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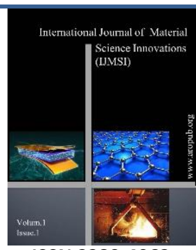

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Permeability properties of Wetland clay treated with sodium bentonite

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A b s t r a c t

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Vertical permeability,

Pozzolan,

Cementation crystals.

The aim of this study is to demonstrate the utilization of sodium bentonite as a pozzolanic additive to reduce the permeability rate of stabilized clay. Sodium bentonite is identified as a natural pozzolan that can utilize to reduce the coefficient of permeability of cemented soil due to its fineness and high content of silica and alumina. Sodium bentonite wherein mixes with cement paste in an appropriate dosage, it is capable to impart pozzolanic effect; hence, reduce the coefficient of permeability of cemented soil. Other than sodium bentonite, ordinary Portland cement and silica sand were also used as the binder and particle size modifier respectively. For this purpose, soil specimens of both plain and treated clay were explored in laboratory. It was revealed that addition of 15% sodium bentonite reduced 2.11 times of coefficient of permeability.

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1. Introduction

Taman Wetland clay is one of the well-known soft clay deposits in Putrajaya, Selangor, Malaysia. It possesses high moisture content with large potential for settlement and quite low inherent shear strength. Natural pozzolans such as kaolin, fly ash and biomass ash have been widely used as replacement materials for Ordinary Portland Cement (OPC) in many applications. The advantageous of pozzolans include cost reduction, CO_2 emission reduction, and chemical resistance enhancement, which make it useful in many industries [1]. Basically, due to alteration of volcanic ash, sodium bentonite could be formed. It is an absorbent aluminum silicate. For sodium bentonite the amount of sodium oxide (Na_2O) is more than that of calcium oxide (CaO). From the aspect of mineralogical composition, the X-ray diffraction analyses confirmed that sodium bentonite predominated by montmorillonite as reported by [1-4]. Generally, clay has large surface area, small particle size, high absorption capacity, high cation exchange capacity and high swelling capacity. Its compound of aluminum silicate is capable to hold a substantial net negative charge to induce large cation exchange capacity. Most of their useful characteristics are developed, or at least enhanced, when the charge on the layers is balanced by sodium ions. With respect to such useful properties, sodium bentonite is commonly used as a natural pozzolan to partially replace cement in the production of cemented materials due to its high reactivity to calcium hydroxide liberated from cement hydrolysis for the generation of pozzolanic cementation bonds. Formation of such pozzolanic cementation bonds is known to improve microstructure of cemented materials. In this research work ordinary Portland cement, sodium bentonite and silica sand were used to stabilize the soft clay. Due to high content of SiO_2 and Al_2O_3 in sodium bentonite the hydration kinetics for the calcium silicate and calcium aluminate in OPC can be modified. Therefore the hydration reactivity can be increased [5]. In addition to the function of sodium bentonite as a filler and pozzolanic additive, ordinary Portland cement also was used. However, research works on the application of sodium bentonite as a natural pozzolan to stabilize soft clay are relatively scarce. Previous research works have documented that the coefficient of permeability of clayey soils could be decreased due to stabilization with cement and pozzolanic materials. Recently, advancement of cement chemistry has been drastically increased. Besides, the partial substitute of OPC with sodium bentonite in stabilized soil offers an environmentally sustainable solution to reduce energy consumption of cement production, which in turn can reduce the effects of global warming and climate change. Cement industry generates around 5% of global CO_2 emissions, due to carbonate decomposition (about 50%), combustion of fuels in the kiln (about 40%) [6]. It is estimated that each tonne of cement produces approximately 1 tonne of CO_2, mainly from the burning of fossil fuels and from the de-carbonation of limestone [7]. The objective of this study is to investigate the coefficient of permeability of stabilized clay with cement, sodium bentonite and silica sand.

