ANALYSIS OF SITE CLASSIFICATION FOR KUALA LUMPUR'S GROUND ASSESSMENT

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UNIVERSITI SAINS MALAYSIA

2003

ANALYSIS OF SITE CLASSIFICATION FOR KUALA LUMPUR'S GROUND ASSESSMENT

By

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Thesis submitted in fulfillment of the
requirements for the degree
of Master of Science

UNIVERSITI SAINS MALAYSIA

July 2003

ACKNOWLEDGEMENT

First and foremost I thank ALLAH for giving me the good health and thus strength to accomplish the work of this research and completed the requirements of the thesis.

I would like to take this opportunity to thank City Hall Kuala Lumpur for allowing me to pursue this study on full time basis and sponsoring the studies. It is important to mention here that the Department of Architects and Special Projects, City Hall Kuala Lumpur had given the best support by giving the permission to use the soil investigation reports, which produced 889 boreholes. These are materials that formed a mini database, which made the research possible. The Kumpulan IKRAM Sdn. Bhd., Malaysia deserved to be commendable for giving their records of soils information, which added to the data. My words of appreciation spread out to my colleagues and friends who always gave me the encouragement and supports both morally and technically.

I am very privileged to be supervised by the main supervisor, Prof. Madya Dr. Mohammad Razip Selamat and the co-supervisors, Prof. Madya Dr. Fauziah Ahmad and Encik Ahmad Shukri Yahaya. They are the people who guided, imparted their knowledge to me, instilled confidence and built up my courage to pursue this work till the end. Thank you very much for the tireless supervisions and discussions.

For the good cooperation and helps, I would like to thank the lecturers and staff of the Civil Engineering Faculty of Universiti Sains Malaysia especially Cik Aida, Puan

Ros, Prof. Madya Dr. Haji Nordin-for his lectures in statistics, and Prof. Madya Dr. Rosli. Also to the former UPA staff especially Puan Ani. Many thanks too, to all the staff at the Universiti Sains Libraries both at Nibong Tebal and at Pulau Pinang for their efforts and helps to find journals, books and notes which I needed for the research.

I am very happy to have acquainted new friends who indirectly built my enthusiasms in studies; they are Lulusi, Anita, Raqib, Nassser, Anas, Faisal, Encik Ahmad Bakri and others. To all of them I really appreciate the friendship and will always be remembered.

To my beloved mother, Puan Hajjah Ramlah Hamidon, thank you for the prayers and love. To all my sisters, brothers, nephews and nieces too, thank you for all the supports and being very understanding. I am dedicating this thesis to two important people in my life, i.e., my late father, Tuan Haji Mansor Mohd Sahood who always wanted me to be successful and my six-year old nephew, Adam Faris Fadill who passed away during my studies.

Finally, of utmost importance is the invaluable cooperation and helps from my beloved husband, Encik Hashim Hamzah Manaf who deserves to share every success that I achieved and who stood by me during my strenuous work. Thank you and you are always my inspiration.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols and abbreviations	Explanation
a	The range in a variogram model
a'	The practical range in a variogram model equals 2/3 a
C	The autocovariance function to test data for spatial correlation
C	The sill in variogram models, denoted by C= $C_0 + C_1$
C_0	The nugget effect in a variogram model
C_{02}, C_{02}, C_{ij}	The covariance between two points
C_h	The autocovariance function for values of lag interval h
CV	The Coefficient of Variation
E_i	The expected frequency in the i_{th} class interval
$f_1, f_2, f_3 ..., f_i ... f_n$	The frequency of observations
H_0	The null hypothesis
H_1	The alternative hypothesis
i_{th}	ith class interval
K	The kurtosis measure
k	The number of class intervals
M_e	The median of a set of observations
m_0, m_1, m_2	The means of the soil properties
N, n	The size of sample
n-h	The number of comparisons between pairs of points

O_i	The observed frequency in the ith class
p	The number of parameters
p-value	The probability value
R^P	The given domain (p=1,2 or 3)
$R(u_i)$	A random part
s	The sample standard deviation
s^2	The sample variance
s_k	The skewness
S.I.	Site investigation
SPT Number, N	Standard Penetration Number
$s_v(x_1), s_v(x_2)$	The standard deviations of variables x_1, x_2 respectively
$u_i(x_i, y_j)$	The location coordinates vector
V(X)	A geotechnical variable
Var_0, Var_1, Var_2	The variances
$W(u)$	The random variable with location coordinates vector, u
w	The soil property
$w(u_i)$	Soil property at location u_i
$w(u_0)$	Soil property at unknown location, 0
$\hat{w}(u_0)$	An estimator of $w(u_0)$
$\bar{x}$	The sample mean
$\bar{x}_{grp}$	Grouped mean
$x_1, x_2, x_3, ..., x_n$	The variables

$Z(x), Z(y), ..., Z(w)$	Observed values at locations x, y and z respectively
Δ	The spacing /distance between observations
Δh	The distance vector between any two points
$\rho(\Delta h)$	The stationary autocorrelation function of soil properties
$\gamma(\Delta h)$	The semivariogram
$\sigma^2(X)$	The variance at point X
$(\sigma_E)^2$	The square error of the estimator
Ω	Ground space as a random field of $W(u)$
λ_1, λ_2	The weights of soil properties at locations 1 and 2 respectively
μ	Lagrange multiplier/ parameter
$\mu_v(x)$	Mean of a variable V(X)
χ_0^2	A chi-square goodness-of-fit test
$\chi^2_{\alpha,k-p-1}$	The experimental chi-square statistic
α	The level of significance

