Geological Society of Malaysia Annual Geological Conference 2001
June 2–3 2001, Pangkor Island, Perak Darul Ridzuan, Malaysia

Physico-chemical properties of carbonaceous shale soils in the Yong Peng area, Johor

TAN BOON KONG AND AZWARI HUSLAN MOHD

Program Geologi, Fakulti Sains & Teknologi
Universiti Kebangsaan Malaysia,
43600 Bangi, Selangor

Abstract: Residual soils of carbonaceous shale in the Yong Peng area have been analysed for their physico-chemical properties. Results indicate that the carbonaceous shale soils are characterised by their predominantly silty nature, low plasticities, generally low compacted densities, highly acidic pore fluids (low pH's), and intermediate dispersivity behaviour. These results indicate similarities in soil properties to graphitic schist soils found in the Melaka and Rawang areas.

Abstrak: Sifat-sifat fiziko-kimia tanah baki syal berkarbon di kawasan Yong Peng telah diuji. Hasil kajian menunjukkan bahawa tanah baki tersebut dicirikan oleh sifat berlodak, keplastikan rendah, ketumpatan pemadatan rendah, air liang berasid tinggi (pH rendah), dan sifat dispersif perantaraan. Hasil ini menunjukkan kesamaan dalam sifat tanah syal berkarbon berbanding tanah syis grafit di kawasan seperti Melaka dan Rawang.

INTRODUCTION

Residual soils of carbonaceous shales are of a rather wide occurrence in Johor and they are notorious as problematic soils in numerous civil or geotechnical works. Cut slopes in carbonaceous shale soils associated with highways, urban development schemes, as well as fill-ground employing carbonaceous shale soils have experienced problems such as slope failures and ground settlement. Some actual incidences of these problems have been encountered previously along parts of the North-South Expressway near the Yong Peng and Air Hitam areas.

As part of a systematic programme of study on the various types of residual soils in Peninsular Malaysia, a study on the physico-chemical and mineralogical properties of the carbonaceous shale soils in the Yong Peng area was completed recently (Azwari Huslan Mohd, 2001). This paper presents a summary of the results of this recent study.

MATERIALS AND METHODS

A total of 10 soil samples (SYH1 to SYH10) were taken from cut slopes in carbonaceous shale soils in the Yong Peng area. The cut slopes sampled were mainly along parts of the North-South Expressway in the vicinity of Yong Peng, as well as in housing development schemes in the area. The carbonaceous shale soils are easily recognised by their black or dark grey colours.

As most samples were taken from shallow depths below the ground surface, they are generally of weathering grade VI (Residual Soils) (Little, 1969). A few deeper samples may represent weathering grade V (Completely Weathered) materials. For simplicity of discussions, however, the materials are not differentiated in terms of weathering grades in this paper. For the interested reader, further reference can be made in the thesis by Azwari Huslan Mohd (2001).

The physical properties tested are: natural water content, specific gravity, grain size distribution, Atterberg limits and compaction characteristics. The chemical properties studied involve the pore fluids chemistry, namely pH, conductivity, pore fluid soluble cation and anion contents.

The test methods adopted are in accordance with the British Standards BS1377 (BSI, 1975) and the Geotechnical Research Centre (GRC) Laboratory Manual (GRC, 1985). Pore fluids of the soil samples were extracted using the "Saturation Extract" method involving vacuum suction (GRC, 1985).

As the method of preparation of the soil samples prior to testing has an effect on the index properties and compaction characteristics of lateritic or tropical residual soils, (eg. Moh and Mazhar, 1969; Brand and Hongsnoi, 1969), all samples were tested after air-drying in the laboratory.

RESULTS AND DISCUSSIONS

Results for the physico-chemical properties of the carbonaceous shale soils are summarised in Tables 1 and 2. Figures 1 to 5 provide some illustrations of some of the physico-chemical properties. Some discussions of the physico-chemical properties are provided below.

Physical Properties

Water Content (Wo) — Natural water contents are generally low, ranging from 8 – 26%. The low water content

Table 1: Physical properties of carbonaceous shale soils (SYH).

