UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A VISUALIZATION MODEL FOR DETECTING FRACTURES IN KUALA LUMPUR LIMESTONE FOR GEOLOGICAL ENGINEERING PURPOSES

SAMY ISMAIL MOHAMED MOHAMED ELMAHDY

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

April 2012

DEDICATION

To soul and memory of my parents who well cared of me

To my wife and my children your patient

And support has been my inspiration

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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April 2012

Chairman: Professor Shattri Bin Mansor, PhD

Faculty : Institute of Advanced Technology

The major geotechnical engineering problems confronted constructions and structure designs on Kuala Lumpur Limestone bedrock in Kuala Lumpur are: cavities, sinkholes, pinnacles, excavation collapses and irregular surface of limestone bedrock. To address these problems, a set of techniques were developed for (1) automatically detecting regional geological structures, (2) detecting geological structure intersections (dissolution zones) and their associated extreme karst features, and (3) visualizing geological structures and their associated karst features. These techniques include geological prediction model, hydro-morphological model and moropho-visualization model. These techniques were applied to Kuala Lumpur Limestone bedrock in Malaysia, by focusing on the adjacent mountainous areas and the geometries of ex-opencast mining ponds, depressions, major rivers and soil moisture. These features were spatially correlated and clarified by rose diagrams and semivariogram models.

Visualizations technique was developed by applying percentile stretching and Soble filter with 10% threshold and equalization enhancement to the calculated thematic maps. Several new geological fractures (faults, joints and bedding plains) were detected, mapped and visualized for the first time using the modified methods. Their orientations are dominantly found in NE-SW, NW-SE, WNW-ESE and E-W directions and correspond well with regional tectonic zones of the South East Asia. The study revealed that the ridge which reflect footwall of fault zone and valley which reflect fault plain represent 47% and 41% respectively.

In Kuala Lumpur city centre, the areas having very high probability occurrence of geotechnical engineering problems show an area of 2.66 km^2 (5%), whereas the areas characterized by low susceptibility for the occurrence of natural hazard is approximately 19 km^2 (36.2 %) of total Kuala Lumpur area. However, the high probability occurrence of geotechnical engineering problems class occupies 6.1 km^2 (11.7%), while the moderate natural hazard susceptibility class occupies 9.49 km^2 (18%) of the map, indicating the overall low and moderate natural hazard susceptible of the Kuala Lumpur city center.

In Seri Serdang area, the predictor map shows that the sites distributed on buried ex-open pit mining ponds, swamps and extensions of geological fractures have high probability for the occurrence of environmental and geotechnical engineering problems. These sites are in Serdang Lama (east) and Seri Serdang (west) and occupy an area of about 2.6 km^2, which is 42.7% of the Serdang areas (6.5 km^2).

Results obtained using the developed techniques were compared to those of subsurface geological fractures reported by means of geophysical survey and field investigation. Results demonstrated the effectiveness of the modified techniques combined with integration of geophysical survey and field survey in detecting and visualizing subsurface geological structures and karst features precisely over multiscale. The modified techniques may be useful for mapping geological fractures in areas of high soil moisture where geophysical survey is difficult and/or not available and is also highly applicable in other parts of Malaysia or south East Asia, permitting a better understanding of the geotectonics and geotechnical engineering setting of the study area.

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

PEMBANGUNAN MODEL VISUALISASI UNTUK MENGESAN KERETAKAN BATU KAPUR KUALA LUMPUR BATU KAMPUR BAGI TUJUAN AKTIVITI KEJURUTERAAN GEOLOGI

Oleh

SAMY ISMAIL MOHAMED MOHAMED ELMAHDY

April 2012

Pengerusi : Profesor Shattri Bin Mansor, PhD

Fakulti : Institute Technology Maju

Masalah kejuruteraan geoteknikal yang utama dalam rekabentuk pembinaan dan struktur hamparan batu kapur Kuala Lumpur Limestone di Kuala Lumpur merangkumi: kewujudan kaviti, lubang benam dan “pinnacle”, risiko runtuhan penggalian, dan juga permukaan hamparan batu kapur yang tidak teratur. Satu set teknik telah diajukan untuk mengatasi masalah-masalah seperti ini bagi tujuan (1) mengesan struktur geologi serantau secara automatik, (2) mengesan sempadan perantaraan struktur geologi (zon disolusi) beserta ciri-ciri kars terlampau yang berkenaan, dan (3) meramalkan struktur geologi beserta ciri-ciri kars yang berkenaan. Teknik-teknik ini termasuklah model peramalan goelogi, model morfologi-hidro dan model visualisasi-morofo. Teknik tersebut ini telahpun diguna-pakai pada hamparan batu kapur Kuala Lumpur Limestone di Malaysia, dengan menumpu kepada kawasan berbukit yang saling bersebelahan, dan juga geometri kolam lombong terguna-pakai, kawasan rendah, sungai utama dan tanah

