UNIVERSITI PUTRA MALAYSIA

CHARACTERIZATION OF DUMPING SOIL AND SETTLEMENT PREDICTION USING MONTE CARLO APPROACH

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By

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APRIL 2013

Chairman : Professor Husaini Omar, Ph.D.
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Failures at the dumping sites are usually associated with settlement. Differential settlements of dumping soil cause leaking of methane gas to the air and infiltration of leachate to the river which are dangerous to human and environment. Settlement of dumping soil occurs for many years due to biodegradation process and creep. The behaviors of dumping soil are to be investigated and characterized so that the settlement could be predicted using Monte Carlo approaches. Dumping soil contains heterogeneous material such as concrete debris, decayed wood, clay, silt, sand and gravel. Dumping soil are characterize based on its characteristics such as Category I: soil like and non soil like, Category II: waste types and Category III: waste or soil. The importance of dumping soil characterization are that it helps the engineer to differentiate between soil and non soil like, the types of waste and to determine whether the soil mostly contains waste or soil. Settlement of dumping soil is very challenging to be evaluated and modeled since the settlement are non-uniform due to the different content of the soil. Waste materials were decomposed by the bacteria biodegrades the organic content in the waste would cause settlement. The settlement rate is assumed to be the amount of subsidence that is directly proportional to the amount of solids solubilized. Five settlement models used to calculate the settlement of dumping soil at Kuala Lumpur open dumping area were reviewed. These models are soil mechanics

based model, Bjarngard and Edgers model, Power Creep function, hyperbolic function and rheological function. These five models are simulated using Monte Carlo approaches. Monte Carlo simulation is a method employed an algorithm that must be used with repeated random sampling of uncertainty for ca. 50-5000 number of iterations in order to obtain the parameters such as primary compression ratio (Cc^*), secondary compression ratio ($C\alpha$), compressive stress($\Delta\sigma$) and ultimate settlement (S_{ult})of the soil at the dumping area. It is predicted that the final settlement of dumping soil can settled up to 20% to 30% of initial fill height. The expected outcome of the research is settlement prediction model of closed dumping area for post-development using Monte Carlo simulation. The predicted settlement by Monte Carlo simulation method could save time and cost. It could also be used by geotechnical engineers to determine the preliminary settlement. Moreover, it gives preliminary total settlement value for the design engineer and decision maker to decide on the remedial works and the depth of foundation level for post-development.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

KRITERIA TANAH SISA DAN RAMALAN MENDAPAN TANAH MENGGUNAKAN KAEDAH MONTE CARLO

Oleh

NUR IRFAH BINTI MOHD PAUZI

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Kegagalan yang berlaku di tempat pelupusan sisa selalunya dikaitkan dengan mendapan. Ketidakseimbangan mendapan tanah sisa boleh menyebabkan kebocoran gas methane dan bahan larut resap daripada sisa buangan ke udara dan air yang boleh mengancam nyawa manusia dan alam sekitar. Mendapan tanah sisa yang berlaku selama beberapa tahun adalah disebabkan oleh proses biodegradasi dan rayap. Tindak balas mendapan tanah sisa akan disiasat dan dikategorikan supaya mendapan tanah sisa dapat diramal dengan menggunakan kaedah Monte Carlo. Tanah sisa mengandungi bahan-bahan yang heterogenus seperti ketulan konkrit, kayu yang reput, tanah liat, tanah kelodak, batu dan pasir. Berdasarkan kajian, tanah sisa boleh dikategorikan kepada 3 categori mengikut kriteria yang terdapat pada tanah sisa tersebut iaitu Kategori I: tanah dan bukan tanah, Kategori II: jenis sisa dan Kategori III: sisa atau tanah. Kepentingan untuk menentukan kriteria tanah sisa ini adalah kerana ia membantu jurutera untuk membezakan antara tanah atau bukan tanah, jenis sisa yang terdapat dalam kandungan tanah itu dan untuk menentukan bahawa tanah itu mengandungi paling banyak sisa atau tanah. Ia juga akan menjadikan satu ketentuan bahawa tanah tersebut adalah jenis tanah sisa dengan 3 jenis kategori tadi. Mendapan tanah sisa adalah paling mencabar untuk dinilai dan dimodel kerana mendapan tanah tersebut tidak sekata oleh kerana kandungan yang heterogenus di dalam tanah sisa itu. Tanah sisa akan

