CHAPTER 2

LITERATURE REVIEW

2.1 Definition of Landslide

The term "landslide" is used to describe a wide variety of processes that result in the perceptible downward and outward movement of soil, rock, and vegetation under gravitational influence. It is also one of the most effective and widespread mechanisms by which landscape is developed. Landslides occur because shear stress (τ) exceeds the resisting forces, i.e. shear strength (S) of the material of concern (Bell, 1983). In general terms the stability of a slope may be defined by a factor of safety (FS) where: FS = S/ τ (Figure 2.1).

G –Gravitational force (kN)

σ - Normal stress (kN/m^2)

τ – Shear stress (kN/m^2)

μ - Pore water pressure (kN/m^2)

S –Shear strength (kN/m^2)

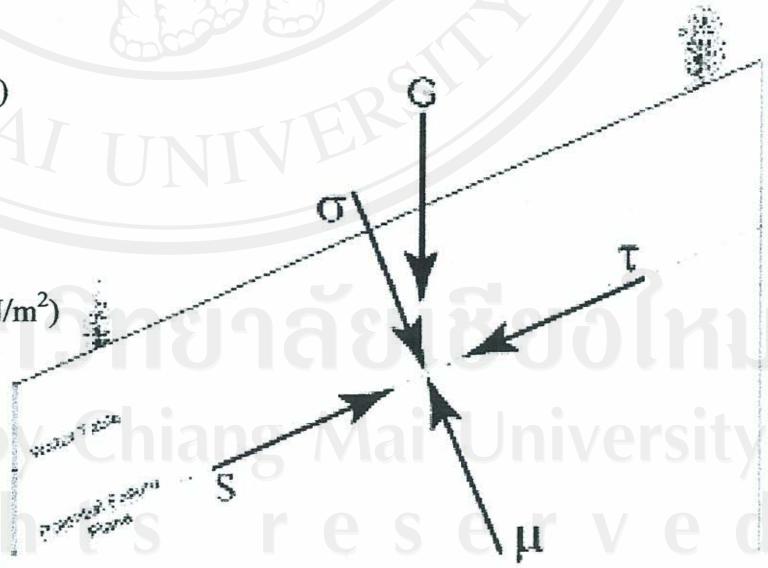

Figure 2.1 Schematic diagram showing forces and stresses acting on a point along the potential failure plane

If the factor of safety exceeds one, then the slope is stable, whereas if it is less than one, the slope is unstable. The materials may move by falling, toppling, sliding, spreading, or flowing (Montgomery, 2000).

Landslides can be triggered by both natural and man-induced changes in the environment. The geologic history of an area as well as anthropogenic activities directly determines or contributes to the conditions that lead to slope failure. The basic causes of slope instability are fairly well known. These include preconditioned factors such as weaknesses in the composition or structure of the rock or soil and triggering factors such as heavy rain, snowmelt, changes in ground-water level, seismic or volcanic activity and anthropogenic activities (Varnes, 1984). The later has been considered serious in the recent years. Human activities such as urban expansion, road-building, and deforestation have increased the potential for landslides and resulted in adverse impacts to the environment (Chung, 2006). These causes will be elaborated in the subsequent topics that follow.

Landslides, floods, debris flows and avalanches can result in massive damage of property and loss of lives. In hilly and mountainous regions, landslide constitutes one of the major hazards that cause losses to lives and property (Pradhan *et al.*, 2006). Of the different spatial and temporal distribution, the landslides initiated in steep mountainous terrain are a major threat to human lives and property.

2.2 Concept of Landslide Hazard and Risk

Almost no portion of the earth's surface is free from the impact of natural hazards (Suzen and Doyuran, 2004) and every year thousands of people all over the world lose their lives and property in natural disasters. Due to an increase in population densities, uncontrolled or poorly-planned development and the expansion of settlements and life-lines over hazardous areas have increased the impact of natural disasters both in the developed and developing world.

