Chemistry, Mineralogy, and Geotechnical Properties of Bangkok Clayey Soils

Suksun Horpibulsuk[1], Runglawan Rachan[2] and Wanchai Katkan[3]
[1,3]School of Civil Engineering, Suranaree University of Technology
111 University Avenue, Muang District, Nakhon Ratchasima, 30000, Thailand
Tel. 044-22-4322, Fax. 044-22-4420
E-Mail: suksun@sut.ac.th
[2]Department of Civil Engineering, Mahanakorn University of Technology
51 Cheum-Sampan Rd., Nong Chok, Bangkok, 10530, Thailand
Tel. 02-988-3655 ext. 281 press 312, Fax. 02-988-3655 ext. 313
E-Mail: runglawa@civil.mut.ac.th

Abstract : From the X-ray diffraction and free swelling test, it is found that Bangkok clay is a non- swelling to low swelling soil in which the tendency of swelling increases with depth. The activity of the Bangkok clay is between 0.5 and 1.0 and it can be regarded as inactive to normal clay. Examination of chemistry in the pore fluid shows that the Na^+ concentration decreases with depth. This leads to the conclusion that the upper zone consists of marine clays deposited from a period during the advance of sea, while the deeper zone deposits under a lesser marine environment. The reduction in salinity with depth results in the tendency of an increase in sensitivity. Even though it is noted that the liquid and plasticity index of the Bangkok clay vary with depth and dependent upon sites, the values are collapsed into a small band above A-line of the plasticity chart, showing a unique relationship between *PI* and *LL*.

1. Introduction

Alluvial marine deposits with non-pyroclastic origins are found in many Southeast Asian countries. Bangkok clay is also a typical alluvial marine deposit with non-pyroclstic origins distributed in the Chao Phraya Plain of central Thailand. Numerous studies on the engineering properties of Bangkok clay have been conducted [e.g. 1 through 7]. However, investigations on the mineralogy and chemistry and their effect on the geotechnical properties of Bangkok clays are very limited and have not been well brought out. Cox [8] mentions that the presence of smectite in Bangkok clay would characterize the high liquid limit and activity of Bangkok clay. The liquid limit and remolded strength are both decreased by the reduction in pore water salinity [9]. The chemistry of the clay, including the pore water salinity and the exchangeable cation species, could play an important role in characterizing the geotechnical index properties. Ohtsubo et al. [10] have investigated the mineralogy and pore water chemistry of Bangkok clay and concluded that Bangkok clay profile consists of three zones. The middle zone is marine clay deposited from a period during the advance of sea, while the surface and the deeper zone are deposited under a lesser marine environment.

The present paper aims to analyze the mineralogy and chemistry of the Bangkok clayey soils. Their effects on the geotechnical properties, especially Atterberg's limits, field vane shear strength and sensitivity are finally illustrated.

2. Experimental Investigation

2.1 Investigation Sites

Bangkok clay samples were collected from two sites; namely, the campus of Asian Institute of Technology, Bangkok, and Bangpee district, Samutpakarn, Thailand for the present investigation. These two sites are selected to investigate the effect of different

RECEIVED 10 May, 2005
ACCEPTED 20 March, 2006

chemistry on geotechnical index properties. The sampler used was a fixed piston sampler whose diameter, length and thickness are 75 mm, 1,000 mm, and 1.5 mm, respectively. The sampling was carried out until the first sand layer was reached which is about 10 meters at AIT and 26 meters at Bangpee. Soil samples, kept in the sampling tubes, were transported to Suranaree University of Technology for testing. The physical and engineering properties are also compiled from boring logs around Bangkok, which are recorded by various consultant companies in Thailand.

2.2 Field Vane Shear Test

A penetration type of the vane shear test without a borehole was used at both sites. The vane used was 13 cm in height and 6.5 cm in diameter. Sleeved torque rods were used to eliminate friction between the vane rod and the subsoils. The vane was withdrawn into a protective shoe to avoid damage during penetration. It was inserted 30 cm further into the ground at the test depth. The shear test was run immediately after insertion of the vane with the rotation speed about 6 degrees/minute. Remolded shear strength was measured after 15 rotations of the vane. The field vane shear strength presented in this paper is uncorrected value since it is used to determine the sensitivity, which is irrespective of correction factor.

2.3 Laboratory Test

The analyses have been carried out on the intact soil specimens. Basic index and engineering properties were determined at Suranaree University of Technology, according to the American Society for Testing and Materials (ASTM) standards. Physicochemical tests included organic matter content, pH and cation and anion concentration in the pore water (the extracted solution) measured by ion chromatography. To obtain the extracted solution, distilled water was added to the soil sample so as to adjust the solid concentration of 10% by weight. The soil suspensions were shaken for 1 hour followed by centrifugation and filtration.

