CRITICAL STATE OF FLY ASH-BOTTOM ASH MIXTURE

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To my beloved father and mother

To my beloved husband and his family

To my dear brother

For their never ending care and support

Thank you for everything

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ABSTRACT

The burning of coal in the process of generating electricity, leads to the production of solid waste such as the fly ash and bottom ash. Numerous studies had been carried out to determine the mechanical properties of fly ash and also bottom ash. An extension of these studies is necessary in order to explore further usage of these ashes, in particular when mixed together in optimum percentage. The critical state boundary surface of the soil or material is important to identify the limit of stress imposed from various stress level and stress history. Hence, this study aimed at developing the critical state boundary surface of a mixture of 60% fly ash and 40% bottom ash by weight, is vital. The results obtained could be used as a guideline when working in the future with coal ash mixture of the same mix ratio. The samples used in this study were collected from Tanjung Bin power station in Johor, Malaysia. The fly ash-bottom ash mixture used in this study had a liquid limit of about 22% and behaved as non-plastic material. The mixture is classified as well-graded sandy silt with specific gravity of about 2.36. From the compaction test it showed that the maximum dry unit weight of this mixture is 14.54 kN/m^3, achieved at 8.5% optimum water content. The critical state parameters of the mixture obtained in this study are λ= 0.032, κ = 0.013, ζ=0.035, N=1.85 and M=1.152. From the critical state parameters obtained, the critical state boundary surface of fly ash- bottom ash mixture (60:40% by weight) had been established.

ABSTRAK

Pembakaran arang batu yang digunakan di dalam proses penjanaan kuasa elektrik telah menyebabkan penghasilan sisa pepejal seperti abu terbang dan abu dasar. Pelbagai kajian telah dijalankan untuk menentukan sifat mekanikal abu terbang dan abu dasar ini. Lanjutan kepada kajian ini perlu dijalankan bagi mengkaji dengan lebih mendalam kegunaan sisa-sisa abu ini terutamanya apabila di campurkan bersama dalam peratus yang optimum. Sempadan permukaan keadaan genting bagi tanah atau bahan adalah penting bagi menentukan had kepada tegasan yang boleh dikenakan, yang mungkin bermula pada tahap dan sejarah tegasan tertentu. Oleh itu, kajian ini yang dijalankan bertujuan untuk menghasilkan sempadan permukaan keadaan genting bagi campuran abu terbang dan abu dasar pada nisbah berat 60% abu terbang dan 40% abu dasar, adalah sangat penting. Hasil keputusan daripada kajian ini boleh dijadikan sebagai panduan kepada kerja-kerja yang melibatkan campuran abu arang batu dengan nisbah campuran yang sama pada masa hadapan. Sampel kajian telah diambil dari stesen janakuasa Tanjung Bin di Johor, Malaysia. Campuran abu terbang - abu dasar yang telah digunakan didalam kajian ini mengandungi had cecair sebanyak 22% dan berkeadaan tidak plastik. Campuran ini juga diklasifikasikan sebagai kelodak berpasir bergred baik dengan nilai graviti tentu sebanyak 2.36. Hasil keputusan daripada ujian pemadatan pula menunjukkan berat unit kering maksimum bagi campuran ini adalah sebanyak 14.54 kN/m^3 yang telah terhasil pada nilai kandungan air optimum sebanyak 8.5%. Parameter keadaan genting yang telah diperolehi dalam kajian ini adalah λ= 0.032, κ = 0.013, ζ=0.035, N=1.85 dan M=1.152. Daripada parameter-parameter keadaan genting yang diperolehi ini, sempadan permukaan keadaan genting bagi campuran abu terbang - abu dasar (60:40% timbangan berat) telah dapat dihasilkan.