2. Experimental procedures

2.1. Materials and methods

An ordinary Portland cement, equivalent to ASTM type I, was used to stabilize the soil sample. The soil used in this research is soft clay, sampled from Taman Wetlands, Putrajaya in the state of Selangor, Malaysia. It was oven dried at ambient temperature (105±5°C) for 24 hours, then sieved (passing through a 2-mm sieve) and finally homogenized. Sodium bentonite was obtained from the Delta Corporation Limited. Locally available well graded silica sand was used as particle size modifier. The physical properties of soft clay are: natural moisture content: 45%, liquid limit: 56%, plastic limit: 24% and specific gravity: 2.46. The X-ray Fluorescence (XRF) technique was used to determine the chemical composition of the clay and sodium bentonite. According to ASTM C618, pozzolan is defined as a siliceous or siliceous and aluminous material, which in itself possesses little or no cementing property, but will in a finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. The chemical composition of the soil sample and sodium bentonite are indicated in Table 1. Based on Table 1 the sum of silica (SiO_2) and alumina (AL_2O_3) for sodium bentonite is 81.06% of the total chemical composition. According to [1], sodium bentonite has very fine particles with very laege surface area. The fine particle of sodium bentonite and high percent of silica (SiO_2) and alumina (AL_2O_3) i.e. more than 70%, is attributed the pozzolanic properties of the sodium bentonite. Therefore, sodium bentonite acts as a pozzolan and filler which function to bind the soil particles and reduce the pore spaces.

Table 1: Chemical compositions of the soil sample and sodium bentonite under study

	Weight (%)	
Oxide compound	Dry clay	Sodium bentonite
Al_2O_3	21.424	17.581
SiO_2	55.264	63.481
Fe_2O_3	12.223	5.031
SO_3	-	0.102
K_2O	6.860	0.787
CaO	1.628	3.701
TiO_2	2.471	0.547
Na_2O	-	5.321

2.2. Experimental test

In order to evaluate the coefficient of permeability of soil sample, laboratory falling head tests were carried out. The aim of laboratory falling head test is to evaluate the coefficient of permeability of both untreated and stabilized soil specimens. The test method is based on the ASTM D5084-03. The compacted soil specimen of untreated soil at optimum moisture content was placed in a mould with 100 mm diameter and 121 mm height which must has a good contact with the sides of the mould. Filter papers were positioned at the top and bottom faces of the soil specimen. Water was allowed to flow through the soil specimen from a standpipe attached to the top of the mould and the soil specimen saturated. The test conducted at various time intervals, with the head of water change in a standpipe recorded.

2.1. Mix design

The trial mix designs of the soil sample and additives are shown in Table 2. Standard proctor compaction tests were performed to obtain the optimum moisture content and maximum dry density of both untreated and stabilized soil specimens. The results of standard Proctor compaction test for each trial mix design are reported in Table 2. Based on the information of Table 2, sodium bentonite ranging between 0 and 15% was utilized in laboratory. In addition to sodium bentonite, ordinary Portland cement ranging from 0 to 15% and 5% silica sand also were thoroughly mixed with the soil sample. Each soil specimen was placed in a compaction mould and compacted in three equal layers. The compacted soil specimen with its optimum moisture content and maximum dry density was tested under permeability falling head tests. Based on Table 2, the highest maximum dry density obtained for the treated soil with 15% cement, 0% sodium bentonite and 5% silica sand. Whereas, the soil specimen with 0% cement, 15% sodium bentonite and 5% silica sand has the lowest maximum dry density. This is due to insufficient cement content in treated soil to produce cementation crystals, thus appropriate density could not be noted. On the other hand as cement content increased, high packing efficiency yielded for the soil specimen. This helped to reduce the void ratio and increased the dry density of the soil sample. After analysis the results of standard Proctor compaction test it was decided to select three test specimen as specified in Table 3. Based on Table 3, effect of stabilization with 15% sodium bentonite and 15% cement on optimum moisture content is depicted. Generally, cement is a well known binder for soil stabilization purposes. Meanwhile, sodium bentonite as a natural pozzolan with very fine particles, enables to bring filler effect and refine the soil pore spaces. Due to utilization of cement and sodium bentonite the cementation crystals would be appeared.

Table 2: Mix designs for laboratory testing

Mix design	OWC (%)	MDD (Mg/m^3)
100% Clay	16.32	1782
80% C+15% OPC+0% SB+5% SS	19.63	1909
80% C+10% OPC+5% SB+5% SS	20.04	1887
80% C+5% OPC+10 % SB+5%SS	21.12	1862
80% C+0% OPC+15% SB+5% SS	19.34	1847

Note:

C: is oven dried clay

SB: is sodium bentonite

OPC: is ordinary Portland cement

SS: is silica sand

OWC: is optimum water content

MDD: is maximum dry density

Table 3: Selected mix designs for laboratory testing

Soil specimen	OWC (%)
Plain soil	16.32
80% C+15% OPC+0% SB+5% SS	19.63
80% C+0% OPC+15% SB+5% SS	19.34

