisés comme une argile limoneuse inorganique à organique de plasticité intermédiaire à élevée et classés de CI à CH. Les résultats d'activité et de retrait linéaire suggèrent que les sols de Kapasia sont de nature normale à active et non critique à critique. Les sols étudiés peuvent être composés d'illite, de kaolinite ou d'un mélange de minéraux argileux illite-montmorillonite. Le sol contient une énorme quantité de matière organique à des profondeurs de 5 à 14 m qui ont une teneur en humidité très élevée (jusqu'à 72 %) et pourraient être associées à l'affaissement survenu dans la région.

1 INTRODUCTION

The study area of Kapasia Upazila of Gazipur district, Bangladesh is situated within lattitude 24° 02'N to 24° 15'N and longitude 90° 30'E to 90° 43'E. The location of the study site is shown in Figure1. Some geo-technical problems such as subsidence (Figure 2) and damage of Kapasia-Sripur road have been reported in the national newspapers (Shome 2009). This research work will help to get a better idea about the engineering geology of Kapasia which will play a pioneer role in the economic and social development of the Kapasia Upazila by building engineering structures safely and economically. The Kapasia and its adjoining area consists mainly of unconsolidated sediment of silt, clays and fine sand with organic matter as revealed from the soil samples encountered in the wells bored. As a part of this research program, disturbed samples were collected from different depth of two boreholes to study the microfabric and geo-technical properties of the clay and determination of the behavior of clay.

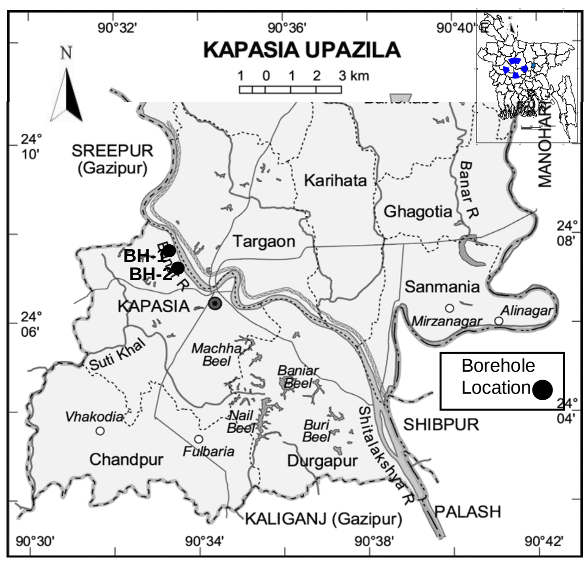

Figure 1. Location map of the study site (Banglapedia 2003)

Figure 2. Subsidence occurred in Kapasia-Sripur road

2 MATERIALS AND METHODS

To collect soil samples, two boreholes (BH-01 and BH-02) were drilled near Kapasia- Sripur road side up to a depth of 17.68 m and 18.90 m respectively. These borehole data are used to evaluate the ground conditions of the investigated area.

Boreholes were drilled by light cable percussion drilling method and wash boring technique. Soil samples both in the undisturbed and disturbed state were collected continuously. Split spoon sampler of the standard penetration test (SPT) method was used for collecting disturbed soil samples and thin open Shelby tubes (U75) were used to collect undisturbed samples. The undisturbed soil samples were used to determine the compressibility characteristics of Kapasia clay soils (Shome et al. 2014) and disturbed soils were used to analyze the grain size, specific gravity, moisture content and Atterberg limits of clay soils.

In this study, the fabric of Kapasia clay soils was studied by scanning electron microscope (SEM) photographs. Two samples were analyzed for microscopic study. One sample was collected from BH-01 at a depth of 5.49 - 13.7 m and another sample was collected from BH-02 at a depth of 1.5 - 5.49 m. EDX (Energy Dispersive X-ray Spectrum) of each sample was also studied in combination with the SEM micrographs to identify the nature of linkage (cements) between grains.