lembap. Ciri-ciri ini adalah saling berhubung-kait, dan boleh dijelaskan melalui Rajah Rose dan Model “Semi-Variogram”. Teknik visualisasi dicipta-pakai dengan mengaplikasikan persentil regangan dan Tapisan Soble dengan 10% nilai ambang dan formula persamaan tambah-baik yang kemudiannya dikembangkan ke atas peta tematik yang dikira. Beberapa retakan geologi baharu (kecacatan, sendi dan dataran “bedding”) telahpun dikenalpasti, dipeta dan divisualisasikan untuk pertama kalinya dengan mengaplikasikan kaedah modifikasi ini. Orientasinya kerap dijumpai di arah NE-SW, NW-SE, WNW-ESE dan E-W, dan ianya bersesuaian dengan perantauan zon tektonik di Asia Tenggara. Kajian telah menjurus kepada penemuan bahawa “ridge” yang merujuk kepada kaki-dinding zon bermasalah, dan lembah yang merujuk kepada dataran bermasalah, adalah masing-masing 47% dan 41%.

Di bandar utama Kuala Lumpur, kawasan-kawasan yang berpotensi besar mengalami kejadian masalah kejuruteraan geoteknik merangkumi kawasan 2.66 km^2 (5%), menakala kawasan-kawasan yang paling kurang potensi mengalami kejadian sedemikian merangkumi 19km^2 (36.2%) daripada jumlah keluasan kawasan Kuala Lumpur. Walau bagaimanapun, kelas berpotensi tinggi mengalami kejadian masalah kejuruteraan geoteknik merangkumi 6.1 km^2 (11.7%), manakala kelas berpotensi sederhana mengalami kejadian sedemikian merangkumi 9.49 km^2 (18%) daripada peta keseluruhan. Keadaan ini sejurus menggambarkan gambaran keseluruhan kawasan berpotensi rendah dan sederhana mengalami kejadian berbahaya di bandar utama Kuala Lumpur.

Di kawasan Seri Serdang, peta peramal menunjukkan bahawa taburan tapak di kolam perlombongan terguna-kambus, paya dan kawasan lanjutan retakan geologi, mempunyai kemungkinan tinggi mengalami kejadian masalah persekitaran dan kejuruteraan geoteknik. Tapak ini terletak di Serdang Lama (timur) dan Seri Serdang (barat), dan menempati jumlah kawasan seluas kira-kira $2.6km^2$, iaitu 42.7% daripada keseluruhan kawasan Serdang seluas $6.5km^2$.

Keputusan yang didapati melalui teknik ini dibandingkan dengan retakan geologi subpermukaan yang dilaporkan melalui pendekatan kaji-selidik geofizikal dan penyiasatan luaran. Keputusan daripada perbandingan ini menunjukkan keberkesanan teknik pengolahan ini yang digabungkan dengan integrasi kaji-selidik geofizikal dan kaji selidik luaran dalam mengesan and meramalkan struktur geologi subpermukaan dan ciri-ciri kars dengan tepat berbanding “multiscale”. Teknik pengolahan ini adalah berguna untuk memetakan retakan geologi di kawasan tanah berkelembapan tinggi di mana kaji-selidik geofizikal sukar dijalankan atau langsung tidak dapat dijalankan, dan juga banyak berguna di tempat-tempat lain di Malaysia atau Asia Tenggara. Teknik ini secara keseluruhannya, memberikan pendekatan yang baik untuk mendalami pemahaman dalam bidang kajian kejuruteraan geoteknik dan geotektonik

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I certify that an Examination Committee has met on 2011 to conduct the final examination of Samy Ismail Mohamed Mohamed Elmahdy on his Doctor of Philosophy thesis entitled "Development of Geological Fractures and Cavities Detection Visualization Model in karst Terrain For Engineering Purposes" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the degree of Doctor of Philosophy.