X-ray diffraction analyses were performed with a Bruker diffractometer. Analysis was carried out on oriented mounts at 100°C heat. The test results are interpreted based on Bragg' law. The scanning electronic photographs of Bangkok clay are taken from freeze-dried samples at various depths.

3. Test Results

3.1 Chemistry and Mineralogy

The chemistry of the Bangkok clay profile at AIT and Bangpee are presented in Figures 1 and 2. At AIT, the Na^+ concentration is between 0.01 and 0.03 mol/L, which is much smaller than that of sea water. The concentration of K^+, Ca^{2+}, and Mg^{2+} are less than 0.003 mol/L. The pH is between 7 and 8.5 and the organic matter obtained from Ignition loss test is between 8 and 10. For Bangpee, the Na^+ concentration decreases with depth. This shows the effect of leaching of salt with depth. Its value is about 0.60 mol/L near the ground surface and reduces to 0.2 mol/L at 26 m depth (the end of borehole). This is high compared to that of AIT site probably due to the site being closer to the sea. The concentration of K^+, Ca^{2+} and Mg^{2+} also decreases with depth. K^+, Ca^{2+}, and Mg^{2+} vary from 0.05 to 0.03 mol/L, from 0.0003 to 0.004 mol/L, from 0.005 to 0,04 mol/L, respectively. These values are close to those of sea water [11]. This confirms that the upper zone consists of marine clays deposited from a period during the advance of sea, while the deeper zone deposits under a lesser marine environment.

Figures 3 and 4 show the XRD patterns of the clay at AIT (depths of 3.0 and 6.0 meters) and at Bangpee (depths of 12.0 and 22.0 meters). It is found that Bangkok clay at AIT consists mainly of quartz and followed by montmorillonite. According to the free swelling test proposed by Prakash and Sridharan [12], the free swelling ratio, FSR (the ratio of equilibrium sediment volume of 10-g-oven dried soil passing a 425μm sieve in distilled water to that in carbon tetra chloride) increases with depth ranging between 1.0 and 1.5, as shown in Figure 5 and Table 2.

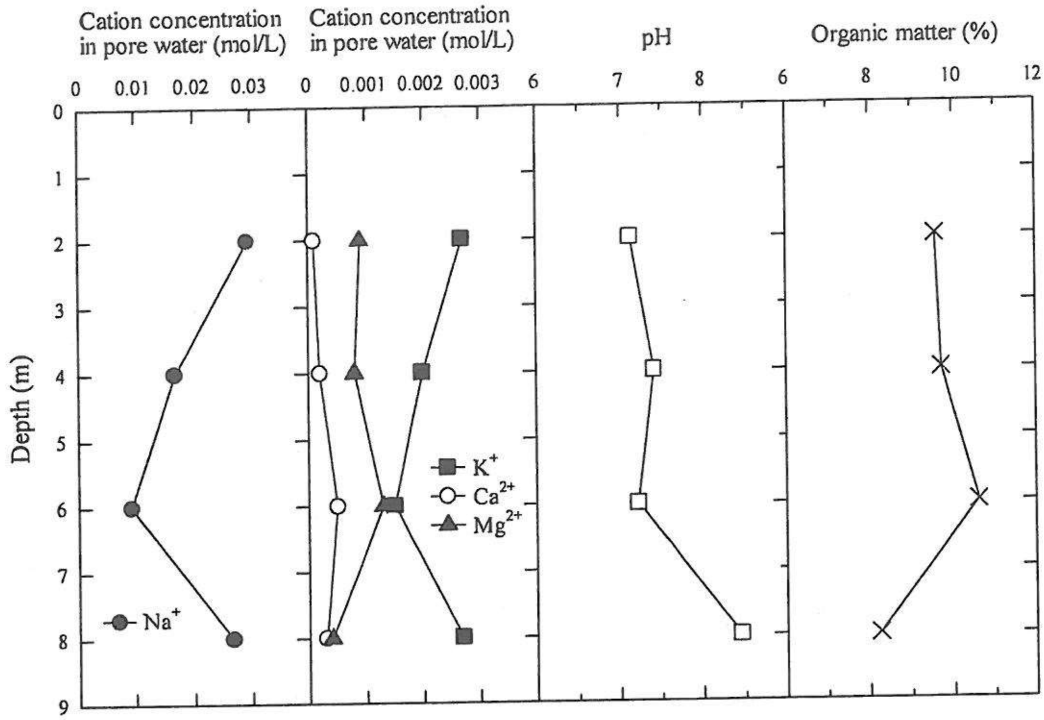

Figure 1 Pore water chemistry of Bangkok clay profile at AIT.