In this research work, various standard methods are used to determine the engineering properties of the material i.e., ASTM (American Society of Testing Material), BS (British Standard) etc. The particle size distribution has been carried out by hydrometer method (ASTM 1974). The natural moisture content (NMC) values of all disturbed samples are determined by oven drying method and the specific gravity of all samples was examined by the density bottle (Pyknometer) method. The Atterberg consistency limits and activity values are determined according to BS1377 (1990). X-ray diffraction (XRD) analyses were conducted by standard methods to find out the mineralogical composition of the study area.

3 RESULTS AND DISCUSSIONS

3.1 Microfabric Characteristics of Kapasia Clay Soils

The scanning electron micrograph images of two samples were taken with magnification of 1000x with an accelerating voltage of 15KV. Scale of micrograph images are 50µm. SEM images of BH-01 and BH-02 are named as SEM_1 and SEM_2 respectively.

The fabric of the soil showed generally an open structure of silt and clay. The fabric is more random due to the presence of many silt grains. Some black areas are traced throughout the micrograph. Such a black area in SEM_1 image may be an intergranular pore space marked by 'X' is shown in the upper right corner of the micrograph (Figure 3). In Figure 3, connector between grains and a silt grain are marked by 'Y' & 'Z' respectively. From the micrograph (SEM_2) of BH-02, a large silt grain was identified and marked by 'X' (Figure 4).

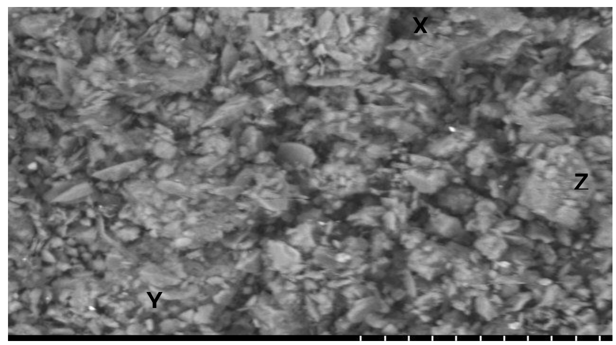

Figure 3. Scanning Electron Micrograph of sample SEM_1 (BH-01). (Scale 50.0um). X= Intergranular space, Y= Connector between grains, Z= Silt grain

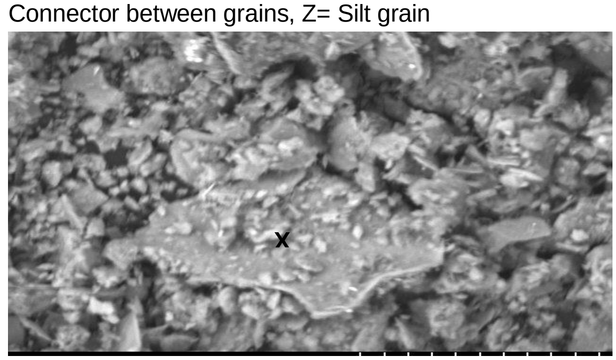

Figure 4. Scanning electron micrograph of sample SEM_2 of BH-02. Scale 50. 0 um. X= A large silt grain

EDX on 'X' point (Figure 5) of BH-01 showed mainly peaks of oxygen (O), silicon (Si), aluminium (Al), iron (Fe), potassium (K) and titanium (Ti). This suggests that the black area (marked by 'X') may be coated with mainly clay, which can be justified by the identified peaks of Si, Fe, K and Al in EDX spectrum. The elemental compositions of SEM_1 sample of BH-01 is shown in Table 1. Iron peaks appear due to the presence of iron which might be associated with the deposition of hydroxides or other chemical alteration of minerals (Hossain 2001).