dibiokomposkan oleh bakteria dengan proses biodegradasi bahan organik di tanah sisa yang boleh menyebabkan berlakunya mendapan. Kadar mendapan tanah sisa adalah dianggarkan sama dengan kadar penurunan di mana ia berkadar terus dengan kandungan pepejal yang larut/terbiodegradasi. Terdapat lima jenis model mendapan tanah sisa yang telah dikenalpasti untuk mengira medapan tanah sisa di kawasan pembuangan terbuka di Kuala Lumpur. Model-model tersebut adalah Model berdasarkan Mekanik Tanah, Model Bjarngard dan Edgers, Fungsi Kuasa Rayap, Fungsi Hiperbolik dan Fungsi Reologi. Kelima-lima model tersebut disimulasikan menggunakan kaedah simulasi Monte Carlo. Kaedah Monte Carlo yang menggunakan konsep algoritma diaplikasikan bersama sampel rawak yang berulang untuk menentukan parameter ketidakpastian pada 50-5000 nombor iterasi supaya parameter seperti nisbah kompresi primer (Cc^*), nisbah kompresi sekunder ($C\alpha$), tekanan kompresif ($\Delta\sigma$) dan mendapan tertinggi(S_{ult}) pada tanah sisa dapat ditentukan. Ianya diramalkan bahawa mendapan terakhir untuk tanah sisa boleh mencapai sehingga 20% ke 30% daripada tinggi tanah tambus yang asal.Hasil daripada penyelidikan ini adalah model ramalan mendapan tanah sisa untuk tapak pembuangan yang telah tutup supaya boleh digunakan untuk pembangunan yang baru dengan menggunakan kaedah simulasi Monte Carlo. Ramalan mendapan menggunakan kaedah simulasi Monte Carlo telah menjimatkan masa dan kos untuk menentukan mendapan tanah sisa di tapak pembuangan sisa terbuka. Ia juga boleh digunakan oleh jurutera geoteknik untuk menentukan mendapan awal. Disamping itu, ia juga memberikan nilai mendapan awal tanah untuk jurutera pereka dan pembuat keputusan dalam menentukan kerja-kerja pembaik pulih yang boleh dilakukan sebelum pembangunan yang baru boleh dilaksanakan.

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Nur Irfah Mohd Pauzi

I certify that an Examination Committee met on 1st April 2013 to conduct the final examination of Nur Irfah Mohd Pauzi on her thesis entitled "Characterization of Dumping Soil and Settlement Prediction using Monte Carlo Approach" in accordance with the Universities and University Colleges Act 1971 and Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the students be awarded the Doctor of Philosophy.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledge. I also declare that it has not been previously and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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NUR IRFAH MOHD PAUZI

Date: 19th September 2013

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LIST OF ABBREVIATIONS

Cc*	Primary compression ratio
Cα	Secondary compression ratio
Cα1	Intermediate coefficient of secondary compression
Cα2	Final coefficient of secondary compression
c	cohesion
BEM	Bjarngard and Edgers Model
DS	Dumping Soil
EDX	Energy Dispersive X-Ray Spectroscopy
H	Initial thickness of waste
HF	Hyperbolic Function
Km	kilometers
KN	kilo Newton
L, l	Length
MPa	Mega Pascal
m	meters
mm	millimeters
MSW	Municipal Solid Waste
NS	Normal Soil
SEM	Scanning Electron Microscope
SMBM	Soil Mechanics Based Model
PCF	Power Creep Function
RM	Rheological Model
t1	time for initial compression
t2	time for intermediate compression
t3	time for total period of time
ϕ	Angle of internal friction
σ^2	variance
σ	standard deviation
μ	mean/Average value

CHAPTER 1

INTRODUCTION

1.1 General Background

Failure of landfill/dumping area usually associated with settlement. Koerner and Soong (2000) and Jones and Dixon (2003) provide information on a range of landfill failures. High profile failure includes Kettleman Hills, USA (Seed et al., 1988; Byrne, 1994), Bulbul Drive, South Africa (Brink et al., 1999), Cincinnati, USA (Eid et al., 2000; Stark et al., 2000), Dona Juana, South American (Hendron et al., 1999) and Payatas, Philippines. There are many other failures that do not get reported since the failures occur at dumping area with no human casualties. The failure of landfill/dumping area are caused by settlement of dumping soil.