			Atterberg Limits				Grain Size Distribution				Compaction Characteristics	
	Wo (%)	Gs	LL (%)	PL (%)	PI (%)	Plasticity Symbol	G (%)	S (%)	M (%)	C (%)	γdmax (g/cm³)	Wopt (%)
SYH1	25.22	2.64	56	30	26	CH	1	11	66	22	1.65	16.4
SYH2	17.03	2.66	35	14	21	CI	2	16	63	19	1.57	15.6
SYH3	7.98	2.67	51	42	9	MH	0	.19	70	11	1.73	15.5
SYH4	12.62	2.59	30	26	4	ML	0	3	65	32	1.60	12.8
SYH5	10.01	2.62	31	16	15	CL	0	4	72	24	1.66	13.0
SYH6	17.19	2.65	37	31	6	MI	6	35	47	12	1.62	14.5
SYH7	25.79	2.62	46	17	29	CI	8	27	54	11	1.67	11.0
SYH8	10.95	2.64	59	24	35	CH	4	17	59	20	1.69	15.5
SYH9	25.93	2.66	45	33	12	MI	5	17	53	25	1.70	14.4
SYH10	25.93	2.63	28	20	8	CL	0	5	66	29	1.66	16.3

Table 2: Pore fluid chemistry of carbonaceous shale soils (SYH).

	pH	Conductivity	Na^+		K^+		Mg^{2+}		Ca^{2+}		SO_4^{2-}	Cl^-	SAR	Monovalent/
		ms/cm	ppm	Meq/l	ppm	Meq/l	ppm	Meq/l	ppm	Meq/l	ppm	ppm		Divalent
SYH1	1.64	2.880	5.98	0.26	3.58	0.09	0.10	0.008	0.06	0.003	352	1.0	3.51	59.75
SYH2	2.14	1.830	9.44	0.41	7.27	0.19	0.18	0.015	0.04	0.002	330	7.0	4.45	75.95
SYH3	3.65	0.920	9.44	0.41	10.45	0.27	0.18	0.015	0.75	0.037	300	7.5	2.54	21.39
SYH4	2.26	1.540	8.88	0.39	9.88	0.25	0.18	0.015	0.64	0.032	260	7.5	2.54	22.89
SYH5	1.88	1.870	7.67	0.33	9.55	0.24	0.18	0.015	0.33	0.016	210	8.0	2.65	33.76
SYH6	1.36	5.860	5.18	0.23	1.27	0.03	0.09	0.007	0.06	0.003	588	1.5	3.25	43.00
SYH7	1.52	4.570	4.28	0.21	0.90	0.02	0.09	0.007	0.06	0.003	378	1.5	2.97	38.13
SYH8	1.48	4.230	6.44	0.28	3.99	0.10	0.16	0.013	0.22	0.011	482	6.5	2.56	27.45
SYH9	1.56	5.200	7.96	0.35	4.22	0.11	0.16	0.013	0.44	0.022	396	7.0	2.65	20.30
SYH10	1.33	3.340	8.82	0.38	5.66	0.14	0.27	0.022	0.39	0.019	466	8.0	2.65	21.94

is related to the low clay contents of the soils, thus low adsorption or retention of soil moisture.

Specific Gravity (Gs) — Gs values are mostly centred around 2.6, with minor variations.

Grain Size Distribution — Since the residual soils are developed from fine-grained rocks (shale), the particle size distributions are dominated by fine-grained components with silt predominating over clay-size particles. Silt contents range from 47 to 72%, while clay contents range from 11 to 32 %. The coarse fractions (gravel + sand) are generally greater than 20%. However, the presence of vein quartz and lateritic bands in the parent rocks can contribute to significantly high amounts of sand- and gravel-sized particles in the carbonaceous shale soils, such as in samples SYH6 and SYH7. Nonetheless, in carbonaceous shale soils devoid of vein quartz and lateritic bands, silt predominates. In the previous studies on graphitic schist soils in the Melaka and Rawang areas, the silt contents are high with values of about 98 % and 70 % respectively (Tan, 1992; Tai, 1999; Tan and Tai, 1999; Tan and Zulhaimi, 2000). Figure 1 shows the grain size distribution curves for the carbonaceous shale soils studied, indicating high fines contents as mentioned.

Atterberg Limits — Being predominantly silty soils, the plasticities are low. Liquid limits range from 28 to 59%, with the majority of the values being below 50%. Plasticity Index values show a broad range from 4 to 35%. Figure 2 shows the data plotted as mostly CL- ML soils, ie. clays and silts with low plasticities. Note also that the natural water contents mostly fall below the PL and LL values, as is generally the case for residual soils. The low plasticities are in part due to the predominantly kaolinitic nature of the clay minerals in the soils, as confirmed from XRD analyses (Azwari Huslan Mohd, 2001).