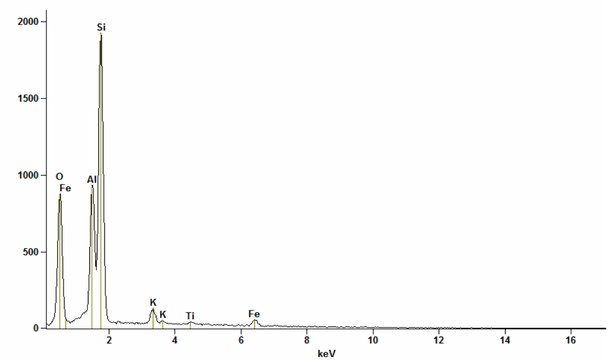

Figure 5. Energy dispersive X-ray spectrum (EDX) of point 'X' of sample SEM_1 of BH-01

Table 1. Elemental composition (weight %) of sample SEM_1 of BH-01

Element	Net counts	Weight %	Weight % error
O	12467	49.98	+/- 0.81
Al	12007	11.76	+/- 0.33
Si	29268	30.19	+/- 0.44
K	1689	2.78	+/- 0.22
Ti	281	0.76	+/- 0.14
Fe	911	4.52	+/- 0.54
Total		100.00	

EDX passed through the sample (SEM_2) showed that it is composed of oxygen (O), silicon (Si), aluminium (Al), iron (Fe), potassium (K) and minor amounts of Mg and Ti (Figure 6). Concentrations of Si, Al and K associated with clay and Fe might be due to the deposition of iron on the grain through leaching and weathering. Elemental compositions with their weight percentage are listed in Table 2. From the overall observations of two micrographs, it is seen that the Kapasia soils are characterized by a matrix of randomly oriented clay flakes and silts. A close consistency is also observed in the overall fabric and elemental composition of the soils at two different sites of Kapasia.

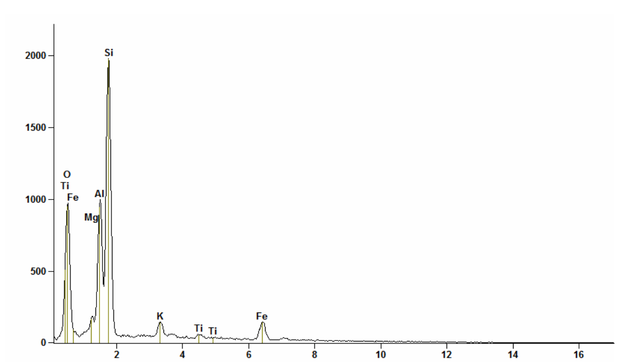

Figure 6. Energy dispersive X-ray spectrum (EDX) of point 'X' of sample SEM_2 of BH-02

Table 2. Elemental composition (weight %) of sample SEM_2 of BH-02

Element	Net counts	Weight %	Weight % error
O	13698	45.82	+/- 0.74
Mg	1003	0.92	+/- 0.10
Al	12815	11.15	+/- 0.40
Si	30465	27.21	+/- 0.41
K	2153	2.96	+/- 0.21
Ti	375	0.85	+/- 0.14
Fe	2672	11.08	+/- 0.66
Total		100.00	

3.2 Basic Engineering Properties

3.2.1 Grain Size Analysis

The grain size distribution of some selected samples from two boreholes is listed in Table 3. The percentages obtained from sedimentation and sieving are plotted on particle distribution chart (Figure 7). The obtained result, showed that the average values of sand, silt and clay percentages of Kapasia soils are 10.87%, 65.37% and 23.75% respectively. The soil comprises higher amount of silt percentages. After silt percentage the abundant grain size is clay. The result suggests that the Kapasia clay soil may be defined as silty clay.