Dumping soil can be defined as that soil that contains concrete debris, decayed wood, paper, clay, silts, sand and gravel. The difference between dumping soil and normal soil is that the dumping soil contains waste materials as much as 30% to 35%. Other than that it also consists of sand, silt, clay and gravel. The waste material grain particle size is in the range of 2 to 6 mm of sieve size with the content of 30% to 35% of waste. Dumping soil is not residual soil. Dumping soil originates from the waste material that

was dumped at the dumping area. The waste which has gone through sedimentation process, chemical reaction between the waste and rainfall, and biodegradation of waste that causing the waste to become dumping soil.

By literature search, settlement of dumping soil occur due to these four attributes namely (1) physical and mechanical processes that includes the reorientation of particles, movement of fine materials into larger voids and collapse of void spaces, (2) chemical processes that include corrosion, combustion and oxidation, (3) dissolution process that consist of dissolving soluble substances by percolating liquids and then forming leachate, (4) biological decomposition of organics with time depending on humidity and the amount of organic present in the waste (Sivakumar Babu et al, 2010a). Moreover, the occurrence of differential settlement due to inhomegeneity of solid wastes promotes other problems such as water ponding on the soil surface and accumulation of water on the drainage layer, hence increasing the rate of water infiltrations into the waste and leachate formation. The understanding on the settlement behavior of dumping soil of dump area is becoming essential in Malaysia, since there are many dumping area to be reused for new constructions where the settlement issues should be considered.

There are three main stages of settlement in dumping soil, namely, initial compression, primary compression and secondary compression. Initial compression, which is defined as settlement that occurs immediately, when an external load is applied to a dumping soil. It is generally associated with the immediate compaction of void

space and particles due to an applied load. Primary compression is consolidation due to the dissipation of pore water and gas from the void spaces. In general, it occurs 30 days after final load placement. Secondary compression is due to creep of the waste skeleton and biological decay. In general, settlement due to secondary compression accounts for a major portion of total settlement of dump area and occurs over many years (El-Fadel and Khoury, 2010).

Numerous studies have been previously conducted on the geotechnical properties of dumping soil so that settlement can be evaluated (Landva and Clark, 1990; Fasset et al., 1994; Gabr and Valero, 1995; Kavazanjian, 2001; Hossain, 2002; Dixon et al., 2005, Zekkos, 2005). A constitutive model is proposed by Sivakumar Babu et al., (2010) to describe the stress-strain behavior of waste type of soil under loading using the critical state of soil mechanics framework. Many mathematical model and settlement model has been developed to simulate settlement mechanism at landfill area (Sowers (1973); Bjarngard and Edgers (1990); Hossain and Gabr (2005); Yen and Scanlon (1975); Edil et al. (1990); Ling et al. (1998); Gibson and Lo (1961); Park and Lee (1997); Hettiarachchi et al. (2009); Marques (2001) and Sivakumar Babu et al. (2010). However, not many focus on settlement prediction of the dumping soil based on Monte Carlo simulation approaches and not many settlement model focuses to the dumping area in Malaysia. This study would attempt to establish the settlement prediction of dumping soil in two dumping area in Malaysia which is Sri Hartamas, Kuala Lumpur and Bukit Chuping, Perlis.

Monte Carlo methods are a class of computational algorithm that must be used together with repeated random sampling in order to compute their results. Monte Carlo methods are usually used together with computer software to simulate the physical and mathematical systems. This method tends to be useful to compute an exact result with a deterministic algorithm. Monte Carlo method are especially useful for simulating systems with many coupled degrees of freedom such as fluids, disordered materials, strongly coupled solids and cellular structure. Monte Carlo is also used to model phenomena with significant uncertainty inputs such as the calculation of risk in business. The Monte Carlo method is further explored to be used as dumping soil settlement prediction so that the total settlement could be determined. The dumping soil settlements are to be studied at the open dumping area rather than landfill because of terms that was widely misused in Malaysia.

