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INFLUENCE OF CEMENT – SODIUM SILICATE GROUT ADMIXED WITH CALCIUM CHLORIDE AND KAOLINITE ON SAPRIC PEAT

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Abstract. Sapric peat is extremely soft, unconsolidated and has high organic content. It is most decomposed peat with less fiber content among all peats. This paper investigates the effectiveness of using different ratios of cement–sodium silicate system grout compounds with kaolinite in mechanical property (shear strength) and micro–structural properties (SEM and EDX) of sapric peat samples after 3 and 30 days of curing. The study showed that the kaolinite was effective in increasing the shear strength and reducing the moisture content of the treated peat. Calcium chloride seemed to have different effects on the grouts strength. It caused to increased shear strength of samples until the net charge of the sample changed to zero and then it decreased with further increase in calcium chloride. By increasing sodium silicate (within 3%), cement and soaking time on treated peat, it was observed that they are able to increase the shear strength and density with a corresponding decrease in moisture content, porous microstructure, and the multitude of voids of confection.

Keywords: peat, calcium chloride, kaolinite, sodium silicate, shear strength, microstructure.

1. Introduction

Peat is defined as a naturally occurring highly organic substance derived primarily from plant materials. Peat formation occurs when the rate of accumulation of organic material is greater than the rate of decomposition. The wide variations in peat happen from the type of plants whose residues contribute to peat formation, and from the environmental conditions in which decomposition takes place. It occurs when organic matter is preserved below a high water table, as in swamps or wetlands. The terms peat and organic soils, used for describing soils with an organic content, were once synonymous but the term organic soils is presently used for superficial deposits or soils that contain organic matter (Huat 2004). From a geotechnical engineer view point, a material with organic content greater than 20% is known as organic soil. Peat is an organic material with organic content more than 75% and is composed largely of vegetation including trees, grasses, mosses, fungi, and various organic remains including insects and animals (Kazemian *et al.* 2011a, b). von Post (1922) stated 10 degrees of humification (H_1–H_{10}) for peat classification based on botanical composition, degree of humification and color of squeezed peat water. According to the American society for testing and materials (ASTM 2008), standard peat classification has been narrowed to three classes: (i) fibric (fibrous; least decomposed with fiber content of more than 67%), (ii)

hemic (semi–fibrous; intermediate decomposed), and (iii) sapric (amorphous; most decomposed with fiber content of less than 33%). The cell structure of sapric peat particles are still visible and are the product of biochemical decomposition and breakdown of fibrous peat and other plant remains. Sapric peat deposits are more likely to include a significant amount of inorganic matter and colloids (Mesri and Ajlouni 2007).

Kruyt (1952), Adamson (1982) and Kwak *et al.* (1986) reported that solid-liquid or liquid-liquid interfaces can acquire an electrical charge through (i) preferential adsorption of ions at the interface, and (ii) the existence of an inherent excess charge in the dispersed phase. The development of a net charge at the particle surface affects the distribution of ions in the surrounding interfacial region, resulting in an increased concentration of counter ions and ions of opposite charge to that of the particle close to the surface. Thus an electrical double layer exists round each particle which is called diffuse double layer.

The diffuse double layer occurs at the interface between the active surface and the soil solution. It is because of the permanent negative charge of the active part of peat (clay and colloid parts) and the cations or counter-ions in the soil solution that balance the negative charge. The counter-ions are influenced by two equal but opposing forces – the electrical force attracting the positive ion to the negative surface, and the diffusive or thermal forces (responsible for Brownian motion) which tend to move

the cations away from the surface. The balance of these two forces gives rise to a distribution of cations in water adjacent to the active surface. This distribution, described as a diffuse electrical double layer or simply diffuse double layer, is made up of the negative active surface and the spread-out (diffuse) distribution of the counte-ions (Moayedi *et al.* 2011; Nova 1999).

The diffuse double layer, cation exchange capacity (CEC) and the charge distribution in the fluid adjacent to soil surface play key roles in determining the flow. An important characteristic of peats is their high cation CEC, which is defined as the degree to which a soil can adsorb and exchange cations or the quantity of negative charges in soil existing on the surfaces of clay and organic matter. CEC is highly dependent upon soil texture and organic content. The CEC range of soils with a high fibrous content is less than the CEC range of soils with a low fibrous content. It is reported as milli-equivalents per 100 grams of solid (meq/100 g).

Volarovich and Churaev (1968) classified water in peat to three parts: (i) mechanically entrained, (ii) capillary water, and (iii) chemically bound water; of which the chemically bound water is around 30–50% of total weight of peat and water, and it does not influence the energetic of its removal (Kwak *et al.* 1986).

Peat deposits are found throughout the world and constitute 5–8% of the earth's land surface. Two-thirds of the world coverage of tropical peat is in South East Asia. In US, peat is found in 42 states, with total area of 30 million hectares. Canada and Russia are two countries with the largest area of peat, 170 and 150 million hectares, respectively. The total tropical peat land in the world amounts to about 30 million hectares. In terms of economic development, this means that engineers have to build constructions in less favorable areas, on soils of high compressibility and low shear strength.

Grouting and chemical grouting technologies have grown and owed its separation as one of the ground improvement techniques in geotechnical engineering practice over the last few decades. For many years, the term chemical grouts was synonymous with sodium silicate grouts but in the last three decades a lot of chemical compounds were produced as chemical grouts which provide a wide selection for grouting (Shroff and Dhananjay 1999). Sodium silicates have been developed into a variety of different grout systems. These systems consist of sodium silicate and a reactor/accelerator (e.g. calcium chloride) which can be compatible with cement to get strong bonding properties in two-compound system, and that sodium silicate and the reactant solution with cement can be injected in two steps separately. Two compound system has been used in grouting below a water table and produces a high-strength, permanent grout if not allowed to dry out (Clarke 1984; Karol 2003; Shroff and Dhananjay 1999; USACE 1995).