3. Results and discussion

A series of laboratory permeability falling head tests were conducted to evaluate the coefficient of permeability of clay treated with cement and sodium bentonite. Effect of addition cement or sodium bentonite to soil sample on coefficient of pearmeability are indicated in Table 4. From Table 4 it is observable that addition of sodium bentonite reduced the coefficient of permeability by almost 2.11 times when compared to that of treated with 15% cement content. An obvious reduction in the rate of permeability happened when the plain soil sample was treated with 15% sodium bentonite and 5% silica sand and compacted at optimum water content. The relevant results of the permeability tests are shown in Fig. 1. It is seen in Fig. 1 that test specimen with 15% sodium bentonite has the highest value of coefficient of permeability which was found to be 3.240E-08 m/s. According to Wong et al. (2013), the fine particles of sodium bentonite fill up the pore spaces of the cemented soil thus resulting in the soil matrix to be reinforced and closely packed as the hydration and pozzolanic products are formed during cemented hydrolysis.

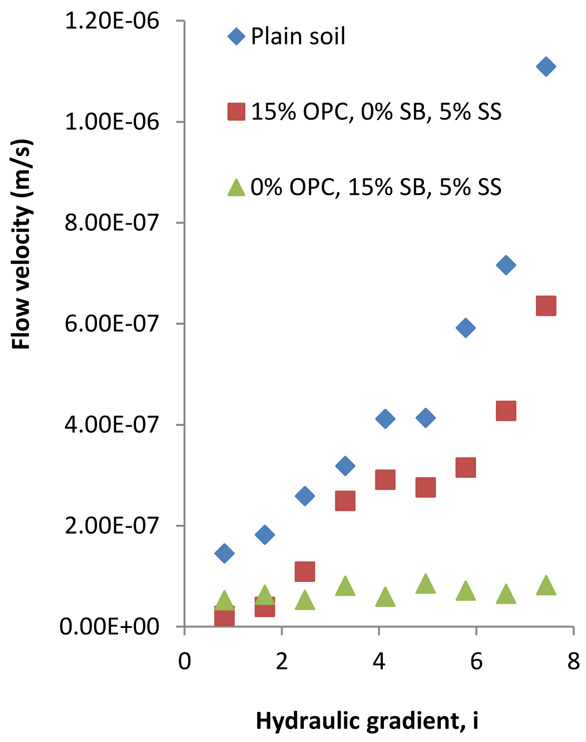

Fig. 1: Coefficient of permeability of the soil specimens

The average value of vertical permeability (k_v) for selected mix designs are tabulated in Table 4. Based on Table 4, addition of 15% cement to soil sample resulted a drastic reduction in permeability of the soil sample by almost 1.7 times.

Table 4: Coefficient of permeability of the soil specimens

Soil specimen	k_v at 20°C
Plain soil	1.144E-07
80% C+15% OPC+0% SB+5% SS	6.839E-08
80% C+0% OPC+15% SB+5% SS	3.240E-08

The flow quantity and elapsed time relationships graphically are illustrated in Fig. 2. From Fig. 2, it is vividly can be seen that the lowest flow quantity is corresponding to treated soil with 15% sodium bentonite. This provides a discussion that sodium bentonite filled the pore spaces and decreased the void ratio of the stabilized soil.