A site may refer to "landfill" when in fact it is an "open dumping" (Idris et al., 2004) due to the differences in the operational aspect of landfill is unclear. There were 77 open dumps, 49 controlled tipping and only 35 landfill in Malaysia (Idris et al., 2004). Besides illegal dumping, landfilling is the only method used for the disposal of municipal solid waste in Malaysia, and most of the landfill sites are open dumping areas, which pose serious environmental and social threats (Yunus and Kadir, 2003). The open dumping will increase over time because the population in Malaysia has been increasing at a rate of 2.4% per annum or about 600,000 per annum since 1994. With this population growth, the municipal solid waste generation also increases. In 2003, the average amount of municipal solid waste generated in Malaysia was 0.5 -0.8

kg/person/day. It has increased to 1.7 kg/person/day in major cities (Kathirvale et al., 2003). By the year 2020, the quantity of municipal solid waste generated was estimated to have increased to 31,000 tons.

The increased in waste generated would become a problem since the land price has increased and the spaces allocated for disposal site are limited in urban area due to increase in population. Thus more illegal open dumping sites would be generated. These illegal open dumping sites are studied to determine the characteristics and to predict future settlement of dumping soil after the closure of the dumping area. The abandoned landfill would pose serious hazards where differential settlement would occur. Differential settlements would result in problems such as surface ponding, and development of cracks. The decomposition of dumping soil would generate gas; leachate and refuse settlement. The differential settlements of dumping soil are cause by different composition of waste. Thus, we need to characterize the dumping soil in order to understand its behavior.

1.2 Problem Statement

The problem statements of this research are as follows:-

a) Dumping area consists of many layers of soil strata which may consist of clay, silt, gravel, sand, decayed wood and waste layers. The heterogeneous content of dumping soil is not easy to characterize. The characterizations of dumping soil need to be determined so that the closed dumping area could be reused for new

constructions. Nowadays, there are increases in the population which will generate the waste. An increase in waste generation would increase the numbers of open dumping area (Kathirvale et al., 2003). Thus, the land for new development would not be enough and need to be reused. This study will help in predicting the settlement of dumping soil at closed or abandoned open dumping area. The determination of dumping soil characterizations are conducted in Malaysia area for this study since there are not many research works has been done on dumping soil characterizations in Malaysia. The Sri Hartamas were chosen to be the study area because that area is to be developed for new substation which was meant to supply electricity for the resident area. Thus the settlements need to be predicted at the Sri Hartamas area before new constructions are to be constructed. Another area is Bukit Chuping area which is not the dumping area so that the soil with natural content could be studied as controlled parameters.

b) Numerous studies have been previously conducted on the geotechnical properties of dumping soil however there are problems in the uncertainty of the data. The uncertainty parameters are such as Cc* (primary compression ratio), Cα (secondary compression ratio), Δσa (primary compressibility stress), Δσb (secondary compressibility stress) and S_{ult} (ultimate settlement) are not easy to be evaluated. The range for the uncertainty need to be established and evaluated based on the performance comparison of settlement prediction models in various

landfill types (Park et. al., 2007). This study is attempted to use the Monte Carlo simulation to choose the range for the uncertainty.

c) The available data for determining geotechnical parameters of dumping soil are not many. One site may consist of 5 to 10 boreholes. The sampling may only be about 20 samples to be used for settlement calculation of geotechnical parameters. Hundreds or more data of geotechnical are needed in order to improve accuracy of the settlement computation and settlement prediction. The Monte Carlo Simulation has the capabilities to simulate the range of geotechnical properties for settlement calculations and predictions.