Karol (2003) explained that when sodium silicate solution and an appropriate solution of alkali metals salt (sodium and potassium) are mixed; the reaction forming a gel is virtually instantaneous. If the silicate solution has not been moved away (by groundwater or gravitational

forces), it is penetrated by thin fingers and lenses of chloride solution. Because the reaction is so rapid, not all the solutions can reach contact, but the unstable interface generally ensures that sufficient contact occurs to provide a continuous gel network through stabilized soil. Sodium silicate grouts offer specifics advantages for soil stabilization: (i) Reliable and proven performance, (ii) Safety and ease of use, (iii) Environmental acceptability and compatibility, and (iv) Adaptability over a wide range of applications (Karol 2003; PQ Corporation 2003).

The microstructure of a material has interdependence with physical and mechanical properties, such as water retention, compressive and tensile strength, Young's modulus and Poisson's ratio (Gleize *et al.* 2003). Malhotra and Mehta (1996) and Taylor (1997) have classified three types of C–S–H morphologies of Portland cement mortars based on their configuration: fibrous-acicular form (type I), reticule or honeycomb form (type II) and denser-almost spheres form (type III). The explanation of these micro-structural changes has been attributed to the chemistry of these sodium silicate-cement and additives system.

This paper is devoted to the influence of different ratio of calcium chloride, kaolinite on cement-sodium silicate grout in improving the shear strength and microstructural of sapric peat by carrying out vane shear test and measuring the moisture content of the samples. Thin slices of air-dried samples were observed several times after soaking for 3 or 30 days and investigating the micro-structural changes to further validate the results obtained from the tests.

2. Materials and Methodology

2.1. Materials

2.1.1. Peat

Sapric peat was collected from different locations in Kampung Jawa, Kelang, southwest of Kuala Lumpur, Malaysia. The physic-chemical properties of sapric peat are presented in Table 1.

2.1.2. Cement

Ordinary Portland cement (hereinafter called cement) used in this study (as first binding agent) was obtained from Anuza Enterprise Company, Serdang, Malaysia. The composition of cement, as reported by the manufacturer, was CaO (65.6%), SiO_2 (21%), Al_2O_3 (5.3%), Fe_2O_3 (3.3%), SO_3 (2.7%), MgO (1.1%), Na_2O (1%) and the loss on ignition was 0.9%.

2.1.3. Kaolinite

Kaolinite $[Al_2Si_2O_5(OH)_4]$ structure is composed of silicate sheets (Si_2O_5) bonded to aluminum oxide/hydroxide layers $[Al_2(OH)_4]$ called gibbsite layers. It consisted predominantly of SiO_2 (45.8%) and Al_2O_3 (39.55%), as detailed in the properties sheet supplied by the manufacturer. It was sourced from Kaolin Sdn. Bhd. factory in Puchong, Malaysia.

Table 1. Physico–chemical characteristics of untreated peat

Parameters	Method	Sapric peat
Moisture content (%)	BS 1377: Part 2: 1990, Clause 3	198.2
Liquid limit (%)	BS 1377: Part 2: 1990, Clause 4.3	231.8
Specific gravity	BS 1377: Part 2: 1990, Clause 8.4	1.38
Organic content (%)	BS 1377: Part 3: 1990, Clause 4	77.31
Fiber content (%)	ASTM D 1997–91	28.3
Bulk density (kN/m^3)	BS 1377: Part 2: 1990, Clause 7	10.78
Shear strength of undisturbed peat (kPa)	BS 1377: Part 7: 1990, Clause 3	9.0
pH	BS 1377: Part 3: 1990, Clause 9	5.45
Degree of humification (%)	von Post (1922)	H_9
Cation exchange capacity, CEC (meq/100g)	Gillman and Sumpter (1986)	85
Surface area (m^2/g)	BET technique (Brunauer *et al.* 1938)	98

2.1.4. Sodium silicate and calcium chloride

Hydrous sodium silicate, a syrupy liquid, was used as the second binding agent. It consisted of SiO_2 (28.7%), Na_2O (8.9%) and the silica ratio (SiO_2/Na_2O) was 3.22. The density was 1.38 Mg/m^3 and pH was 11.3, as reported by the manufacture. Calcium chloride ($CaCl_2$), an anhydrous powder, was used as a reactor/accelerator. It behaves as a typical ionic halide, and is solid at room temperature. It can serve as a source of calcium ions in a solution as, unlike many other calcium compounds, calcium chloride is soluble. Sodium silicate and calcium chloride were obtained from Merck Sdn. Bhd., Petaling Jaya, and Bendosen Company, Selangor, Malaysia respectively.

2.2. Methodology

2.2.1. Sample preparation

In order to investigate the influence of cement-sodium silicate grout with calcium chloride and kaolinite on sapric peat, different quantities of calcium chloride (0.5 mol/L), kaolinite, sodium silicate and cement were admixed with specific amounts of sapric peat as shown in Table 2. For preparing the samples, sapric peat was first thoroughly homogenized at its natural water content by household mixer and then desired amount of kaolinite, calcium chloride, cement and sodium silicate were added to it. Three samples were prepared according to the percent weight of wet peat and as per the ratio of additives (Table 2). The confection was then transferred to a cylin-

drical container, kept in a tray, for curing. Vane shear tests were performed on the samples at the end of 3 and 30 days of curing. It should be noted that the accuracy of shear strength values higher than 125 kPa is limited because this represents the upper limit of accuracy of this testing apparatus. This implies that values higher than 125 kPa must be considered only for indicating how the samples are comparable together. In the second step of sample preparation, the samples were carefully cut with a sharp knife, after 3 and 30 days of curing, to make about 3–5 mm long sticks and were frozen immediately in nitrogen slush at – 210 °C. While still frozen, the specimens were broken into small size and put into vacuum desiccators. Finally, they were coated with a thin layer of gold-platinum for performing SEM and EDX analyses.