Table 3. Grain size distributions of the Kapasia clay soils

BH no.	Depth (m)	Sample no.	Grain percent (%)		
			Sand	Silt	Clay
BH -01	5.49-13.72 m	S-1	12.5	64.5	23
	13.72-16.76 m	S-2	8	67	25
BH -02	5.49-9.14 m	S-1	9	63	28
	10.67-16.19 m	S-2	14	67	19
	Average		10.87	65.37	23.75

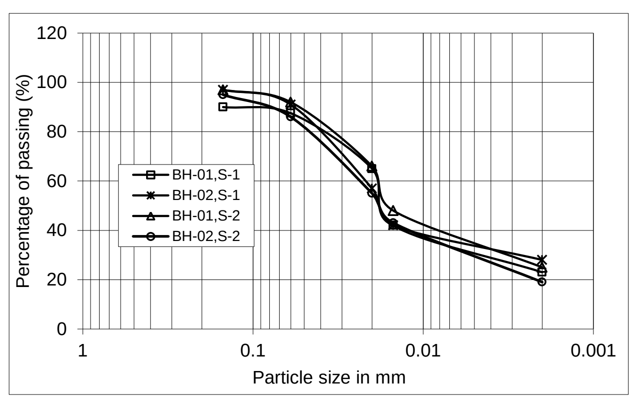

Figure 7. Grain size distributions of two borehole samples

3.2.2 Moisture Content and Specific Gravity

The natural moisture content (NMC) and specific gravity values of Kapasia clay soil are listed in Table 4 and found that the values vary with depths and boreholes. These small variations may be due to the variation of size range, pretest preparation technique, the type of clay minerals and the degree of desiccation or drying (Gidigasu 1976). The NMC lie between 20.79 to 72.26% and the specific gravity values lie between 2.30 to 2.88. High natural moisture content values were observed at depths between 5.49 to 13.72 m and low specific gravity values observed at 6.1 to 13.72 m depth for both boreholes. The higher values of moisture content and lower values of specific gravity might be due to the existence of organic matter. Clay minerals generally have higher values in the range of 2.70 to 2.85 and organic soil has a low and quite variable specific gravity such as 2.20 to 2.64 (Singh 1992). Gidigasu (1976) reported that the specific gravity of illite is 2.64 to 3.0, of chlorite is 2.60 to 3.0, of kaolinite is 2.60 to 2.68 and of montmorillonite is 2.22 to 2.75. The observed specific gravity values of all samples are closer to the recommended values of Singh (1992) and Gidigasu (1976) for illite, kaolinite and montmorillonite.

Table 4. Moisture content and specific gravity values of the studied soil samples

BH no.	Depth (m)	Sample no.	NMC (%)	Specific Gravity
BH-01	1.52-5.49	S-1	32.27	2.57
		S-2	37.05	2.57
	5.49-13.72	S-3	72.26	2.37
		S-4	35.00	2.66
		S-5	48.49	2.30
	13.72-16.76	S-6	21.66	2.47
BH-02	1.52-5.49	S-1	26.45	2.65
		S-2	25.23	2.52
	5.49-13.72	S-3	34.00	2.67
		S-4	40.00	2.66
		S-5	35.68	2.88
		S-6	28.57	2.36
	13.72-16.76	S-7	39.00	2.57
		S-8	20.79	2.66

3.2.3 Atterberg Limits

The obtained Atterberg limit values (liquid limit, plastic limit, plasticity index and liquidity index) are listed in Table 5 and their comparison and variations with NMC (%) and depth for both boreholes are shown in Figures 8 and 9. The liquid limit values range from 29.30 to 89.20%. The higher value at depth 5.49 to 13.72 m may be due to the presence of high organic matter. Fine clay soils containing significant amount of organic matter usually have high to very high liquid limits (Craig 1990).

