SOME MECHANICAL AND CHEMICAL PROPERTIES OF CEMENT STABILIZED MALAYSIAN SOFT CLAY

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All Glory, Honour and Praise be unto the Lord Jesus Christ,

my Lord and Savoiur.

Specially dedicated to my beloved daddy, Garry Ho Fon Khiong, mummy, Mary Chee Inn Lai and my only sibling, brother Michael Ho Jiann Woei. Thank you for being so understanding and supportive in my whole Master studies. Mummy, thank you fro your unceasing prayers, care and encouragement.

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For God so loved the world that He gave His One and Only Son, that whoever believes in Him shall not perish but have eternal life.

- John 3 :16 -

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ABSTRACT

Soft clays are defined as cohesive soil whose water content is higher than its liquid limits. Materials such as these display extremely low yield stresses, high compressibility, low strength, low permeability and consequently low quality for construction. Thus, soil-cement mixing is adopted to improve the ground conditions by enhancing the strength and deformation characteristics of the soft clays. For the above mentioned reasons, a series of laboratory tests were carried out to study some fundamental mechanical and chemical properties of cement stabilized soft clay. The test specimens were prepared by varying the portion of ordinary Portland cement to the soft clay sample retrieved from the test site of RECESS (Research Centre for Soft Soil) at UTHM. Comparisons were made for both mechanical and chemical properties by relating the effects of cement stabilized clay of homogeneous and columnar system specimens for 0, 5 and 10 % cement and curing for 3, 28 and 56 days. The mechanical properties examined included one-dimensional compressibility and undrained shear strength, while the chemical properties included pH values and the percentage of oxide concentration. For the mechanical properties, both homogeneous and columnar system specimens were prepared to examine the effect of different cement contents and curing periods on the stabilized soil. The one-dimensional compressibility test was conducted using an oedometer, while a direct shear box was used for measuring the undrained shear strength. Chemical properties of the stabilized material were examined using the X-Ray Fluorescence (XRF) method to obtain the percentage of oxide concentration while a pH meter was used to determine the pH values. The chemical study was also to ascertain the extent of leaching effect from the stabilized column to the surrounding soils. The higher the value of cement content, the greater is the enhancement of the yield stress and the decrease of compression index. The value of cement content in a specimen is a more active parameter than the curing period. It can be proposed the following relationship for RECESS soft clay from this study: $\sigma_y' = 1.5871\ \tau$. The chemical results showed that cement-stabilized column give environmental effects to the soil surrounding the column. The pH values for cement content of 5 % and 10 % in the soil-cement column specimens gradually decreases with the curing days for both consolidated and without consolidated specimens. Soil-cement column specimen with consolidation gave a higher pH compare to the specimens without consolidation. Major to minor relative values of the percentage of oxide concentrations are SiO_2 > Al_2O_3> Fe_2O_3 > SO_3 > K_2O > CaO.

ABSTRAK

Tanah liat lembut didefinasikan sebagai tanah melekit di mana kandungan air dalam tanah adalah lebih tinggi daripada had cecair. Kandungan tanah seperti ini menunjukkan tekanan rintangan yang sangat rendah, kebolehmampatan yang tinggi, kekuatan yang rendah, kebolehtelapan yang rendah dan juga mempunyai kualiti yang rendah untuk pembinaan. Oleh itu, campuran tanah-simen digunapakai untuk memperbaiki keadaan tanah dengan menambah kekuatan dan membaiki sifat-sifat deformasi tanah liat lembut. Seperti sebab-sebab yang dinyatakan di atas, satu siri ujian makmal untuk mendapat sifat-sifat asas mekanikal dan kimia dijalankan bagi tanah liat lembut yang distabilkan oleh simen. Spesimen-spesimen disediakan dengan menambah beberapa kandungan simen Portland biasa dengan tanah liat lembut yang diperolehi dari tapak ujian RECESS (Research Centre for Soft Soil) di UTHM. Perbandingan dilakukan untuk sifat mekanikal dan kimia dengan menghubungkait kesan tanah yang distabilkan sama ada homogenus ataupun sistem tiang bagi 0, 5 and 10 % simen dan tempoh awet selama 3, 28 dan 56 hari. Ujian untuk sifat-sifat mekanikal termasuklah ujian satu-dimensi pemadatan dan ujian kekuatan ricih tak tersalir, manakala, ujian pH dan ujian peratusan kepekatan oksida dilakukan bagi mengenalpasti sifat kimia. Bagi sifat mekanikal, kedua-dua spesimen homogenus and sistem tiang telah disediakan untuk menguji kesan-kesan ke atas tanah yang distabilkan dengan perubahan kandungan simen dan tempoh awet. Ujian satu-dimensi pemadatan dijalankan menggunakan oedometer, sementara ujian kekuatan ricih menggunakan kotak ricih terus untuk mengukur kekuatan ricih tak-tersalir. Sifat kimia untuk tanah distabilkan diuji dengan menggunakan kaedah pendaflour sinar-X (XRF) untuk memperoleh peratusan kepekatan oksida, sementara meter pH digunakan untuk mendapatkan nilai pH. Ujian kimia dijalankan untuk mengetahui kesan daripada aliran kandungan dalam tanah yang distabilkan kepada tanah yang