2.2.2. Experimental methods

Physical properties of natural peat were determined and the parameters evaluated are; organic content, water content, liquid limit and specific gravity in accordance with BS 1377-3 (1990) and BS 1377-2 (1990) respectively. The bulk unit weight, pH and fiber content were specified based on test procedures according to BS 1377-2 (1990), BS 1377-3 (1990) and ASTM D 1997-91 (2008) respectively. Further, von Post scale was used to find the degree of humification (von Post 1922), CEC based on Gillman and Sumpter (1986) and surface area was determined based on BET technique (Brunauer *et al.* 1938).

Table 2. Different concentrations of compounds used for samples and grout formulae with notations

Grout Formula (%)	Grout Formula (%)	Grout Formula (%)	Grout Formula (%)	Grout Formula (%)
20K 30Na 0Ca 20Ce	30K 30Na 0Ca 20Ce	20K 20Na 0Ca 20Ce	30K 0Na 2Ca 20Ce	20K 50Na 1Ca 20Ce
20K 30Na 1Ca 20Ce	30K 30Na 1Ca 20Ce	20K 20Na 1Ca 20Ce	30K 10Na 2Ca 20Ce	30K 20Na 1Ca 20Ce
20K 30Na 2Ca 20Ce	30K 30Na 2Ca 20Ce	20K 20Na 2Ca 20Ce	30K 50Na 2Ca 20Ce	20K 50Na 2Ca 10Ce
20K 30Na 4Ca 20Ce	30K 30Na 4Ca 20Ce	20K 20Na 4Ca 20Ce	30K 20Na 2Ca 20Ce	20K 30Na 2Ca 10Ce
20K 30Na 6Ca 20Ce	30K 30Na 6Ca 20Ce	20K 20Na 6Ca 20Ce	30K 30Na 2Ca 0Ce	20K 10Na 1Ca 20Ce
0K 20Na 1Ca 20Ce	0K 30Na 1Ca 20Ce	0K 30Na 2Ca 20Ce	20K 0Na 2Ca 20Ce	20K 20Na 2Ca 0Ce
10K 20Na 1Ca 20Ce	10K 30Na 1Ca 20Ce	10K 30Na 2Ca 20Ce	20K 10Na 2Ca 20Ce	30K 50Na 2Ca 40Ce
20K 30Na 2Ca 30Ce	20K 20Na 2Ca 30Ce	30K 30Na 2Ca 30Ce	20K 50Na 2Ca 20Ce	30K 30Na 2Ca 40Ce
40K 20Na 1Ca 20Ce	40K 30Na 1Ca 20Ce	40K 30Na 2Ca 20Ce	20K 50Na 2Ca 40Ce	30K 30Na 2Ca 40Ce
20K 0Na 1Ca 20Ce	30K 30Na 2Ca 10Ce	20K 30Na 2Ca 40Ce		

K: Kaolinite, Na: Sodium silicate, Ca: Calcium chloride, and Ce: Cement

The effectiveness of calcium chloride, kaolinite, sodium silicate, and cement were evaluated by measuring the undrained shear strength according to BS 1377-7 (1990) and by micro-structural changes from SEM and EDX results.

3. Results and Discussion

3.1. Influence of kaolinite

The effect of kaolinite on samples was investigated by preparing different samples based on grout Nos 1 and 2 (Table 3). In Table 3, the different grouts are arranged according to increasing compound ratio (grout Nos 1–8). The grout Nos I to V were used for micro-structural studies (figures in the parenthesis are days of curing). The grout Nos 1 and 2 consist of different amounts of kaolinite (0, 10, 20, 30 and 40% by weight of wet peat) to the same amounts of other additives.

For samples (with grout Nos 1 and 2) after 30 days of curing (Figs 1 and 2), the shear strength is observed to increase by increasing the kaolinite percentage, but the moisture content is found to decrease. For grout No. 1 (Fig. 1), the shear strength increased from 8.32 to 102.9 kPa of curing. Furthermore, the moisture content decreased from 233.5 to 125.1% for the same curing time. The trend of variations in shear strength and moisture content for the samples for the grout No. 2 (Fig. 2) was similar to grout No. 1 as seen in Fig. 2. Similar trends were observed for samples after 3 and 30 days as well.

Kaolinite has different effects on the confection. Stevenson (1994) reported that humic substance (organic parts of sapric peat) connect with mineral fraction in the following ways: (i) action of acids on minerals or salts of minerals, (ii) salt of humic substance with alkaline cations, (iii) chelate with metal ions, and (iv) as substances held on clay mineral surfaces (van der Waals force, bonding by cation bridge, and H–bonding).

The increase in shear strength tallies well with the fact that, by adding kaolinite and calcium chloride, the adsorption of organic compounds will have increased and calcium chloride might have caused a bridge or connection (mentioned above) between organic compound and the mineral part of sapric peat and kaolinite.
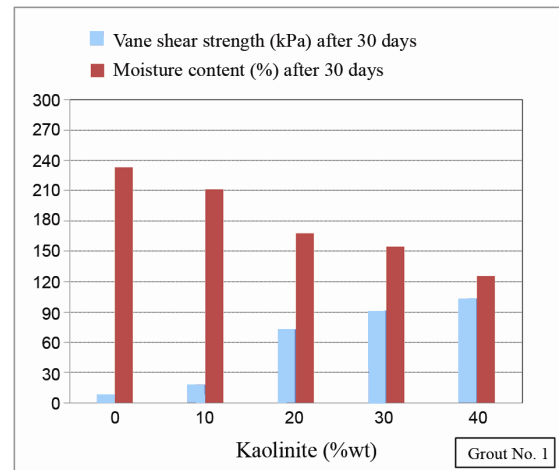

