LANDSLIDE MONITORING USING GLOBAL POSITIONING SYSTEM AND INCLINOMETER TECHNIQUES

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DEDICATION

To my beloved parents, Hasnah Binti Ariffin and Zainon Bin Endot (1929-1998). Thank you for all the sacrifice, the love and courage that you give me all this while. I could never be at this level if it wasn't because of you.

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Muhammad Khatimul A'kif and Muhammad Khatimul Ahnaf.
Make this as an impetus and inspiration for success
to achieve what is desired

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ABSTRACT

Landslide is one of the prominent geo-hazards that continuously affect many tropical countries including Malaysia, especially during the monsoon seasons. For the past 25 years, landslides have occurred throughout the country that caused property destruction and loss of life, especially near the hillside areas. A landslide monitoring scheme is therefore very crucial and should be carried out continuously. Various studies have been conducted to monitor landslide activities such as conventional geotechnical and geodetic techniques. Each of these techniques has its own advantages and limitations. Therefore, this study focuses on the effectiveness of the combination approach of GPS technology and inclinometer techniques for landslide monitoring. The study area is located at residential area Section 5, Wangsa Maju, Kuala Lumpur, Malaysia. In the first stage, the geotechnical data have been collected using Mackintosh probe whereby the laboratory test on disturbed soil sample has been carried out to identify the composition of the soil structures. Next, the probe test was also conducted to determine the soil layer and soil contents at the study area. The inclinometer instrument has been placed at five (5) selected monitoring points and nine (9) epochs of inclinometer measurements were made. At the same time, the GPS observations have also been carried out for nine (9) epochs separately using four (4) GPS techniques such as static, rapid static, single base Real Time Kinematic (RTK) and RTK network. This GPS network consists of four (4) control points and eleven (11) monitoring points. The GPS observations data were validated, processed and adjusted using four (4) adjustment software namely Trimble Geometry Operations (TGO) software, Topcon Tools, STARNET and GPS Constraint Program. Next, GPSAD2000 and Static Deformation programmes were used to analyse the displacement of the monitoring points. The results have shown that the GPS technique can be implemented with inclinometer technique to detect horizontal displacements up to ± 40 mm and vertical displacements less than ± 80 mm,

ABSTRAK

Tanah runtuh merupakan salah satu fenomena bahaya yang memberi kesan berterusan kepada banyak negara-negara tropika termasuk Malaysia ketika musim monsun. Semenjak 25 tahun yang lalu, tanah runtuh telah berlaku di seluruh negara menyebabkan kemusnahan harta benda dan kehilangan nyawa, terutamanya berhampiran kawasan lereng bukit. Oleh itu, pemantauan tanah runtuh sangat penting dan perlu dilaksanakan secara berterusan. Pelbagai kajian telah dijalankan untuk memantau aktiviti-aktiviti tanah runtuh seperti teknik geoteknik and geodetik konvensional. Setiap satu daripada teknik ini mempunyai kelebihan dan batasan tersendiri. Oleh itu, kajian ini memberi tumpuan kepada keberkesanan kombinasi pendekatan teknologi GPS dan teknik *inclinometer* dalam pemantauan tanah runtuh. Kawasan kajian terletak di kawasan perumahan Seksyen 5, Wangsa Maju, Kuala Lumpur, Malaysia. Di peringkat pertama, data geoteknik telah dikumpul menggunakan *Mackintosh probe* dan ujian makmal ke atas sampel tanah yang terganggu telah dijalankan untuk mengenal pasti komposisi struktur tanah. Seterusnya, ujian *probe* juga dijalankan untuk menentukan lapisan tanah dan kandungan tanah di kawasan kajian. Alat *inclinometer* telah dipasangkan di lima (5) titik pemantauan yang dipilih dan sembilan (9) epok pengukuran *inclinometer* telah dilaksanakan. Pada masa yang sama, cerapan GPS telah dijalankan dalam sembilan (9) epok secara berasingan menggunakan empat teknik GPS seperti *static*, *rapid static*, *Real Time Kinematik* (RTK) bes tunggal dan jaringan RTK. Jaringan GPS ini terdiri daripada empat (4) titik kawalan dan sebelas (11) titik pemantauan. Data cerapan GPS telah disah, diproses dan dilaraskan dengan menggunakan empat (4) perisian iaitu *Trimble Geometry Operations* (TGO), *Topcon Tools*, *Starnet* dan *GPS Constraint Program*. Seterusnya, program *GPSAD2000* dan *Static Deformation* telah digunakan untuk menganalisis anjakan titik pemantauan. Hasil kajian menunjukkan bahawa teknik GPS boleh dilaksanakan dengan teknik *inclinometer* untuk mengesan anjakan mendatar sehingga ± 40 mm dan anjakan menegak kurang daripada ± 80 mm.