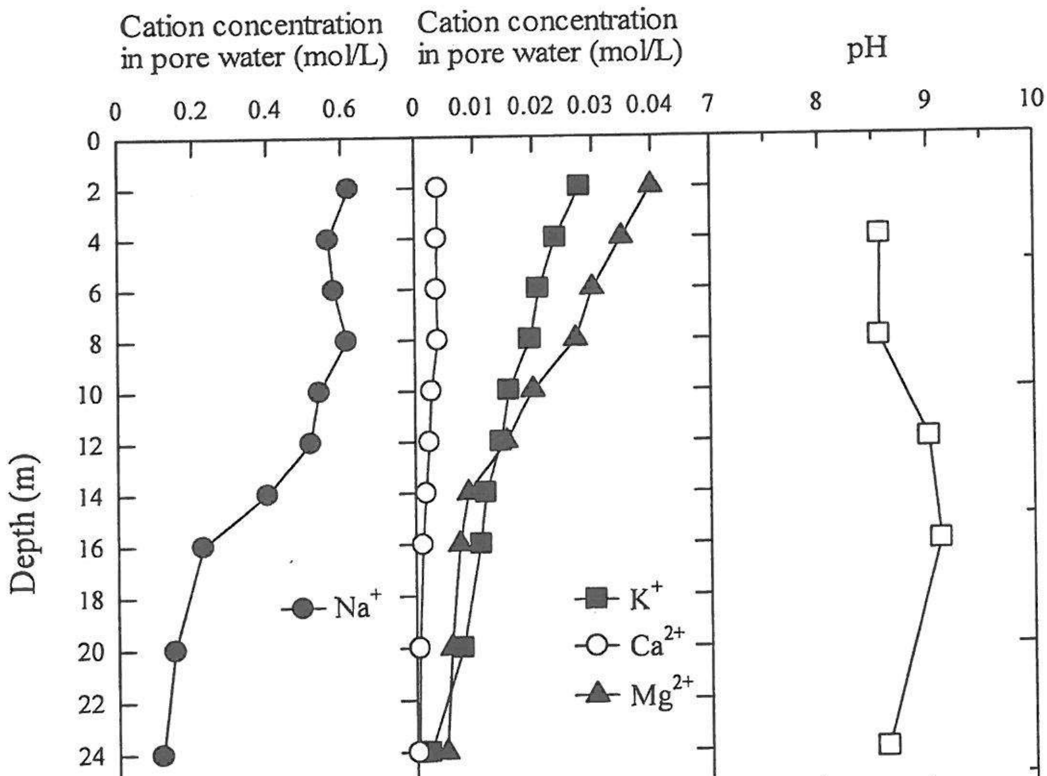

Figure 2 Pore water chemistry of Bangkok clay profile at Bangpee.

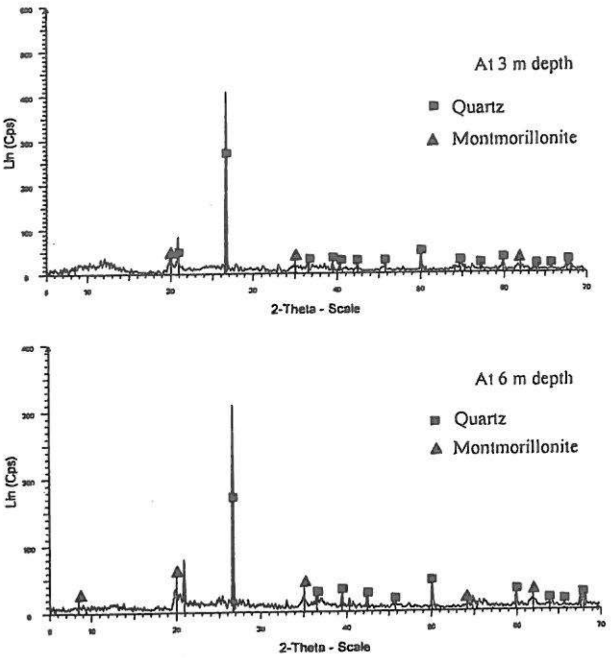

Figure 3 X-ray diffraction patterns of Bangkok clay at AIT.