A systematic study of landslides involves identification and description of the danger, evaluation of the hazard probability and assessment of the risk so that effective preventive measures can be adopted (Anbalagan and Singh, 1996). While hazard refers to the probability of occurrence of danger, the risk refers to the losses incurred as a result of the danger. Using the above approach, a safe site for a village in danger may be discovered or siting satellite towns for a hill city may be planned.

2.2.1 Landslide Hazard

The hazard refers to a probability of occurrence of a danger. The period of time may be indicated in relative terms for different types of hazards (Anbalagan and Singh, 1996). For example in a predicted high hazard slope, the landslide may occur early compared to a moderate hazard or a low hazard slope. The hazards may be analyzed on regional scales (1:25000-1:50000) or on medium-regional scales (1:10000-1:15000) or on larger or detailed scales (1:1000-1:2000) (Chau *et al.*, 2004). While the studies on regional scales and semi-regional scales are generally based on empirical approaches, the detailed studies are based on analytical methods. In regional and semi-regional studies, the landslide hazards are rapidly assessed and hence larger areas can be covered in a short duration. These methods are based on basic causative factors of slope instabilities and help to identify hazard prone areas for further detailed studies. The analytical methods are employed in detailed studies for deterrent segments of a slope (Anbalagan and Singh, 1996). These studies determine the status of stability in terms of factor of safety taking into consideration the total shear stresses acting on the slope and the shear strength of the slope materials.

The intensification of land-use changes has raised the level of landslide susceptibility, particularly in mountainous regions (Saha *et al.*, 2002; Ramakrishnan *et al.*, 2002). Landslides that are initiated in steep mountainous terrain are a major concern to land-use managers worldwide. Human activities, such as urban expansion, road-building, and deforestation increase the potential for landslides and result in adverse impacts to the environment.

2.2.2 Landslide Risk

One of the most useful definitions of risk is presented by Varnes (1984) as the expected number of deaths, injury, property damage and economic disruption due to a particular damaging phenomenon for a given area and reference period. Therefore, risk refers to the nature of damage likely to be caused if the failure occurs. Risk assessment refers to an estimation of the extent of damage likely to result if the landslide occurs. The extent of damage is dependent on the existing landuse pattern of the area likely to be affected and the population. For example a major landslide in a remote area may cause less damage as compared to a smaller landslide in a densely populated area. In other words a small landslide in an inhabited area carries more risks than a major landslide in a deserted area. Hence risk is a function of hazard and the damage potential (van Westen *et al.*, 2006). The degree of damage will also depend on how fast or slow the slope fails. The loss of life and injuries may be significant when the landslide occurs all of a sudden and in a short time while the damage to land and/or property is unavoidable in all landslide events.

Landslides, as one of the major natural hazards with great risk, account each year for enormous damage in terms of both direct and indirect costs around the world. In many countries, the economic losses and casualties due to landslides are greater than commonly recognized and generate a yearly loss of property larger than that from any other natural disaster, including earthquakes, floods and windstorms (Duman *et al.*, 2005). Metternicht *et al.* (2005) reported that in the recent world disaster report (International Federation of the Red Cross and Red Crescent Societies, 2001) flooding, avalanches and landslides account for 42% of the global incidence of natural disaster, with average yearly economic losses due to landslides mounting to billions of dollars (e.g. Japan, India, Italy, USA) to millions in the countries like Canada, Nepal, and Sweden.

Landslides have caused large number of casualties and huge economic losses especially in mountainous areas of the world (Dai *et al.,* 2002). The disaster include the loss of lives and property, damage to natural resources (e.g. soil, water, land and vegetation) and hamper developmental activities such as roads and bridges and communications (Saha *et al.*, 2002). The most disastrous landslide can claim a large number of lives besides damaging million dollars worth of property and natural resources. For example, it was estimated that 200,000 people died in 1920 from an earthquake-induced loess flow in Kansu Province China (Hansen, 1984). Naithani (1999) estimated that in the Himalayan range, the damage caused by landslide is more than US$ 1 billion besides causing more than 200 deaths every year, which overall is considered as 30% of such types of losses occurring worldwide. The landslides caused casualties in Italy from 1410 to 1999 was estimated to be 12,421 deaths and injuries (Guzzetti, 2000); these casualties were caused by at least 996 landslides. This yields a casualty rate of 21 deaths and injuries per year in Italy span over a period of 590 years. The actual casualties could probably be higher than this value since the dataset for landslides causing low casualty rate might have been incomplete before the 19th century.