Table 5. Atterberg consistency limit values of Kapasia clay soils

BH no.	Depth (m)	Sample no.	Atterberg consistency limit (%)			
			LL	PL	PI	LI
BH-01	(1.52-5.49)	S-1	39.20	20.48	18.72	0.63
		S-2	51.50	26.44	25.06	0.42
	(5.49-13.72)	S-3	89.20	52.54	36.66	0.54
		S-4	52.00	27.00	25.00	0.32
		S-5	76.70	40.34	36.36	0.22
	(13.72-16.76)	S-6	46.70	20.88	25.82	0.03
	Average		*59.22*	*31.28*	*27.94*	*0.36*
BH-02	(1.52-5.49)	S-1	33.30	24.08	9.22	0.26
		S-2	39.60	22.09	17.51	0.18
	(5.49-13.72)	S-3	56.00	28.00	28.00	0.21
		S-4	47.00	28.00	19.00	0.63
		S-5	49.95	25.19	24.76	0.42
		S-6	39.70	19.73	19.97	0.44
	(13.72-16.76)	S-7	56.00	29.00	27.00	0.15
		S-8	29.30	19.26	10.04	0.33
	Average		*43.86*	*24.42*	*19.44*	*0.37*

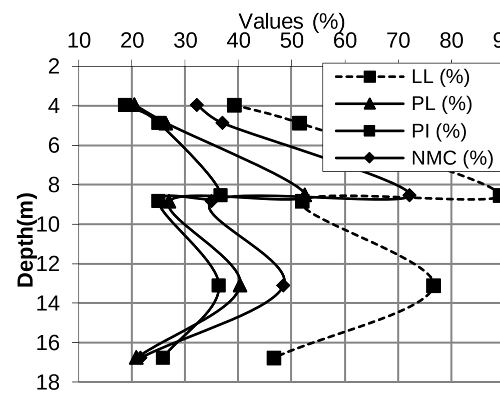

Figure 8. Variation of Atterberg consistency limit values and NMC (%) with respect to depth for BH-01 samples

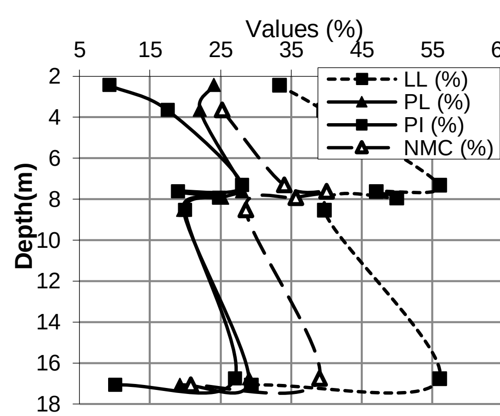

Figure 9. Variation of Atterberg consistency limit values and NMC (%) with respect to depth for BH-02 samples

Grim (1962) noted that the liquid limit (LL) values for pure montmorillonites varies from 119 to 700%, illites 29 to 100%, kaolinites 35 to 75% and illite-montmorillonite mixture 48 to 62%. According to Hough (1957), the liquid limit value of montmorillonite, illite and kaolinite range from 140 to 710%, 78 to 120% and 38 to 59% respectively. According to Grim (1962) and Hough (1957) the liquid limit values of Kapasia clay soil are closer to the typical values for montmorillonite, illite and kaolinite.

The plastic limit values (PL) range from 19.26 to 52.54%. The values are relatively higher at depth 5.49 to 13.72 m which may be due to the presence of high organic matter. White (1955) pointed out plastic limit values of montmorillonite, illite and kaolinite range from 51 to 97%, 34 to 43% and 26 to 38% respectively. Grim (1962) mentioned that plastic limit values vary from 48 to 97% for montmorillonite, 21 to 26% for illite, 30 to 37% for kaolinite and from 25 to 36% for mixtures of illite and montmorollonite. The obtained plastic limit values of Kapasia clay soils are closely related to the values reported by White (1955) and Grim (1962).