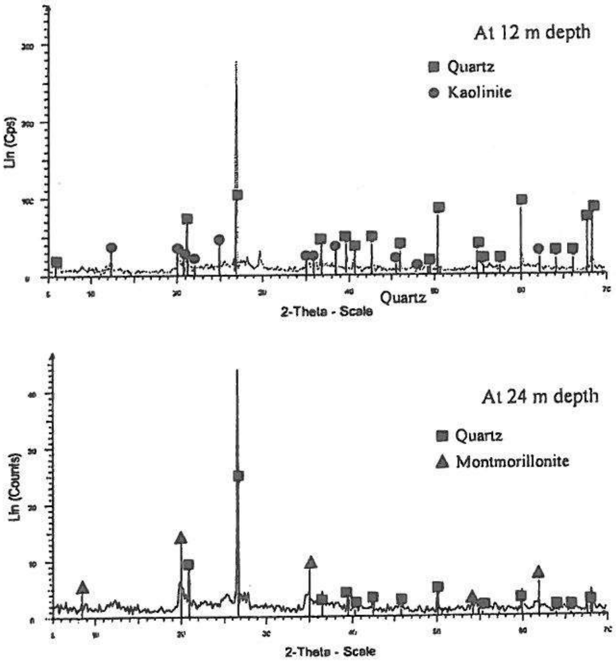

Figure 4 X-ray diffraction patterns of Bangkok clay at Bangpee.

The soil is classified as low swelling type even though the XRD pattern shows the existence of motmorillonite. This is probably due to the large amount of quartz. For Bangpee, the soil consists of quartz, kaolinite, and montmorillonite. Amount of montmorillonite increases with depth (*vide* Figure 4). The XRD patterns are consistent with the result of free swelling test (Figure 5 and Table 3). The predominant clay mineral at depths of 3 to 17 meters (soft to stiff clay) is kaolinite and classified as non-swelling type. Whereas the dominant clay mineral at 19 to 25 m depths is montmorillonite followed by kaolinite (*vide* XRD pattern) and the FSR is between 1.15 and 1.70, hence the clay is classified as low swelling type. The increase of the FSR with depth for both sites is realized, leading to the conclusion that the amount of montmorillonite increases with depth, hence the potential of swelling increases with depth. Since the Bangkok clayey soil is non to low swelling type, the activity of the clay is low being between 0.5 and 1.0, as shown in Figure 6. This figure shows the activity of Bangkok clay compared with that of other clays (collected from Tanaka et al. [13]). It is shown that except Ariake and Bothkennar clays, the activity of Bangkok clay and others are in the same range and the clays are classified as inactive to normal clay.

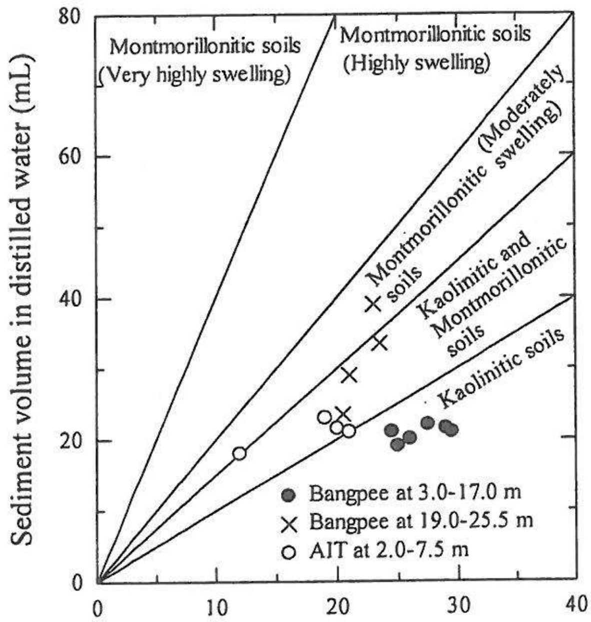

Figure 5 Classification of soils as swelling and non-swelling types according to Prakash and Sridharan [12].

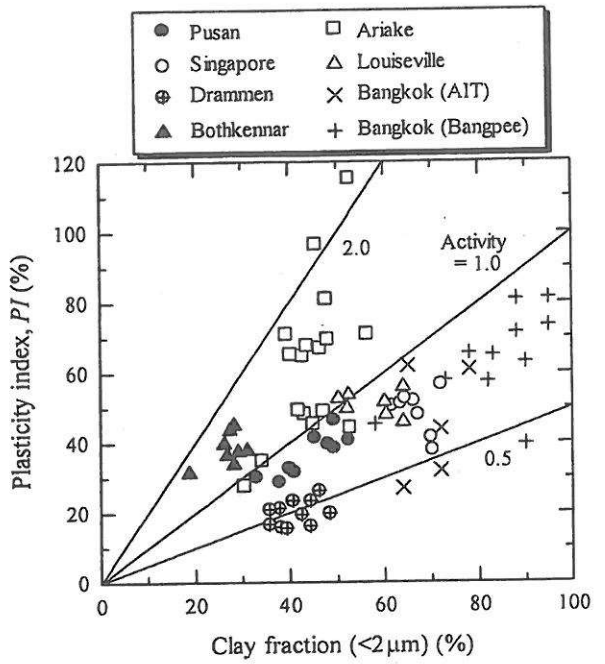

Figure 6 Activity of Bangkok clay compared with other clays.

