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IMPROVEMENT OF SOIL GEOTECHNICAL PROPERTIES USING PULVERIZED FUEL ASH

Uwieng anak Gimos

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Dedicated to my family and beloved one

IMPROVEMENT OF SOIL GEOTECHNICAL PROPERTIES USING PULVERIZED FUEL ASH

UWIENG ANAK GIMOS

This project is submitted in partial of fulfillment of
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ABSTRACT

The present study aimed at the use of locally available pulverized fuel ash (PFA) from Sejingkat Power Corporation (SPC), Kuching, Sarawak, to improve the geotechnical properties of soil. To achieve this, the soil samples were mixed with different percentages (i.e., 5, 10, 15 & 30%) of PFA contents. The amount of PFA added was on the basis of mass replacement (i.e., Soil-PFA mixture with 30% of PFA means, 70% of Soil and 30% of PFA). Standard Proctor test and California Bearing Ratio (CBR) test were conducted to determine the strength of the mixtures. The compaction results reveal that there is an increase in maximum dry density with the increase of PFA, while decreasing in optimum moisture content (OMC). The soaked CBR values for Soil-PFA mixtures were found to increase by 0.784% and 0.12% with the increase of PFA content of 15% and 30%, respectively. The improvement of engineering properties of soil indicates that PFA can be used as a soil stabilizer and it would also provide an opportunity for the utilization of an industrial waste.

ABSTRAK

Kajian yang telah dijalankan bertujuan menggunakan *pulverized fuel ash* (PFA) tempatan yang diperolehi dari Sejingkat Power Corporation (SPC), Kuching, Sarawak, untuk memperbaiki ciri-ciri geoteknikal tanah. Untuk mencapai tujuan ini, sampel tanah telah dicampur dengan peratusan PFA yang berbeza (iaitu 5, 10, 15 & 30 peratus). Jumlah PFA yang ditambah ke dalam sampel tanah adalah berdasarkan penggantian jisim (contohnya campuran tanah-PFA dengan 30% PFA bemaksud, 70% peratus tanah dan 30% PFA). Eksperimen Standard Proctor dan California Bearing Ratio (CBR) telah dijalankan untuk menentukan kekuatan campuran itu. Keputusan eksperimen pemadatan telah menunjukkan peningkatan dalam nilai *dry density* maksimum manakala penurunan dalam kandungan kelembapan minimum (OMC) dengan meningkatnya kandungan PFA. Nilai CBR untuk campuran tanah-PFA yang direndam didapati meningkat masing-masing sebanyak 0.784% dan 0.12% dengan peningkatan kandungan PFA dari 15% dan 30%. Peningkatan dalam ciri-ciri geoteknikal tanah menunjukkan yang PFA boleh digunakan untuk menstabilkan tanah dan ia juga menyediakan peluang untuk menggunakan sisa pembuangan industri ini.

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ϕ	angle of internal friction
%	percent
c	cohesion
cm	centimeter
C_v	coefficient of consolidation
D	diameter
g/cm^3	gram per cubic centimeter
G_s	specific gravity
in	inches
K	percentage by mass finer than D
kg	kilogram
kN/mm^2	kilo Newton per milimeter square
kPa	kilo Pascal
LL	liquid limit
m	meter
m^2/kg	meter square per kilogram
mm	millimeter
^oC	degree Celcius
PI	plasticity index
PL	plastic limit
q_u	unconfined compressive strength
t	elapsed time
γ_b	bulk density
$\gamma_{d\ max}$	maximum dry density
ε	strain
η	dynamic viscosity of water
μm	micrometer
ω	moisture content

CHAPTER 1

INTRODUCTION AND OBJECTIVE

1.1 Introduction

Soil improvement is probably the oldest but, from a technical point of view, still the most intriguing technique of all common execution methods in civil engineering. Nowadays, improvement of soil is or frequently termed *soil stabilization* becoming more feasible and attractive. It is possible to improve the engineering properties of soils by mechanical stabilization or with the addition of chemical stabilizers. Several efforts have been made by different researchers to improve the geotechnical properties of soils by the addition of various additives such as lime, pulverized fuel ash (PFA), cement, chemicals etc. independently as well as an admixture of different percentages. It is apparent from the test results that the stabilization agents improved the geotechnical properties of the soil. Examples of soil improvement are increased strength, reduced compressibility and reduced permeability.