The obtained plasticity index (PI) values lie between 9.22 to 36.66% and the values are relatively higher at depth ranges from 5.49 to 13.72 m, which may be due to the presence of organic matter in this zone. According to Bell (2000) organic clays have medium to high plasticity index value. Hough (1957) noted that the plasticity index value for montmorillonite ranges from 70 to 650%, for illite 31 to 63% and for kaolinite 11 to 28%. Grim (1962) pointed out that montmorillonite, illite and kaolinite have plasticity index ranges from 75 to 600%, 23 to 50% and 1 to 10% respectively. The observed value of Kapasia clay soil also show consistency with the values quoted by Hough (1957) and Grim (1962) for kaolinitic and illitic soil.

The liquidity index (LI) value ranges from 0.03 to 0.63. If the water content is equal to the liquid limit, the liquidity index is 1.0. If the water content is greater or lower than the liquid limit, the liquidity index values are less than 1 (Grim 1962). The obtained values of the LI in each case are mainly less than 1.0.

3.2.4 Activity

The obtained activity value of Kapasia clay soils ranges from 0.68 to 1.58, with an average of 0.96 and are listed in Table 6.

Table 6. Activity values of the Kapasia clay soils

BH no.	Depth (m)	Sample no.	Activity (A_c)
BH-01	5.49-13.72m	S-1	1.58
		S-2	1.09
	13.72-16.76m	S-3	1.47
		S-4	1.03
BH-02	5.49-9.14m	S-1	1.00
		S-2	0.68
	10.67-16.19m	S-3	1.30
		S-4	1.05

Based on activity values, Skempton (1953) subdivided soils into five groups as follows: Group 1-Inactive with activity less than 0.5, Group 2: Inactive with activity 0.5 to 0.75, Group 3: Normal with activity 0.75 to 1.25, Group 4: Active with activity 1.25 to 2 and Group 5: Active with activity greater than 2. Head (1992) recommended some activity values for clay soils, which are as follows: inactive clays, <0.75; normal clays, 0.75 to 1.25; active clays, 1.25 to 2.00 and highly active clays >2. Rowe (2001) mentioned that the activity of a soil may be used as an indication of the type of clay present in the soil: kaolinite (low activity, 0.4), illite (intermediate activity, 0.9) and montmorillonite (high activity, Ca-montmorillonite, 1.5; Na-montmorillonite, 6.0). The obtained results suggest that except one sample, all the studied soil samples are normal to active in nature.

3.2.5 Linear Shrinkage

The obtained linear shrinkage values range between 1.78 to 14.71% which are presented in Table 7. The results are in well agreement with the linear shrinkage values of several authors (Haque and Hossain 2002 and Hobbs et al. 1982). The values increase up to a depth of 13.72 m and after that the values are decreased and a consistency is observed for both boreholes.

Table 7. Linear shrinkage values of Kapasia clay soils

Depth (m)	Sample no.	BH-01	BH-02
1.52-5.49	S-1	6.78%	1.78%
	S-2	9.50%	7.28%
5.49-13.72	S-3	13.27%	9.18%
	S-4	14.71%	10.93%
13.72-16.76	S-5	10.37%	3.78%

Altmeyer (1955) mentioned that clays with linear shrinkage <5% are "non-critical" in terms of volume change, 5% to 8% are "marginal" and value >8% are "critical". The obtained results suggest that the studied clay is considered as non-critical at shallow depths to critical at greater depths. The obtained linear shrinkage values are close to the typical values of illite & kaolinite minerals as quoted by White (1955).

3.3 Mineralogical Composition

The XRD analyses were conducted over some selected soil samples to identify and confirm the mineralogical composition as indicated by the limit values. The data revealed that the mineralogical composition of Kapasia clay soils is mainly dominated by quartz and feldspar with clay minerals such as kaolinite, illite/muscovite and some montmorillonite. The results are consistent with researches (Kamal et al. 2021) done on mineralogical composition of soil samples of Bangladesh. The XRD spectrum of the examined soil samples are shown in Figure 10.