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LIST OF SYMBOLS

BS	-	British Standard
C.V.R	-	Critical Void Ratio
CCPs	-	Coal Combustion Products
CSL		Critical State Line
CU	-	Consolidated Undrain
Gs	-	Specific Gravity
LL	-	Liquid Limit
MCC	-	Modified Cam Clay
NCL	-	Normal Consolidation Line
OCR	-	Over Consolidation Ratio
PI	-	Plasticity Index
PL	-	Plastic Limit
RL	-	Recompression Line
SL	-	Swelling Line
USCS	-	Unified Soil Classification System
w_{opt}	-	Optimum Moisture Content
$\gamma_{d\ max}$	-	Maximum Dry Unit Weight
Δu	-	Change of Pore Water Pressure
σ_3'	-	Effective minor principal stresses
σ_1'	-	Effective major principal stresse
q	-	Deviator Stress
p'	-	Mean Normal Effective Stress
M	-	The Slope of Critical State Line on The p'-q' Plane
v	-	Specific volume
Γ	-	Intercept of Critical State Line with the $v-$ axis

λ	-	The slope of normal consolidation line in $v - p'$ space
ϕ'_c	-	Critical Internal Friction Angle
ζ	-	The Slope of Recompression Line on The q-p'-Plane
N	-	Intercept of Normal State Line with the $v -$ axis
k	-	The Slope of Swelling Line on The q-p'-Plane
e	-	Void Ratio
H	-	The Slope of The Hvorslev Surface on The p'-q' Plane
%	-	Percentage
p'_c	-	Effective Consolidation Stress
p'_e	-	Equivalent Consolidation Pressure
B	-	Pore Pressure Coefficient

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CHAPTER 1

INTRODUCTION

1.1 Background

Coal-burning in the process of generating electricity, leads to the production of solid waste such as fly ash, bottom ash, boiler slag and flue gas desulphurization (FGD) materials (Vom Berg, 1998). During combustion in an electric power plant, the first step is crushed the coal, then injected into the boiler furnaces, where the coal is burned. The organic matter in the coal is burned off at once, whereas the incombustible material melting and tends to fuse together to form ash. The coarse particles of the ash is the bottom ash and boiler slag, settles at the bottom of the boiler furnace. Fine particles, is fly ash, remain suspended in the flue gas stream (Kim *et al.*, 2006). Figure 1.1 shows the procedure of generating coal ash in power plants. Electricity is one of the basic inputs required for the development of any country. In India nearly 73% of installed power generation capacity is thermal, of which about 90% is coal-based generation (Singh, 2005). In United States; over one-half of the electricity is generated by burning coal. The large consumption of coal generates a large volume of coal ash. In the US, the coal-burning power produced last year about 70 million tons of coal more (ACAA, 2008).

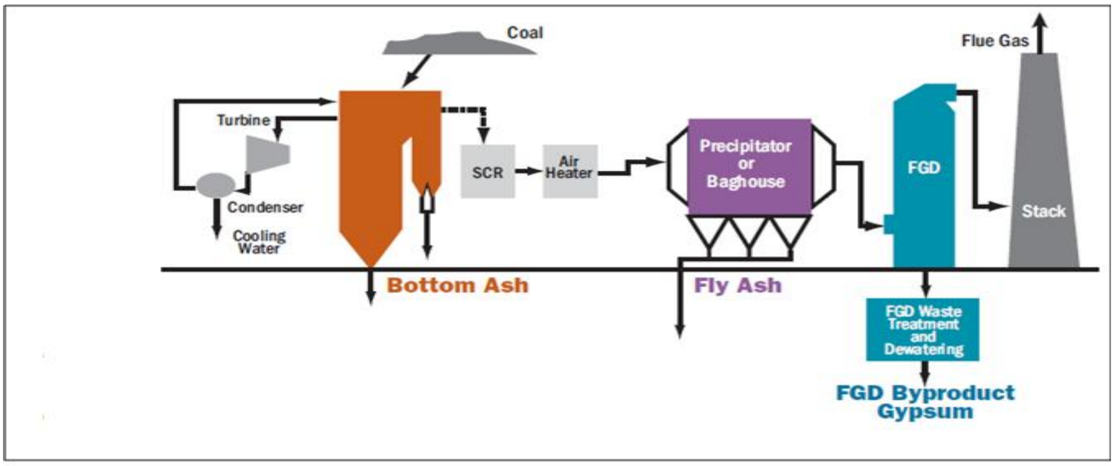

Figure 1.1 The Graphical Diagram of Coal Ash Generation (EPA, 2005)