Compaction Characteristics — Silty soils in general cannot be compacted properly and will yield low compacted densities. The values for the compacted maximum dry densities show a consistent range from about 1.6 g/cm³ to about 1.7 g/cm³. Most values, however, are low, i.e. less than 1.7 g/cm³, as would be expected from the silty nature of the carbonaceous shale soils. Optimum moisture contents also vary within a narrow band of about 11 to 16%. It would appear from the data obtained (see also Table 1) that the influence of the amount of coarse fractions (gravel + sand) on the compacted densities is not significant in this case.

The rather high carbon contents of the carbonaceous shale soils is yet another factor contributing to the low

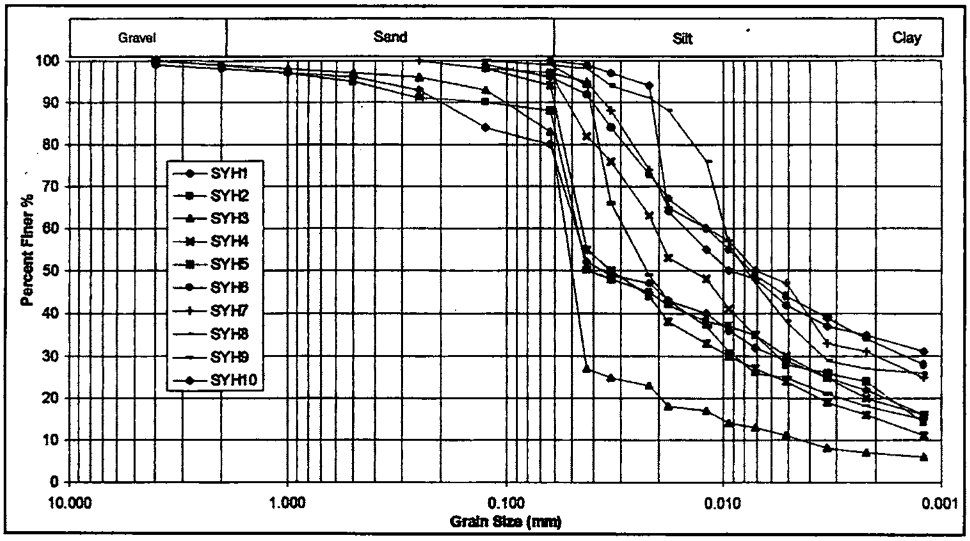

Figure 1. Grain size distribution curves.

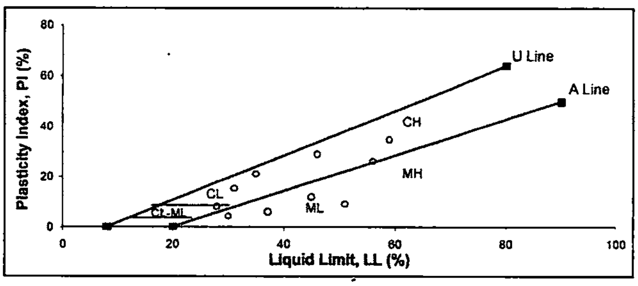

Figure 2. Plasticity chart.

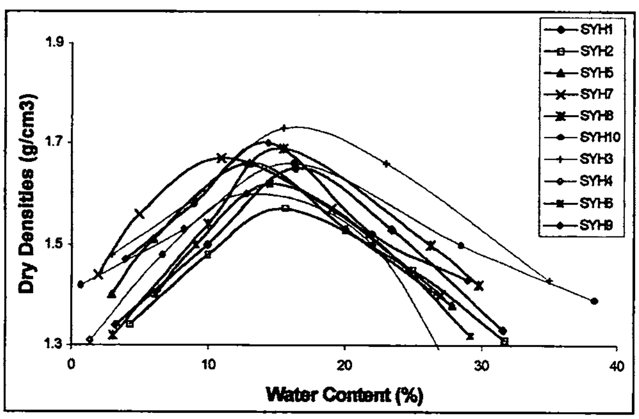

Figure 3. Compaction characteristics.

