

ENGINEERING PROPERTIES OF BATU PAHAT SOFT CLAY STABILIZED WITH
LIME, CEMENT AND BENTONITE FOR SUBGRADE IN ROAD CONSTRUCTION

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ABSTRACT

Constructions on soft clay are often affected by stability and settlement problems. Ground improvement methods have been used in many parts of the world to minimize these problems. The aim of this research is to evaluate the engineering properties of Batu Pahat Soft Clay (BPSC) mixed with three types of admixtures. This research presents the stabilization of BPSC using admixtures lime, cement and natural sodium bentonite at varying binder contents (5%, 10%, 15%, 20% and 25%). The basic soil properties such as compaction, unconfined compression strength, California bearing capacity and permeability testing methods were used to gauge the behavior and performance of the stabilized soils. From the tests conducted, the researcher has found that the addition of lime, cement and natural sodium bentonite decreased the maximum dry density and increased the optimum moisture content. The tests conducted gave some indication that the unconfined compressive strength increased with the percentage of stabilizer and curing periods for cement treated sample compared to lime and bentonite treated sample. It also showed that an increase in the binder content and curing periods results in a reduction of the permeability of the stabilized soils. The results of California Bearing Ratio (CBR) indicated that the increase of curing periods and percentage of stabilizers led to an increase in the CBR values for cement treated sample compared to lime and bentonite treated sample.

ABSTRAK

Pembinaan di atas tanah liat lembut sering berlaku masalah kestabilan dan pemendapan. Bagi meminimumkan masalah ini, kaedah pemulihan sifat tanah boleh digunakan dengan pelbagai cara atau kaedah. Tujuan kajian ini adalah untuk menentukan ciri – ciri fizikal dan kejuruteraan tanah liat lembut Batu Pahat (BPSC) yang dicampurkan dengan tiga jenis bahan. Kajian ini adalah mengenai penstabilan tanah liat lembut Batu Pahat dengan menggunakan kapur, simen dan bahan berasaskan *natural sodium bentonite* pada kandungan campuran yang pelbagai (5%, 10%, 15%, 20% dan 25%). Kaedah ujian bagi menentukan ciri-ciri asas tanah, kekuatan mampatan, keupayaan galas (*California bearing ratio*) dan kebolehtelapan dijalankan untuk mengukur tingkah laku dan prestasi kestabilan tanah. Keputusan ujian pemadatan menunjukkan bahawa penambahan kapur, simen dan *natural sodium bentonite* mengurangkan ketumpatan kering maksimum dan meningkatkan kandungan lembapan optimum. Ujian yang dijalankan menunjukkan bahawa kekuatan mampatan tak terkurung meningkat dengan peningkatan peratusan penstabil dan tempoh pengawetan bagi sampel distabilkan oleh simen berbanding sampel distabilkan oleh *bentonite* dan kapur. Ia juga menunjukkan bahawa peningkatan dalam peratusan penstabil dan tempoh pengawetan akan menurunkan kebolehtelapan tanah yang stabil. Keputusan *California Bearing Ratio* (CBR) menunjukkan bahawa peningkatan tempoh pengawetan dan peratusan penstabil membawa kepada peningkatan dalam nilai CBR bagi sampel distabilkan oleh simen berbanding sampel distabil dengan kapur dan *bentonite*.

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LIST OF ABBREVIATIONS AND SYMBOLS

A	Area of specimen
Al ₂ O ₃	Aluminum Oxide
a	Area of manometer tube
BPSC	Batu Pahat Soft Clay
CaO	Calcium Oxide
CaOH ₂	Calcium Hydroxide
CaCO ₃	Calcium Carbonate
CBR	California Bearing Ratio
C _u	Cohesion
C _m	Meniscus Correction
D	Particle Diameter
Fe ₂ O ₃	Ferric Oxide
GCLs	Geosynthetic Clay Liner
G _s	Specific Gravity
H _R	Effective Depth
h ₁	Heights of water above datum
h ₂	Heights of water above datum
k	Coefficient of permeability
L	Length of specimen permeability
LL	Liquid Limit
MgO	Magnesium Oxide
Na ₂ O	Sodium oxide
NBPSC	Natural of Batu Pahat Soft Soil

OMC	Optimum Moisture Content
P	Axial force
p_s	Pressure to achieve equal penetration on standard soil
PC	Portland Cement
PI	Plasticity Index
PL	Plastic Limit
q_u	Compressive strength
RECESS	Research Centre Soft Soil, Malaysia
RGCL	Geosynthetic Clay Liner
STC	Samples treated with cement
STL	Samples treated with hydrated lime
STB	Samples treated with natural sodium bentonite
SO ₂	Sulphur Dioxide
t	Elapsed time of test
TiO ₂	Titanium Dioxide
UBPSC	Untreated of Batu Pahat Soft Soil
UTHM	Universiti Tun Hussien Onn, Malaysia
UCT	Unconfined Compression Test
w	Moisture content
θ°	Internal Friction Angle
ρ_s	Particle Density
ρ_d	Dry density of soil
ρ_b	Bulk density of soil
ρ_w	Density of water

CHAPTER 1

INTRODUCTION

1.1 Background

In Malaysia, the development of national road networks, residential and commercial properties have encroached into the areas underlain with very soft soils. The soft clay has created a challenge to the construction industry, particularly in road construction. The characteristic of soft soil are high compressibility, low shear strength and low permeability. General construction problems in this deposit are insufficient bearing capacity, excessive post construction settlement and instability on excavation and embankment forming.