Members of the Examination Committee were as follows:

Associate Professor Abdul Halim b. Ghazali**, PhD**
Faculty of graduate studies
Universiti Putra Malaysia
(Chairman)

Associate Professor Helmi Zulhaidi Mohd Shafri**, PhD**
Faculty of graduate studies
Universiti Putra Malaysia
(Internal Examiner)

Dr. Zainuddin b. Md. Yusoff**, PhD**
Faculty of graduate studies
Universiti Putra Malaysia
(Internal Examiner)

Professor Katsuaki KOIKE**, PhD**
Faculty of graduate studies
Universiti Putra Malaysia
(External Examiner)

SEOW HENG FONG, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date :

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as partial fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Shattri Bin Mansor, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Bujang B. K. Huat, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ahmad Rodzi Mahmud, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Shaharin Ibrahim,PhD
Associate Professor
Faculty of Environmental Science
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except that for quotations and citations which have been duly acknowledged. I also declare that it has not been previously , and is not concurrently submitted for any other degree at University Putra Malaysia or other institutions

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SAMY ISMAIL MOHAMED MOHAMED ELMAHDY

Date:

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LIST OF ABBREVIATIONS

GIS	Geographic Information System
planc	Plan convexity
crosec	cross sectional curvatures
minic	minimum curvatures
maxic	maximum curvatures
TWI	Topographic Wetness Index
DTA	Digital Terrain Analysis
GPR	Ground Penetration Radar
ER	Electrical Resistivety
UPM	Universiti Putra Malaysia
SMART	Storm Management and Road Tunnel
LRT	Light Rail Transit
MERI	Multielectrode resistivity Imaging
ERT	Electrical Resistivety Tomography
m.s.l	mean sea level
2D	two Dimensions
3D	Three Dimensions
SPT	Standard Penetration Test
SCI	Shape Complexity Index
GPS	Global Positioning System
UTM	Universal Transverse Mercator
NMM	National Mapping Malaysia
SRTM	The Shuttle Radar Topography Mission

CHAPTER 1

INTRODUCTION

1.1 Background

About 40% of Kuala Lumpur, Malaysia is found on highly fractured limestone bedrock and extreme karst features. The only outcrop of Kuala Lumpur Limestone is in Batu Caves in the form of hill of 213 m in height. Kuala Lumpur Limestone is carbonate rock metamorphosed into marble rock by thermal metamorphism (Tan, 1986a). Urban development in areas underlain by highly fractured limestone presents unique problem and challenge for geotechnical engineers and directly impacts on constructions and designing structures.

Several unpredictable environmental and geotechnical engineering problems have occurred during construction and designing structures over Kuala Lumpur Limestone. For example, the Petronas Twin Towers have been shifted 500m away from their proposed location to one entirely within the Kenny Hill formation (meta-sediments).

This is due to the geological fractures and karst features forming an irregular surface of Kuala Lumpur Limestone bedrock, described as the worst terrain in the world (Tan, 1986a; Tan, 1986b; Tan, 1987; Azam et al., 1996; Gue et al., 2001; Xeidakis et al., 2004; Zabidi et al., 2006; Samy et al., 2010a,b; Samy et al., 2011a,b). In addition to cavities and sinkholes, geological fracture displacements show unpredictable piling problems.

Although construction sites were basically scanned and tested using an integration of geophysical methods and boreholes, several unpredictable geotechnical engineering problems in terms of piling stuck, piling deflection and wall excavation collapses were encountered. The limitations of these methods come out from the fact that the fault zones may extend for more than 500 m width and hundred kilometers in length. This demonstrates the need for a powerful tool to precisely map the geological and karst features on a large scale, whilst at the same time being time and cost effective.

The use of remote sensing permits the revealing and mapping of geological fractures that are associated with unpredictable geotechnical engineering and piling problems. In general, most mapping and modelling of geological fractures has been applied from optical remote-sensing using visual interpretation (Arlegui and Soriano, 1998; Leech et al., 2003; Ricchetti and Palombella 2005; Hung et al., 2005), and directional and non-directional filters (Koch and Mather 1997; Suzen and Toprak, 1998; Samy 2006; Rammli et al., 2009).

