GEOSTATISTICAL MODELLING OF SOIL PROPERTIES IN EAST JAVA FOR SITE SUITABILITY ASSESSMENT

MARELIANDA AL DIANTY

UNIVERSITI SAINS MALAYSIA
2016

GEOSTATISTICAL MODELLING OF SOIL PROPERTIES IN EAST JAVA FOR SITE SUITABILITY ASSESSMENT

by

MARELIANDA AL DIANTY

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

September 2016

ACKNOWLEDGMENTS

In the first place, I give thanks to the Almighty Allah SWT for the strength and wisdom to put these words together. Higher appreciation goes to my supervisor, Prof. Ahmad Shukri Yahaya for all your assistance, guidance, support and always believe with me. His insightful reviews of my research were greatly appreciated. I express my gratitude to my co-Supervisor, Prof. Dr.Fauziah Ahmad for her support and guidance. May Allah SWT richly bless to both of you and family.

This thesis is the result of many hours of hard work and support from family. I deeply thank to my family, Gusti Amri., Msc, H.Harun Al Rashid, Hj.Susilawati, Densury Al Dian., MBA, dr. Devi Feriani who have supported me throughout educational endeavour. Thank you for the opportunity to pursuing higher education and helping me in financial support. Thank you for the all prayers, take care of my son and all the encouragement. I owe a lot with you. My blessings and love to my son, Akhtarelgusya Al Dian, I am sorry leave you and I am not beside you.

I would like to express grateful thanks to Dr. Fabio Veronessi (Cranfield University) who has helped me to understand geostatitical modelling with R software. Thank you for your useful information and references that was valuable for my research. I always disturb you with my entire question.

Sincerely thank and deep appreciation to my entire friend from Iran, Iraq, Nigeria, Philippine, China and of course Malaysia who always support me and encouragement throughout this process more than my friend from my own country. I would like to thank for my last employer, Huawei Co., Ltd and my team in NTS project 2G/3G. I wish to express biggest also thank to all staffs and all lectures at school of civil engineering. Last, special thanks to all cleaning services and securities in civil engineering school and in my hostel who always give me warm greeting and smile when they see me. They call me “Ina” because I am from Indonesia.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	One-factor analysis of variance
AHP	Analytical Hierarchy Process
BTS	Base Transmitter System
BSC	Base Switching Centre
CDF	Cumulative Distribution Function
COV	Coefficient of Variation
MLM	Maximum Likelihood Method
PDF	Probability Distribution Function
REML	Residual Maximum Likelihood
RNP	Radio Network Planning
RMSE	Root Mean Square Error
PA	Prediction of Accurancy
IA	The Index of Agreement
RMSD	Root Mean Square Deviation
Cov	Covariance
OK	Ordinary Kriging
USCS	Unified Soil Classification System

LIST OF SYMBOLS

C	The sill in variogram models
C_o	The nugget effect in a variogram model
H_0	The null hypothesis
H_1	The alternative hypothesis
N	The size of sample
p-value	The probability value
Ak	Unknown coefficients
$\varepsilon(x)$	Spatially dependent random component
$a_k f_k(x)$	Deterministic component
$\mu_{(s)}$	Mean
H	Lag (separating)
$Z(x)$	regionalized variable
$\gamma_{(h)})$	Semivariance
N	Porosity
E	Void ratio
R^2	Coefficient of determination
N_h	Number of separating distance
P_i	Predicted value
O_i	Observed value
$\overline{P}$	Mean value of predicted
$\overline{O}$	Observes values of predicted
σ_p	Standard deviation of predicted
σ_o	Standard deviation of observed
R	Pearson product moment correlation

LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
W_c	Water Content
G_s	Specific Gravity
γ_t	Unit weight
γ_d	Unit Density
γ_{sat}	Unit Saturated
ϕ	Angle of friction
c	Cohesion
τ	Shear strength
σ_n	Normal stress

PEMODELAN GEOSTATISTIK SIFAT TANAH DI JAWA TIMUR UNTUK PENILAIAN KESESUAIAN TAPAK

ABSTRAK

Kepelbagaian spatial mempengaruhi tingkah laku asas dan oleh itu prestasi struktur geoteknikal. Kajian ini telah menjalankan analisis kuantitatif untuk pencirian tapak dan untuk ramalan sifat kejuruteraan tanah menggunakan statistik dan teknik pemodelan geostatistik yang telah digunakan dalam analisis geoteknikal tetapi jarang digunakan dalam bidang telekomunikasi. Penyiasatan tapak telah dijalankan berdasarkan prosedur projek telekomunikasi penyokong di wilayah Jawa Timur, Indonesia. Petunjuk kesesuaian bagi projek Jawa Timur adalah empat asas ciri-ciri kejuruteraan tanah iaitu indeks keplastikan, nisbah lompang, keliangan dan kekuatan ricih. Tanah Jawa Timur yang berkaitan dengan asas projek telekomunikasi mempunyai keplastikan yang kebanyakannya tinggi. Empat petunjuk kesesuaian telah digunakan dalam ramalan dan pemetaan. Corak spatial indikator ini digunakan untuk mengenal pasti kawasan-kawasan yang mempunyai ciri-ciri yang sesuai untuk pembinaan. Hasil daripada autokorelasi spatial telah menunjukkan bahawa model variogram dengan penganggar REML lebih sesuai untuk ramalan dan pemetaan berbanding dengan model tanpa REML. Penyelidikan ini peta ramalan dengan resolusi 1 km^2 grid terhadap 73 tapak di lapan zon yang berbeza. Penilaian pemetaan tapak kesesuaian dijalankan berdasarkan penglihatan, topografi, penggunaan tanah dan ciri tanah, menggunakan proses analisis hierarki (AHP) untuk menentukan kepentingan relatif semua faktor-faktor yang dipilih. Hasil penilaian kesesuaian tapak menunjukkan bahawa Zon 2, Zon 3, Zon 4 dan Zon 8 dapat dikenal pasti