In this formation, usually the hard layer and bedrock are very deep and results in higher cost of foundation. Geotechnical works in deep deposits of highly compressible soft clay is often associated with problems such as excessive differential settlement, negative skin friction and bearing capacity failure. In order to counter these problems, one has to know the engineering properties of the soft clay. The conventional ground treatment methods such as soft soil replacement; expedite pore water dissipation and platform settlements through the insertions of prefabricated vertical drains (PVD) and surcharge fills; modify subsoil bearing capacity through the installation or stone column or combination of these techniques are widely used in Malaysia. The applications of these

methods are constrained by technical feasibility, space, time constraints and construction cost. Early selection and application of the most appropriate ground improvement techniques can improve considerably not only the design and performance of foundations and earth structures, including embankments, cut slopes, roads and railways but also result in their cost-effectiveness.

Chemical stabilization methods are presented to provide soil strength improvement, mitigation of total and differential settlements, shorter construction period, reduced construction costs, and other characteristics which may impact on their utilization to specific projects on soft ground. This research addresses these deficiencies by performing laboratory tests on the three types of binder mixed with natural Batu Pahat soft clay (BPSC) at Research Centre for Soft Soils (RECESS). This report can be used as a guide to help select an appropriate stabilizer type and amount based on soil properties and desired strength.

1.2 Problem statement

Over the past 5 years, residential and commercial developments have increased in Batu Pahat. This development was constructed on soft clay. The civil engineering components of the project included construction of flood control, main drainage and access road. The construction on soft soil is increasing due to lack of suitable land for infrastructures and other developments. Imported soils from cutting of hills and highlands are used for various construction purposes. Many parts of Johor and other coastal areas consist of soft soils or peat soils.

In this research, study is carried out in Batu Pahat district which is known to have abundance of soft clay. This type of clay called Batu Pahat soft clay (BPSC) is available up to a depth of 40 meters from ground level (Chan, 2008). According to Hashim and Masirin (2008), roads in Batu Pahat district experienced many types of failures such as cracks, large surface deformation and structural deformation of pavement layers and the subgrade. They suggested that in order to reduce these failures, Batu Pahat soft clay

needs to be utilized in order to reduce imported soil from other places and reduced the possibility of environmental damages.

BPSC at Research Centre for Soft Soil (RECESS) has a plasticity index (PI) that range from about 36% to 46% in which the higher the PI, the greater the potential for problems (Chan and Ibrahim, 2008; Robani and Chan, 2009). Clays, especially highly plastic are subject to swell when their moisture content is increased. Moisture control is perhaps the most important single factor in the success of foundations on shrinking and swelling clays. The percentage of clay in a soil and the activity of clay minerals are reflected qualitatively by the value of the plasticity index. The larger content of clay minerals, and the more active the clay mineral, the greater is its potential for swelling, creep and changes in behavior (Duncan, 2005). The Building research Establishment (BRE) (Anon, 1980) suggests that the plasticity index over 35% provided an indication of volume change potential is very high. These volume changes can give rise to ground movements which can cause damage to buildings.

Therefore, in order to prevent the problems, it is essential for engineers to stabilize the existing soil soils before commencing the construction activities. By stabilizing the soil, it is hoped that the soil will be more suitable as road subgrade and any road construction. Thus, one method to ensure that existing BPSC is suitable for construction is by mixing it with cement, lime and bentonite as a stabilizer.

1.3 Aim

This research is aimed to evaluate the engineering properties of Batu Pahat soft clay (BPSC) which is stabilized with different admixtures such as lime, cement and natural sodium bentonite.

1.4 Objectives

The objectives of this research are as follows:

1. To determine the physical and engineering properties of Batu Pahat soft clay (BPSC).
2. To analyze the compaction, compressive strength, CBR values and permeability characteristics of different mixtures of stabilized BPSC with curing periods.
3. To evaluate the engineering properties and the effectiveness of the stabilizers mixed with BPSC at the optimum moisture content against curing periods.

1.5 Research Location

This research was carried out at Research Centre for Soft Soils (RECESS) Malaysia. The test site is situated on soft soil, located about 20km from the Batu Pahat town center towards Ayer Hitam. The topography of the test area is relatively flat with the original ground about 1.35m to 1.80m above the mean sea level. The site is selected due to the suitability of the test site and the uniformity of soft clay. The test area consists of very soft clay to a depth of 27 meters from the surface (Masirin, 2006).