Geological fractures have been modelled using the study of the periodicity of geological fractures in a digital elevation model using semivariogram and Fourier transform analysis (Harrison and Lo 1996; Jordan et al. 2005; Koike et al., 2006), and the use of wavelet transform analysis to study the spatial pattern and morphometry of a single geological fractures (Curran, 1988; Jordan et al., 2005).

Several computer softwares and automatic detection algorithms have been used to extract geological fractures in mountainous areas (Koike et al., 1995; Koike et al., 1998; Karnieli et al., 1996; Arlegui and Soriano, 1998; Argialas and Mavrantza, 2004; Kocal et al., 2004; Mostafa and Bishta, 2005; Hung et al., 2003; Masoud and Koike, 2011). Most of these studies have dealt with surface geological fractures in rough mountainous areas, using optical and active remote sensing where the geological features can be easily discriminated.

The most important geomorphic elements for both studying and revealing subsurface geological fractures are average elevation, average slope and organization strength (Guth, 2003). Average elevation represents a primary controlling on climate for precipitation and erosion; slope depicts the surface roughness of the landscape, while organization values measure the tectonic activity responsible for terrain deformation (Guth, 2003). Terrain characterization, flatness parameters and organization of relief are methods of spatial analysis which involve rules of correspondence between real entities (ridges and valleys) and numerical forms (classes).

In this study, geological fracture extraction and analysis using optical images presents three main problems. The first is environmental, a result of the areas underlain by limestone being covered by urban development (subsurface limestone). The second problem is that the extent of the geological fractures revealed in optical images is constrained by cloud and vegetation cover, which produce bias. The third problem is that the study area has a characteristically low slope and relief.

The use of a RADARSAT images and the digital elevation model (DEM) can be used to recognize and map the geological and geomorphological features of areas covered by vegetation and urban development.

These features include the ridges which reflect the footwall of subsurface faults and valleys (channels) which reflect the subsurface fault zones. The integration of visual interpretation and topographical fabric algorithm (Guth, 1999b) via the use of a digital elevation model (DEM) to create a map of ridges and valleys has proven particularly successful.

The use ridges and valleys represent an advance in terrain characterization and subsurface geological fracture extraction in a DEM, but cannot reveal and detect a regional fault zone curvilinear in shape (Jordan et al., 2005). Thus, visual and automatic methods are also required for geological fracture extraction. In this research, we developed morphometric techniques to map, visualize and spatially analyze the surface and subsurface geological fractures that are associated with unpredictable geotechnical engineering and piling problems.

The most remarkable aspect of the integration of the developed techniques is its application on a terrain analysis basis. The main objective of this research is therefore to precisely detect, visualize and analyze the spatial pattern of subsurface geological fractures and their associated karst features of the Kuala Lumpur limestone bedrock.

We also aim to provide a more detailed view of the geotectonic and geotechnical engineering setting of one of the worst (fractured) terrains in the world and compare them with adjacent mountainous areas (granite and Kenny Hill formation).

The developed method was found on establishing spatial association between structural geology, geomorphology and hydrology. It should be based on integrating surface and subsurface modelling. The model can be established based on significant relationship between its parameters namely aspect, slope, plan convexity (*planc*), cross sectional curvatures (*crosec*), minimum curvatures (*minic*) and maximum curvatures (*maxic*), streams and topographic wetness index (*TWI*) and geological fractures and their associated karts features. Following such a philosophy, this study was started by studying the regional geologic setting and their influence on the trends and patterns of geological fractures, ex-opencast mining ponds and rivers in the study area.

Such methods can help to establish advantages and disadvantages of several modeling techniques and thus, can facilitate in choosing an appropriate model for detecting geological fractures and their associated karst features development. In addition, provide answers that contribute to solve the unpredictable geotechnical engineering and environmental problems that are closely associated with regional geological fractures and their associated karst features development.

1.2 Problem statements

The major problems confronted by engineers designing structures in karst terrain are the difficulties in excavation, collapse of the roof over subsurface voids, subsidence of cover soil over sinkhole, difficulties in finding a structure over an irregular or pinnacled rock head, loss of water from dam reservoirs and pollution of groundwater (Chan and Hong, 1985; Tan, 1986a; Tan, 1987; Xeidakis et al., 2004; Zabidi et al., 2006; Samy et al., 2010a; Samy et al., 2011b). These problems have been known to be related to fault displacements, geological fractures intersections and their associated extreme and well- developed karst features (Waltham and Fookes, 2003). Geological fractures, including fault zones, joints, and bedding plains are essential parameters that affect the development and distribution of karst features, thus piling stability during construction and design (Figure 1.1).