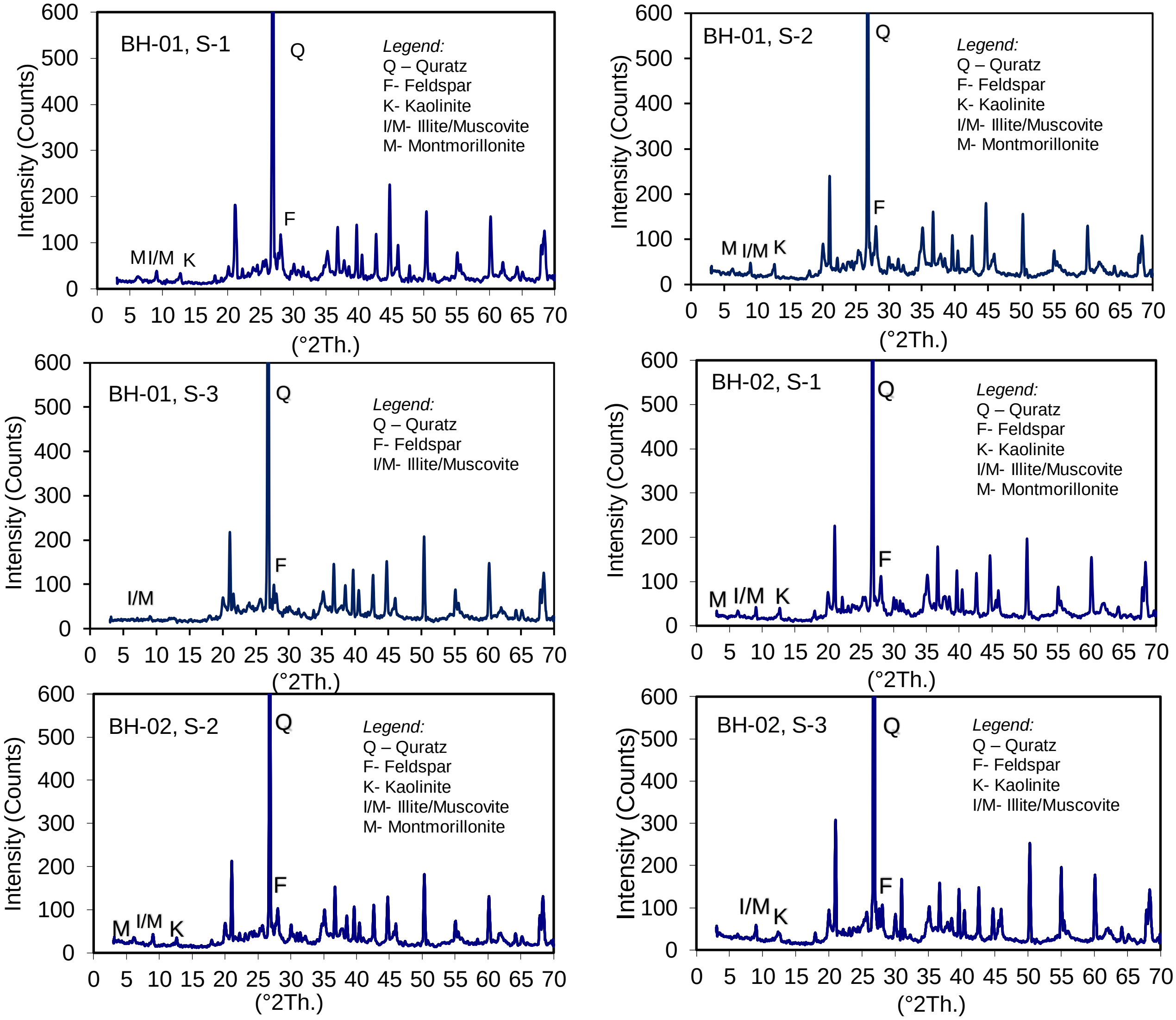

Figure 10. Mineralogical composition of Kapasia clay soils

3.4 Engineering Soil Classification of Kapasia Clay Soils

The obtained results of liquid limit and plasticity index are plotted in the standard plasticity chart (BS 5930, 1981) (Figure 11). Most of the samples lie above "A-line". Some samples lie below the line, which have high liquid limit values. The higher value at depth 5.49 to 13.72 m may be due to the presence of high organic matter. Craig (1990) mentioned that fine clay soils containing significant amount of organic matter usually have high to extremely high liquid limits and samples fall below the "A-line" as organic silt. According to British soil classification system, the Kapasia clay soils can be characterized as intermediate to high plasticity inorganic to organic silty clay and classified as CI to CH from their position on the plasticity chart.

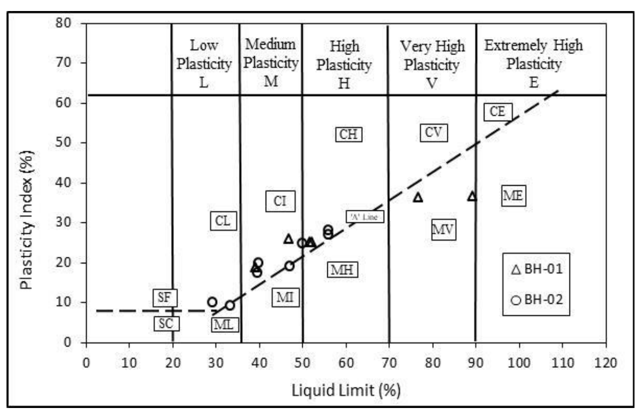

Figure 11. Engineering classification chart of Kapasia clay soils (*from* BS 5930 1981)

4 CONCLUSIONS

The microfabric study of the Kapasia clay revealed that the soil showed a random mixture of silt and clay with some intra and intergranular porespace. Clay particle matrices are binding agent. EDX spectra results showed the presence of Si, Fe, O, K and Ti.

Kapasia clay is silt dominated clay with some fine sand. Silt percentage varies from 63 to 67% and clay fraction varies from 19 to 28%. The moisture content values range from 20.79 to 72.26% and the specific gravity value mainly varies from 2.30 to 2.88. The higher values of moisture content and lower values of specific gravity between 5.49 to 13.72 m depth might be due to the presence of organic matter. The liquid limit, plastic limit and plasticity index values lie between 29 to 89%, 19.26 to 52.54% and 9.22 to 36.66% respectively. The higher