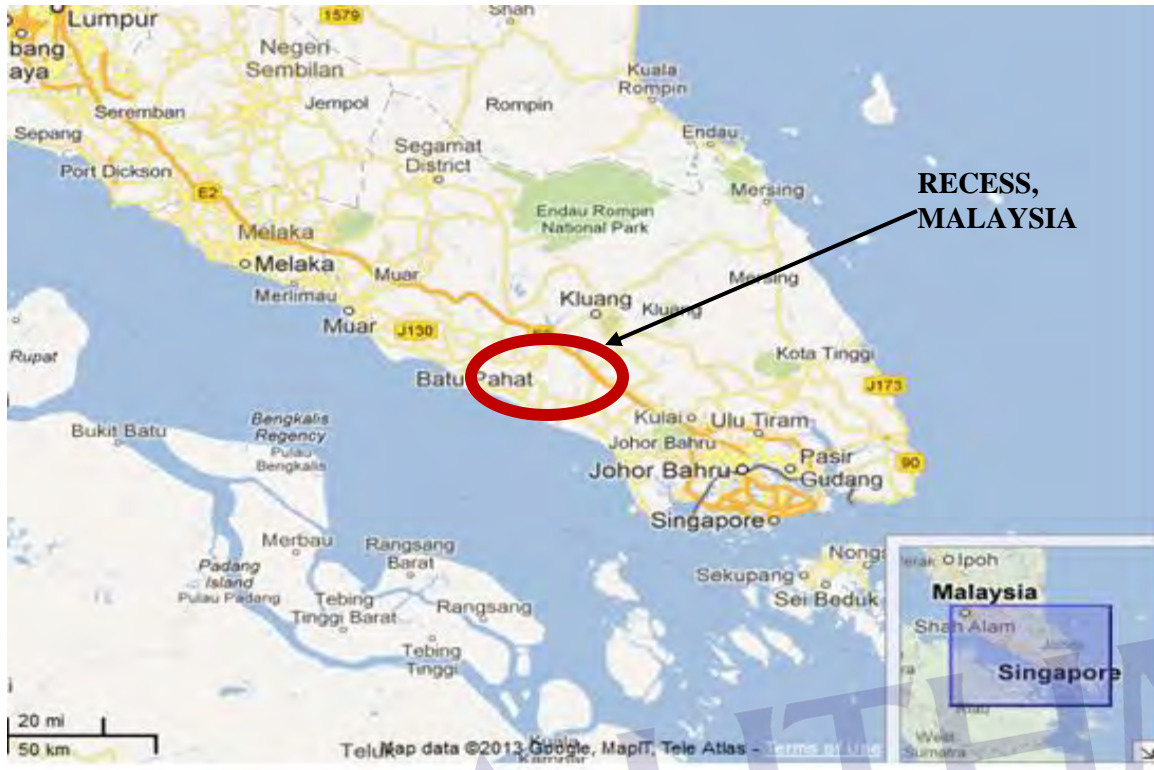


Figure 1.1: Topographic map of RECESS, Malaysia (Source: UTHM,2013)



Figure 1.2 : Research Centre for Soft Soil building



Figure 1.3: Location of sampling in RECESS, Malaysia

1.6 Scope of Study

The scope of the project includes the testing of BPSC obtained from UTHM campus. This research focused on stabilizing BPSC using selected stabilizing agents that were hydrated lime, Portland cement and natural sodium bentonite. Laboratory testing methods used to gauge the behavior and performance of the stabilized soils which include standard compaction, unconfined compressive strength (UCS), California bearing ratio (CBR) and falling head permeability test.

Physical and Engineering Properties testing of BPSC was also conducted to enhance the researcher's understanding on BPSC characteristics. All testing was conducted at geotechnical engineering laboratory, Universiti Tun Hussein Onn (UTHM) and Politeknik Merlimau, Melaka. Observations and evaluation of the testing conducted with the following correlations between:

- a) Compaction results against stabilizer percentage.
- b) Unconfined compressive strength (UCS) against stabilizer percentage with curing periods.

- c) California bearing ratio (CBR) against stabilizer percentage with curing periods.
- d) Coefficient of permeability against stabilizer percentage with curing periods.

1.7 Significance of Study

The work presented in this research is a contribution to the application of chemical stabilization techniques, for different concentrations lime, cement and bentonite for Batu Pahat soft clay, where several cases were reported disorders characterized by cracks in the subgrade construction and the foundation level. Therefore, this research provides insight into which stabilizers are most effective for stabilizing Batu Pahat soft clay. This report can be used as a guide to select an appropriate stabilizer type and the amount of stabilizer based on soil properties and the desired strength. In addition, the laboratory procedure developed for this research can be used to help evaluate specific soils for specific projects.



CHAPTER 2

LITERATURE REVIEW

2.1 Soil Types

Soils may be separated into three very broad categories: cohesionless, cohesive, and organic soils. Cohesive soils are characterized by very small particle size where surface chemical effects predominate. The particles do tend to stick together – the result of water-particle interaction and attractive forces between particles. Cohesive soils are therefore both sticky and plastic. Cohesive soils (mostly clays, but also silty clays and clay-sand mixtures with clay being predominant) exhibit generally undesirable engineering properties compared with those of granular soils. Clayey soils cannot be separated by sieve analysis into size categories because no practical sieve can be made with openings so small; instead, particle sizes may be determined by observing settling velocities of the particles in a water mixture (Coduto, 1999).

Clayey soils tend to have low shear strengths and to lose shear strength further upon wetting or other physical disturbances. They can be plastic and compressible, and they expand when wetted and shrink when dried. Some types expand and shrink greatly upon wetting and drying. Cohesive soils can creep (deform plastically) over time under constant load, especially when the shear stress is approaching its shear strength, making them prone to landslides. They develop large lateral pressures and have low permeability (Coduto, 1999).

Particle sizes in soils can vary from over 100 mm to less than 0.001mm. In BSCS the sizes ranges detailed in Figure 2.1 are specified. The terms clay, silt, sand, gravel, cobbles and boulders are used to describe only the sizes of particles between specified limits (Craig, 2004).

Clay	Silt			Sand			Gravel			Cobbles	Boulders
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse		
0.001	0.002	0.006	0.02	0.06	0.2	0.6	2	6	20	60	200
		0.01		0.1				10		100	
Particle size (mm)											

Figure 2.1: Particle size range (Craig, 2004)

2.2 Clay Soils

Soils that consist of silt, sand and, or gravel are primarily the result of physical and mild chemical weathering processes and retain much of the chemical structure of their parent rocks. However, this is not the case with clay soils because they have experienced extensive chemical weathering and have been changed into a new material quite different from the parent rocks. As a result, the engineering properties and behaviour of clays also are quite different from other soils (Coduto, 1999). Clays are generally has particle sizes less than about $2\mu\text{m}$. According to the British Soil Classification System (BSCS), clay soil comprising 35% to 100% fines where the clay particles predominate to produce cohesion, plasticity and low permeability. The characteristics of clay soil are shown at Table 2.1.

Table 2.1: Characteristics of Clay Soil (Meschyan, 1995).