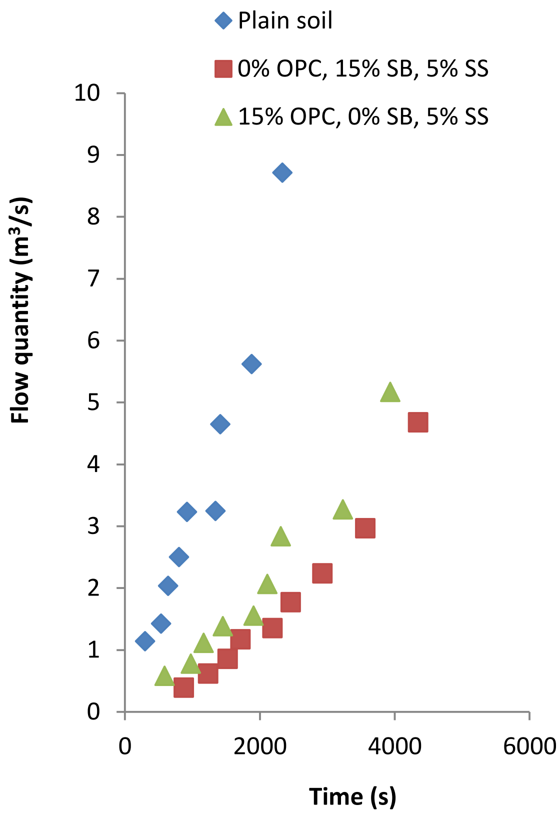

Fig. 2: Flow quantity of the soil specimens

From the laboratory permeability falling head tests, the average value of void ratio was determined as shown in Fig. 3. Since permeability is not constant for a given soil but is related to the dynamic water viscosity which varies with temperature, it is convenient to relate permeability data to a standard temperature of 20 °C [8]. At the standard temperature, k_v value of treated soil specimen with 15% sodium bentonite was found to be 3.240 × 10^{-08} m/s. According to [9], such rate of permeability is equivalent to that of soft clay. [9] have studied the impact of adding cement to clay on its coefficient of permeability. The rates of permeability for stabilized soil specimens with various cement contents were investigated. Based on the results a sharp decrease in the rate of permeability was observed for test specimen with 20% cement content.

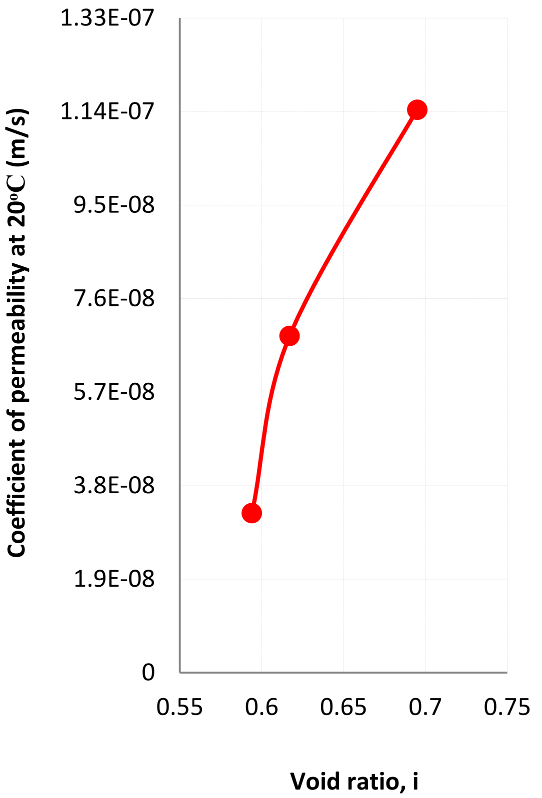

Fig. 3: k_v-void ratio relationships of plain and treated soil

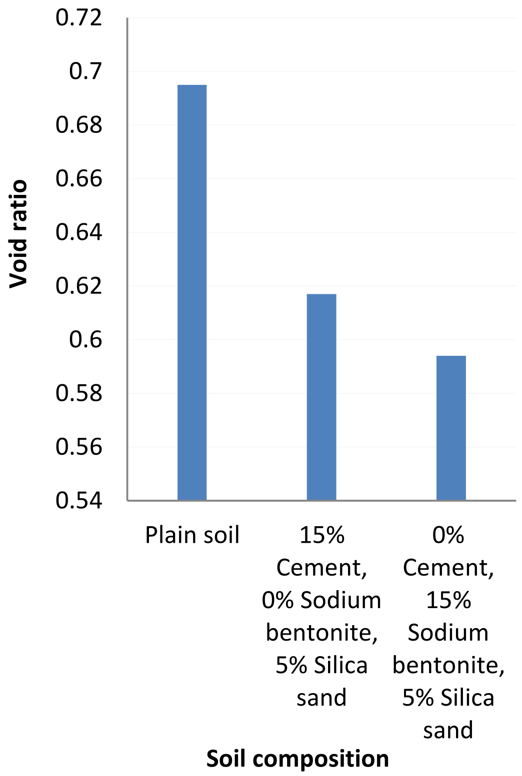

Fig. 4: Effect of binder composition on void ratio of the soil sample

Influence of binder compositions on void ratio of soft clay are platted in Fig. 4. Based on Fig. 4, addition of 15% sodium bentonit to soil sample was more effective than to that of treated with 15% cement content.

According to soil mechanic books the rate of permeability of clayey soils strongly depend on various parameters. Some of these parameters are particle size, particle shape and orientation, saturation of soil, porosity and density. Among the above parameters, effect of density is utmost. With respect to this, influence of dry density on coefficient of permeability are shown in Fig. 5. Based on Fig. 5, addition of 15% cement and 15% sodium bentonite decreased the coefficient of permeability when compared to that of plain soil. This is due to the finness of sodium bentonite that fill up the pore spaces of the soil, resulting in the soil matrix to be densed and closely packed as the pozzolanic activity occured. The consistent decline in the coefficient of permeability with increasing maximum dry density confirmed the fact that the pore spaces of the soil specimen refined and soil prosity decreased. It is evident that the inclusion of 18% sodium bentonite in the stabilized soil had the utmost impact.