Table 2 Sediment volume of the <2 μm clay fractions at AIT.

Depth (m)	Sediment volume (mL/10gm)		
	in distilled water (a)	in CCl_4 (b)	FSR Ratio (a/b)
2.0-2.5	21.50	20.00	1.07
3.0-3.5	21.00	21.00	1.00
6.0-6.5	23.00	19.00	1.21
7.0-7.5	18.00	12.00	1.50

Table 3 Sediment volume of the <2 μm clay fractions at Bangpee.

Depth (m)	Sediment volume (mL/10gm)		
	in distilled water (a)	in CCl_4 (b)	FSR Ratio (a/b)
3.0-3.5	21.00	24.50	0.86
5.0-5.5	22.00	27.50	0.80
7.5-8.0	21.00	29.50	0.71
9.0-9.5	21.50	29.00	0.74
12.0-12.5	20.00	26.00	0.77
15.0-15.5	19.00	25.00	0.76
16.5-17.0	42.50	55.00	0.77
19.5-20.0	33.50	23.50	1.43
21.0-21.5	23.50	20.50	1.15
22.5-23.0	29.00	21.00	1.38
25.0-25.5	39.00	23.00	1.70

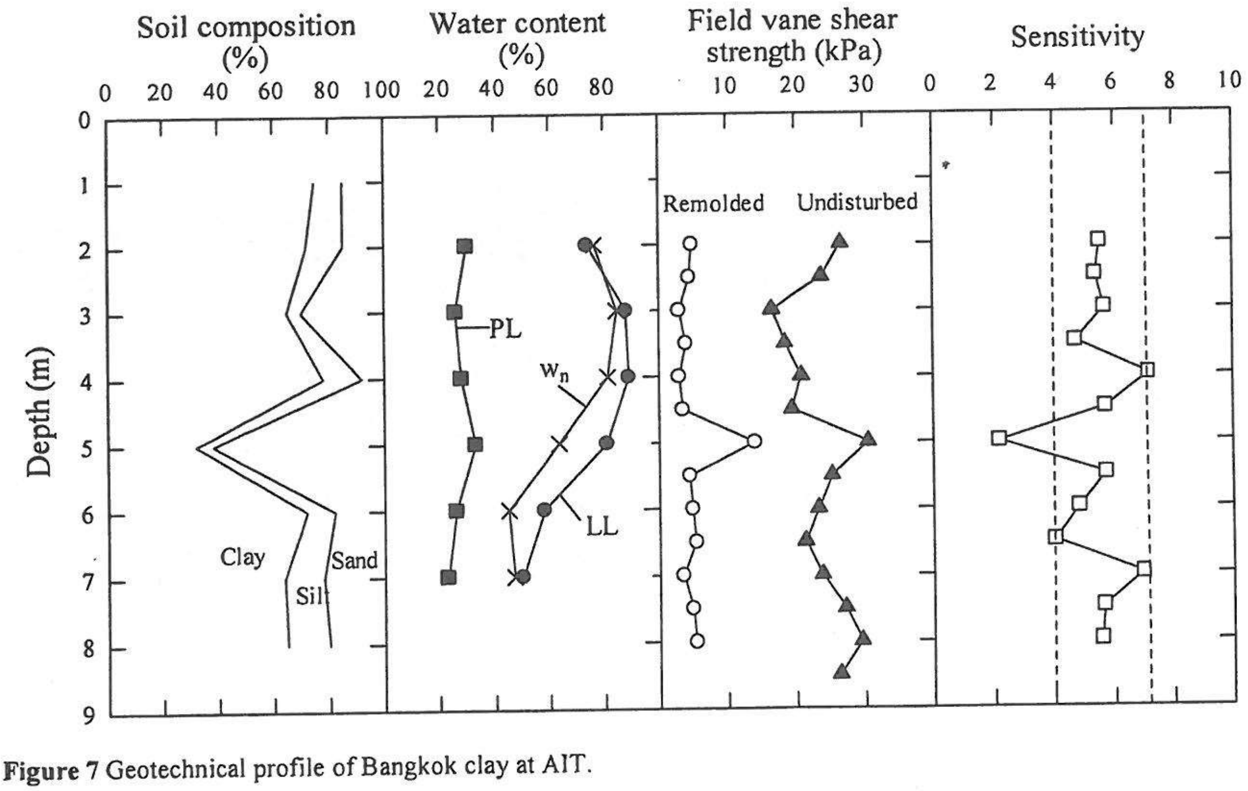

Figure 7 Geotechnical profile of Bangkok clay at AIT.