CHARACTERISTICS OF CLAY SOIL	
Specific Gravity	2.55 – 2.75
Bulk Density (Mg / m^3)	1.50 – 2.15
Dry Density (Mg / m^3)	1.20 – 1.75
Void Ratio	0.42 – 0.96
Liquid Limit (%)	Over 25
Plastic Limit (%)	Over 20
Effective cohesion (kPa)	20 - 200

The properties of clay soil depend on the mineral composition of the particles, their shape and size, the type and strength of structural bonds, the structure, texture and interaction with water (Das, 2006). To construct on such soils, either pre-treatment or specially designed foundations can be used for low-cost construction to build houses and road infrastructures (Chan, 2006). It is therefore not deemed practical to be removed and replaced for construction works as this process is expensive and time-consuming. These applications require the knowledge of physical properties of soft clay and their implications on the usage of soft clay in the field.

Clay according to the Unified Soil Classification System (USCS), are fine-grained soils with more than 50% by weight passing No. 200 US Standard Sieve (0.075mm) which have much larger surface areas than coarse-grained soils and responsible for the major physical and mechanical differences between coarse-grained soils.

2.3 Batu Pahat Soft Clay

Soft soils in the grounds of Universiti Tun Hussein Onn, are low in shear strength and bearing capacity, and suffer large settlements when subjected to loading (Chan, 2006). Based on the index properties of the soil, the soil can be categorized as CH (Inorganic Clays of High Plasticity) according to Unified Soil Classification System (Robani and Chan, 2009; Chan and Ibrahim, 2008).

The physical properties of Batu Pahat soft clay at RECESS have been experimentally investigated by many researchers as shown in Table 2.2. A study carried by Chan and Ibrahim (2008), found that clay soil at RECESS, UTHM contained 10.8 % clay, 79.5 % silt and 10.7 % sand. They reported some physical properties of typical Batu Pahat soft clay at RECESS. Robani and Chan (2009) also conducted a study of Batu Pahat soft clay at RECESS test site, UTHM at a depth of ± 1.8 m. The sample was disturbed sample and the basic characteristics of the in-situ soft soil are reported with the average moisture content was about 84 %. They also identified that the clay soil at RECESS, UTHM contained 10.23 % clay, 89.2% silt and 0.57 % sand. Ho and Chan (2011) also studied the correlation of mechanical properties of Batu Pahat soft clay and the effect towards the surrounding soft clay when the soft clay is being stabilized homogenously and in a columnar system. The

mechanical properties examined included one-dimensional compressibility and undrained shear strength. They reported that the higher value of cement content, the greater is the enhancement of the yield stress and the decrease of compression index.

Table 2.2: Physical properties of Batu Pahat soft clay (Chan and Ibrahim, 2008; Robani and Chan, 2009; Ho and Chan, 2011)

Parameters	Researchers		
	Chan and Ibrahim (2008)	Robani and Chan (2009)	Ho and Chan (2011)
Bulk Density (Mg/m ³)	1.36	-	-
Specific Gravity	2.66	2.62	2.62
Plastic Limit (%)	31	32	32
Liquid Limit (%)	77	68	68
Plasticity Index (%)	46	36	-
Moisture Content (%)	-	84	85

The study indicated that Batu Pahat Soft Clay has high moisture content (Chan and Ibrahim, 2008; Robani and Chan, 2009; Ho and Chan, 2011), low shear strength, low permeability, high compressibility, shrinks when dried and expands when wetted (Chan 2006). As the moisture content increases a clayey or silty soil will become softer and stickier until it cannot retain its shape when it is described as being in a liquid state. If the moisture content is increased further then there is less and less interaction between the soil particles and slurry, and a suspension is formed. If the moisture content is decreased the soil becomes stiffer as shown in Table 2.3 until there is insufficient moisture to provide cohesiveness when the soils becomes friable and cracks or breaks up easily if remoulded.

Table 2.3: Typical moisture contents (Barnes, 2000)

Soil type	Moisture content %
moist sand	5-15
'wet sand'	15-25
moist silt	10-20
'wet silt'	20-30
normally consolidated clay low plasticity	20-40
normally consolidated clay high plasticity	50-90
overconsolidated clay low plasticity	10-20
overconsolidated clay high plasticity	20-40
organic clay	50-200
extremely high plasticity clay	100-200
peat	100->1000

Abood et al. (2007), also found that difficult problem in civil engineering works exists when the sub-grade is found to be clay soil. Soils having high clay content have the tendency to swell when their moisture content is allowed to increase. Thus, the used of stabilising agents can improve and maintain soil moisture content, increase soil particle cohesion and serve as cementing and water proofing agents in road construction.

2.4 Chemical Stabilization

Chemical stabilization involves the blending of natural soils with chemical agents such as portland cement, lime and asphalt. These agents generally are potential binders and as such effectively bind together the soil aggregates to achieve properties binders and as such as improved load, carrying and stress, distributing characteristics, and the control of shrinkage and swell (Garber and Hoel, 2009).

Chemical admixture always involves for the treatment of natural soil with some kind of chemical compound, which when added to the soil would result in chemical reaction (Bujang 2005). The chemical reaction modifies or enhances the physical and engineering properties of that soil such as volume stability and strength. However, chemical stabilized like cement, lime and bentonite has two folds effect on soil characteristics of fluctuation, the clay particles are electrically attracted and aggregated with each other. This results in an increase in the effective size of clay size aggregation and such aggregation converts clay into the mechanical equivalent of fine silt. Also, a strong chemical bonding force develops between the individual particles in such aggregation. The chemical bonding depends upon the type of stabilizer employed (Bujang 2005). The physical and mechanical properties of stabilized soils depend on several factors, mainly the properties of base material and the environmental aspects. The strength development of stabilized soil depends on many factors such as type and properties of soil, quantity and type of admixture, moisture content, mixing and compaction method, condition and curing time, temperature, soil minerals and used admixture.