1.3 Research Aims and Objectives

The main research aim is to determine the dumping soil characterization and settlement prediction using Monte Carlo approaches. The characterizations are important in the determining the behavior of dumping soil for post closure of the dumping area. The settlement needs to be predicted so that the risks of settlement are known before construction of the new project. The research objectives developed in order to achieve the research aims are as follows:-

I. To characterize dumping soil settlement based on its categories such as soil like or non soil like properties, waste types and soil or waste

II. To calculate and evaluate settlement based on dumping soil settlement model

III. To predict settlement by Monte Carlo simulation approaches and validate dumping soil settlement

1.4 Scope and Limitation

The study focuses on the determination on the characterization of dumping soil and prediction of dumping soil settlement using Monte Carlo approaches. The characterizations of dumping soil are based on its category such as soil like or non soil like, waste types and waste or soil. The data on the geotechnical properties, mineral composition and particle size distribution would determine the category of the dumping soil. The characterizations are done to confirm the soil consists of waste and settlements that occur are due to the waste that consists most of the dumping soil.

Once characterization has been done, the total settlement of dumping soil settlements were calculated using five settlement models such as Soil Mechanics Based Model, Bjarngard and Edgers model, Rheological model, Hyperbolic function and Power Creep Function model. The Monte Carlo Simulation are integrate with these 5 models to simulates hundreds and more data for better accuracy in predicting the total settlement at the open dumping area.

The limitations of the study are the types of bacteria that decomposed the waste. Different types of bacteria would decompose the waste in different rate of decomposition depending on the types of waste. The urban area tends to have more plastic waste compared to organic matter. Plastic are not easy to degradable compared to organic waste. This study would not investigate the types of bacteria to decompose the waste with different rate of settlement.

1.5 Significance of Study

a) The characterization of dumping soil would help the operator of landfill/dumping area to maintain and monitor long-term settlement of the landfill/dumping area in Malaysia.
b) To help geotechnical engineer to understand the behavior of waste settlement at the closed dumping area in Malaysia
c) To characterize the dumping soil into category I, II and III at open dumping area in Malaysia so that the geotechnical properties of dumping soil in Malaysia could be established for long term monitoring and future development
d) To predict settlement at open dumping area so that the dumping area could be used for future constructions where the land are very limited to be used for dumping area with increase of solid waste generations and populations.

1.6 Expected Outcome of the Research

The expected outcomes from the research are the development of characterization of dumping soil category based on the behavior of waste or soil and the settlement prediction via Monte Carlo approaches. The total settlement is the output from the settlement analysis. The potential to settle of dumping soil settlement are assessed based on the total settlement determine from the settlement model. Settlement evaluation statement and the level of risk for the calculated total settlement would give the suggestion work that could be applied at the dumping area. This suggestion work could be used as preliminary decision on managing the dumping soil settlement problems at the open dumping area.

1.7 Thesis Organization

The thesis is divided into 5 chapters. The chapters are organized as follows:-

I. **CHAPTER 1: INTRODUCTION**

   In this chapter, the introductions about settlement at open dumping area. The objectives, the problem statement, scope and limitation, expected outcome of the research and thesis organization are also defined in this chapter.

II. CHAPTER 2: LITERATURE REVIEW

In this chapter, the composition of dumping soil in Malaysia is compared with Asian region, and European country. The summary of the composition is made based on the comparison. The composition of waste is compared as to know the difference in the content of the waste for different countries. The review on the geotechnical properties of dumping soil are also included in this chapter based on the previous researcher. The geotechnical properties such as moisture content, waste classification system, particle size distribution, hydraulic conductivity, compressibility for primary settlement, secondary settlement and total settlement, shear strength, and settlement model of MSW. The settlement model for landfill method is compared with the settlement model for open dumping method.

III. CHAPTER 3: METHODOLOGY

This chapter explained on the methodology of the research. The characterization based on geotechnical properties of dumping soil are obtained from the experimental work. The experimental work involves are sieve analysis test, specific gravity test, SEM-EDX test, compaction test, consolidation test, direct shear test and triaxial test. The electrical resistivity test and borehole logging test are also used in this research to characterize the heterogeneous content of dumping soil layers at dumping area. The methods on integration of Monte Carlo simulation to calculate settlements and probability are also explained.

IV. CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter described the results and discussions of the dumping soil settlement characterization, the dumping soil settlement calculation for determining the total settlement. The modeling of dumping soil settlement are also analyzed and discussed by integrating existing model and simulation of the model using Monte Carlo simulation. The data interpretations and discussions are also included in this chapter.

V. CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The conclusion and recommendations of the research is concluded in Chapter 5. The major findings, minor findings and future studies are described in this chapter.

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