2.3 Prevention of Landslide Risk

The most reliable way to prevent landslide-induced casualties and economic losses is to avoid any developmental activities and building of towns and cities in the vicinity of landslide-prone areas or steep terrains. But this is considered impracticable or impossible in many countries due to the rapid growth of human population or due to the expensive cost in relocation (Chau *et al.*, 2004). However, social and economic losses due to landslides can be reduced by means of effective planning and management. These approaches include restriction of development in landslide-prone areas, use of physical measures (drainage, slope geometry modification, and structures) to prevent or control landslides, development of warning systems, and use of construction codes (Montgomery, 2000). Implementation of all these approaches makes necessary for planners and decision makers to know in advance where and when to apply the measures. Therefore, the need for landslide hazard and risk assessment to identify the likelihood of hazard and risk of an area in advance becomes imperative in order to reduce landslide related damages (Anbalagan and Singh, 1996). Landslide hazard map is very useful in estimating, managing and mitigating landslide hazard for a region (Anbalagan, 1992). Many review articles have addressed the issue of landslide hazard and risk analysis and management.

2.4 Causes of Landslide

Landslides are the results of two interacting sets of factors the preconditioned and triggering factors. The preconditioned factors, which govern the stability conditions of slopes, are generally naturally induced while the preparatory and the triggering factors are induced either by natural factors or by human interventions (Komac, 2006). Landslides can be triggered by a variety of external stimuli, such as intense rainfall, earthquake shaking, water level change, storm waves or rapid stream erosion that cause a rapid increase in shear stress or decrease in shear strength of slope-forming materials (Varnes, 1984). In addition increasing population and urbanization, human activities such as deforestation or excavation of slopes for road cuts and building sites etc., have become important triggers for landslide occurrence (Montgomery, 2000).

The influences of some of the factors leading the slope failure are discussed in the following topics:

2.4.1 Geological Causes

One of the geologic factors that contribute to landslides is a type of material from which the slope is formed. The materials can be plastically weak, sensitive or collapsible materials. These materials, in presence of certain triggering factors, can easily lead to landsliding by breaking apart the structure and thus reducing the strength and creating a finer-grained equivalent of quick sand that is prone to landsliding (Montgomery, 2000).

The degree of weathering and the thickness of the weathered soil also influence the occurrence of landslide to a great extent. Weathering is the physical and chemical disintegration or decomposition of geologic deposits (Watkins *et al*., 1975). Highly weathered rock has low shear strength. Increase in thickness of a residual soil due to weathering increases the overburden pressure causing an increase in the shear stress in the soil mass.

The occurrence of a landslide also depends strongly on the rock type, jointed, sheared, and fissured materials and their orientation.

2.4.2 Morphological Causes

Morphological processes shape the earth continuously. Important morphologic processes which triggers landslide are tectonic uplift, volcanic uplift, glacial rebound, fluvial erosion of the slope toe, wave erosion of the slope toe, glacial erosion of the slope toe, erosion of the lateral margins, subterranean erosion (solution, piping), deposition loading of the slope or its crest, and vegetation removal by erosion, forest fire, drought (Montgomery, 2000).