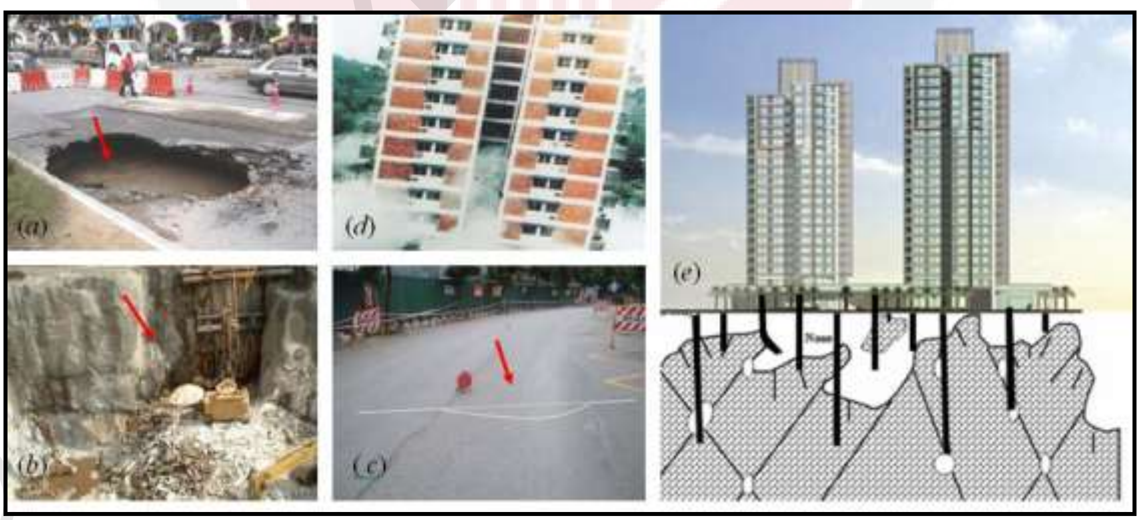

Figure 1.1: Several forms of unpredictable environmental and geotechnical engineering problems such as sinkholes (*a*), excavation collapse (*b*), earth surface subsidence (*c*), building collapse (*d*), and piling problems owing to irregular surface of limestone (*e*). These are a result of subsurface geological fractures displacements and dissolution zones in Kuala Lumpur limestone bedrock

For better understanding of the geological and geotechnical setting of the Kuala Lumpur Limestone, many questions can be arisen: (1) What are the spatial correlations between the surface and subsurface geomorphological and geological features?, (2) What is the spatial association among geological fractures, karst features development, drainage pattern, topographic wetness and surface curvature?, (3) What is the spatial relationship between morphometic features such as ridges, channels, peaks and pits and geological fractures and their karst features development?, (4) How the multi-elevation cavities and the pinnacles (karst features) are developed?, (5) How to detect the buried cavities and pinnacles locations as well as surface topography of limestone bedrock?, (6) Where are the areas that will succumb of geohazard and geotechnical engineering problems?, and (7) How we model the subsurface limestone bedrock in high urbanisation areas are covered with dense vegetation using remote sensing technique? If the answers to these questions are positive, is it possible to detect and model the subsurface geological fractures and their associated karst features development? This study will address these concerns.

1.3 Objectives

The aim of this study is to develop a visualization model for detecting fractures in Kuala Lumpur Limestone for engineering purposes where most bedrock is covered by vegetation and urban. Such model must be a multi-disciplinary in geomorphology, hydrology, structural geology and geophysical survey. More elaborately, this study has the following objectives,

- To delineate the geological fractures cutting across the Kuala Lumpur Limestone bedrock by focusing on the only Kuala Lumpur Limestone outcrop in Batu Caves, the ex-open pit mining ponds, and the adjacent mountainous area.

- To study the spatial correlation between patterns of surface geological fractures crosscut the Kuala Lumpur Limestone outcrops and their adjacent mountainous areas and subsurface geological fracture crosscutting the Kuala Lumpur Limestone by analysing and interpreting SAR imageries and DEM using the integration of visual and semi-automated methods.
- To develop geological fractures and their associated karst features detection visualisation method by applying percentile stretching and a 3×3 non linear filter with 10% threshold and equalisation enhancement to the thematic maps produced by Wood's algorithm.