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LIST OF ABBREVIATIONS

RTK	-	Real Time Kinematic
RMS	-	Root Mean Square
GPS	-	Global Positioning System
DOP	-	Dulation of Precision
VRS	-	Virtual Reference Station
GPSAD2000	-	GPS Adjustment and Deformation Detection 2000
RTCM	-	Radio Technical Commission for Maritime Services
GSM	-	Global System for Mobile Communication
GPRS	-	General Packet Radio Services
NMEA	-	National Marine Electronics Association
DGPS	-	Differential Global Positioning System
EDM	-	Electronic Distance Measurements
m	-	Meter
mm	-	Millimeter
cm	-	Centimeter
ppm	-	Part per million

LIST OF SYMBOLS

A	-	The design matrix
b	-	The misclosure vector
$\boldsymbol{C}_{\hat{x}}$	-	Covariance matrix
$Q_{\hat{d}}$	-	Cofactor matrix
I	-	identity matrix
l	-	The vector of observations
l_o	-	Vector of computed observation
n	-	Number of observations
u	-	Number of parameter
W	-	The weight matrix
x	-	The vector of unknown parameters
$\hat{x}_1, \hat{x}_2$	-	The vector of corrections to the approximate values
$\hat{v}$	-	The vector of residuals
$\hat{x}$	-	The vector of corrections
$\boldsymbol{\sigma}_o^2$	-	A priori variance factor
$\hat{d}$	-	Displacement vector

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CHAPTER 1

INTRODUCTION

1.1 Background

Landslide is considered as one of the worst natural phenomenon that threat human life and property all over the world, including Malaysia. As one of the developing country, Malaysia has grown with rapid economic development over the last decades. These have necessitated the cutting of many hill slopes in order to maximize land utilization Hui (1999). Thus, the development of highlands area such as housing, highway and golf course construction and intensive forest logging have resulted in frequent occurrences of landslides. Therefore, an efficient and effective monitoring technique should be established in order to detect the rate of movement, size and the direction of the landslide. Assessment of real landslide occurrences includes the efforts to monitor land movement continuously. Brennan (1999) had categorized landslide research into three important phases:

a. Defining and classification of landslide,
b. Monitoring activities for landslide, and
c. Analysis and movement trend (deformation modelling).

This study focuses on the effective methods of GPS observation and data processing techniques, the trend analysis between GPS and inclinometer technique to detect deformation of slope and to produce suitable monitoring procedure using GPS and inclinometer application. This chapter briefly introduces the background of the research followed by problem statements, objectives and the statement of scopes of the research.

Landslide in non-horizontal position will encourage several gravitational force components to act upon them and force the land to slide when other external factors such as water, trigger the displacement. The land movement will occur when the inner layer or the outer layer of the earth is exposed to natural slipping motion. The earth will develop an unstable area outlined by a weak line named slip plane. Tubbs (1975) appointed that if there is any disruption along the slip plane area that would endanger the stability of the earth, and then a landslide will occur.