2.4.3 Physical Causes

Physical environment has a major role to play in the process of landsliding (Montgomery, 2000). However, each factor differs from place to place in terms of their effect, intensity, frequency, etc. Rainfall is considered as one of the most important physical factors responsible for triggering landslide (Lan *et al*., 2003). Occurrence of landsliding also will depend on the water holding capacity and nature of materials the slope is made of. For instance, shrink and swell weathering of expansive soils in the presence of high moisture content could lead to slope failure. In the high altitude region rapid melting of deep snow, freeze and thaw weathering and thawing of permafrost are of important factors which enhance the possibility of occurrence of landslide. Other physical factors include natural phenomenon such as earthquake and volcanic eruption. Earthquake shocks and vibrations in granular soils not only increase the external stress on slope material but they can cause a reduction in the pore space which effectively increases pore pressures.

2.4.4 Anthropogenic Causes

Human activities are considered as one of the causes of most of the recent landslides. A study carried out by Remondo *et al*. (2005) found a fairly good correlation between landslide frequency and socioeconomic indicators of human activity in the two study areas in Spain. Human activities triggering landslides are mainly associated with landuse pattern, construction, and changes in slope and surface-water and groundwater system. Inappropriate form of landuse such as removal/stripping of stabilizing vegetation to develop agricultural or settlement areas expose sloping soil, and make area susceptible to landslides. Change in slope result from quarrying or open-pit mining operations, terracing for agriculture, cut-and-fill construction for highways, and the construction of buildings and railroads. If these activities and facilities are improperly designed or constructed, they can increase slope angle, decrease toe or lateral support, or load the head of an existing or potential landslide. Slopes cut in unconsolidated materials at angles higher than the angles of repose of those materials are by nature unstable, especially if there is no attempt to plant stabilizing vegetation (Montgomery, 2000). Changes in irrigation or surface runoff can cause changes in surface drainage and consequently increase erosion, loading a slope, or raising the groundwater table. The groundwater table can also be raised by lawn watering, wastewater effluent from leach fields or cesspools, leaking water pipes, swimming pools or ponds, and application or conveyance of irrigation water. High groundwater level results in increased pore-water pressure and decreased shear strength, thus facilitating slope failure. Conversely, lowering of the local groundwater table as a result of rapid drawdown by water supply wells, or the lowering of a lake or reservoir, can also cause slope failure as the buoyancy provided by the water decreases and seepage gradients steepen.

2.4.5 Role of Water in Landsliding

It is generally agreed that in most landslides, groundwater constitutes the most important single contributing cause. The rapid infiltration of water (rainfall), causing soil saturation and a temporary rise in pore water pressures is generally believed to be the mechanism by which most shallow landslides are triggered during storms (Lan *et al.*, 2003).

An increase in water content not only adds the weight of the unstable mass but it also causes a decrease in shear strength either by reducing the apparent soil cohesion or through the increase of pore water pressure at the potential slip surfaces. The presence of water also softens clay minerals that may be present and thus reduce strength and cohesion inducing slope failure. Significant volume change may occur in some materials, notably clays, on wetting and drying out (Bell, 1983). Seepage force within a granular soil can produce a reduction in strength by reducing the number of contacts between grains. Water can also weaken slope material by causing materials to alter or bringing about their solution.

The role of water is also seen to vary considerably depending on the degree of weathering of rock. A study in weathered granitic rocks conducted by Phien-wej *et al.* (1993) in Khao Luang, southern Thailand, revealed that different grade of weathering exhibits different shear strength at different degrees of saturation. The self explanatory result of the study is presented in Figure 2.2.