limit values might be due to the presence of organic matter at medium depth. The obtained limit values suggest that the studied Kapasia soil can be characterized mainly as an intermediate to high plasticity inorganic to organic silty clay and classified as CI to CH according to their position on the soil plasticity chart.

The liquidity index value of Kapasia clay soil is low which ranges from 0.03 to 0.63. The activity values range from 0.68 to 1.58, suggesting normal to active nature of soils. The linear shrinkage values range from 1.78 to 14.71% which increases with increasing liquid limit, plastic limit and plasticity index values. The obtained values indicate that the Kapasia soils may be considered as "non-critical" at shallow depth to "critical" at greater depths.

All the analyzed values of engineering properties along with XRD results suggest the soil may be composed of illite, kaolinite and illite-montmorillonite mixture and the ground contain huge amount of organic matter at 5 - 14 m depths. Soil moisture content values (up to 72%) and liquid limit values are very high in this zone. High water holding capacity and the presence of high organic contents indicate the highly compressible nature of the soil and might be related with the subsidence occurred in the region. Therefore, the geotechnical engineers need to pay proper attention to build any heavy structures in this study area.

5 ACKNOWLEDGEMENTS

The authors would like to express their gratefulness to the authority of Kapasia Upazila, for giving the permission to conduct the field works and Department of Geological Sciences, Jahangirnagar University, Savar, Bangladesh Atomic Energy Commission, Dhaka and Bangladesh Council of Scientific & Industrial Research (BCSIR), Dhaka for their kind permission to use the laboratory facilities.

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