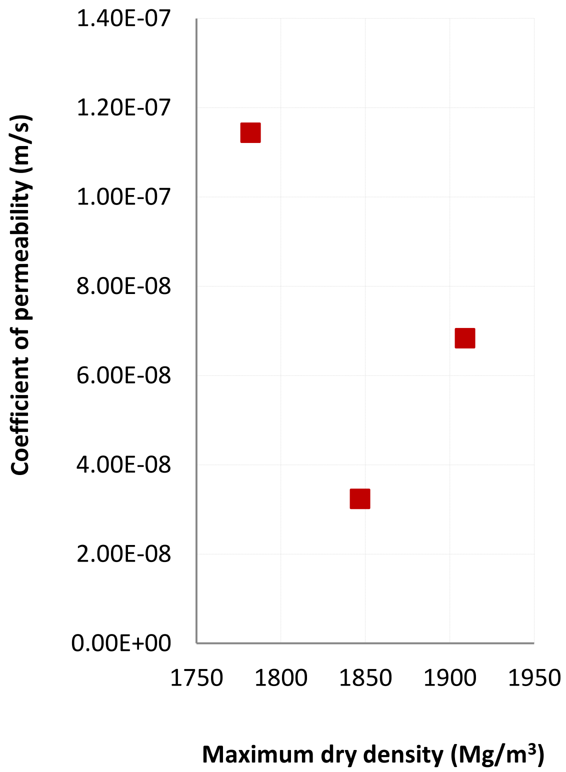

Fig. 5: Effect of dry density on rate of permeability

Aside from dry density of the soil specimens, results of optimum water content also were analyzed. As shown in Table 3, the optimum water content of treated soil specimens with 15% sodium bentonite increased by almost 1.2 times in compare to that of plain soil. This is due to the water holding capacity of the sodium bentonite particles. According to [1], sodium bentonite possess physical properties such as small particle size, large surface area, high cation exchange capacity, high absorption capacity and high swelling capacity, which make it useful in many industries. Its compound of aluminum silicate is capable to hold a substantial net negative charge to induce large cation exchange capacity. Therefore, the cementation crystals could be produced in presence of high free water content.

4. Conclusions

The rate of permeability of Wetlands clay was investigated in this study through the laboratory testing. From the results of laboratory falling head tests following conclusions can be deriven:

(1) Addition of 15% cement or 15% sodium bentonite decreased the flow quantity and permeability rate of the soil specimens.

(2) Due to pozzolanic properties of sodium bentonite, the cementation crystals bind the soil particles and reduced the voids.

(3) Comparison of the results of standard Proctor compaction tests revealed that treated soil sample with cement is possessed the highest maximum dry density.

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References

[1] Wong, L.S., Hashim R. and Ali F. Utilization of sodium bentonite to maximize the filler and pozzolanic effects of stabilized peat, *Engineering Geology,* 2013; 152: 56–66.

[2] Allo, W.A., Murray, H.H., Mineralogy, chemistry and potential applications of a white bentonite in San Juan province, Argentina, *Applied Clay Science,* 2004;25: 237–243.

[3] Ito, H., Komine, H., Dynamic compaction properties of bentonite-based materials, *Engineering Geology,* 2008; 98: 133–143.

[4] Ye, W.M., Chen, Y.G., Chen, B., Wang, Q., Wang, J., Advances on the knowledge of the buffer/backfill properties of heavily-compacted GMZ bentonite, *Engineering Geology,* 2010: 116: 12–20.

[5] Andersen MD, Jakobsen HJ, Skibsted J. Characterization of white Portland cement hydration and the C–S–H structure in the presence of sodium aluminate by 27Al and 29 Si MAS NMR spectroscopy. *Cem Concr Res,* 2004; 34: 857–68.

[6] Velosa, A.L., Cachim, P.B., Hydraulic-lime based concrete: strength development using a pozzolanic addition and different curing conditions *Construction and Building Materials* 2009; 23: 2107–2111.

[7] Rehan, R., Nehdi, M., Carbon dioxide emissions and climate change: policy implications for the cement industry, *Environmental Science and Policy,* 2005; 8: 105–114.

[8] Head KH, Manual of soil laboratory testing. Permeability shear strength and compressibility tests, 1st ed., vol. 2. London: Pentech Press; 1982.

[9] R. Bahar, M. Benazzoug, S. Kenai. Performance of compacted cement-stabilised soil *Cement and Concrete Composites,* 2004; 26: 811-820.