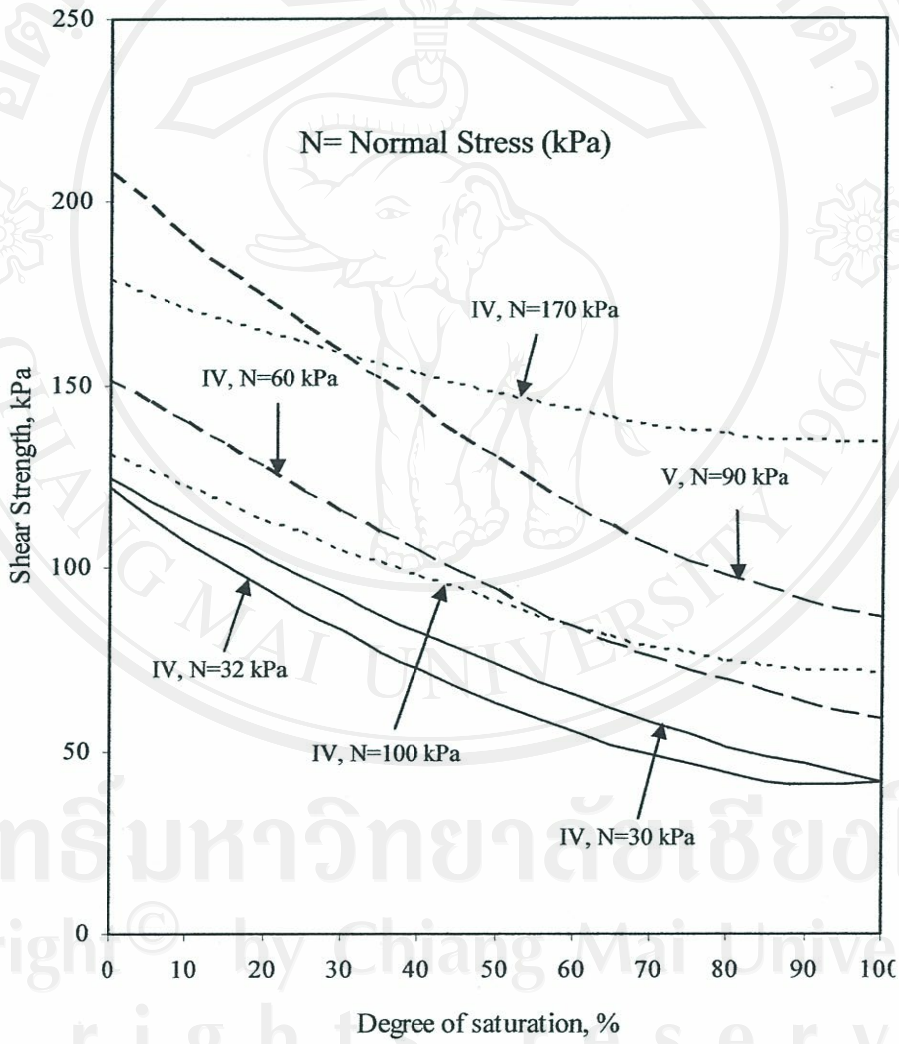

Figure 2.2 Effect of moisture on strength of weathered granite. Grade VI – granitic residual soil, Grade V – completely weathered granite, Grade IV – highly weathered granite (after Phien-wej *et al.*, 1993)

Submerged and most partly submerged slopes are comparatively stable as the water pressure acting on the surface of the slope reduces shearing stresses. If however, the water level falls as it does due to rapid drainage of a reservoir or due to tidal effect, the stabilizing influence of the water disappears (Bell, 1983). If the slope consists of cohesive soils, the water table will not be lowered at the same rate as the body of water. This means that the slope is temporarily overloaded with excess pore water, which may lead to failure. Thus rapid drawdown may be critical for slope stability (Montgomery, 2000)

2.5 Landslide Hazard Mapping

Landslide hazard zonation (LHZ) refers to a division of the land surface into zones of varying degrees of stability based on an estimated significance of causative factors in inducing the instability (Anbalagan and Singh, 1996). Hazard zoning of an area requires the identification and mapping of a group of factors which are directly or indirectly correlated with slope instability. They then involve an estimate of the relative contribution of the instability factors in generating slope failures, and the classification of the land surface into domains of different hazard degree. Anbalagan and Singh (1996) pointed out the usefulness of the LHZ map as follows:

- To identify and delineate unstable hazard prone areas, so that unfavorable sites for development schemes, such as buildings, dams, and road constructions can be avoided in such areas.
- The maps help planners to identify and delineate hazard-prone areas, so that environmental regeneration programmes can be initiated adopting suitable mitigation measures.