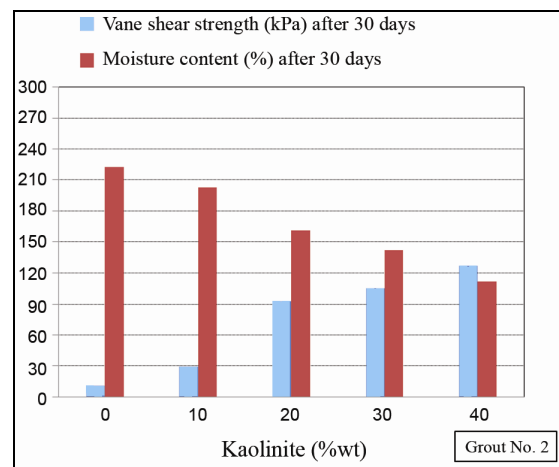**Fig. 1.** Influence of kaolinite concentration for grout No. 1

Fig. 2. Influence of kaolinite concentration for grout No. 2

Table 3. Grout formulae with their notations and grout numbers

Grout No.	Grout Formula (%)	Grout No.	Grout Formula (%)	Grout No.	Grout Formula (%)	
1	0K 2Na 1Ca 20Ce	2	0K 3Na 1Ca 20Ce	3	20K 3Na 0Ca 20Ce	
	10K 2Na 1Ca 20Ce		10K 3Na 1Ca 20Ce		20K 3Na 1Ca 20Ce	
	20K 2Na 1Ca 20Ce		20K 3Na 1Ca 20Ce		20K 3Na 2Ca 20Ce	
	30K 2Na 1Ca 20Ce		30K 3Na 1Ca 20Ce		20K 3Na 4Ca 20Ce	
	40K 2Na 1Ca 20Ce		40K 3Na 1Ca 20Ce		20K 3Na 6Ca 20Ce	
4	30K 3Na 0Ca 20Ce	5	30K 0Na 2Ca 20Ce	6	20K 0Na 2Ca 20Ce	
	30K 3Na 1Ca 20Ce		30K 1Na 2Ca 20Ce		20K 1Na 2Ca 20Ce	
	30K 3Na 2Ca 20Ce		30K 2Na 2Ca 20Ce		20K 2Na 2Ca 20Ce	
	30K 3Na 4Ca 20Ce		30K 3Na 2Ca 20Ce		20K 3Na 2Ca 20Ce	
	30K 3Na 6Ca 20Ce		30K 5Na 2Ca 20Ce		20K 5Na 2Ca 20Ce	
7	30K 3Na 2Ca 0Ce	8	20K 2Na 2Ca 0Ce	I	20K 3Na 2Ca 40Ce	(30)
	30K 3Na 2Ca 10Ce		20K 2Na 2Ca 10Ce	II	30K 3Na 2Ca 40Ce	(30)
	30K 3Na 2Ca 20Ce		20K 2Na 2Ca 20Ce	III	20K 1Na 2Ca 10Ce	(3)
	30K 3Na 2Ca 30Ce		20K 2Na 2Ca 30Ce	IV	20K 1Na 2Ca 10Ce	(30)
K: Kaolinite, Na: Sodium silicate, Ca: Calcium chloride, and Ce: Cement				V	20K 3Na 2Ca 10Ce	(30)

The last effect of mineral part of sapric and kaolinite in the samples are the reactions between mineral part of peat, cement (pozzolanic reactions) and sodium silicate which will be discussed later, and leads to an increase in the shear strength and a decrease in the moisture content.

The SEM micrograph showing the microstructure of untreated peat is shown in Fig. 3, which has a lot of mesopores and macropores, and for samples prepared as per grout Nos I to V, are presented in Figs 4, 5, 6, 7, and 14. The results of EDX analysis are presented in Table 4 and Fig. 15.

In addition, the influence of kaolinite and soaking time on micro-structural changes of the samples were investigated by preparing two samples with different amounts of kaolinite (grout Nos I and II) and one sample with different soaking time (grout Nos III and IV) as shown in Table 3. It is observed from the SEM micrographs (Figs 4 and 5) that there is a marked reduction in the porosity of sample with grout No. II and an apparent reduction in the size of the voids, probably due to the formation of C–S–H gel (type III). This is due to an increase in the mineral part of peat; they linked continuously with sodium silicate gel and C–S–H gel accompanied by the reactions that linked kaolinite with others, thus contributing to a stronger filling effect of cement and sodium silicate in grout No. II relative to grout No. I. This behavior explains the effect of kaolinite in the confection in changing the stabilized peat micro-pore structure. These findings agree well with EDX results that, by

increasing kaolinite amount, the ratio of Ca, Si, and aluminum in the sample increased (Table 4 and Fig. 15) in comparison with those in grout No. I.

These findings also show that the introduction of a fine mineral admixture in a cementing mixture generates significant modifications in the properties of the confection by physic-chemical, micro-structural and chemical effects and agree with the findings of Boudchicha *et al.* (2007).