ABSTRACT

Data from a total of 889 boreholes from 144 locations in the Federal Territory of Kuala Lumpur were collected and a database was set up. Most of these borehole logs were taken from site investigation (S.I.) reports of the Department of Architects and Special Projects, City Hall Kuala Lumpur and 12 records for Mukim Cheras were sourced from Kumpulan IKRAM Sdn Bhd., Malaysia. For this research, four site characteristics were recorded for each borehole log. These characteristics are basic and play important roles in determining the quality of each site. The first characteristic was the depth when an achieved value of Standard Penetration Test (SPT), N is 50. The second was the total thickness of clay in each borehole. The third was the total soft clay thickness in the borehole portion where SPT Number, N is less than or equals to 4. The fourth characteristic was the total thickness of soft and loose soils, other than the soft clay, in the borehole portion where SPT Number, N is less than or equals to 4. The four characteristics were assessed in the comparative study of the subsurface soils of the seven sub-districts in Kuala Lumpur. Sites were grouped based on the characteristics so that a generalization could be attempted to describe the quality of ground at locations within Kuala Lumpur. The variability of the substrata soils from one place to another was also studied. Based on depths when SPT count of N equals to 50, four classes of sites were appointed. Based on the total thickness of clayey soil in each borehole, five classes of sites were appointed. Based on the total thickness of soft clayey soil in each borehole, five classes of sites were also appointed. Based on the total thickness of soft and loose soils in each borehole, another five classes of sites were appointed. The data collected for this work were analysed in three stages. First, a descriptive statistics was carried out on the data. Second, the clay thickness data were tested if they fit a normal form of distribution by using the chi-square goodness-of-fit test. Finally, the ordinary kriging technique was used to predict the clay thickness at unvisited locations. The second and third analyses were carried out as case studies involving clay thickness for Bandar Kuala Lumpur. In terms of thickness of clayey soils, the highest percentage was found in Mukim Batu and the lowest percentage was in Mukim Petaling. Based on the results of analyses on the characteristics, the soils in Mukim Batu were found as relatively unfavorable to work with because they had the most amounts of clayey and soft-loose soils. In similar consideration, the three best areas to work with were Mukim Petaling, Bandar Kuala Lumpur and Mukim Ampang. In the case study, the clay thicknesses of all 283 samples in Bandar Kuala Lumpur fitted the log-normal distribution. After eliminating the zero-clay data and outlier data i.e. those with more than 22.0 m of clay, the data of the remaining 152 samples fitted the normal distribution. The probability of clay thickness being 2.0 m in a borehole in Bandar Kuala Lumpur is 0.26. In the other case study, statistical analyses involving ordinary kriging was attempted to estimate the clay thickness at five locations in Bandar Kuala Lumpur. The result was that four out of five predictions were as accurate as the actual clay thickness. The overall product of the study is a procedure of analyzing S.I. data for an area when the amount of data is sufficient.

ANALISIS PENGELASAN TAPAK BAGI

TUJUAN PENILAIAN TANAH KUALA LUMPUR

ABSTRAK

Data 889 lubang gerek daripada 144 lokasi di sekitar Wilayah Persekutuan Kuala Lumpur telah dikumpulkan dan satu pengkalan data telah dibangunkan. Kebanyakkan rekod lubang-lubang gerek diperolehi daripada lapuran penyelidikan tapak di Jabatan Arkitek dan Projek Khas, Dewan Bandaraya Kuala Lumpur manakala 12 rekod bagi Mukim Cheras diperolehi daripada Kumpulan IKRAM Sdn. Bhd., Malaysia. Dari penyelidikan ini, empat ciri tapak telah direkodkan dari setiap lubang gerek. Ciri-ciri tersebut adalah perkara asas dan memainkan peranan yang penting bagi menentukan kualiti sub-stratum tanah disetiap tapak. Ciri pertama ialah kedalaman apabila nilai Ujian Penusukan Piawai (SPT), N mencapai 50. Ciri kedua ialah jumlah ketebalan tanah liat di dalam setiap lubang gerek. Ketiga ialah jumlah ketebalan tanah liat lembut di dalam lubang gerek apabila Nombor SPT, N kurang atau sama dengan 4. Akhir sekali ciri keempat, jumlah ketebalan tanah lembut dan longgar, selain dari tanah liat lembut, di dalam lubang gerek apabila Nombor SPT, N kurang atau sama dengan 4. Empat ciri tersebut telah dianalisa bagi melaksanakan kajian perbandingan sub-stratum tanah di dalam tujuh mukim di Kuala Lumpur. Tapak-tapak dibahagikan kepada kumpulan berdasarkan ciri-ciri tersebut bagi menerangkan kualiti tanah dan keberubahan substratum tanah dari satu tempat ke

tempat yang lain juga dikaji. Berdasarkan kedalaman apabila Nombor SPT, N mencapai 50, empat kelas tapak telah ditentukan. Berdasarkan jumlah ketebalan tanah liat di dalam setiap lubang gerek, lima kelas tapak telah dinamakan. Berdasarkan jumlah ketebalan tanah liat lembut di dalam lubang gerek, lima kelas telah juga ditentukan. Berdasarkan jumlah ketebalan tanah lembut dan tanah longgar di dalam lubang gerek, lima kelas tapak yang lain telah ditentukan. Data terkumpul telah dianalisa di dalam tiga peringkat dengan menggunakan kaedah statistik. Pertama, statistik perihalan dilaksanakan keatas data. Kedua, data ketebalan tanah liat diuji sama ada sesuai dengan bentuk taburan normal menggunakan ujian kebagusan penyuaian khi-kuasa dua. Ketiga, teknik penganggaran krige biasa telah diguna untuk meramal ketebalan tanah liat di lokasi tidak dilawati. Peringkat kedua dan ketiga dilaksanakan secara kajian kes melibatkan data ketebalan tanah liat di Bandar Kuala Lumpur. Mukim Batu mempunyai peratus ketebalan tanah liat yang tertinggi sementara peratus terendah ialah di Mukim Petaling. Berdasarkan keputusan analisa ciri-ciri keadaan tanah, secara relatifnya didapati Mukim Batu mengandungi amaun tertinggi tanah liat, tanah lembut dan tanah longgar. Oleh itu perlaksanaan kerja-kerja di kawasan ini boleh dikatakan sukar. Di dalam pemerhatian yang sama tiga kawasan terbaik dari segi perlaksanaan kerja geoteknik ialah Bandar Kuala Lumpur, Mukim Petaling dan Mukim Ampang. Kajian kes keatas 283 sampel ketebalan tanah liat di Kuala Lumpur mendapati bahawa data sesuai diterangkan dalam bentuk taburan log-normal. Tetapi setelah mengeluarkan data ‘tiada tanah liat’ dan data terpinggir iaitu yang mempunyai lebih daripada 22.0 m tanah liat bagi setiap lubang gerek, data baki 152 sampel sesuai diterangkan dalam bentuk taburan normal. Keberangkalian wujudnya tanah liat setebal 2.0 m bagi sesuatu lokasi di Bandar