- To develop a methodology for quantifying the spatial association between geological fractures and morphometric and hydrologic parameters as inputs to geotechnical engineering predictive mapping of geotechnical engineering problems where limited geological information are available.

- To construct predictor maps of the areas underlain by Kuala Lumpur Limestone bedrock using the features extracted.

The above objectives are to be met by integrating various geological, hydrological and geomorphological database and information sources. This involves integrating geological, hydrological and geomorphological database into GIS environment and integration procedures.

1.4 Scope of Study

This study focuses on development of geological fractures detection visualization model in karst terrain using remote sensing data with the support from field observation and geophysical survey. This study includes the application of remote sensing and GIS in detection visualisation of geological fractures and karst features.

The significant spatial association between geological fractures and morphometric parameters, elevation, slope, aspect, openness and surface curvature, and geomorphomteric features, stream networks and soil wetness was used to detect, map and visualise geological fractures and their associated karst features in Kuala Lumpur Limestone bedrock.

The SAR imageries and DEM in conjunction of LiDAR data set, sets of morphometric and geomorphometric parameterisation and modelling together with image processing and GIS functionality are widely used for spatial and statistical analysis of the results in the study. The results were validated by conducting field investigation in selected sites and comparing the results of geophysical survey with modified methods. The results of modified methods coincide with the results from field observation and geophysical survey.

1.5 Significance of Study

The remote sensing may increases the benefits of detection, modelling and visualisation of subsurface geological fractures and their associated kast features in limestone bedrock over multi-scale that are time and cost effective.

In tropical regions, the common limitation of geophysical instruments is that soil moisture and traffic noise attenuate electromagnetic waves. Furthermore, the geophysical instruments cannot scan regional fault zones of tenth kilometers in length and hundred meters in width.

This study, the first attempt, presents a geological fractures and cavities detection and visualization model based on integration between geomorphology, hydrology and structural geology by using remote sensing data, GIS and geophysical survey in karst terrain for engineering purposes to the Kuala Lumpur Limestone. The proposed model offers better understanding of the geologic, geotechnical and geomorphologic settings of Kuala Lumpur Limestone and could be the reference for the geologists and the geotechnical engineers. This model presents precise mapping and accurate results and solves the bias of geological fractures and their associated karst features detection by using geophysical instruments.

1.6 Thesis organisation

This dissertation synthesises results of the research work to develop geological fractures and cavities detection visualisation model in karst terrain for engineering purposes.
This research an anthology of ten scientific articles published in conference proceedings and peer-reviewed international journals since 2008. This thesis is organised into five chapters. The first chapter is the introduction that explains the background of geotechnical engineering problems that are closely associated with geological fractures and cavities. It also includes the objectives, scope and the significance of the study.

Chapter two is about the literature review that presents the methods, models and concepts done in geological fractures and their associated karst features using geophysical survey, remote sensing and GIS. The study area, datasets description, includes DEM accuracy assessment, established and new and modified methods for detection and visualisation geological fractures and their associated karst features. Chapter three presents the procedures and techniques that used for modelling approach. These include data preprocessing, data processing, feature recognition and geophysical survey and field observation. Chapter four presents the results, main findings and discussions. Chapter five presents the summaries of the research and provides suggestions for further research.

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BIODATA OF STUDENT

Samy Ismail Mohamed Mohamed Elmahdy was born in Al Qalubia government, Egypt in 1964. He obtained his early education at Al Qalag Primary School and Al Kankah Secondary School. He studied geology at Ain Shams University, Cairo, Egypt where he obtained his B.Sc. degree in 1987. He then joined ministry of education, Dubai, UAE as a geology senior teacher during the period from 1991 to 2004. Then he proceed with his master degree in remote sensing at the department of remote sensing, University Teknologi Malaysia in 2006. His current research interests include geology, hydrology and remote sensing applications. Now he is a PhD student in Institute of Advanced Technology, Universiti Putra Malaysia (ITMA). Currently, he is a potential reviewers for Hydrology journal, journal of contamination hydrology and journal of geological and geotechnical engineering.

LIST OF PUBLICATIONS

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