On the other hand, the effect of curing time can be seen clearly on comparison of results of grout Nos III and IV from the SEM micrographs shown in Figs 6 and 7. It can be observed from Fig. 6 that there are very little sodium silicate gel and C–S–H gel available in the sample
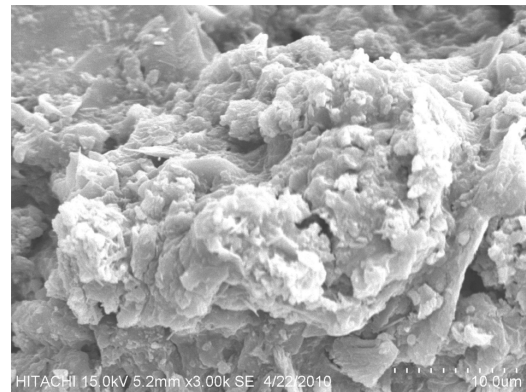

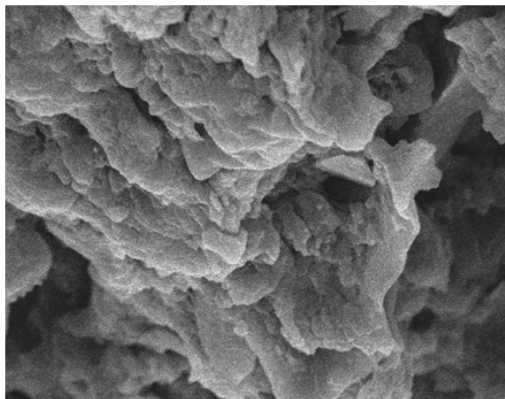**Fig. 5.** SEM micrograph of peat with grout No. II

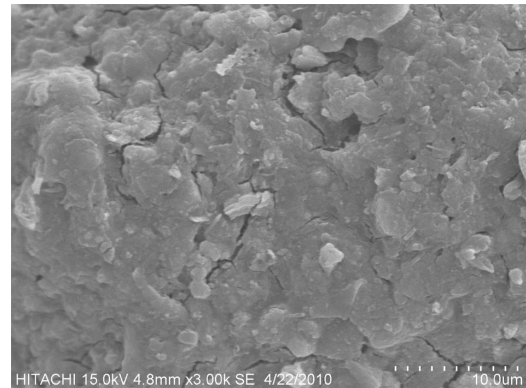**Fig. 3.** SEM micrograph of untreated peat

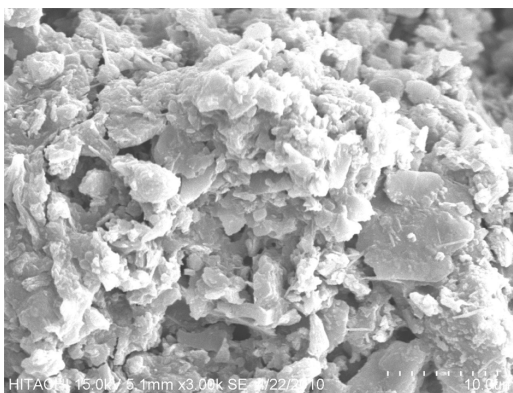**Fig. 6.** SEM micrograph of peat with grout No. III

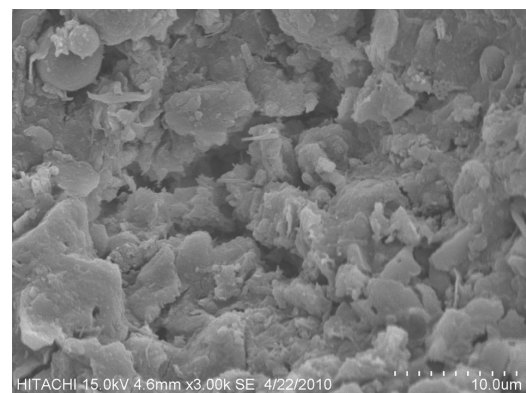**Fig. 4.** SEM micrograph of peat with grout No. I

Fig. 7. SEM micrograph of peat with grout No. IV

with grout No. III after 3 days of curing, as compared with grout No. IV (Fig. 7) which is after 30 days of curing. Further, there are extremely fine sized and very few spherical C–S–H gel formation or other types of that, which exhibit nominal hydration. These findings agree well with the findings of Sarkar and Wheeler (2001), who also reported similar micro-structural development with cement and some additives. For sample (grout No. IV) after 3 months of curing, the C–H–S gel (type III) is observed to increase dramatically in the sample structure with the addition of sodium silicate gel. As mentioned earlier, according to EDX results (Table 4) after 3 months of curing, the Ca/Si ratio of grout No. III increased from 0.573 to 0.735 in grout No. IV. This implies more hydration and pozzolanic reactions occurring with an increase in curing time.

3.2. Influence of calcium chloride

The influence of calcium chloride was studied by preparing different samples with different calcium chloride concentrations (0, 1, 2, 4 and 6% by weight of wet peat) as per different grouts (Nos 3 and 4) (Table 3) and performing undrained shear strength and determining the moisture content of each sample. The effect of calcium chloride on shear strength and moisture content of samples with grout Nos 3 and 4, after 30 days of curing, are presented in Figs 8 and 9.

It's observed that (Fig. 8) by increasing calcium chloride concentration in the grout No. 3 from 0 to 2%, the shear strength of the samples increased from 81.4 to 109.3 kPa and the moisture content decreased from 174.8 to 140.4% after 30 days of curing.