Stabilized clay is the end product of “stabilization”, a ground improvement technique where chemical substances known as ‘binders’ or ‘stabilizers’ are added in existing soft soil to increase its strength and reduce its compressibility (Schaefer et al. 1997; Lin and Wong 1999). Rafizul et al. (2012) , studied the geotechnical parameters of

stabilized soil prepared in the laboratory by mixing cement, lime and bentonite at varying content of 5, 10, 15, 20 and 25 % of dry mass of organic soil. The effect of admixtures content on compressive strength (q_u), changes of liquid limit (W_L) with mixing water, variation of compaction parameters with admixture and organic content as well as develop a linear regression model using SPSS were highlighted by the author. The liquid limit of stabilized soil decreases with the increases of admixtures content, however, the stabilized soil for 100 % mixing of water had more liquid limit than that of stabilized soil of 50 % mixing of water. Moreover, the maximum dry density was increase, while the optimum water content decreases with the increasing of admixtures content. The computed compressive strength from the developed regression model was almost same as the laboratory measured value and the degree of accuracy was more accurate and reliable. The higher strength was obtained from stabilized soil that have been cured for 28 day compared with the 1, 3, 7 and 14 day cured samples, moreover cement stabilized soil depicts the highest compressive strength than that of lime and bentonite stabilized soil.

2.4.1 Cement Stabilization

Soil strengthening is required in many land reclamation projects. The desired properties of the improved soil are increased strength, reduced compressibility, and appropriate permeability to solve stability, settlement, ground water, and other environmental-related problems. Soft clay formations, especially those with high in situ water contents, are susceptible to large settlements and possess low shear strength unless they are naturally cemented. Precompression of such deposits with geodrains can prevent this large settlement and thus enhance shear strength. But this mode of attacking the problem often requires more time than is practically available. An alternative to this is cementation of the soft clay with supplementary cementing materials such as lime and cement (Horpibulsuk, *et al.*, 2004).

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. 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 (Gueddouda et al., 2011). The study

of the treatment of clays using several methods of stabilization (addition of NaCl salt, lime, cement, and association lime+ cement, and association lime + salt) show that for certain combinations the reduction rate in swelling potential more than 90% (Gueddouda et al., 2011).

Ordinary Portland Cement (OPC) is one of the most successfully used soil stabilization. It will reduce soil plasticity with resultant effects on swelling and similar behavior (Marian & Raymond, 1999). They found that the improvement of soil characteristics depended on the chemical components of cementing agent and the properties of the soil. OPC and soil mixed at the proper moisture content has been used increasingly in recent years to stabilize soils in special situations. The hardening process of cement stabilized soils happens immediately upon mixing soil with cement slurry. The hardening agent produces the hydrated calcium silicates, hydrated calcium aluminates, and calcium hydroxide and forms hardened cement bodies.

In other study, Saadeldin et al. (2006), evaluated the performance of a road embankment constructed on cement-stabilized soft clay (CSC). The undrained shear strength of the soft clay was experimentally determined before and after stabilization with cement. The results of the experimental work were used to simulate the behavior of the foundation soil under the road embankment using a 2-D finite element model. The foundation soil consisted of two layers: CSC having a variable thickness ranging from 1 to 5m, followed by soft clay layer extending to 15m below ground surface. The performance of the embankment founded on CSC was compared to that obtained if the CSC was replaced with compacted sand fill. Cement stabilization enhanced the performance of the embankment with respect to safety against shear failure more than sand soil replacement. It also found, the unconfined compressive strength of cement-stabilized soft clay increased as the cement content increased. The unconfined compressive strength increased as the curing time increased up to about 28 days, after which the compressive strength practically stabilized.

The physical properties of soil cement depend on the nature of soil treated, the type and amount of cement utilized, the placement and cure conditions adopted (Purushothama, 2005). He suggested that soil-cement content varying from 5% to 20% for satisfactory stabilization. For clays, cement content may range from 3 to 16% by dry weight of soil, depending on the type of soil and properties required. Generally as the clay content of soil increases, so does the quantity of cement required (Bell, 1996).

2.4.2 Lime Stabilization

Lime is produced by burning limestone. Laboratory testing indicates that lime reacts with medium, moderately fine, and fine-grained soils to produce decreased plasticity, increased workability, and increased strength (Little, 1995). Strength gain is primarily due to the chemical reactions that occur between the lime and soil particles. These chemical reactions occur in two phases, with both immediate and long-term benefits. The chemical reaction involves immediate changes in soil texture and soil properties caused by cation exchange. In addition, the mixture of soil and lime must be thoroughly compacted; otherwise the desirable cementation will not take place (Holt, 2010).

Bell (1996) and Guney et al. (2005) indicated that, flocculation is primarily responsible for the modification of the engineering properties of clay soils when treated with even a small amount of lime. The studies also showed that the addition of lime increased the optimum water content, shrinkage limit and strength, and reduced the swelling potential, liquid limit, plasticity index and maximum dry density of the soil. Guney found that the optimum addition of lime needed for the stabilization of the soils is between 2% and 8% lime by dry weight of the soil.

Lime stabilization results in higher bearing capacity and lower compressibility of the treated soil mass (Deboucha et al., 2008). They found, increase in CBR value corresponded to increase of the additives content and curing period. Furthermore, the added lime reacts with the pore water, resulting in chemical bonding between soil particles, a reduction in water content and, in turn, an increase in undrained shear strength. While, according Wahab et al. (2011), lime stabilization creates a number of important engineering properties in soils to improved workability, providing a working platform for subsequent construction, reducing plasticity to meet specifications, conditioning the soil for further treatment.