Landslide brings destructiveness and prominent geo-hazard that continuously affecting many tropical countries, especially in the monsoon season. For the past 25 years, rainfall has induces many landslides throughout Malaysia that strikes the citizens, especially near the hillside areas where several properties are damaged, human death and injuries have been reported. For example, landslide tragedy that occurred at Genting Highland on 30 June 1995 had killed 20 lives and more than 20 persons injured. Similarly, the landslide incident occurred in North-South near *Gua Tempurung* had caused extremely big loss and the cost of repair amount to ten million *Ringgit Malaysia* (Utusan Malaysia, 2002a). The landslide incident at *Kampung Pasir, Hulu Klang* in 31 Mei 2006 had killed four persons and caused a lot of property damage (Bernama, 2008). According to Marzita (2000), there are more than 100 areas in Peninsular Malaysia and 149 areas along the North South Highway that has been identified as the potential area of landslide.

Generally, there are various types of investigation and instrumentation being used to monitor landslide phenomena. The main investigations are geological structure, surface deformation, ground water and geotechnical. According to Nakamura (1996), the landslide boundaries, size and the movement directions can be determined by the surface deformation investigation using various type of measurement which include extensometer, tiltmeter, field-based geodetic method such as precise levelling, close range photogrammery, aerial photographs, and by satellite-based method such as Global Positioning System. Geological survey relies on probing, geophysical analysis and the evaluation of slide plane using the geotechnical instruments depending on the accuracy and magnitude requirements. Investigation of ground water includes ground water tracing test, ground water level, pore water

pressure, and ground water logging, geothermal survey, and geophysical logging Nakamura, (1996).

Usually, the easy way to define landslide evolution and analyses of any kinematics movement is to carry out survey works on the land surface. In many cases, survey work must be carried out more effectively especially from the aspect of time and cost. Research on landslide phenomena need continuously effort especially the deformation monitoring on existing landslide location from many aspect. This will help to decrease risk of landslide tragedies. Landslide phenomena are always correlated with the changes of the slope land or the failure of slope land.

Nowadays, Global Positioning System (GPS) has become a useful tool for the positioning of object. Robustness of GPS equipments, its reliability and its ease-of-use are some of the factors why GPS system is popular in survey works. With emerging of new GPS technology, many positioning methods and sophisticated software have been developed to collect field data efficiently whether for real-time purposes or post-processing purposes. Thus, GPS technology has became more progressive and has been applied in survey jobs, engineering surveys and other mapping purposes. GPS is beneficial in enabling deformation monitoring.

According to Forward (2002), GPS has several advantages over the other types of technology:

i. GPS operates 24-hour in any weather conditions.
ii. GPS works without direct visibility between two points with the minimal user interaction.
iii. GPS observation allows large number of acquisition with high speed and resolution.
iv. GPS can monitor large areas with three-dimensional (3D) positioning information.

In landslide research, GPS technology can be a tool to provide 3D coordinates for monitoring point. In this type of research, establishment of stable monitoring monuments are vital to ensure the success of such research. The monuments played an important role in such research that involved landslide. In order to explain the

deformation and to obtain more satisfied results, it is better to combine the geotechnical with GPS methods in landslide monitoring Kalkan *et al.*, (2002), Yalçınkaya and Bayrak (2002a and 2002b).

1.2 Problem Statement

Recently, landslide phenomenon has become a serious problem in Malaysia. This phenomenon occurred due to uncontrolled development especially at hilly terrain such as Penang, Kuala Lumpur, etc. The landslide tragedies have killed many people and also destroy the facilities such as buildings, roads, recreational park, houses, bridges and others. This phenomenon also causes a major socio economic impact on people and their whole live. All these tragedies were triggered by heavy rain. Therefore, real time rainfall values are valuable indicator of the risk level of landslides at the hilly terrain. As a result, preventing and reducing landslide effects can be solved by monitoring and solving the landslides mechanism Kalkan *et al.*, (2002).