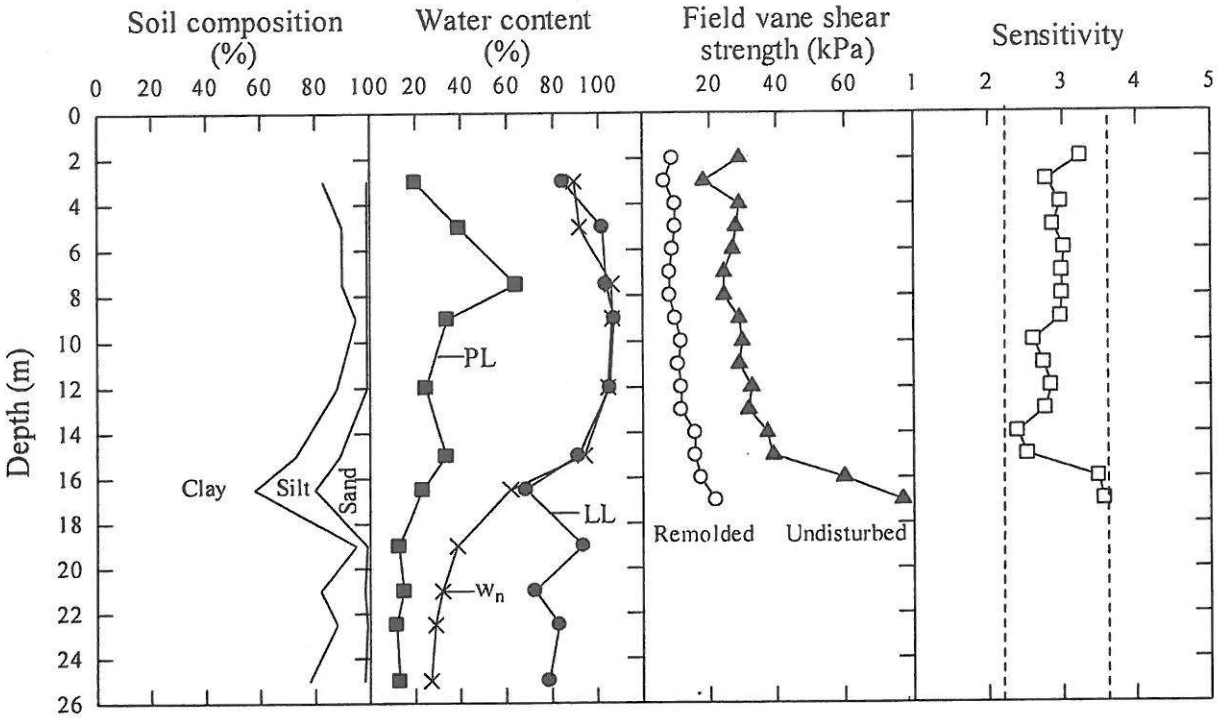

Figure 8 Geotechnical profile of Bangkok clay at Bangpee.

3.2 Geotechnical Characteristics

The geotechnical properties of Bangkok clay profiles at AIT and Bangpee are presented in Figures 7 and 8. The liquid limit is in the range of 60% to 95% for AIT and 80% to 110% for Bangpee. For both sites, the natural water content is close to the liquid limit (Liquidity index is about 1.0) near the ground surface, and decreases with depth. For Bangpee, the water content starts to reduce at the depth of about 15 meters, which divides soft and medium stiff clays. As such the fabric of these two clay layers would be different. The pore space is smaller and the clay cluster is larger for medium stiff clay layer. Hence the strength is higher. This change of the clay fabric is clearly shown in Figures 9 and 10, which are the scanning electron photographs of the Bangkok clay sample from Bangpee at the depths of 7 and 17 meters.

The tendency of the decrease of liquid limit with depth might be due to the reduction in pore water salinity. This response is the typical of non swelling soil in which the fabric towards flocculation and the liquid limit increases with the increase in the concentration [14 and 15]. Even though the liquid and plastic limits vary with depth and sites due to the difference of clay minerals and pore fluid, the (*PI*, *LL*) points of Bangkok clays at various depths lie above the A-line in the plasticity chart, as shown in Figure 11.