disekeliling. Semakin tinggi nilai kandingan simen, maka semakin tinggi tekanan rintangan dan pengurangan indeks kompresi. Nilai kandungan simen di dalam satu spesimen merupakan parameter yang lebih aftif daripada tempoh awat. Dapat disyorkan bahawa hubungan tanah lembut RECESS daripada kajian ini adalah seperti berikut: $\sigma_y' = 1.5871\ \tau$. Ujian kimia menunjukkan sistem tiang tanah yang distabilkan memberi kesan kepada alam sekitar iaitu terhadap tanah di sekeliling tiang tersebut. Nilai pH untuk spesimen tanah-simen sistem tiang 5 % dan 10 % kandungan simen semakin menurun dengan penambahan tempoh awet bagi kedua-dua spesimen yang dipadatkan dan tanpa pemadatan. Spesimen tanah-simen sistem tiang yang dipadatkan memberikan nilai pH yang lebih tinggi berbanding dengan spesimen yang tidak dipadatkan.Nilat relatif daripada terbanyak ke paling sedikit peratusan kandungan oksida adalah $SiO_2 > Al_2O_3 > Fe_2O_3 > SO_3 > K_2O > CaO$.

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LIST OF SYMBOLS

°	-	Degree
km^2	-	Kilometer square
%	-	Percent
et al.	-	And other people
RECESS	-	Research Centre for Soft Soil
XRF	-	X-ray Fluorescence
UTHM	-	Universiti Tun Hussein Onn Malaysia
m	-	Meters
$Mg_3(OH)_6$	-	Brucite
$Al_2(OH)_6$	-	Gibbsite
µm	-	Micrometer
nm	-	Nanometer
MH	-	Micaceous, Diatomaceous fine sandy or silty soils or elastic silts
pH	-	A measurement of the acid or alkaline level
$\Delta\sigma$	-	Total stress
$\Delta\sigma'$	-	Increase in the effective stress
$\Delta\mu$	-	Increase in the pore water pressure
log	-	Logarithm
C_c	-	Compression index
C_r	-	Recompression index
t	-	Number of days after the installation of columns
$\Delta c_{u,total}(t)$	-	Total strength increment
$\Delta c_{u,thix}(t)$	-	Strength increment due to thixotropy

$\Delta c_{u,cons}(t)$	-	Strength increment due to consolidation;
$\Delta c_{u,chem.}(t)$	-	Strength increment due to chemical processes.
σ_y'	-	Yield stress
ε_{pl}	-	Plastic strain
e	-	Void ratio
ΔH	-	Differences in height
H_o	-	Initial height
N	-	Normal force
F	-	Shear force
τ_f	-	Shear strength at failure
A	-	Area of the block
ø'	-	Friction angle
c'	-	Cohesion
ΔH	-	Horizontal displacement
ΔV	-	Vertical displacement
τ	-	Shear stress
in.	-	Inches
Ca^{2+}	-	Calcium ion
K^+	-	Potassium ion
SO_4^{2+}	-	Sulfate ion
SiO_2	-	Silica
Al_2O_3	-	Alumina
Fe_2O_3	-	Iron Oxide
MgO	-	Magnesium Oxide
Na_2O	-	Sodium Oxide
K_2O	-	Potassium Oxide
SO_3	-	Sulphur Trioxide
TiO_2	-	Titanium Oxide
CaO	-	Calcium Oxide
Mg^{2+}	-	Magnesium ion
ASTM	-	American Society for Testing and Materials
C_3S	-	Tricalcium silicate
C_2S	-	Dicalcium silicate
C_3A	-	Tricalcium aluminate