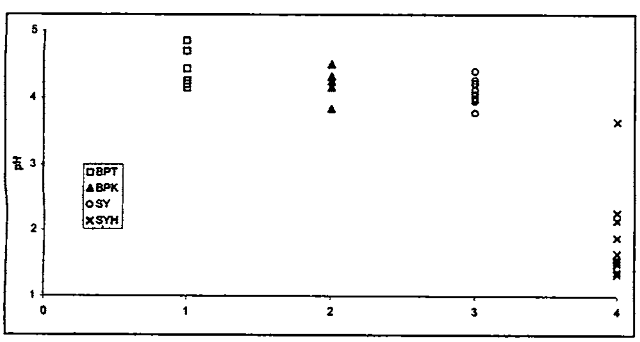

Figure 4. pH of pore fluids. SYH is residual soil from carbonaceous or black shale. BPT and BPK are residual soils from sandstones, while SY is residual soil from non-carbonaceous shale.

compacted densities of these soils. Thus, carbonaceous shale soils are poor candidates for use in fill embankments, and in fact have given rise to problems in highway embankments as mentioned previously. Figure 3 shows the compaction curves of the soil samples tested, all of which are centred around a narrow or close range of maximum dry densities and optimum moisture contents.

Pore Fluids Chemistry

pH — pH is a measure of the acidity of the pore fluids. The carbonaceous shale soils are characterised by highly acidic pore fluids, with pH values ranging from 1.33- 3.65, with the majority of values being < 2. The cause of the high acidity of the carbonaceous shale soils is well known, even to the highway or geotechnical engineers. Carbonaceous shales, as is also the case for graphitic schists, contain a high amount of pyrite, which on exposure to the elements undergoes oxidation and hydrolysis reactions producing sulphuric acid and iron oxides/hydroxides. Typical chemical reactions area as follows:

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$$
$$4FeSO_4 + O_2 + 2H_2SO_4 = 2Fe_2(SO_4)_3 + 2H_2O$$
$$Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 3H_2SO_4$$

The practical implications of these chemical reactions are: failures in turfing of cut slopes due to highly acidic soils, staining (brown/red) of concrete pavements and drains due to the iron oxides/hydroxides released from the reactions, swelling and disintegration of the soil structure (hence severe drop in soil shear strength) due to the reactions and further formations of other secondary minerals. Corrosion of steel reinforcements in concrete structures located in close proximity to the carbonaceous shale soils is also possible. Thus, the acidity of the carbonaceous shale soils affect engineering works in a direct manner, in particular the stability of the cut slopes.

Figure 4 shows the very low (mostly <2) pH values of carbonaceous shale soils in comparison to some other soil types in the Yong Peng area.

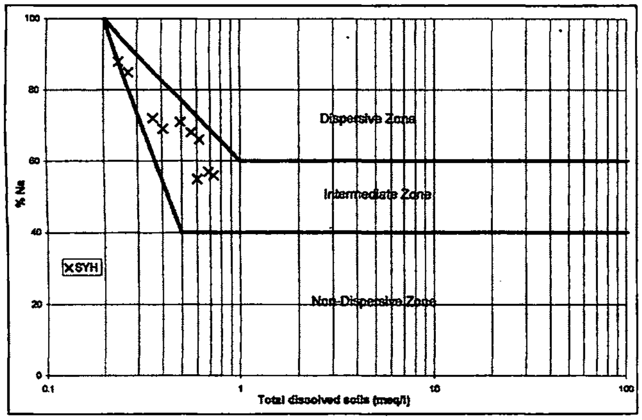

Figure 5. Dispersitivity plot (Sherard *et al.*, 1976).

Conductivity — Conductivity is a measure of the total cations content in the pore fluids. The values obtained range from 0.92 to 5.86 mS/cm. In comparison to other soil types such as granitic, quartz-mica schist and basaltic soils (Tan, 1996, 2000), these conductivity values are very much higher. The highest value of 5.86 mS/cm corresponds to a low pH value of 1.36, while the lowest value of 0.92 mS/cm corresponds to the highest pH value of 3.65. These indicate, as to be expected, that the more aggressive the soil (lower pH), the greater the amount of cations that are leached/dissolved from the soil. The higher H^+ content of the acidic soils would, of course, also contribute to the higher conductivity values.

Soluble Cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) — The soluble cations are dominated by Na^+, with the general order of abundance as follows: $Na^+ > K^+ >> Ca^{2+} > Mg^{2+}$. The predominance of the monovalent cations ($Na^+ + K^+$) over the divalent cations ($Ca^{2+} + Mg^{2+}$) is also shown by the values for the monovalent/divalent ratios which range from about 20 to 76. Predominance of monovalent cations, in particular Na^+, can contribute to the dispersivity of the soil. In addition, the values for the sodium adsorption ratio (SAR), also show mostly >2 (range from 2.54 to 4.45), also indicating the dispersive nature of the carbonaceous shale soils. Figure 5 shows the Sherard's plot for dispersivity of soils (Sherard *et al.*, 1976), and the data indicate the intermediate dispersivity nature of the carbonaceous shale soils. However, the authors would like to caution that these conclusions are based solely on pore fluids chemistry alone. Further supporting tests, such as the pin-hole test may be necessary.