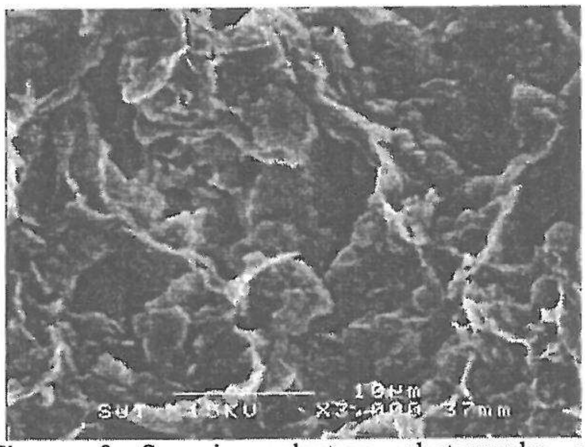

Figure 9 Scanning electron photographs of Bangkok clay samples from 7 m depth.

It is indicated that the plasticity index of soils bears a functional relationship with the liquid limit. The relationship between the plasticity index and liquid limit of Bangkok clayey soils takes the linear form:

$$PI = 0.79(LL - 13) \quad (1)$$

with a correlation coefficient of 0.97.

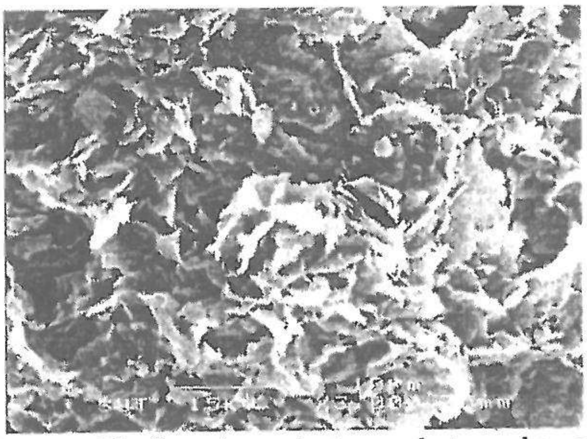

Figure 10 Scanning electron photographs of Bangkok clay samples from 17 m depth.

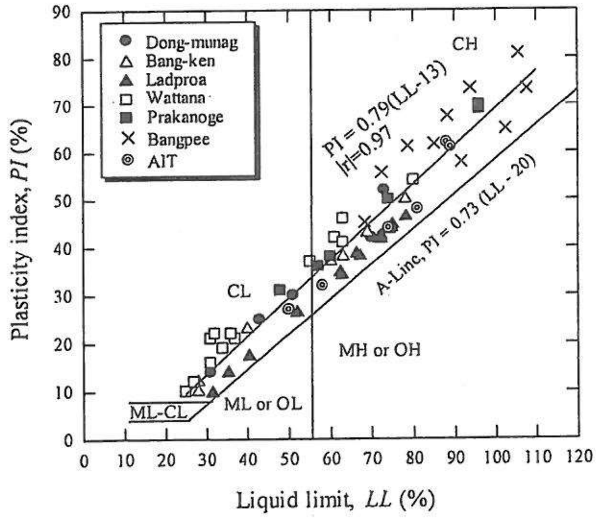

Figure 11 Plasticity index versus liquid limit of Bangkok clayey soils.

The role of Na^+ concentration on the sensitivity of the Bangkok clay is also found in Figures 7 and 8. At AIT, since the Na^+ concentration is very low (0.01-0.03 mol/L) (*vide* Figure 1), the sensitivity of the clay is quite high in the order of 4 to 7. The strength at the depth of 5 meters is higher than that at other depths since the soil is composed of higher amount of sand particles; hence, lowest sensitivity. Whereas at Bangpee, due to very high value of Na^+ concentration (0.4-0.6 mol/L) at surface to 15 m depth, close to that of sea water, sensitivity is low about 2.2 and 3.2. Below 15 m depth, the sensitivity tends to increase due to the reduction in Na^+ concentration. It can thus be concluded that the higher the Na^+ concentration, the lower the sensitivity. This conclusion is in agreement with that reported by Skempton and Northey [16] and Bjerrum [17].

4. Conclusions

This paper deals with the analysis of mineralogy and chemistry of Bangkok clayey soils and the study of their effect on the geotechnical characteristics. The conclusion can be drawn as follows.