Kuala Lumpur ialah 0.26. Kajian kes terakhir melibatkan analisis statistik menggunakan krige biasa untuk menganggar ketebalan tanah liat dilima lokasi di Bandar Kuala Lumpur. Keputusan menunjukkan empat daripada lima ramalan telah menepati ketebalan tanah liat yang sebenarnya. Keseluruhan kajian ini telah menghasilkan satu produk di dalam bentuk kaedah menganalisa data S.I.bagi sesuatu kawasan dengan menggunakan data yang mencukupi.

CHAPTER 1

INTRODUCTION

1.0 DEVELOPMENT IN KUALA LUMPUR

The Federal territory of Kuala Lumpur is 243 km^2 in area and is subdivided geographically into seven sub-districts namely Bandar Kuala Lumpur, Mukim Kuala Lumpur, Mukim Setapak, Mukim Batu, Mukim Ampang, Mukim Petaling and Mukim Cheras. From here onwards, Federal Territory Kuala Lumpur will always be referred to as Kuala Lumpur only. Figure 1.1 is a map of Kuala Lumpur that shows the seven sub-districts. The research is focused towards Kuala Lumpur because of its social and economic importance. The development in metropolitan Kuala Lumpur is very rapid and diversified. The construction activities in Kuala Lumpur range from the modest to mega projects. Examples of buildings built are multipurpose halls in Kepong, public housing in Pantai Dalam and the magnificent Twin Towers of Kuala Lumpur City Centre (KLCC) in Ampang. There are two main Light Rail Transit (LRT); the STAR is running two lines, from Ampang to Sentul Utara and Ampang to Sri Petaling and the PUTRA line, runs from Gombak to Subang. There is also the Express Rail Links (ERL) spanning from KL-Sentral at Jalan Brickfield to the Kuala Lumpur International Airport (KLIA) in Sepang. The elevated highways in Ampang and Cheras, the tunnels under Jalan Ampang and Jalan Tun Razak and the conceptual Linear City, which is put on hold its implementation for the time being, are the recent engineering constructions and proposal in Kuala Lumpur.