Furthermore, by increasing calcium chloride up to 6% the trend of shear strength and moisture content curves showed a reversal, i.e., the shear strength decreased from 109.3 to 55.2 kPa and the moisture content increased from 140.4 to 173.5%. Similarly, the shear strength and moisture content of the samples varied with an increase in curing time from 3 to 30 days for grout No. 3, and the trend was similar for grout No. 4 also, as seen in Fig. 9.
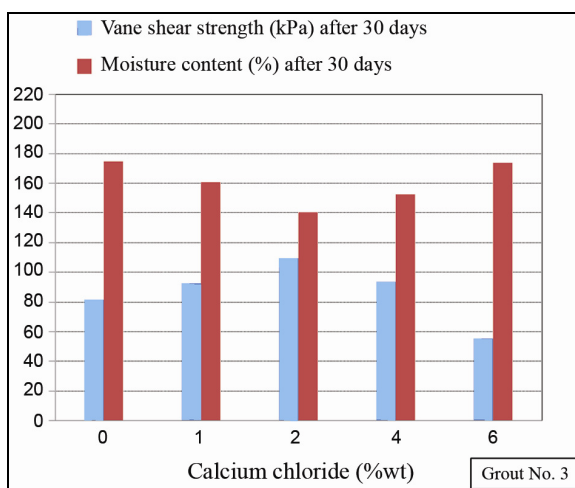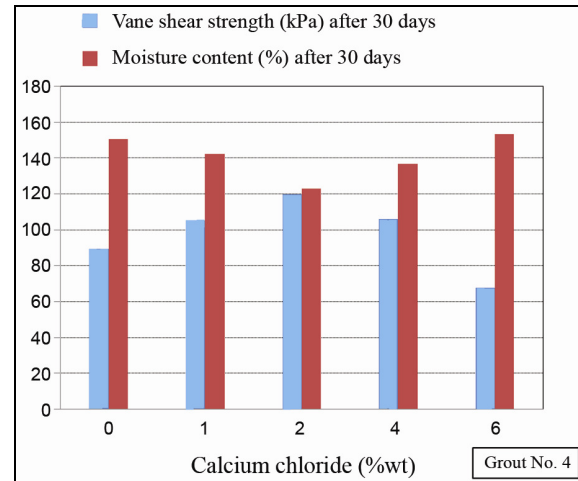

Fig. 9. Influence of calcium chloride concentration for grout No. 4

As mentioned before, the colloidal particles can affect the rheological properties of the confection. By adding calcium cation to the confection, it affects the peat colloids and kaolinite together (effect of kaolinite on confection and the influence of Ca^{++} on kaolinite were discussed earlier). The calcium cations are absorbed by peat colloids due to their high CEC (Table 1) and the charge distribution in the fluid.

Asadi *et al.* (2009) and Hunter (1981) described that increasing the cation valence reduced the affinity of water to the organic soil surface and decreases water content due to (i) the mechanisms that increase the adsorption of organic compounds by mineral fraction of organic soils (kaolinite mineral in this study which was added to the confection), and (ii) the changes in soil charges.

At this condition (first step), soil particles in peat–water tend to the zero net charge and will not repel each other but tend to aggregate and form larger particles. This may be the reason for the increase in shear strength and a decrease in the moisture content of the samples. Conversely, by adding extra calcium cation (more than 2%) the charge balance was affected giving a positive charge to peat and thereby leading to re-stabilization of the colloidal fraction and deflocculating of the larger particles.

3.3. Influence of cement and sodium silicates

The effects of sodium silicate (grout Nos 5 and 6) and cement (grout Nos 7 and 8) on sapric peat samples were investigated by adding separately, sodium silicate (0, 1, 2, 3 and 5%) and cement (0, 10, 20, and 30%) by weight of wet peat (Table 3) and the results are presented in Figs 10 to 13.

As observed from Fig. 10, by increasing the concentration of sodium silicate from 0 to 3% in the samples with grout No. 5, the shear strength increased from 47.4 to 118.1 kPa after 30 days of curing. Similarly, the moisture content decreased from 163.9 to 120.6% after 30 days. The trend of variation in shear strength and moisture content for grout No. 6 was similar to grout No. 5 after 3 and 30 days (Fig. 11).
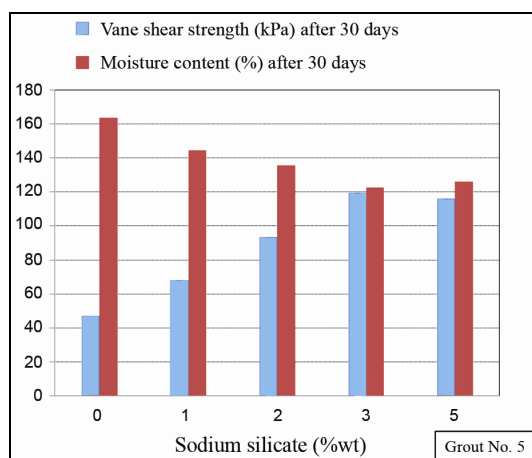

Fig. 8. Influence of calcium chloride concentration for grout No. 3

Fig. 10. Influence of sodium silicate concentration for grout No. 5

Fig. 12. Influence of cement concentration for grout No. 7

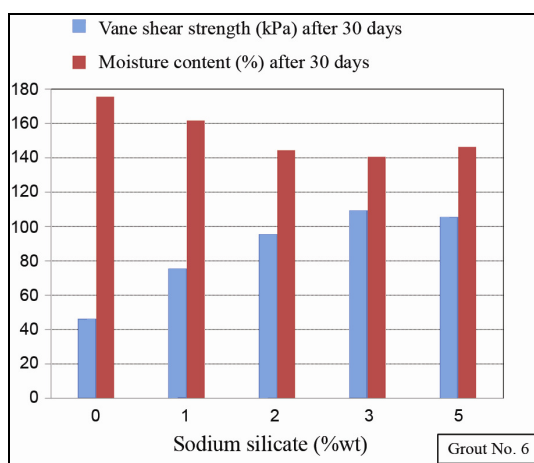**Fig. 11.** Influence of sodium silicate concentration for grout No. 6

Fig. 13. Influence of cement concentration for grout No. 8

On the other hand, with the addition of cement from 0 to 30% (grout Nos 7 and 8), the same trends for shear strength and moisture content have been observed. It was observed that the shear strength of samples increased by around 300–500% after adding 0 to 30% cement by weight of wet peat. Furthermore, their moisture content decreased by around 30–50% (Figs 12 and 13).

The above findings (increase in shear strength and decrease in moisture content by adding cement) agree well with the fact that cement initiates chemical reaction with water called hydration (Kazemian *et al.* 2011c; Huat *et al.* 2011).