In the pass, there are various types of instruments and methods that have been used to monitor landslide phenomena such as geological methods, geodetic methods, and geotechnical methods. All the investigations are carried out before and after any landslide tragedy. However, in Malaysia, the investigation is only carried out immediately after the incident occurred by the government sectors such as the Mineralogy and Geological Survey Department of Malaysia (JMG), Department of Public Worker (JKR) and other private sectors such as Malaysian Public Worker Institutes (IKRAM). Although the zonation of landslide is already known where is the prone area, but when it happen is unknown? They mostly used the geological method and geotechnical methods using the inclinometer techniques on the landslide area where sometime it is hard to assessable to the prone are. This will take longer time to identify the rate of landslide movement. In many cases, measurements must be efficient in terms of time and budget. Hence, to overcome this problem, this study investigates an appropriate procedure on the effectiveness of GPS observation and processing for landslide monitoring. The GPS technology is selected because of it is

one of the latest surveying technologies that has been proven very reliable to monitor landslide phenomenon. GPS methods provides satisfying result of the landslide behaviour, however, it provides limited information on the surface movement (Chrzanowski, 1986).

The GPS technique is capable of providing 3D coordinates in single or multi epoch observation and can be used to determine displacement through the recognized displacement coordinate relationship. This study also investigates the techniques to quantify the 3D GPS coordinates into deformation magnitude and direction. Beside that, these studies also investigate whether the achievable value is a significant deformation or vice-versa.

Generally, the geotechnical method such as inclinometer technique gives limited information of the sub-surface of deformable body, which are capable of providing measurement in one-dimension (Hill and Sippel, 2002). Additionally, geotechnical instruments are expensive or very costly and could only use limited number and location. Normally, geotechnical instrument could not be installed at the most critical site and the installation required significant effort. In order to have a better and more detail information on the characteristics of landslide, GPS survey method should be whenever possible to complemented with geotechnical method such as inclinometer technique (Kalkan *et al.*, 2002). The combination of these techniques can define the mechanisms and the processes of landslide as well as the relationship between the physical soil and the slope stability. Based on these techniques, appropriate procedure for landslide monitoring is produced in this study.

1.3 Aim and Objective of Study

The main aim of the study is to determine the effectiveness of GPS and inclinometer techniques to monitor landslide deformation. Therefore, the following objectives are presented to achieve the aim: -

a. To utilize GPS and geotechnical techniques in landslide monitoring.

b. To determine the magnitude of horizontal and vertical displacement of the study area periodically by using GPS and geotechnical methods.

c. To evaluate the effectiveness of GPS technique in monitoring positioning station for purpose of landslide deformation. The procedure focuses on the use of few GPS technique such as static, fast static, real time kinematic and real time kinematic network (MyRTKnet).

d. To investigate an appropriate procedure on the effectiveness of GPS and inclinometer observation and make comparative analysis between GPS and inclinometer for landslide displacement trend.

1.4 Scope of Study

Landslide studies require high precision measurements and proper structural deformation networking and analysis technique due to it slow moving nature. The geotechnical data and the satellite data system through the GPS technologies are capable of giving deformation conditions of the slope for safety purposes. The method of GPS employed for this study is the static, fast static, real time kinematic and real time kinematic network positioning mode, while for the geotechnical techniques, the data were taken using the Mackintosh Probe method, laboratory test and inclinometer investigation technique. These two methods are reliable, accurate and efficient for landslide monitoring deformation.

1.5 Research Methodology

Landslide researches need continuous monitoring efforts in order to keep track of the land movement evolutions in certain landslide locations. This session discusses in brief the experimental research for landslide monitoring. There are three phases in this research methodology as shown in Figure 1.1. The first phase includes the reconnaissance stage which includes the preliminary investigation such as site

reconnaissance, topographic investigation and preliminary analysis of existing geotechnical data such as boring result. The methodology starts by carried Literature review on GPS technology and geotechnical and their applications in landslide monitoring. This followed by choosing the suitable landslide location which is relevant to the research scopes. Next, soil probing using Macintosh probe techniques and soil sampling test in laboratory work was carried out at the landslide area.