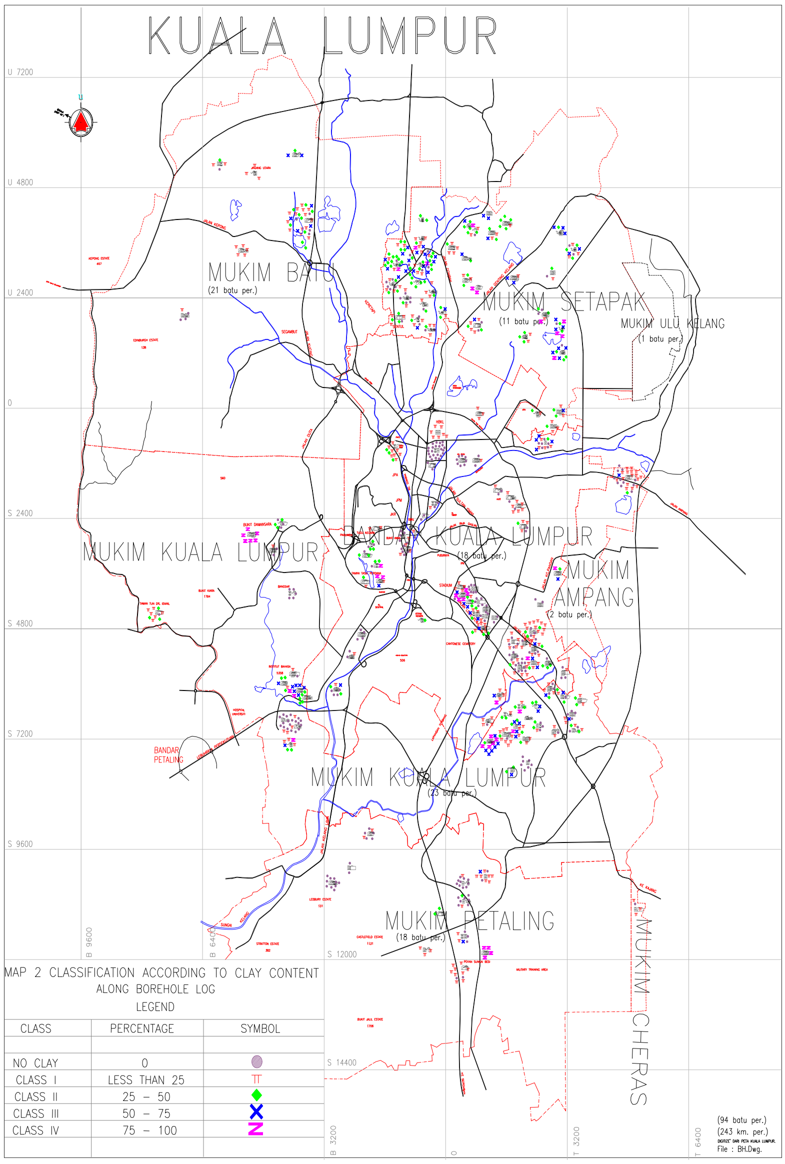


Figure 1.1 : Map of Kuala Lumpur showing the seven sub-districts

The e-knowledge and e-economy drives the engineering development in Kuala Lumpur to be parallel with the progress of Information and Communication Technology (ICT) age. The practice of handling soil information as hard copies is laborious, needs a lot of storage space and not readily retrieved. Database of soil information should be neat, presentable and can be retrieved faster. At present, Kumpulan IKRAM Sdn. Bhd. is known as the largest site investigation contractor in Malaysia (Mahmud et al., 2002), has generated tremendous amount of information and data on soil and rock profile from the states of Malaysia. They are actively developing a system to provide soil and rock profile database for boreholes information and geotechnical site investigation works. The system, upon completion, will be a major source of preliminary geotechnical design parameter for any specific location in Malaysia. Thus, this research is conceptually similar in nature to Kumpulan IKRAM Sdn. Bhd. and it is going to be a contribution towards developing database for the Kuala Lumpur City Hall and in future for the Klang Valley.

1.1 SITE INVESTIGATION

Soils are unique engineering material and form the basic elements of the earth besides water and voids. Researches and studies are carried out to know about the soils' early formation, their physical properties (i.e., texture, grain size), mechanical properties (i.e., shear strength), their behaviors and capabilities to withstand structures built upon and with them. The findings are collated, accumulated and served as materials of reference to planning and designing engineers, academicians, developers and contractors. By definitions, soil, in an engineering sense, is the relatively loose agglomerate of mineral and organic materials and sediments found above the bedrock. On the other hand, soils, to a geologist are just decomposed and disintegrated rocks generally found in the very thin upper part of the crust. Whatever are the definitions for the soils, the ultimate aim is to have the right information that can be applied for safe and economical plan, design and construction.

Quite often, a new project insists on prescribing a fresh site investigation even when the area is already occupied by developments. Usually, it will be quite cumbersome for the new developer to gain access to soil investigation documents due to poor data management and lack of geotechnical engineering assessment for the whole locality. Moreover, the common practice is to assume the foundation for that particular site as different to those surrounding it and therefore a fresh soil investigation is warranted. Quite frequently, however, soil investigation records are held by the same organization such as the city council or a large consultant firm, (Mansor et al., 2001).

Usually a site investigation carries out drilling of boreholes to obtain soil samples and to note the blow counts of the hammer when it drops onto each layer of soils. From the borehole logs the soil characteristics such as hard strata depths, thickness of clay and thickness of other soft soils are taken as raw data for the purpose of this research. There are no new boreholes required on the sites since the number of data collected is 889 altogether and is sufficient to carry out the analysis.

It is noticed that all the locations of the boreholes were not stated in terms of coordinates on the plan when soil investigation works were carried out on the sites.

Usually the locations of boreholes were determined by measuring distances on the plan and then transferred it to the ground by referring to certain landmarks.

1.2 SITE CLASSIFICATION

A soil classification system represents, a language of communication between engineers. It provides a systematic method of categorizing soils according to their probable engineering behaviors, and allows engineers access to the accumulated experience of other engineers. A classification system does not eliminate the need for detailed soils investigations or for testing the engineering properties. Thus, by knowing the soil classification, the engineer has a good general idea of the way the soil will behave in engineering situation, during construction and under structural loads. Today, the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) system are commonly used in civil engineering practice (Holtz and Kovacs, 1981). In this thesis, as sites are the one classified and are not really the soils, the title of this section could not be more aptly named as site classification instead of soils classification. However, the sites are classified based on the presence of some particular types of soils; the determination of these types of soils can only be performed using the established soil classification system.

For a start, four basic soils characteristics are selected for this work. They are as shown in Table 1.1 below.

Table 1.1 : Four soil characteristics chosen

Soil characteristics	Criteria
1	Depths when the value of SPT Number, N is 50
2	Total thickness of clay in each borehole
3	Soft clay thickness when SPT Number, $N \leq 4$
4	Soft and loose soil when SPT Number, $N \leq 4$ (This is other than soft clay)

These soils characteristics are the important criteria when making estimation for depths of shallow foundations, depths of driven piles and also whether a site needs to use ground improvement techniques to rehabilitate its soils.

It is to be noted here, that the clay is taken in this context as a broad category. Soils are generalized as clay when they are termed as sandy clay or silty clay. However, soils, whereby clay is minor such as clayey sand and clayey silt, they are not categorized as clay but sand and silt respectively.

Firstly, the data of the four soils characteristics in the seven sub-districts were analysed as descriptive statistics. Towards the middle part of the work, the analyses involving advanced probability and prediction used only clay data in the sub-district, Bandar Kuala Lumpur.

1.3 SITE ASSESSMENT

The geotechnical input for development generally can be categorized into four important stages. The stages are planning, analysis, construction and maintenance. Site assessment is at the planning development stage which has four major sections;

desk study, site reconnaissance, subsurface investigation and planning layout. The desk study includes reviewing geological maps, memoirs, topographic maps and aerial photographs of the site and the adjacent areas so that engineers are aware of the geology of the site, geomorphology features, previous and present land use, current development, construction activities and problem areas like slope failure. The desk study is usually followed by site reconnaissance. This is required to confirm the information acquired, and also to obtain additional information from the site. Signs such as the type of vegetation and the stability of the buildings on the particular site, contribute in making inference about the soil types. In carrying out site assessment, subsurface investigation for a development usually is carried out on two or more stages. Preliminary subsurface investigation consists of boreholes and geophysical survey. The field tests are carried out with the intention to obtain the overall subsurface condition like general depth of soft soil, hard stratum, thickness of clay and the SPT Number, N values. The general information on the subsurface profile and properties will be useful when planning the cut and fill and formation of the platform because the depths of the hard stratum and bedrock will have major influence on the cost and construction time for earthworks (Gue and Tan, 2002). The detailed subsurface investigation should be carried out during the process of detailed geotechnical designs. The ground information obtained during construction is also essential for the maintenance of the structures and construction of nearby buildings.