In addition, this behavior of peat is because of the reason that when the soil particles, particularly clay present in peat, react with cement, cation exchange and flocculation takes place and these are responsible for the improvements in shear strength with a decrease in moisture content. The cement produces free calcium cations (Ca^{++}) when it comes in contact with water and replaces dissimilar adsorbed cations on the colloidal surface (pozzolanic reactions). Practically all fine- grained soils display rapid cation exchange and flocculation-agglomeration reactions when treated with cement in the presence of water with increasing curing time and is also evident in peat (Figs 11 and 12).
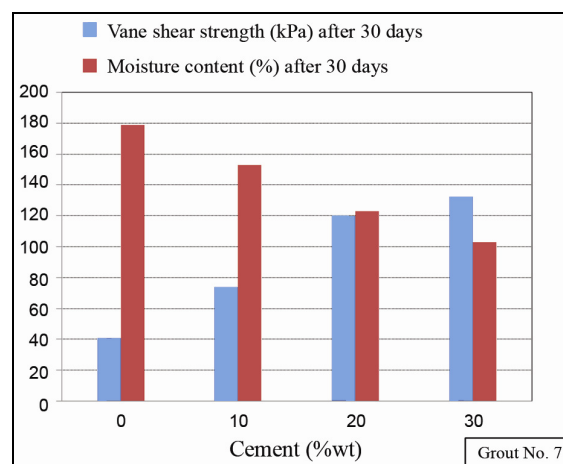
The increase in shear strength and a reduction in the moisture content are obvious as the amount of sodium silicate is increasing (within 3%) (Figs 10 and 11). This is due to the fact that almost all systems are based on reaction of silicate solution to form a colloid which polymerizes further to form a gel that binds soil or sediment particles together and fills voids.

Yonekura and Kaga (1992) and Karol (2003) have also reported that if alkaline solution with sodium silicate (sodium silicate solutions are alkaline) concentration above 1 or 2 percent by volume is neutralized by reactants (calcium chloride), colloidal silica will aggregate to form a gel.

The high concentration of Ca^{++} and OH^- ions is created in the confection immediately after addition of water to the cement. The supersaturation of the pore solution with calcium ions strongly hinders the dissolution of the clinker phases. In several hours, when the supersaturation reaches values several fold exceeding the equilibrium concentration of $Ca(OH)_2$, first nuclei of $Ca(OH)_2$ appears. This initiates growth of the C–S–H gel, the supersaturation decreases, and the dissolution of cement particles resumes (Brykov *et al.* 2002). On the other hand, by adding sodium silicate solution to the confection, calcium ions that pass into solution are bound by silicate ions of the additive and concentration of Ca^{++} is considerably lower than the saturation concentration at the correspond-

ing pH value. Further, as the initial pH values of the confections with addition of water-soluble silicates increase, the equilibrium concentration of Ca^{++} decreases and, at a certain stage, the liquid phase in the confection with sodium silicate solution will also be a saturated solution. In this condition, hydration continues in all probability even when the solution becomes supersaturated and the pH value stabilizes at values exceeding that of the pure past.

As a result, the effect of sodium silicate solution and cement in presence of calcium chloride, as Aborin *et al.* (2001) explained, while the confection is far from super-saturation with Ca^{++} ions, the clinker minerals contained in the confection are intensively hydrated and OH^- ions pass into solution to be consumed there for depolymerization and hydrolysis of silicate anions of the additive and for an increase in the pH value of the liquid phase. During this period, hydrated calcium silicates are formed both via precipitation of silicate ions of the additive and via release of silicate and aluminate ions from the clinker. In addition, as mentioned before, sodium silicate is basic and will be precipitated as a gel by neutralization. Thus, a dilute sodium silicate solution mixed with certain acids or acid salts will form a gel after a time interval related to chemical concentrations (Karol 2003). The effect of sodium silicate on the microstructure of the confection will be discussed in the next section.

It's observed that (Figs 7 and 14) by increasing sodium silicate in grout Nos IV and V from 1 to 3% (by weight of wet peat), the density of the confection increased after 30 days of curing and the multitude of voids decreased dramatically due to production of hydrated calcium silicates and formation of gel by neutralization. The EDX analysis of the samples revealed that the presence of Si and Ca in grout No. V is higher than that in grout No. IV (Table 4). This strongly suggests the formation of hydrated calcium silicates in the samples. Similar findings are reported by Kazemian *et al.* (2011d), and Martinez–Ramirez and Palomo (2001).

The effects of cement on micro-structural of samples were examined by increasing cement from 10% in grout No. V to 40% in grout No. I (by weight of wet peat) and the SEM micrographs are shown in Figs 4 and 14, and the EDX results are also presented in Table 4. It was observed that (Fig. 4) abundant massive and spherical or coralloid aggregation formed in the samples. Further, there are extremely few spherical C–S–H particles or other types of C–S–H morphologies of cement which exhibit nominal hydration in grout No. V (Fig. 14).

It appears that the C–S–H gel (type III) were produced more in grout No. I (denser-almost spheres form) and it combined with hydro calcium silicate gel to make a denser confection in comparison with grout No. V, which seems to have only neutralized gel of sodium silicate. It is understandable that by increasing the Ca/Si ratio, the confection's density increases and this agrees well with the EDX results that the Ca/Si ratio in grout No. V increased from 0.676 to 0.813 in grout No. I (Table 4). Gleize *et al.* (2003) have also reported similar increase in density with an increase in Ca/Si ratio.

Fig. 14. SEM micrograph of peat with grout No. V

It should be mentioned that the Ca/Si ratio in cement (without additives) is about 1.5 (Monteiro 1993; Taylor 1997), the reason of difference between Ca/Si in this study and the published results may be due to the existence of high amount of silicate from sodium silicate in the samples (Gleize *et al.* 2003).