Amu et al. (2011) studied the suitability and lime stabilization requirement of some selected lateritic soil samples as pavement construction materials. Soil samples A, B, and C collected from a dam site and stabilized with 0, 2, 4, 6, 8, and 10% of lime were subjected to preliminary tests (natural moisture content, specific gravity, particle size analysis and Atterberg's limits) and strength tests (compaction, California bearing ratio (CBR), unconfined compression and undrained triaxial). Results of the preliminary tests classified the samples as fair to poor pavement construction materials. The suitability of

samples A, B and C was improved by optimum lime stabilization at 8, 6, and 6% respectively. The addition of lime to the samples caused a reduction in the plasticity indices of the samples. The CBR of A increased from 10.6% at 0% to 29.0% at 8% lime, while that of C improved from 2.5% to 8.6% at 6% lime. The compressive and shear strengths were also improved; the uncured compressive strength of B improved from 119.13kN/m² at 0% to 462.81 kN/m² at 6% lime. With optimum stabilization, samples A and B will be suitable as base materials while sample C will perform well as sub-grade material in pavement construction. The optimum lime contents for samples A, B and C are 8, 6 and 6% respectively. In their natural states, samples A and B will be suitable for sub-grades and fairly for sub-bases and unsuitable for base courses while sample C is unsuitable for any of these. However, samples A and B can be made suitable as base course material in pavement construction if stabilized with lime at optimum lime contents of 8 and 6% respectively.

2.4.3 Natural Sodium Bentonite Stabilization

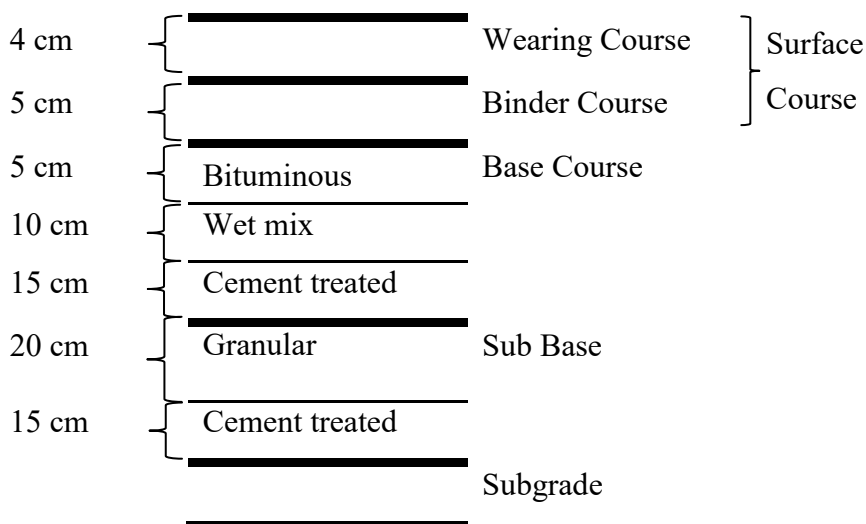
Many researchers have studied the mechanism that contributes to the stabilization process of soils treated with natural sodium bentonite. According Hashim and Islam (2008), to evaluate the strength characteristics of stabilized peat, laboratory investigation on early strength gain of the stabilized soil was conducted to formulate a suitable and economical mix design that could be effectively used for the soil stabilization. To achieve such purpose, the study examined the effect of binder, sodium chloride as cement accelerator and siliceous sand as filler on the unconfined compressive strength of stabilized peat soils after 7 days of curing. Binders used to stabilize the peat were Ordinary Portland cement, ground granulated blast furnace slag, natural sodium bentonite, kaolinite, lime and bentonite. Ordinary Portland cement and sodium bentonite have been mixed in a ratio of 85:15 and well graded sand (25% by volume of wet peat) has been mixed in mixing machine. The test results revealed that the stabilized peat specimen (80% OPC: 10% Ground Granulated Blast Furnace: 10% Natural Sodium Bentonite) with addition of 4% sodium chloride by weight of binder and 50% well graded siliceous sand by volume of wet peat at 300 kg m⁻³ binder dosage yielded the highest unconfined compressive strength of 196 kPa. Such finding implied that the higher the dosage of siliceous sand in stabilized peat, the more solid particles were available for the binder to

unite and form a load sustainable stabilized peat. The results also found that strength increased with increasing in curing time.

Sing et al. (2008), was conducted field and laboratory study to find engineering properties of peat soil and to stabilise peat soil collected from Peninsular, Malaysia. A set of fabricated mixing tools and tools for injecting binder were used in this experiment. Ordinary Portland cement, natural sodium bentonite and well graded sand were used as binder. Unconfined compression test was performed to observe effect in unconfined compressive strength after stabilisation. The test was conducted after 1day, 3 days, 7days and 28 days to examine the effect of curing time on strength. Mixing quality and formation of column was observed by visual inspection. It was observed that the unconfined compressive strength of stabilised column was increased considerably. Strength of stabilised column increases with the increases of curing time. 28 days strength is 50% higher than the strength of 7 days.

2.5 Road Construction

Roads are built up in several layers, consisting of *sub-grade*, *sub-base*, base and surface layer. These layers together constitute the *pavement* as shown in Figure 2.2. Subgrade is the uppermost part of the soil, consists of natural or imported soil to supporting the load transmitted from the overlying layers (Arahan Teknik Jalan 5/85, Public Works Department). Therefore, subbase course serves as an aid to disperse the load from the base course before transmitting it to the subgrade. The base course which is overlying the subbase course plays a prominent role in the support and dispersion of the traffic loads. Surface course consists of binder course and wearing course. Binder course layer works as a supporting, dispersing traffic load and resists shear, while the topmost layer (wearing course) resists abrasion and prevent skidding.