The findings of this work are very useful especially at the preliminary planning stage when desk studies, preliminary designs, estimation of cost and duration of construction are being worked out.

1.4 GEOTECHNICAL DEVELOPMENT IN KUALA LUMPUR

Before building plan is approved and construction takes place on site, Kuala Lumpur City Hall, under its Planning and Building Control Department imposed that the development requires an independent geotechnical audit to be undertaken. The imposition is especially for some of these types of development:

i) The buildings within the development are greater than five storey

ii) The slopes surrounding the buildings are more than 21 degrees to horizontal direction, and

iii) The height of the slopes is more than 3.0 meters.

Besides the requirements by the local authority, problematic lands such as ex-mining areas, dumping sites and wetland areas need careful studies before building on them.

1.5 THE PRACTICE IN KUALA LUMPUR CITY HALL

The Kuala Lumpur City Hall is one of the local authorities in Malaysia but at the same time a developer cum implementer of projects. The projects are developed to give the best facilities and services to the people. Examples of infrastructure projects are laying efficient drainage system to mitigate the flash floods and excess water runoff, construction of roads, bridges, elevated highways and pedestrian walkways and creating gardens inclusive of recreation centers. The superstructure projects are public housing, multi purpose halls, markets, sports complexes, mosques and schools. For each of these projects, there is a soils report submitted by appointed contractors upon completion of investigation works at the sites. The time taken to produce a soil report for a contract of work to carry out more than three boreholes was two months. The soil information forms a section in the project's proposal report, which was tabled to the top management for approval. Reliable geotechnical database with classification system will be a great help to speed the planning stage and thus complete a project as scheduled.

1.6 OBJECTIVES OF THE RESEARCH

The objectives of this research are the following:

1. The main objective of this research is to establish a geotechnical database for Kuala Lumpur City Hall as had been set up in the Institute of Lowland Technology, Saga University, Saga Plain, Japan (Li and Hayashi, 1999), Geo-Database for Kansai area, Osaka, Kobe and Kyoto, Japan (Mimura et al., 2002), and Comprehensive Ground Information System, Hong Kong (Lam, 2002). This work is also aimed towards setting up Kuala Lumpur geotechnical database.

2. To compile the basic and simple information on soils characteristics in Kuala Lumpur areas, to classify and to analyze them for inferences.

3. To explore the underlying subsoil strata of Kuala Lumpur for the quantity of existence of each of these soil characteristics, that is, hard soil substrata when SPT Number, N is 50, total thickness of clayey soils, total thickness of soft clay when SPT Number, N is less than or equals to 4 and finally other soft and loose soils thickness when SPT Number, N is less than or equals to 4. Presently, there is no

documented information in this format on these four characteristics for Kuala Lumpur.

4. To make a generalization about the sites' classification in Kuala Lumpur based on the chosen soils characteristics. Thus the profiles of the sub-strata in various locations can be outlined.

5. To obtain the form of distribution for data samples of clay thickness in Bandar Kuala Lumpur. The probability of clay occurrence could be calculated using the mean and standard deviation of the normally distributed data.

6. To predict the thickness of clay at unvisited locations by interpolation technique called ordinary kriging.

1.7 SCOPE OF THE RESEARCH

The data are collected and collated. Analyses are carried out in three main stages as below:

1. The first stage is to analyze statistically the data from every sub-district and for all soils characteristics. The computer softwares such as Microsoft Excel and SPSS assisted in the tabulation of data and analyzing them.

2. To find out the forms of distribution that fit the clay thickness data using the chi-square goodness-of-fit test and then to calculate the probability of clay thickness occurrence.

3. To use ordinary kriging technique to predict the thickness of clay at unvisited locations. A model variogram that fitted samples data has to be produced in order to get the necessary parameters, which are useful to calculate the semivariance and covariance values. The parameters are the range, sill and nugget. Then the values of weights for the estimator are applied to predict a sample at unvisited location. Computer softwares are used to assist in the calculations.

The second and third stages of the research are carried out as case studies and the data used is clay thickness from Bandar Kuala Lumpur.

1.8 APPROACH OF THE RESEARCH

The work in this research are analytical and not field intensive exercise. Statistical methods are applied to the soil characteristics data as to obtain the descriptions of the soils' geometric properties. Altogether there are 889 borehole logs from 144 sites in Kuala Lumpur and collection of extra, new data are not necessary to be carried out.

All of these S.I. reports are reorganized and sorted into the existing sub-districts in the Federal Territory of Kuala Lumpur. The sub-districts are in accordance to the geographical classification of Kuala Lumpur as used by the Department of Planning, Kuala Lumpur City Hall.

1.9 THE SUMMARY OF THE CHAPTERS IN THE THESIS

Chapter 1, as an introduction, described the development in the metropolitan Kuala Lumpur. It also described the roles of the Kuala Lumpur City Hall in controlling constructions on slopes and problem grounds. The general idea about the objectives, scope and the approach of the thesis are highlighted too.

Chapter 2 discussed the literature review. Three journals were used as the main references. They are on the urban geology, geostatistical and spatial data, kriging technique and its application. There are also journals of equal importance that discussed similar interests and topics, which were utilized as references.

Chapter 3 is about the collection of data and how the data were organized. The source from where the data comes from was also mentioned. The process started by grouping the data into the respective seven sub-districts, choosing four basic soils characteristics and categorizing them into classes.