Second phase is field investigation which includes set up monitoring networks design with respect to the specified monitoring technique. Than followed by the determination of control stations and plant monitoring stations location on the study area. Next is the field measurements that involve the GPS technique such as static, fast static, real time kinematic and real time kinematic network positioning mode and inclinometer techniques at the control and monitoring stations within certain epochs (after completing the monuments at the test sites).

Third phase is landslide assessment that includes the strategies of data processing and deformation analysis. The processing and analysis of GPS data is done to detect any deformation between first epoch and rest of the epochs using deformation software such as GPSAD2000 and Static Deformation Program. While, for the inclinometer data are processed and analysed using In-Site software. This followed by the detection of deformation based on geotechnical data using inclinometer instrument. Finally, the rate of displacement from both GPS and inclinometer techniques are compared and analysed.

1.6 Significant of Study

The contribution of this study is summarized as follows. Firstly, the precise GPS survey techniques are utilized to provide sub-centimetres precision for the slope stability analysis. Secondly, the suitability and effectiveness GPS techniques are utilized in deformation detection for landslide monitoring in Malaysia. The method of deformation applied in this study provides a perspective to the relevant authority or department to apply the approach for landslide monitoring.

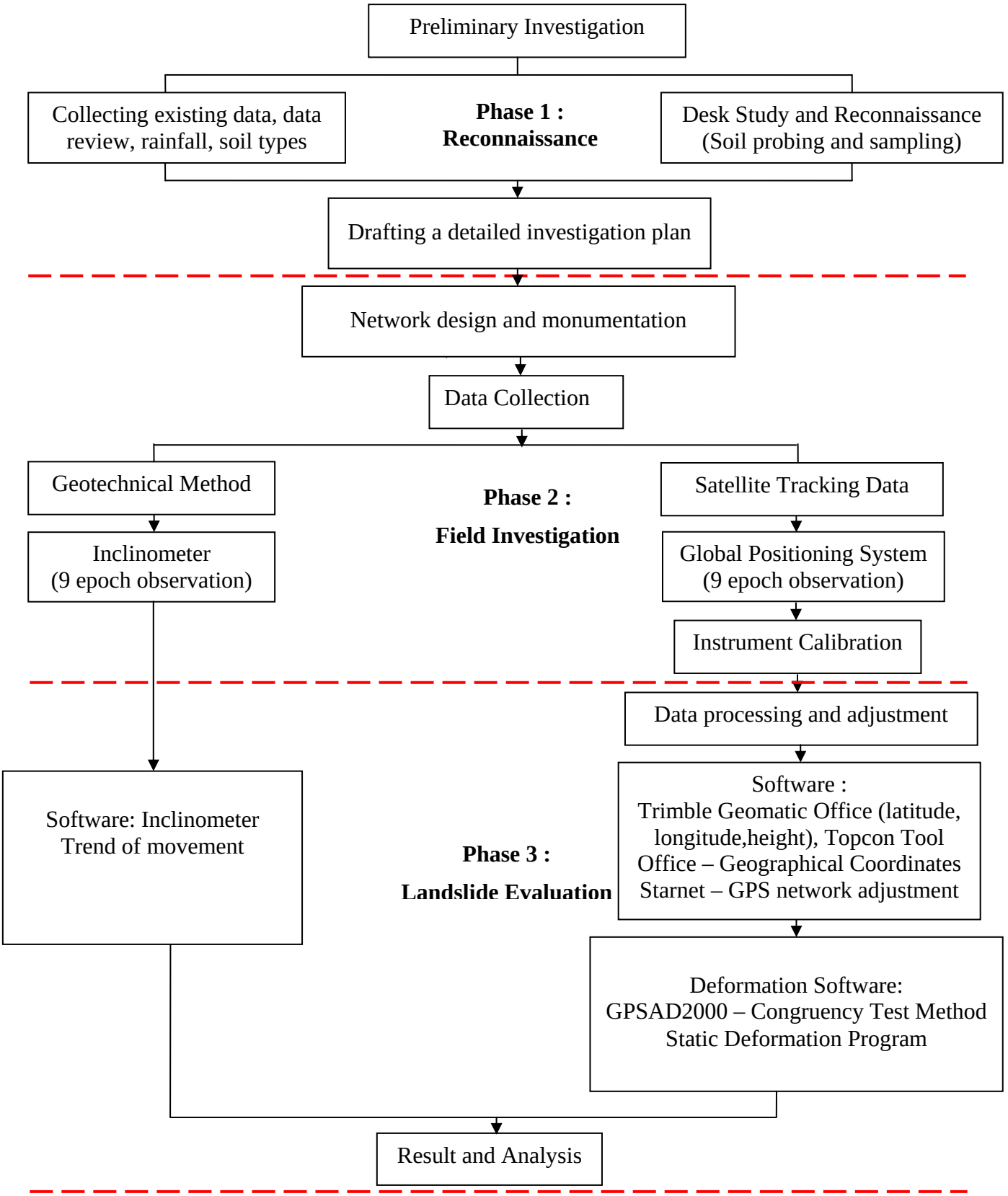

Figure 1.1: Flowchart of research methodology

The GPS and inclinometer techniques implemented in this study will provides better information of position changes in horizontal and vertical. The processing strategy of the technique should be obtained for true deformation without error or bias. This study customizes data processing algorithm for deformation which can provides a precise result. The benefit of this approach is that it verifies the reliability of the GPS technique for precise application such as landslide deformation monitoring.

The other contribution is to apply GPS and inclinometer techniques result for deformation monitoring in order to give an early result of the area that prone to landslide phenomenon. This could give benefit to the people at the surrounding area for an early prevention step and to reduce the damage caused by landslide.

1.7 Organisation of Thesis

This thesis consists of six chapters, appendices and a list of references. Chapter 1 explains the related introduction of this study including background of study, objectives, scopes and contribution of the study.