**Figure 2.2: Cross-section of a flexible pavement with minimum layer thickness
(Arahan Teknik Jalan 5/85, Public Works Department)**

A soft sub grade in construction of roadways is one of the most frequent problems for highway construction in many parts of the world. These problematic soils do not possess enough strength to support the wheel loads upon them either in construction or during the service life of the pavement. The usual approach to soft subgrades stabilization is removes the soft soil, and replaces it with stronger materials likes crushed rock. The high cost of replacement causes highway contractors to explore alternative methods of highway construction on soft sub grades (Gueddouda et al., 2011). This soil must be, therefore, treated to provide a stable subgrade or working platform for the construction of the pavement. One of the strategies to achieve this is soil stabilization. The soil stabilization includes both physical stabilization (such as dynamic compaction) and chemical stabilization (such as mixing with cement, fly ash, and lime). One of the most important layers of the road is the subgrade. Where the subgrade is founded in an inherently weak soil, this material is typically removed and replaced with a stronger granular material.

Chemical soil stabilization has been widely practiced in many countries to stabilize the soft sub grade. Chemical soil stabilization using lime, cement and other chemical stabilizing agents for road construction is applied in Brunei, USA, Canada, Japan, Indonesia and Malaysia (Qing and Cheong, 2008). Holt (2010) conducted chemical soil stabilization in Canada as an alternative to ensure the engineering characteristics and performance of the host material is enhanced to allow for its use within the pavement structure. In the treatment process, he used the following phases:

- a) Preparation of soil
- b) Spreading of the hydraulic binder on the soil to be treated as shown in Figure 2.3.
- c) Mixing of the hydraulic binder into the soil at a prescribed depth as shown in Figure 2.4.
- d) Compaction of the treated material at the appropriate water content and grading to final level depth as shown in Figure 2.5.



Figure 2.3: Spreading of hydraulic binder as a powder and as a slurry (Holt, 2010)



Figure 2.4: Self-powered rotary mixers blending host soil and hydraulic binders (Holt, 2010)



Figure 2.5: Initial compaction (pad foot) followed by final compaction (steel wheel) (Holt, 2010)

Many researchers conducted the laboratory investigation on chemical stabilization such as lime, portland cement (PC), fly ash and bottom ash as stabilizer of six types of clay sub-grades from random places in Kuantan, Pahang (Wahab, Nazmi and Rahman, 2011). The California Bearing Ratio (CBR) tests were performed to determine the strength properties of the soil–lime, soil-PC, soil-fly ash and soil-bottom ash mixtures and the optimum mixture contents which can achieve better preferred sub-grade. Stabilized soil specimens were prepared at 4%, 8%, 12% lime, PC, fly ash and bottom ash. The samples were subjected to compaction tests and CBR tests. In this study the engineering properties quality improved by adding PC, fly ash and bottom ash as stabilizer in soil stabilization (Wahab, Nazmi and Rahman, 2011). The increasing CBR value with increasing PC, fly ash, bottom ash content for all sample tested have the potential to offer an alternative for clay soil subgrades improvement of highway construction and this will reduce the construction cost and solving disposal problems.

Chan and Ibrahim (2008) investigated the modified soft soil in Batu Pahat in order to recommend methods to improve its suitability for road construction. They included raw rice husk in their study as stabilizer. The geotechnical investigations indicated that the alternative road construction materials especially in rural area can be produced from modified soft soils, where the initially weak and soft material was significantly improved and strengthened.

2.6 Engineering Properties

Engineering properties soil classifications have been evolved based on the suitability of a soil for use as a foundation material or as a construction material (Venkatramaiah, 2008). He stated that engineering properties of soil are important as a preliminary guide to the engineering behaviour of the soil. Therefore, an engineering soil classification should be conducted in connection with the use of soil in any important project, since different properties govern the soil behaviour in different situations. Furthermore, the engineering properties are a function of the proposed end utilization (Holt, 2010).

The fundamental engineering properties of stabilized soil have been experimentally investigated by many researchers. The role of cement kiln dust and volcanic ash on the strength development in the blended cement admixed clay has been investigated for low-cost construction to build houses and road infrastructures (Hossain & Mol, 2011). These

investigations mainly focus on the influence of water content and cement content on the engineering properties. They conducted comprehensive series of laboratory tests consisting of standard Proctor compaction, unconfined compression strength, splitting tensile strength, modulus of elasticity, California bearing ratio (CBR).

Miqueleiz et al. (2012) observed the engineering properties of stabilised Spanish clay soil in producing an economical, ecological and sustainable building material especially for clay masonry bricks production. The laboratory tests consisting of compaction effort, compressive strength, rate of water absorption, density and durability were used as a practical indicator to investigate the strength development of unfired masonry bricks.

2.6.1 Soil compaction

The compaction effort test conducted by Miqueleiz et al. (2012) shows that in order to obtain maximum strength and durability of clay soil, it is necessary to carefully establish the kind and quantity of additive used, the optimum moisture content to maximize the compaction effort and the achievable dry density. Using the compaction results, the different mix combinations were moulded as near to their optimum moisture contents as possible, thus enhances engineering properties and optimizing compaction effort. The effect of stabilizers on maximum dry density and optimum moisture content was studied by Hossain and Mol (2011). They found that maximum dry density decreases and the optimum moisture content increases with the increase of volcanic ash, lime, fly ash and rice husk ash stabilized clayey soils

2.6.2 Shear Strength

The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside it. For most soil mechanics problems, it is sufficient to approximate the shear stress on the failure plane as a linear function of the normal stress. The shear strength of a soil in any direction is the maximum shear stress that can be applied to the soil structure in that direction. When this maximum has

been reached, the soil is regarded as having failed, the strength of the soil having been fully mobilized (Murthy, 2008). Stabilization of a soil is commonly assessed in terms of strength gain over a certain period of time (cure). Strength gain is typically assessed by unconfined compressive strength (UCS) shear strength testing (Holt, 2010). According to Murthy (2008), UCS is preferred for clays because that UCS strength can exist only for clay by virtue of their cohesion component of the shear strength.