Chapter 4 is on the analysis of data by statistical methods on the soil characteristics. Computer software, SPSS was used extensively to calculate the descriptive statistics and to plot histograms. Results of findings in every sub-district were discussed in detail.

Chapter 5 concentrated on the Geostatistical method of interpolation using semi-variograms, covariograms and interpolation by ordinary kriging to predict the clay thickness at unvisited locations. As a case study, data of clay thickness in Bandar Kuala Lumpur were chosen.

Chapter 6 summarized and discussed the results of the work that had been carried out. Lastly, conclusions on the research were made. For future work and references, some recommendations and comments were noted down.

The next chapter will be the literature reviews of three main journals that generate initial ideas for this research to be made possible. The discussion concentrates more on the topics that are related and to be applied to this work.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Three main topics are the main reference to develop this thesis. First, is the City of Kuala Lumpur as the focus because of its nature as the business hub and center of developments in Malaysia. The wealth of soil information available is to be managed, analyzed and the information kept for future references. Second, the importance of site exploration and the site investigation reports. Third, is to analyze the data and to document the results, which in turn will form part of the geotechnical database for Kuala Lumpur. The use of statistical methods and geostatistical techniques for interpreting results of soil exploration, give confidence to engineers and others to apply the data in the future works.

Kuala Lumpur is the area of interest because it has been developing rapidly since the last decade. It is the socio-economic and cultural centers of Malaysia. Thus, here is the place where most of the first happenings evolve. The area in Kuala Lumpur is divided into the ‘good’ and the ‘poor’ grounds. From the early days, usually the good grounds attract the establishment of settlement. Similarly, Kuala Lumpur developed on the good grounds and the poor grounds were left untouched. This notion has to be pushed aside because there are increasing economic development over soft ground areas (Ting et al., 1988). The poor grounds have to be ventured and encroached. Development on poor ground is a challenge since there are more problems to solve and thus there are always new technologies that will be learnt and applied. The learning process starts when there are problems and accumulated knowledge plus valuable experiences are compiled, shared and improved.

Site investigation is the basic need to any project. Failure to carry out site investigation will incur big losses during construction. Carrying out the proper and appropriately accurate site investigation is important because the results govern the assumptions in producing reliable and safe designs.

As observed when collecting and recording the boreholes from the S.I. reports, Kuala Lumpur City Hall has been carrying out site investigation since 1970's onwards. The records are kept in hard copies and are not easily retrieved especially those reports of more than ten years old. The advancement in computerization will enable the database of soil information to be set up.

When setting up the geotechnical database system, the soils information must be managed and organized properly. The data kept as soft copies must be safely stored for easy retrievals. The database has to be updated consistently so that the soils information is always developed and expanded. Statistical methods and geostatistical techniques are the tools for analyzing the soils characteristics that add to the existing database.

2.1 URBAN GEOLOGY

Tan and Komoo (1990) described urban geology as the study that concerns the application of geology to urban centers, urban development and planning. They discussed in detail about this subject and focused on Kuala Lumpur as the location of case study. Kuala Lumpur provides an ideal case study of urban geology in view of its rapid development within the past two decades. There are many construction projects such as high-rise buildings; housing development schemes and highways that also provide many case histories of engineering geological problems that are encountered. The various engineering geological problems are studied and published so that the experiences and such information are useful to the construction engineers who can use it for the planning of construction works.

2.1.1 Geologic maps

The General geology of Kuala Lumpur area has been well documented by Gobbett (1964) and Yin (1976). It shows the bedrock geologic map of Kuala Lumpur areas, which indicated that the heart of Kuala Lumpur is formed of Kenny Hill formation. The areas bounded by Salak South, Pudu, Jinjang, Batu Caves, Ulu Klang and Ampang are made of Kuala Lumpur limestone, the Sentul and Setapak areas together with Cheras areas showed granite formation and the Hawthornden Schist formed in the Ulu Klang areas. However this map has its limitations because it does not show the surficial or the soil deposits such as alluvial deposits, mine tailings and residual soils.

An engineering geological map, which shows the characteristics of earth materials (soils and rocks) in the Kuala Lumpur area listed nine different material types as follows:

Table 2.1: The types and characteristics of earth materials in the Kuala Lumpur area

TYPES	CHARACTERISTICS OF EARTH MATERIALS
1	moderately weathered to fresh quartz veins
2	the moderately to highly weathered metasediments
3	the moderately to slightly weathered schist
4	the moderately weathered to fresh limestone
5	the sand and clay (river alluvium)
6	the clayey or silty sand
7	the sandy clay
8	the clay to silty clay
9	the sandy silty clay

There is a relative slope stability map of Kuala Lumpur that categorizes four-slope stability. Firstly, the unstable, secondly, the stable, the third is the generally stable and fourth is marginally stable to unstable. The maps can guide the planner and engineer to plan on favorable and stable sites. If they are forced to carry out projects on unfavorable sites, they are already forewarned of possible problems to be anticipated.

2.1.2 Problematic soils

Soil deposits in Kuala Lumpur area consist of alluvial deposits, mine tailings, man-made fills, organic mud and peat, and residual soils of the various rock formations. The main concerns are the soft soils such as mining slimes, municipal wastes and the very weak collapsed zone above the limestone bedrock.

2.1.3 Foundations associated with problematic soils

Studies had been carried out to use suitable types of foundations for the different types of soils. For instance, foundations in limestone have been of greatest concern. The problems of foundations in limestone are namely the highly pinnacled roofs over cavities, boulders embedded in soils, overhangs and cliffs, sinkholes and weak collapsed zone above the limestone bedrock.