Chapter 2 discusses the issues of landslide phenomenon in detail, including the definition of landslide phenomenon in various perceptions, existing characteristics of landslide, and its connection with slope failure, landslide occurrence factors, the investigation methods and the examples of landslide phenomenon and the investigation methods in Malaysia.

Chapter 3 explains in depth the details of the scientific methods in landslide monitoring such as the instrumentation that being used in this study which are GPS and inclinometer. A detail explanation of both techniques is discussed. This include a discussion reviewing the GPS segment; the error sources involved in using GPS; positioning method and mechanism; processing differenced data; baseline solution; GPS dilution and GPS processing packages. Summaries of basic concept and techniques of inclinometer measurement are also presented in this chapter. The basic

concepts and methods of deformation analysis, types of network monitoring and techniques used for deformation monitoring are also discussed in this chapter.

Chapter 4 focuses on the observation procedure and research methodology. The observation procedure consists of network configuration, control network, monument design, types of GPS observation, and number of inclinometer casing based on the landslide rank from the ROM scale that has been developed Marzita (2000). This chapter also explained the operational scheme of combining the GPS and geotechnical methods for the landslide investigation. The implementation and application of the operational procedures using both GPS and geotechnical method at one existing landslide area that has been chooses as a sample. The detail explanation of the network design, monitoring campaign, processing and others related processes are discussed in this chapter. In the first sub-chapter, the preliminary study of the types of soil and laboratory test is highlighted in this chapter. The next section covers the network design and designation of the monitoring points. This chapter also briefly presents the observation procedures and analyses of processing GPS data for deformation monitoring landslide phenomenon using few GPS processing packages such as Trimble Geometry Operations (TGO), Topcon Tools and STARNET software.

Chapter 5 explains the results and discusses the work accomplished. The analysis consists of GPS network adjustment, GPS network deformation analysis, processing strategy using GPSAD2000 and Static Deformation Software, and the inclinometer detection.

Finally, Chapter 6 draws an overall conclusion and some important recommendation to future investigation of landslide monitoring in Malaysia. These conclusions and recommendations address the objectives stated in Chapter 1.

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