In thermal power plants, the total amount of coal ash (i.e., Pulverized Fuel Ash, PFA) produced consists of *fly ash* and the *bottom ash*. The PFA can be, and is being successfully used, for different applications. Some of these applications are listed below:

- as a stabilizer of sub-grade and sub-bases in pavement construction,
- as a filler material, specially for the reclamation of low lying waste lands and refuse dumps, filling of mines, to improve foundation soils, etc.,
- treatment of polluted water and soils unsuitable for agriculture,
- used as canal lining,
- to dry out wet soils, due to high permeability values,

- in the removal of heavy metal ions from aqueous solution, by precipitation and adsorption,
- in making different types of bricks and other building units,
- to manufacture sintered aggregates for making lightweight concrete, and
- for replacement of cement in mass concrete construction (such as dams and barrages).

Binding property rather than the self-hardening property is the most important property of the PFA in most of these applications. Pulverized fuel ash (PFA) is a pozzolan, i.e., it reacts with CaO and water to form cementitious material. Several researchers have shown that the binding property of the PFA increases with addition of lime, cement and other chemicals. However, characteristics of the PFA from Sejingkat thermal power plant, Kuching, Sarawak, as such, as a construction material or as a stabilizer agent of soft soil, have not been studied in details. This would be of great importance in making a judicious choice for PFA utilization and evolving a methodology to work out the finer details for the same. Pulverized fuel ash (PFA), has been used for many years for a variety of applications such as an additive that and has been found very beneficial in the stabilization of soil (Ferguson, 1993).

However, not much attention has been paid locally to the characterization and the use of PFA as a stabilizer for the acute soft soil problem in Sarawak. This study, therefore, also aims to characterize the local PFA for the investigation of its potential feasibility as a stabilizer for soft soil.

1.2 Ash production

Pulverized fuel ash (PFA) is a mineral by-product that typically results from coal combustion at electric power generating plants. Coal is crushed into powder or "pulverized" before it burnt as the fuel to generate electricity. The ash produced from the burning of pulverized coal in a coal-fired boiler is a fine-grained, powdery particulate material. The pulverized coal leaves two types of ash; the first looks like grey sand and is known as Furnace Bottom Ash (FBA); the second looks like grey powder and is known as Pulverized Fuel Ash (PFA). Physically, PFA is primarily made up of spherical particles ranging in size from 2 to 200 microns. FBA though chemically the same as PFA, is much coarser and falls to the bottom of the furnace where it is collected.

1.3 Properties of pulverized fuel ash

Pulverized fuel ash (PFA), or fly ash as it is known in many countries, has pozzolanic, chemical and physical properties. These properties are important for uses in geotechnical engineering. Bulk uses of PFA are found in many geotechnical applications such as embankments, fill behind retaining walls, reclamation fill, dams, etc. The properties of PFA that are important for use in geotechnical engineering are low unit weight, low compressibility and pozzolanic reactivity. Compared with other properties, pozzolanic reactivity is found to vary more from one PFA to another. Pozzolanic means that it will react with lime and moisture to form cementitious compounds producing strength increases with time. This pozzolanic property makes them valuable as a stabilizing agent for soils. The pozzolanic reactivity of fly ash depends on its reactive silica, free lime content, fineness, carbon content and iron content. However, strength gains are variable and depend on the exact composition of PFA.

1.3.1 Physical properties

PFA consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The carbonaceous material in PFA is composed of angular particles. The particle size distribution of most particles of PFA is between 2 to 200 microns diameter, i.e. fine sand to fine silt. The specific gravity of PFA usually ranges from 2.1 to 3.0, while its specific surface area may range from 170 to 1000 m^2/kg. The colour of PFA can vary from tan to grey to black, depending on the amount of unburned carbon in the ash. The carbon content is lower as the lighter of the colour. Lignite PFA are usually light tan to buff in colour, indicating relatively low amounts of carbon as well as the presence of some lime or calcium. Bituminous PFA are usually some shade of grey, with the lighter shades of grey generally indicating a higher quality of ash.