The Kenny Hill formation occurs as outcropping low-lying hills as well as bedrock and also often encountered in foundation works. The Hawthornden and Dinding schists occur as isolated hills north of Kuala Lumpur and are related to slope and hillside development works through shallow foundations such as along Jalan Ulu Kelang. Granite occurs in Cheras area, Damansara Utama, Taman Tun Dr. Ismail and Kepong. It is mainly concerned with hillside development and slope problems. In Setapak granite occurs as a stock extending to greater depths below ground level and plays important role in deep foundation works.

2.2 GEOTECHNICAL DATABASE FOR MODELLING SPATIAL VARIABILITY OF SOIL PROPERTIES

2.2.1 Introduction

Site exploration gives important information about the ground profile and important soil properties. The accuracy of such information, however, depends upon the number of sample, the quality of test data and the location of sample. If the information from such exploration is limited and there is a need to estimate the ground information or the soil properties at unsampled location, one may ask how reliable is the estimate to meet the safety requirement in the design. By carrying out additional exploration or increasing the number of samples, it can reduce uncertainty due to spatial variability of soil properties. Sometimes, the information collected is redundant and become wasteful. Thus, it is important to choose an optimum exploration spacing that gives the best estimate of the ground profile and the soil properties considering overall aspects of safety and economy.

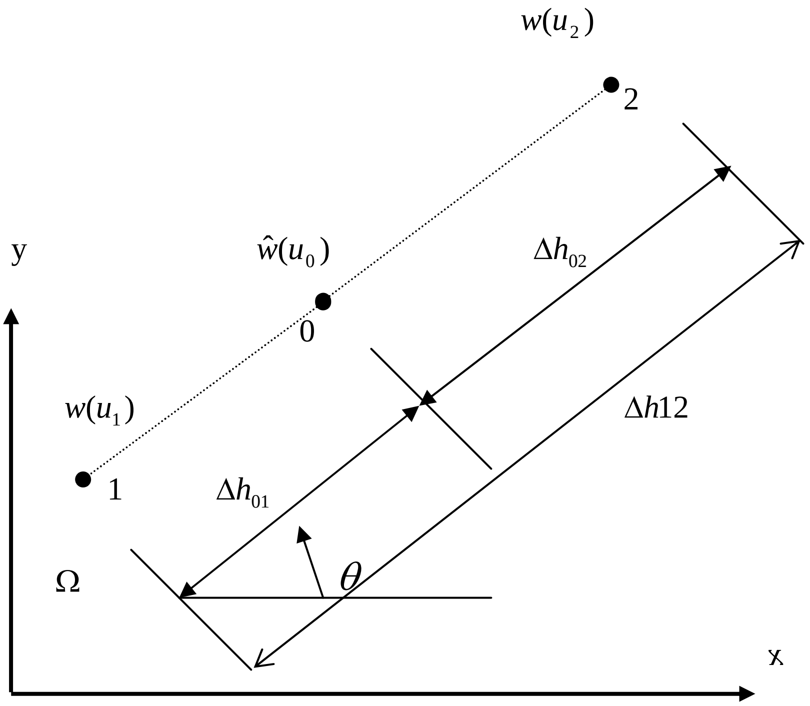
Although the ground thickness or engineering soil properties at unsampled location on the ground can be directly estimated from neighboring boreholes either by interpolation or geotechnical judgments, the estimation errors cannot be determined in such deterministic procedures. The predictive geostatistical procedures, such as ordinary and universal kriging based on the theory of regionalized variables (Matheron, 1971) are best suited for this purpose; not only that they give better interpolation than deterministic methods but also evaluate estimation errors for such interpolations. Kriging is a collection of generalized linear regression techniques for minimizing an estimation error obtained from a *priori* model for a covariance (Journel and Huijbregts, 1978; and Deutsch and Journel, 1998). Although kriging was initially introduced to provide estimates for unsampled values (Krige, 1951; and Matheron, 1971), it is being used increasingly to build probabilistic models of uncertainty about these unknown values (Journel, 1989).

Based on the kriging principle mentioned above, Li and Hayashi (1999) presented a simple probabilistic model that evaluated unknown value and estimation error of soil properties at unsampled location in the ground. This model was capable to evaluate the borehole spacing. However, the model required statistical parameters, namely, a correlation distance and variance of soil properties as important data input. The geotechnical database system for Saga Plain, Japan provided the parameters needed. Finally, the exploration spacing for different values of estimation error was suggested for site investigation.

2.2.2 Probabilistic estimation model

Predictive geostatistics characterize any unsampled value of soil property w as a random variable W and its probability distribution (mean and standard deviation) is usually location-dependent (Webster and Burgess, 1983): hence this variable is denoted as $W(u)$ where u is a location coordinates vector.

Figure 2.1 shows the ground space Ω as a random field of $W(u)$. $W(u_i)$ is a random variable of soil property. $w(u_1)$ and $w(u_2)$ are soil data at boreholes, locations 1 and 2 and the soil properties are known. The interpolated data $w(u_0)$ and its estimation error are required at the unsampled location 0.



Legend:

1,2	Sampled locations
0	Unsampled location
Ω	Ground space as a random field of $W(u)$
$W(u_i)$	Soil property as a random variable
$u_i(x_i, y_j)$	Location coordinates vector
$w(u_i)$	Soil property at location u_i
$\hat{w}(u_1)$	An estimator of $w(u_1)$

Figure 2.1 : Concept of the Parabolic Estimation Model (Li and Hayashi, 1999)

Let $\hat{w}(u_0)$ to be an estimate of $w(u_0)$, which can be modeled as a linear combination of $w(u_1)$ and $w(u_2)$ as follows (Krige, 1951; and Matheron, 1971):

$$\hat{w}(u_0) = \lambda_1 w(u_1) + \lambda_2 w(u_2) \tag{2.1}$$

where λ_1 and λ_2 are the weights to be determined.