sebagai kawasan yang sesuai manakala Zon 1, Zon 5, Zon 6 dan Zon 7 dapat dikenal pasti sebagai kawasan yang tidak sesuai untuk pembangunan. Pemodelan geostatistik menggunakan 'kriging' biasa telah berjaya digunakan untuk mencirikan sifat kejuruteraan tanah di setiap zon. Teknik ini boleh digunakan sebagai alat diagnostik untuk mengenal pasti sifat-sifat kejuruteraan tanah di tapak semasa fasa perancangan awal. Keputusan menunjukkan bahawa kaedah ini boleh digunakan untuk membuat keputusan mengenai kesesuaian tapak telekomunikasi walaupun dengan set data yang lebih kecil. Prosedur kajian ini juga boleh digunakan untuk menyediakan panduan yang lebih baik dalam mengutamakan zon untuk pembangunan bidang telekomunikasi. Tambahan pula, kaedah ini menawarkan pendekatan yang lebih dipercayai dan bermaklumat yang boleh digunakan dalam membuat keputusan untuk perancangan tanah selamat dan menjimatkan untuk wilayah Jawa Timur.

GEOSTATISTICAL MODELLING OF SOIL PROPERTIES IN EAST JAVA FOR SITE SUITABILITY ASSESSMENT

ABSTRACT

Spatial variability influences the behaviour of foundation and therefore the performance of geotechnical structures. This research has carried out a quantitative analysis for site characterization and for prediction of soil engineering properties using statistics and geostatistical modelling techniques that are already used in geotechnical analyses but are rarely applied in the field of telecommunications. Site investigations have been carried out based on the procedures of telecommunication projects proponent in East Java province, Indonesia. The indicators of suitability for the East Java projects were the four elementary soil engineering properties namely plasticity index, void ratio, porosity and shear strength. The soil of East Java associated with the foundation of telecommunication projects were mainly high plasticity. The four indicators of suitability were used in the prediction and mapping. The spatial pattern of these indicators we used to identify the areas that have suitable characteristics for construction. Results from spatial autocorrelation have shown that the variogram modelling by REML estimator to be more acceptable for prediction and mapping in comparison to modelling without REML. This research produced prediction maps with a resolution of 1 km^2 grids over 73 sites at eight different zones. The evaluation of site suitability mapping was carried out based on visibility, topography, land cover and soil properties, using the analytical hierarchy process (AHP) in order to determine the relative importance of all the selected factors. The result of site suitability assessment indicate that at Zone 2, Zone 3, Zone 4 and Zone 8 could be identified as suitable areas while Zone 1, Zone 5, Zone 6 and Zone 7 could be identified as unsuitable areas for development. Geostatistical modelling using the ordinary kriging has been successfully used to characterize soil engineering properties in each zone. This technique could be used as a diagnostic tool in order to identify the engineering properties of soils at site during the initial planning phase. The results indicate that this method could decide on the suitability a telecommunication site even with a smaller dataset. The procedures of this research could also be used to provide better guidance in prioritizing zones for site development. Furthermore, they offer a more reliable and informative approach that may be applied for in decision-making for the safe and economical land planning for the province of East Java.

CHAPTER ONE

INTRODUCTION

1.1 Overview

The choice of foundation type largely depends on the results of site investigations and laboratory tests on local soils and rocks. Soil engineering properties are the important items in the analysis of site conditions and structural foundation such as practiced in the telecommunication towers construction activity. Basic elementary soil properties, including specific gravity, moisture content, dry density, wet density, and plasticity limits (e.g., liquid limits, plastic and limits), may eventually contribute to the decision making process regarding the suitability of a site. However, the relevant geotechnical properties like shear strength and compressibility would be the primary quantities used for designing foundations. Thus, the analysis of elementary soil engineering properties can be significant to land and site management, especially for the telecommunications network projects.