1. Bangkok clay is composed mainly of quartz, with the main clay minerals of kaolinite and montmorillonite. The amount of montmorillonite increases with depth, hence the swelling tends to increase with depth. The large component of quartz results in low value of the free swell ratio and activity. The clay is classified as non to low swelling type.
2. Since Bangkok clay is non to low swelling clay, its activity is low ranging from 0.5 to 1.0. It is thus regarded as inactive and normal clay.
3. Na^+ concentration significantly influences the sensitivity. Even though the concentration is different for both tested sites, it decreases with depth due to the leaching of salt. As such the sensitivity of the medium stiff clay (lower zone) is higher than that of soft clay (upper zone).
4. The liquid limit and plasticity index of Bangkok clay vary with depths and sites due to the difference in clay mineral and pore medium chemistry. However, the (*PL*, *LL*) relationship shows a unique relationship, lying above the A-line in plasticity chart.

5. Acknowledgement

The authors would like to acknowledge the funding provided by the Thailand Research Fund (TRF) under the contract No.

MRG4780195. The authors are indebted to Ms. Chanchira Ruchirawan, scientist, Suranaree University of Technology for technical assistance.

References

[1] C. Muktabhant, "Bangkok soils", Proc. of Conference on Architecture and Structural Engineering in Relation to the Construction of Large Building, Bangkok, Thailand, 1973, pp.223.

[2] J.B. Cox, "Geotechnical characteristic of soil along the Thon Buri-Pak Tho Highway, Thailand", Proceedings of 4th Asian Regional Conference on Soil Mechanics and Foundation Engineering, Bangkok, Thailand, 1971, pp.249-255.

[3] C.C. Ladd, Z.C. Moh, and D.G. Gifford, "Undrained strength of soft Bangkok clay", Proceedings of 4th Asian Regional Conference on Soil Mechanics and Foundation Engineering, Bangkok, Thailand, 1971, pp.135-140.

[4] A.S. Balasubramaniam, "Stress history effect on the stress-strain behaviour of a saturated clay", Geotechincal Engineering Journal, Vol.4, 1973, pp. 91-111.

[5] S.K. Kim, T.H. Seah, and A.S. Balasubramaniam, "Formulation stress strain behavior inside the stress boundary surface", Proceedings of 13th International Conference on Soil Mechanics and Foundation Engineering, India, Vol.1, 1994, pp.51-56.

[6] O. Suzuki, "Measure of soft ground and irrigation, drainage and reclamination engineering-a review of the engineering characteristics of soft Bangkok clay", Journal of Japan Society of Irrigation, Drainage and Reclamination Engineering, Vol.63, No.9, 1995, pp.71-77 (in Japanese).

[7] S. Horpibulsuk, and R. Rachan, "Novel approach for analyzing compressibility and permeability characteristics of Bangkok clayey soils", Proceedings of 15th Southeast Asian Geotechnical Engineering Conference, Bangkok, Thailand, 2004, pp.3-8.

[8] J.B. Cox, "A review of the geotechnical characteristics of the recent marine clay in Southeast Asia", Asian Institute of Technology Research Report, Vol.6, 1968.

[9] K. Egashira and M. Ohtsubo, "Swelling and mineralogy of smectites in paddy soils derived from marine alluvium, Japan", *Geoderma*, Vol.29, 1983, pp.119-127.

[10] M. Ohtsubo, K. Egashira, T. Koumoto, and D.T. Bergado, "Mineralogy and chemistry, and their correlation with the geotechnical index properties of Bangkok clay: comparison with Ariake clay", Soils and Foundations, Vol.40, No.1, 2000, pp.11-21.

[11] H.U. Sverdrup, M.W. Johnson, and R.H. Fleming, The Oceans, their Physics, Chemistry and General Biology, New York: Prentice-Hill, 1942.

[12] K. Prakash, and A. Sridharan, "Free swell ratio and clay mineralogy of fine-grained soils, Geotechnical Testing Journal, ASTM. Vol.27, No.2, 2004, pp.220-225.

[13] T. Tanaka, O. Mishima, M. Tanaka, S.Z. Park, G.H.. Jeong, and J. Locat, "Characterization of Yangsan clay, Pusan, Korea", Soils and Foundations, Vol.41, No.2, 2001, pp.89-104.

[14] A. Sridharan, S.M. Rao, and N.S. Murthy, "Liquid limit of montmorillonite soils", Geotechnical Testing Journal, ASTM, Vol.9, No.3, 1986, pp.156-159.

[15] A. Sridharan, S.M. Rao, and N.S. Murthy, "Liquid limit of kaolinitic soils", Geotechnique, Vol.38, No.2, 1988, pp.191-198.

[16] A.W. Skempton, and R.D. Northey, "The sensitivity of clays", Geotechnique, Vol.3, 1953, pp.30-53.

[17] L. Bjerrum, "Problem of soil mechanics and construction on soft clays and structurally unstable soils", Proceedings of 8th International Conference on Soil Mechanics and Foundation Engineering, Moscow, Vol.3, 1973, pp.111-159.