From Equation (2.1), the expectation E ($\hat{w}(u_0)$) of $\hat{w}(u_0)$, can be derived as follows:

$$E(\hat{w}(u_0)) = \lambda_1 m_1 + \lambda_2 m_2 = m_0 \quad (2.2)$$

Where, m_0, m_1 and m_2 are the means of $w(u_0)$, $w(u_1)$ and $w(u_2)$, respectively.

Let us separate the random variable $w(u_i)$ (i =0,1,2) into a random part $R(u_i)$ of zero mean and a trend part $m(u_i)$, and by virtue of Equation (2.2), the square error ${\sigma_E}^2$ of the estimator $\hat{w}(u_0)$ can be obtained as follows:

From Equation (2.2),

$$E(\hat{w}(u_0)) = \lambda_1 m_1 + \lambda_2 m_2 = m_0$$

$${\sigma_E}^2 = E\{[w(u_0) - \hat{w}(u_0)]^2\} \quad (2.3)$$

$$= E\{[R(u_0) - \hat{R}(u_0)]^2\} \quad (2.4)$$

$$= E[R^2(u_0)] - 2E[R(u_0)\hat{R}(u_0)] + E[\hat{R}^2(u_0)] \quad (2.5)$$

$$= Var_0 - 2\lambda_1 C_{01} - 2\lambda_2 C_{02} + {\lambda_1}^2 Var_1 + 2\lambda_1\lambda_2 C_{12} + {\lambda_2}^2 Var_2 \quad (2.6)$$

where C_{ij} is covariance of $R(u_i)$ and $R(u_j)$ ($i \neq j$, $i = 0,1,2$; $j = 0,1,2$).

Var_i is variance of $R(u_i)$ ($i = 0,1,2$).

From Equation (2.2) and Equations (2.3-2.6), a new function F is obtained using Lagrange parameter μ, as follows:

$$F = {\sigma_E}^2 - \mu(\lambda_1 m_1 + \lambda_2 m_2 - m_0) \quad (2.7)$$

The parameter λ_1, λ_2, m_0, and μ may be obtained by minimizing ${\sigma_E}^2$ in Equations (2.3 - 2.6) as given below:

$$\partial F / \partial \lambda_1 = 2\lambda_1 Var_1 + 2\lambda_2 C_{12} - 2C_{01} - \mu m_1 = 0 \quad (2.8)$$

$$\partial F / \partial \lambda_2 = 2\lambda_1 C_{12} + 2\lambda_2 Var_2 - 2C_{02} - \mu m_2 = 0 \quad (2.9)$$

$$\partial F / \partial m_0 = \mu = 0 \quad (2.10)$$

$$\partial F / \partial \mu = \lambda_1 m_1 + \lambda_2 m_2 - m_0 = 0 \quad (2.11)$$

Thus, from Equations (2.8 - 2.11), the authors derived the values of λ_1 and λ_2 represented by the variance and auto correlation function as follows:

$$\lambda_1 = (C_{01} Var_2 - C_{02} C_{12}) / (Var_1 Var_2 - C_{12}{}^2)$$

$$= \sqrt{(Var_0 / Var_1)}[(\rho_{01} - \rho_{02}\rho_{12}) / (1 - \rho_{12}{}^2)] \quad (2.12)$$

$$\lambda_2 = (C_{02} Var_1 - C_{01} C_{12}) / (Var_1 Var_2 - C_{12}{}^2) = \sqrt{(Var_0 / Var_2)}[(\rho_{02} - \rho_{01}\rho_{12}) / (1 - \rho_{12}{}^2)]$$

$$(2.13)$$

where ρ_{ij} is the auto correlation function between points i and j ($\rho_{ij} = C_{ij} / \sqrt{(Var_i Var_j)}$)

Substituting back λ_1 and λ_2 into Equation (2.6), the minimized square error is obtained, as follows:

$$\sigma_E{}^2 = Var_0 - \{(C_{02}{}^2 Var_1 + C_{01}{}^2 Var_2 - 2C_{01} C_{02} C_{12}) / (Var_1 Var_2 - C_{12}{}^2)\} \quad (2.14)$$

Which may be written as:

$$\sigma_E{}^2 = Var_0 \{1 - [(\rho_{01}{}^2 + \rho_{02}{}^2 - 2\rho_{01}\rho_{02}\rho_{12}) / (1 - \rho_{12}{}^2)]\} \quad (2.15)$$

The term stationarity is often used to describe assumptions under which inference is performed. Most of the techniques such as kriging used for estimating spatial correlation require the data to be stationary. This requires that the mean of the variable not to change over the region of interest. Also, there is stationarity of variance; that is, the variance of the function is constant over the region of interest.

Since no assumption has been made, so far, on stationarity for auto correlation function while deriving the above equations, it follows that Equations (2.14) and (2.15) can be applied to non-stationary space such as, for example in case where the correlation function are location-dependent.

Previous studies (Alonso and Krizek, 1975; Matsuo and Asaoka, 1977; Vanmarcke, 1977; Tang, 1979; and Bergado, 1994) have shown that empirical autocorrelation function of soil properties usually can be idealized by using an exponential decay function of the form given below:

$$\rho(\Delta h) = \exp[-(\Delta h / a)^m] \qquad (2.16)$$

where, $\rho(\Delta h)$ is a stationary autocorrelation function of soil properties,

(Δh) is a distance vector between any two points, and m and a are decay parameters.

Taking advantage of the stationary form of $\rho(\Delta h)$ in Equation (2.16), and substituting it into Equation (2.15), another form of the minimized square error ${\sigma_E}^2$ is obtained as follows:

$${\sigma_E}^2 / Var_0 = [1 - \exp\{-2A\} - \exp\{-2nA\} + \exp\{-2(1+n)A\}] / [1 - \exp\{-2(1+n)A\}]$$

$$(m=1) \qquad (2.17)$$