1.3.2 Chemical properties

The chemical properties of PFA are influence by those of the coal burned and the techniques used for handling and storage. There are basically four types of coal, each of which varies in terms of its heating value, its chemical composition, ash content, and geological origin. The four types of coal are anthracite, bituminous, subbituminous, and lignite. In addition to being handled in a dry, conditioned, or wet form, PFA is also sometimes classified according to the type of coal from which the ash was derived. The PFA basic components of PFA are oxides of silicon (SiO_2), aluminium (Al_2O_3), iron (Fe_2O_3) and calcium (CaO). Other constituents include magnesium oxide (MgO), sulphur oxide (SO_3), sodium oxide (Na_2O) and potassium oxide (K_2O). As per American Society of Testing Materials, ASTM, C618 has two classes of fly ash:

- Class F Fly Ash: Primarily from bituminous coal, has high silica and high alumina content. In Class F fly ash, total calcium oxide (CaO) typically ranges from 1 to 12 percent.
- Class C Fly Ash: Primarily from sub-bituminous and lignite coal, has higher lime content and may be cementitious. In contrast, Class C fly ash may have reported calcium oxide (CaO) contents as high as 30 to 40 percent.

It is important to recognize that not all fly ashes are able to meet requirements, then it generally to apply to PFA on the basis of its original coal type or Calcium Oxides (CaO) content.

1.4 Objectives

The objective of this study is to first characterize the locally produced PFA, such as at Sejingkat Thermal Power Plant (STPP) and to ascertain the effectiveness of pulverized fuel ash (PFA) as soil improvement or stabilizing agent.

The main objectives of the project work are as follows:

1. Physical characterization of the pulverized fuel ash (PFA) and soil.
2. To investigate the effect of pulverized fuel ash on soil and the changes of the geotechnical characteristics of soil.
3. To obtain the appropriate proportion of admixtures and
4. To recommend the use of pulverized fuel ash as soil stabilizer

This study will give an alternative to admixtures such as lime, cement and chemicals, which are costly for soil stabilization.

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter reviews the existing literature on pulverized fuel ash (PFA) or often termed as fly ash, as a soil stabilizer. The first part of the literature review deals with the general stabilization process with PFA alone or with the addition of lime or cement. While, the second part presents the stabilization of soil specially the subgrade soil stabilization with PFA.

2.2 Soil stabilization

Indraratna, *et al.* (1991) has studied the influence of fly ash on the stabilization of a dispersive soil in Thailand. The research discussed the effect of various proportions of fly ash on the rate of erosion, dispersiveness, strength and frictional properties and the compaction and consolidation characteristics. Based on the experimental findings of this research, addition of fly ash up to 8 % will increases the rate of erosion due to loss of cohesion of the blended soil. However, the compressive and shear strength continue to increase at higher fly ash contents. The maximum dry density also increases while optimum moisture content of the treated dispersive soil decreases in the addition of fly ash. The peak strength of unconfined compressive strengths stabilized samples is attained at curing period of two weeks. This relates that the self-hardening nature of fly ash which contributes to time-dependent strengthening of the stabilized soil. Preconsolidation pressure also increases at fly ash content up to 8 %, while the compression index decrease continuously with the fly ash content. This indicates that the stabilized soils would experience lower settlements compared to natural soil at the same surcharge load.

McManis, *et al.* (1993) carry out a research to further evaluate the characteristics of locally produced fly ash and to develop test procedures that would further the evaluation of fly ash stabilized soils. Comparisons of fly ash stabilization with materials from the well-established cement and lime stabilization techniques were also required. In this research, the soil types used are A-3 sand and bentonite clay. The stabilizers used with the sand were cement, fly ash, and mixtures of lime and fly ash with various percentages respectively. A unique relationship exists between maximum dry density, optimum moisture, and the percentage of fly ash used with sands. The largest dry density corresponds to the least amount of compaction water, which is at optimum moisture content. For the different percentages of Portland cement or Class C fly ash alone, the strength curves shows a guide for predicting the percentages of fly ash required to produce comparable strengths developed with soil cement. Use of lime with the Class C fly ash in sand and coarse aggregates was observed for long-term advantages.

Indraratna, *et al.* (1995) studied the effect of fly ash with lime and cement on the strength and deformation characteristics of Bangkok clay. The results shows that after two weeks of curing, compressive strength of 2-3 times greater than the natural clay when treated with 18% fly ash and 5% lime. With fly ash contents greater than 25%, it causes tensile splitting of unconfined compression. In the other hand, if cement is use instead of lime, the initial rate of strength increases significantly. This study has shown that the coefficient of consolidation (C_v) can be increased 15 to 20 times by a relatively high fly ash content (18% - 25%) with a small amount of cement (not greater than 5%).