Table 4. Concentration of grouts for microstructure study from EDX test

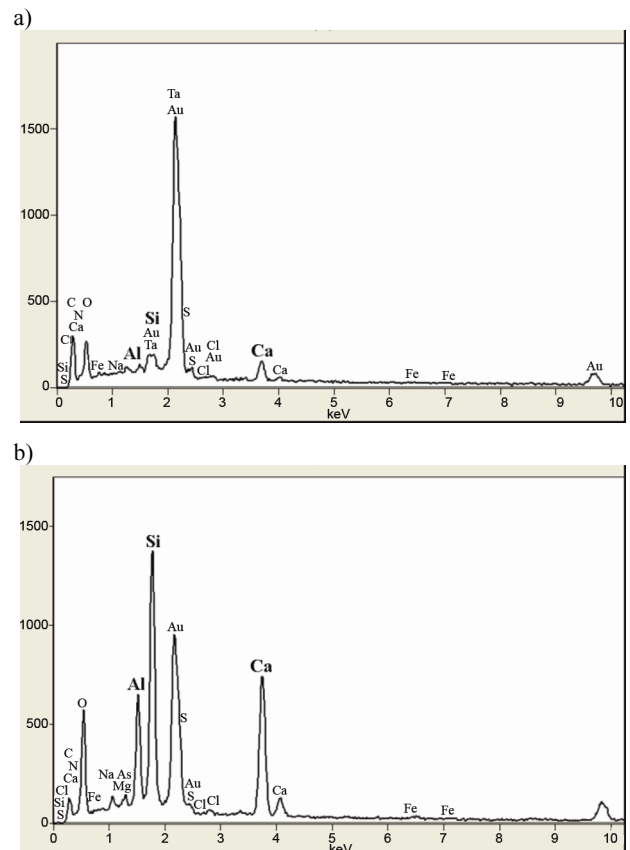| Grout No.	Concentration by weight (%)				
	Na	Al	Ca	Si	Ca/Si ratio
I	3.31	8.23	12.61	15.51	0.813
II	2.97	10.8	12.81	16.10	0.796
III	2.10	6.13	6.48	11.30	0.573
IV	2.60	7.10	9.63	13.10	0.735
V	3.10	7.5.	10.35	15.30	0.676

Fig. 15. a) – EDX of untreated peat; b) – EDX of grout No. II

4. Conclusions

This study presents the influence of the various quantities of different ratio of kaolinite, calcium chloride on cement-sodium silicate grout in improving the mechanical property (shear strength) and micro-structural property (SEM and EDX) of sapric peat samples after 3 and 30 days of curing.

The following conclusions are drawn based on this study:

1. Kaolinite effected the shear strength of the samples and increased the shear strength of sample by increasing kaolinite, it caused to decreased the moisture content as well, due to the connection of active part of sapric peat (colloid part and clay) with kaolinite by Ca^{++} ions and pozzolanic reactions with cement and chemical reactions with sodium silicate.

2. By increasing the amount of calcium chloride, due to the net effects of charge, the trend of gain in shear strength changed. It increased until the net charge of the sample changed to zero and then it decreased with further increase in calcium chloride because of deflocculating of the larger particles. These phenomena are responsible to reverse the trend of the change in moisture content of the samples.

3. The effect of cement and sodium silicate (within 3%) on the samples showed that by increasing the percentages of these compounds, the shear strength increased and the moisture content decreased. This happens since the hydration and pozzolanic reactions of cement and the fast reaction between cement and sodium silicate cause hydrated calcium silicates to be formed, both via precipitation of silicate ions of the additive and via release of silicate and aluminate ions from the clinker.

4. The soaking time causes an increase in the density of samples by producing more C–S–H gel (type III), and increasing the Ca/Si ratio in the confection as well.

5. The increase in shear strength and a reduction in the moisture content are obvious as the amount of sodium silicate (within 3%), cement, kaolinite and soaking time are increasing. These findings agree well with SEM and EDX results. The SEM micrographs of the sample before and after treatment validate the results obtained by EDX.

Acknowledgment

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SAPROGENINIŲ DURPIŲ POVEIKIS CEMENTO IR NATRIO SILIKATO SKIEDINIO SU KALCIO CHLORIDU BEI KAOLINITU SAVYBĖMS

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S a n t r a u k a

Durpės, susidarančios pūvant, yra ypač minkštos, nevienalytės struktūros, turi daug organikos. Durpių struktūra yra chaotiška, jose mažai fibrų. Šiame darbe nagrinėjamos skirtingų skiedinių (cemento ir natrio silikato su pūvant susidarančiomis durpėmis ir kaolinitu) mechaninės (šlyties stipris) ir mikrostruktūrinės savybės (SEM ir EDX) po 3, 30 ir 90 dienų. Nustatytas tokių durpių ir kitų priedų naudojimo veiksmingumas skiediniuose. Tyrimai parodė, kad kaolinito priedas padidina šlyties stiprį ir sumažina durpių vandens poreikį. Taip pat nustatyta, kad kalcio chloridas gali skirtingai veikti skiedinių stiprį. Įvertinta, kad bandinių šlyties stipris didėja, kai kalcio chlorido kiekis mišinyje artimas nuliui, didinant kalcio chlorido kiekį, stipris mažėja. Atlikus tyrimus pastebėta, kad didinant natrio silikato, cemento kiekį ir ilginant apdorotų durpių įmirkymo laiką, bandinių šlyties stipris ir tankis didėja, mažėja vandens poreikis ir tuštumų skaičius, kinta mikrostruktūros parametrai.

Reikšminiai žodžiai: durpės, kalcio chloridas, kaolinitas, natrio silikatai, mikrostruktūra.

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