New telecommunication sites and its facilities are needed when telecommunication providers initiate coverage in a geographic area. These new sites should supplement the inadequate coverage from existing base stations, or the inadequate capacity of existing base stations that no longer capable of handling the number of users to be serviced. The planning for site telecommunications and all wireless telecommunication facilities, such as towers, shelters, base stations, feeders, and antennas, should correspond to the current update of the community's comprehensive plan. A comprehensive plan outlines the vision of a community for the future, areas for resource conservation, and targeted areas for growth and development. However, towers are being proposed by companies that do not have immediate plans for antenna installation (towers built on speculation) (Carpenter et al., 2001). Therefore, site suitability planning needed to consider the systematic assessment of land, water potential, and alternatives for land use. This site suitability planning can be used any construction for future not only telecommunication network sites.

1.1.1 Soil variability and uncertainty

Soil is a unique and natural engineering material with different physical properties. Its uniqueness is due to its variability and how it is formed the continuous processes of the environment that alter it (Uzielli et al., 2007; Adhikari et al., 2012; Rahardjo et al., 2012). Even for the same soil type, the nature of soils is not identical because soil properties vary from site to site. Variability is not only defined with respect to time or location, but is also represented by a frequency distribution that shows the variation in a characteristic of interest over time or across a population (Frey and Rhodes, 1999). Soil is modified continuously by different stresses, weathering, chemical reactions, introduction of new substances, and, in some cases, human intervention (e.g., soil improvement, excavation, filling). Variability in soil properties are often caused by small changes in topography that affect the transport and storage of water across and within the soil profile (Brady and Weil, 2002).

The uncertainties in soil properties inherent in the quality and quantity of soil samples, characteristics of the testing device, and operator's experience may have a significant effect on the measured geotechnical properties. These uncertainties should be recognized and quantified to adequately and logically determine the appropriate parameters for engineering analysis and design. Analysing the variability and uncertainty of engineering properties to help in the speedy judgment of soil condition at any development site prior to commencement of construction is necessary to minimize the volume of work and the accompanying cost involved in determining all engineering properties required before deciding on the foundation design parameters.

The inherent variation of soils from one location to another is called spatial variability. Statistical and geostatistical analysis can determine the spatial variability of soil properties from a data set in a more logical and accurate manner than otherwise determined (Baecher, 1987; Uzielli et al., 2007; Akbas and Kulhawy, 2010). When dealing with different uncertainties related to soil properties, the use of those stochastic methods generates better geotechnical designs by accurately assessing the influence of spatial variability of different soil properties on structural behavior. This process is also achievable through the use of spatial statistical structures. When these methods are used to analyze the spatial variability of soil properties, they can quantify unknown soil property variations at a site, offer better estimates for unsampled locations, and provide valuable information to systematically treat the sources of uncertainty of soil property measurements in reliability analyses. Therefore, statistical and geostatistical modeling are major contributors to spatial variability analysis in geotechnical engineering.

1.1.2 Site suitability planning

The planning on site suitability of every construction is highly required, such as in telecommunication network sites. A continuous demand for telecommunication technology leads to its rapid evolution. Currently, the new telecommunication industry has created new business imperatives for Telecommunication Company and its strength has improved the company's ability to influence industry trends. As changes in technologies have occurred, many operators of the companies are competing with each other to build telecommunication sites. Every years one operators can build 13,000 new tower telecommunication. Nowdays, around 600,000 of tower telecommunication was already build in Indonesia.

Numerous problems arise during the implementation of telecommunication site construction such as the issues of poor examination of groundwork and pit, such as pit dimensions, soil appearance, soil moisture, layer thickness, soil density, and slope stability. Figure 1.1 shows the poor quality of the pit that endangers slope stability on the soil. Those problems as well as tower failures can be avoided if the soil properties are properly studied, and soil exploration results are correctly understood and intelligently applied to the design as well as construction of earthworks and structural foundations (Mhaske and Choudhury, 2009).

Figure 1.1: Site telecommunication defect

East Java province was used as study area which is the first national region that going to launch a new telecommunications operator which have many issues during the implementation. This province covers total area of 47902.7679 Km^2 and has a population close to 40 millions, making East Java as the second most populated province in Java Island. East Java has strategic planning included the issue of the development of strategic infrastructure such as transportation, energy and telecommunications. It is explained in spatial and land use planning of East Java province nombor 5 year of 2012 about strategic provincial spatial planning year of 2012 - 2031 (National Coordinator for Survey and Mapping Agency of Republic Indonesia, 2012).

Topographic conditions of East Java province indicate a large forest potential. Forest pose agricultural potential as source of sufficient water, which flows throughout the year and can be used for irrigation. This district is considered as a district that have many volcanoes. Volcanoes and large rivers serve as means of spreading nutrient-rich substances resulting from volcanic eruptions and thus contribute to increased soil fertility. Several volcanoes which are still active include Mount Kelud, Mount Merapi and Mount Raung. In addition, the Bengawan Solo River, Brantas River, Solo River, Madiun River, and Konto River are all responsible for the translocation of fertile soil. Mreover, the southern part of East Java and the Madura Island often experience water related problems. In these regions, the soils are drier and barren, in contrast to the condition in the west and central parts of East Java where soils are more fertile (Syafitri, 2012). Hence, the variability of soil engineering around East Java province is considered high because of the variation of material.