Indraratna, (1996) carry out a study on utilization of hydrated lime, milled slag and fly ash on the engineering behaviour was performed on an erosive (fine grained) colluvial soil in New South Wales, Australia. The effect of admixtures on the stabilization of colluvial deposits of poor geotechnical properties is the main purpose of this study. Particularly, hydrated lime and milled slag treated specimens showed an improvement in their engineering properties. In contrast, the significant results could not be obtained by blending with the fly ash due to the very low, free lime content (ASTM Class F). For instance, the uniaxial compressive strength increases from 2250 kPa to 4000 kPa with 5 % of lime content. However, fly ash does not significantly increase the compressive strength. The compressibility of the stabilized soil decreases the consolidation results for all three additives. This study presents that small percentage (5%) of additives are adequate to achieve the maximum friction angle of the blended specimens (i.e. 47° for slag, 43° for lime and 42° for fly ash).

Conn and Sellakumar, (1999) worked out a study on utilization of Circulating Fluidized Bed (CFB) Fly Ash for construction applications. The effects of composition of fly ash on unconfined compressive strength and the technical feasibility of CFB ash use in construction applications are the objectives of this work. CFB ashes can be used for variety of construction applications including cement replacement and manufacturing, structural fills road base, synthetic aggregate, and soil stabilization. On the soil stabilization area, the effect of CFB fly ash addition on the strengthening of clays was evaluated. The mixture of 15% fly ash was added to fine kaolinite and illite clays. CFB ashes that exhibit self-cementing characteristics have been proposed as feasible stabilizing agents. High-sulfur bituminous and petroleum coke fly ashes resulted in significant strengthening of the clays, probably due to their relatively high free lime contents. The refuse derived fuel (RDF) fly ash did not increase the strength of the clays significantly. Based on the results of this work, the CFB ashes can be used for construction applications depends to test and application standards.

Misra, (2000) conducted a research on utilization of western coal fly ash in construction of highways in the Midwest using sub-bituminous coal from Wyoming. This research project focused upon the design, construction and environmental issues relates to utilization of Class C fly ash for soil stabilization. The design issues for Class C fly ash soil stabilization may be approach through laboratory experimentations using eight different soils. The soil-fly ash blends exhibited up to three times strength gain when compacted without delay after blend preparation, but 60% loss in strength after 2-hour delay. The environmental issues for leaching behaviour where Class C fly ashes that leach a very small quantity of contaminants. Therefore, these Class C fly ashes are particularly suited for use as soil improvement agents.

Sahu and Piyo, (2001) also conducted an investigation to improve the strength characteristics of white Kalahari sands by adding fly ash alone as a stabilizer. There is a significant increase in both UCS and CBR value with the increase of fly ash proportion and the curing time. For pure sand, the UCS value is zero but with the addition of fly ash and after 21 days of curing, the UCS increased to a limit of about 240 kN/m^2 with 32 % addition of fly ash. The CBR increased from 30 % for pure sand to 60 % with addition of 20 % of fly ash and the Maximum Dry Density (MDD) decreases while Optimum Moisture Content (OMC) increases. With fly ash more than 32 % and 21 days of curing both unconfined compressive strengths and California Bearing Ratio (CBR) are increased to a level which makes the material suitable for sub-base and base course of a low traffic road.

Pandian, *et al.* (2001) investigates the effect of different percentages of fly ash addition to black cotton soil on California Bearing Ratio values. The study indicates that CBR values of black cotton soil/fly ash mixtures increase up to an optimum fly ash content wherein fly ash acts as a coarser material. In contrast, when black cotton soil acts as a binder, the CBR values decrease beyond this optimum fly ash content and again increase to an optimum value. The investigation reveals that there are two optimum fly ash content values at which black cotton soil/fly ash mixtures give the higher CBR values. The results prove that the effective utilization of fly ash can be effective admixtures for improving the soil quality. On the other hand, afford a means to disposal of the industry byproduct without adversely affecting the environment in India.

Wartman and Riemer, (2002) used the Class C fly ash to alter the geotechnical properties of artificial model clay. This fly ash acted as a chemical reactive material attribute to the high calcium oxide content when mixed with artificial kaolinite-bentonite model clay. The soil is stiffened because of cementacious pozzolanic reaction when fly ash is added to the model clay. The fly ash-clay mixture are remolded several days after initial mixing to avoid increased of the strength of the model soil.