Such wastes are of the major concern for the electric power plants, because they constantly need to expand the areas of solid waste disposal and this leads to increased costs. This problem fast becomes a social problem since the expansion in disposal area may become another environmental problem. EPA(2005) mentioned that the solid wastes include (fly ash, bottom ash**,** boiler slag and flue gas desulfurization (FGD) have been used in civil engineering applications as structural fills, sheetrock, replacement for Portland cement and as agricultural fertilizer.

Fly ash is a fine part of the coal combustion products (CCPs). It has particle sizes ranging between fine silts and fine sands. It is a light weight and self draining material compared to natural soil. Therefore, fly ash has been successfully used as a structural fill material for constructing highway embankments (Chand and Subbarao, 2007).

Bottom ash and boiler slag, are coarse with sizes varying from sand to gravel. They are composed of non-combustible particles and unburned carbon, similar to fly ash. They fall to the bottom of the furnace and are removed as non molten particles (clinkers). The type of by product produced depends on the type of furnace used to burn the coal.

There are many investigations about the properties of separated single types of ash (fly ash or bottom ash), but there are a few studies about the fly ash-bottom ash mixtures with high fly ash contents. Commonly both the production and disposal ratio of fly ash and bottom ash are approximately 80:20 by weight. Therefore, in most cases uses the same percentage of disposed ash with its high content of fly ash to increase the benefit, with less cost and time to finish the project (ACAA, 2001). However Kim *et al*. (2005) tried to analyse the mechanical properties such as compressibility, stiffness, strength, permeability and compaction to samples with different mixture ratios of fly ash and bottom ash (50%, 75%, and 100% fly ash by weight) collected from two power plants in Indiana. They found the coal ash mixture compare favourably with the granular materials. Yoon *et al*. (2009) described the construction and the instrumentation of a demonstration embankment built with an ash mixture (60:40 by weight of fly ash-bottom ash) on State Road 641, Terre Haute, Indiana, USA. They found that this ash mixture can be considered an acceptable embankment construction material.

1.2 Problem Statement

A number of studies had been carried out to determine the engineering properties of the coal ash mixture. An extension of this work is necessary in order to explore further usage of coal ash particularly when mixed together in optimum percentage. The critical state boundary surface of the soil or material is important to identify the limit of stress imposed from various stress level and stress history. Hence, the study aiming at developing a critical state boundary surface for a mixture of 60% by weight of fly ash and 40% of bottom ash is vital. The results could be used as a guideline when working with this coal ash mixture in civil engineering work.

1.3 Objective of the Study

This study is aimed at developing a critical state boundary surface of 60:40 (% by weight) of fly ash–bottom ash mixture. Hence the followings objectives had been formulated:

1. To determine the basic characteristics of the coal ash mixture.
2. To evaluate the compaction characteristics of coal ash mixture.
3. To determine the shear strength parameters for the compacted coal ash mixture of various over consolidation ratio at the critical state condition.
4. To produce a critical state boundary surface of coal ash mixture.

1.4 Scope of the Study

This study focuses on the critical state boundary surface of fly ash-bottom ash mixture for the materials taken from Tanjung Bin power plant station, Johor, Malaysia. The mixture used in this study is 60:40 % by weight of fly ash to bottom ash. This study includes determination of the basic characteristics for the coal ash mixture (particle size distribution, specific gravity and Atterberg limit), evaluation of the compaction characteristics (maximum dry density and optimum water content), and the determination of the shear strength parameters for the compacted coal ash mixture of various over consolidation ratio (OCR=1, 2.5, 4, 10) at the critical state condition.

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