C_4AF	-	Tetracalcium alumino-ferrite
C_2SH_x, $C_3S_2H_x$	-	Hydrated calcium silicates
C_3AH_x, C_4AH_x	-	Hydrated calcium aluminates
$Ca(OH)_2$	-	Hydrated lime
CSH	-	Hydrated gel
SiO_2	-	Soil silica
Al_2O_3	-	Soil alumina
C-S-H	-	Calcium-silicate-hydrate
i.e.	-	In other words
e.g.	-	For example
BS	-	British Standards
w/s.w.	-	Weight by soil weight
mm	-	Millimeters
kPa	-	Kilo Pascal
g	-	Gram
ml	-	Milliliters
w_o	-	Initial water content
S_{ro}	-	Initial degree of saturation
$\sigma_v'_{SOIL}$	-	Stress for 0 % cement (or natural condition)
$\sigma_v'_{COL}$	-	Stress for 5 % or 10 % cement
$\sigma_v'_{TEST}$	-	Stress form test
$\sigma_v'_{PRED}$	-	Stress form calculation
P_{COL}	-	Force on column
P_{SOIL}	-	Force on column
A	-	Area of ring
a	-	Area of column system
ε_v	-	Vertical strain
>	-	Greater than

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Soft clays are well known for their low strength and high compressibility. Usually, due to sedimentary process on different environment, both physical and engineering properties of the clays (namely void ratio, water content, grain size distribution, compressibility, permeability and strength) show a significant variation. Furthermore, they exhibit high compressibility (including an important secondary consolidation), reduced strength, low permeability and compactness, and consequently low quality for construction.

Thus, the soil-cement mixing is adopted to improve a soft clay foundation and provides stability during the construction process. It has been used since the 1970's to improve the strength and deformation characteristics of these soft soils (Jaritngam and Swasdi, 2007). The cement mixing method was developed simultaneously in Sweden and Japan (Broms, 1996). For the above mentioned reasons, a comprehensive laboratory testing programme was carried out in order to study the effect of inclusion of cement on mechanical and engineering behaviour of soft clay.

In this project, soil is improved or stabilized by mixing in cement. The principle mechanism of ground improvement is done by forming chemical bonds between the soil particles. When the soil particles are bonded, it will be strengthened and become more stable physically and mechanically. The main benefits are increased stiffness and durability, and better volume stability (i.e. the soil becomes less susceptible to shrinkage or swelling) (Powrie, 2004).

Soft clay, when mixed with cement, will be stabilized because cement and water react to form cementitious calcium silicate and aluminate hydrates, which bind the soil particles together. In addition, the hydration reaction releases calcium hydroxide, $Ca(OH)_2$ or slaked lime, which may in turn react with some components of the soil, in particular clay minerals. Hydration of the cement occurs immediately when it contact with water, but the secondary reactions are slower and may continue for many months (Bergado, 1996).

According to Powrie (2004), cement stabilization can be used successfully in a wide range of soils, because the primary reaction, i.e. hydration, is independent of the soil type. Difficulties are normally only encountered with coarse gravels or soils with high organic content because they are not able to absorb or keep the water. The effectiveness of the treatment depends on adequate mixing and compaction, which in high-plasticity soils (i.e. clays), can be difficult to achieve.

Various methods of soil mixing, mechanical, hydraulic, with and without air, and combinations of both types have been used widely world wide. Deep mixing differs to cement-soil stabilization methods because it is can be done for a deeper depth and larger construction, whereby also require larger cost (Huat et al., 2005). Deep mixing is performed in order to change the physical properties of the soil. This is done by introducing binders to the soil. They will react with water and other components of the soil and change also the chemical properties of the soil. By introducing binders of various origins, the total content of harmful substances may increase in the soil. For deep mixing, there is a significant problem that occurs when

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