2.6.2.1 Unconfined Compression Strength

The UCS tests are carried out only on saturated samples which can stand without any lateral support (Murthy, 2008). Therefore, it is applicable to cohesive soils only. The test is an undrained test and based on the assumption that there is no moisture lost during the test. There are currently many researches in the field of soft soil stabilization used UCS tests around the world. Kalantari and Huat (2008), studied the potentialities of those stabilizers for peat soils. He included Ordinary Portland Cement (OPC) as binding agent and Polypropylene fibres as additive. The result of strength tests show significant strength improvement of stabilized peat soil after 28 days curing period. These suggested that the UCS values will increase through air curing process caused stabilized peat soil samples to gradually lose their moisture contents and become drier and as the stabilized peat soil become drier (water content is reduced).

Ali (2012), studied the improvement of engineering properties mixed with different proportions of liquid chemical consists of lime, cement and fly ash. The results showed that the liquid stabilizer is effective to improve strength especially after 7 days of curing period. He suggested that the chemical components of the liquid stabilizer were actively reacted with the clay platelets. The clay platelets that were neutralized were orderly arranged and produced relatively better inter particles bonding between each molecule. Higher inter particle bonding between each molecule is an indication of strength improvement.

The ratio of the unconfined compressive strength of the stabilized soil to that of the untreated and undisturbed soil is known as strength gain factor and strength gain effective factor respectively (Das, 1994) as in Equation 3.8 and Equation 3.9. Furthermore, Das (1994) suggested the general relationship between unconfined compressive strength and the quality of the subgrade soils used in pavement applications as in Table 2.4.

Table 2.4: Relationship between unconfined compressive strength and the quality of the subgrade (Das, 1994)

q_u value (kPa)	Quality of Subgrade
<25	Very soft
25-50	Soft
50-100	Medium
100-200	Stiff
200-380	Very stiff
>380	hard

Study was carried out by Horpibulsuk, Rachan, and Suddeepong (2011) to investigate the role of fly ash and biomass ash on the strength development of cement admixed low-swelling Bangkok clay. The unconfined compressive (UC) test and thermal gravity (TG) analysis tests were performed at fly ash and biomass ash vary from 0% to 60% by weight of cement. Unconfined compression (UC) tests were run on samples after 7, 14, 28, 60, 90, and 120 days of curing. The relationship among strength, cement ratio, and curing time for the blended cement admixed Bangkok clay is verified. It results showed, an addition of 25% ash is recommended for effectively increase the stiffness of the soft clay and economic mix design.

Further Robani and Chan (2009), conducted bender element test to evaluate the potential benefit of admixing potential of palm oil clinker (POC) in cement stabilization of soft clay. The specimen consisted of 5 % cement and various amounts of POC that was 5, 10 and 15 % respectively. The specimens were cured for 3, 7, 14 and 28 days before being tested using bender element test. The results showed that the cement-POC as a soft soil stabiliser could effectively improve the stiffness of originally soft and weak clays.

Ho and Chan (2011) studied the correlation of mechanical and chemical properties of Batu Pahat soft clay and the effect towards the surrounding soft clay when the soft clay is being stabilized homogenously and in a columnar system. Comparisons were made for both homogeneous and columnar system specimens by relating the effects of cement stabilized clay of for 0, 5 and 10 % cement and curing for 3, 28 and 56 days. They showed that the strength of cement stabilised is dependent upon the value of cement content. To obtain high strength, enhancement of the yield stress and the decrease of compression index, which can be achieved either by increasing input of cement content.

2.6.3 Permeability

Permeability refers to the movement of water within soil. Actual water movement is through the voids, which might be thought of as small, interconnected, irregular conduits. Because the water moves through the voids, it follows that soils with large voids (such as sands) are generally more permeable than those with smaller voids (such as clays). Additionally, because soils with large voids generally have large void ratio, it may be generalized that permeability tends to increase as the void ratio increase. Because water movement can have profound effects on soil properties and characteristics, it is an important consideration in certain engineering applications (Craig, 2004).

A study was carried by Wong et al. (2008) found that peat soil stabilized by a mixture of Ordinary Portland Cement, ground granulated blast furnace slag and siliceous sand was able to reduce initial permeability with increasing curing time. They found that the reduction of coefficient of permeability in the stabilized peat soil is dependent on several factors: fluid viscosity, pore-size distribution, grain-size distribution, void ratio and degree of saturation. In clayey soils, structure plays an important role in the coefficient of permeability. Other major factors that affect the permeability of clays are the ionic concentration and thickness of layers of water held to the clay particles.

Marzano et al. (2008) conducted a laboratory testing to examine the effect of the cement and different soils (gravely sand, silty clayey gravely sand, silty clay and pure clay) on the mechanical and physical properties of the resulting treated soils. They found that an increase in the binder content results in a reduction in the permeability of the stabilised soils. Furthermore, the soil type has a great influence on the permeability of stabilised soils and that the presence of clay and silt, in the treated soil, results in lower permeability values. The permeability value is also influenced by the water : cement ratio.

Laboratory tests are relatively simple and inexpensive to carry out and are ordinarily performed following either the constant-head method or falling-head method. The falling head method can be used to find the coefficient of permeability for both fine-grained soils and coarse-grained, or granular, soils. The falling head permeability test is used for measuring the permeability of soils of intermediate and low permeability, i.e. silts clay. The value of the coefficient of permeability (k) varies widely for different soils. Typical

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