Soluble Anions (SO_4^{2-}, Cl^-) — The anions are dominated by the SO_4^{2-} as expected, with values reaching as high as 600 ppm. The SO_4^{2-} is a direct product of the oxidation/hydrolysis of the pyrite, thus a direct correlation with the pH of the soil as well. High SO_4^{2-} corresponds to low pH and vice versa.

Cl^- contents are comparatively low, ranging from about 1 to 8 ppm.

CONCLUSIONS

A detailed study on the physico-chemical properties of a soil is essential in understanding the behaviour of the soil. The carbonaceous shale soils are characterised by a silty nature, low plasticities, low compacted densities; highly acidic/low pH and intermediate dispersivity nature. The physico-chemical properties, coupled with the clay mineralogy, would dictate the behaviour of the soil and hence its contribution to stability or problems in engineering works.

REFERENCES

AZWARI HUSLAN MOHD, 2001. *Sifat fiziko-kimia dan mineralogi lempung tanah baki sekitar bandar Yong Peng, Johor.* B.Sc. (Hons) thesis, Program Geologi, FST, UKM. 55 p.

BSI (BRITISH STANDARDS INSTITUTION), 1975. *BS 1377: Methods of test for soils for civil engineering purposes.* British Standards Institution, London.

BRAND, E.W. AND HONGSNOI M, 1969. Effects of method of preparation on compaction and strength characteristics of lateritic soils. *Proc. Specialty Session on Engineering Properties of Lateritic Soils, 7th Int. Conf. on Soil Mechanics & Foundation Engineering, Mexico City,* vol. 1:107-116.

GRC (GEOTECHNICAL RESEARCH CENTRE), 1985. *Laboratory Manual,* GRC, McGill University, Montreal, Canada (unpublished).

LITTLE, A.L., 1969. The engineering classification of residual tropical soils. *Proc. Specialty Session on Engineering Properties of Lateritic Soils, 7th Int. Conf. on Soil Mechanics & Foundation Engineering, Mexico City,* vol. 1:1-10.

MOH, Z.C. AND MAZHAR, M.F., 1969. Effects of method of preparation on index properties of lateritic soils. *Proc. Specialty Session on Engineering Properties of Lateritic Soils, 7th Int. Conf. on Soil Mechanics & Foundation Engineering, Mexico City,* vol. 1: 109-120.

SHERARD, J.L., DUNNIGAN, L.P. AND DECKER, R.S., 1976. Identification and nature of dispersive soils. *ASCE J. Geotech. Eng. Div.*,102(GT4):287-301.

TAI, T.O., 1999. *Sifat fiziko-kimia dan mineralogi tanah sekitar Kota Melaka.* B.Sc. (Hons.) thesis, Dept. of Geology, FSFG, UKM, 84 pp.

TAN, B.K., 1992. A survey of slope failures along the Senawang-Air Keroh Highway, Negri Sembilan/Melaka, Malaysia. *Proc. 6th Int. Symposium on Landslides, 10-14 Feb., 1992, Christchurch,* 1423-1427.

TAN, B.K., 1996. Physico-chemical properties of some granitic soils from Peninsular Malaysia. *Proc. 12th SE Asian Geotechnical Conf., 6-10 May, 1996, Kuala Lumpur,* vol. 1:595-600.

TAN, B.K., 2000. Physico-chemical properties of some residual soils in Peninsular Malaysia. *Proc. GeoEng 2000: Int. Conf. On Geol. & Geotech. Engnr., Nov. 19-24, 2000, Melbourne.*

TAN, B.K. AND TAI, T.O., 1999. Physico-chemical properties of graphitic schist soils from Malacca, Peninsular Malaysia. *Proc. 2nd Asian Symp. on Engineering Geology & Environment, IAEG/IGM, 23-25 Sept., 1999, Bangi,* 2-8 to 2-10 (Abstract).

TAN, B.K. AND ZULHAIMI ABDUL RAHMAN, 2000. Physico-chemical properties of graphitic schist soils in the Rawang area, Selangor. *Proc. GSM Annual Conf. 2000, Sept. 8-9, 2000, Pulau Pinang,* p. 283-286.