Even if hazardous areas cannot be avoided altogether, their recognition in the initial stages of planning may help to adopt suitable precautionary measures. However, management of the landslide disasters can be successful only when detailed knowledge is obtained about the expected frequency, character and magnitude of the mass movement in an area (Ramakrishnan *et al.*, 2002) besides using LHZ maps. The zonation of landslides hazard must be the basis for any landslide mitigation strategy and should supply planners and decision-makers with adequate and understandable information.

2.6 Landslide Hazard Mapping Methods

Numerous methods have been developed and tried to assess the probability of landsliding in different parts of the world. van Westen (2000) divided these methods into inventory, deterministic, statistical and heuristic approaches.

The most straightforward initial approach to any study of landslide hazard is the compilation of a landslide inventory, and such inventories are the basis of most susceptibility mapping techniques. It is based on the assumption that slope failures in the future will be more likely to occur under the conditions which led to past and present slope movements (Varnes, 1984). They can be prepared by collecting historic information on landslide events or from aerial photograph interpretation coupled with field checking. Inventory maps can be used as an elementary form of hazard map because they show the locations of recorded landslides. The historic frequency of landslides in an area can be determined to provide realistic estimates of landslide probability throughout a region where landslides have caused a significant amount of damage (Guzzetti *et al.*, 1999). The approach has been used by many, notably, Uromeihy and Mahdavifar (2000), Cevik and Topal (2003), Chau *et al.* (2004), Pachauri *et al.* (1998), Guinau *et al.* (2005), Rautela *et al.* (2000), and Anbalagan and Singh, (1996) to assess landslide hazard and risk.

Fall *et al.* (2006) and Shou *et al.* (2005) among the others have attempted to assess landslide hazard and risk using deterministic method. The deterministic approaches, based on stability models, is very useful for mapping hazard at large scales, for instance for construction purposes. Deterministic landslide hazard maps normally provide the most detailed results, expressing the hazard in absolute values in the form of safety factors, or the probability of failure given a set of boundary conditions for groundwater levels and seismic acceleration (Barredo *et al.*, 2000). However, deterministic models require the availability of detailed geotechnical and groundwater data, and they may lead to oversimplification if such data are only partially available.

Another approach includes bivariate or multivariate statistical analysis. The combination of factors that have led to landslides in the past are determined statistically, and quantitative predictions are made for areas currently free of landslides. In these methods the use of complex statistics requires the collection of large amounts of data to produce reliable results (Barredo *et al.*, 2000). These methods are most suitable to predict future landslides at medium scales (1:25,000 to 1:50,000). Each landslide type should be analysed separately, since it is related to a different combination of input factors. The approach has been used by many workers, e.g. Suzen *et al.* (2004), Komac (2006), Chung (2006), and Duman *et al.* (2005).

The last approach is the heuristic approach. The heuristic approach utilizes data integration techniques, including qualitative parameter combination, in which the analyst assigns weighting values to a series of terrain parameters and to each class within each parameter (Barredo *et al.,* 2000). The parameter layers are then combined within the GIS to produce hazard values. Heuristic methods use selective criteria, which need expert knowledge to be suitably applied. Some of the studies with this approach include Barredo *et al.* (2000), Saha *et al.* (2002), Leynes *et al.* (2005), and Ayalew *et al.* (2006).

2.7 GIS as a Tool for Landslide Study

As the occurrence of landslides is dependent on many factors, the evaluation of landslide hazard is a complex task and involves the handling and interpreting a large amount of factual, geological and simulated data (Chau *et al*., 2004). In the past decades, several field-based hazard zonation studies with manual integration of data have been carried out in different parts of the world (e.g. Anbalagan 1992, Pachauri and Pant 1992, Gupta *et al.* 1993, Virdi *et al*., 1997). However, these approaches have several drawbacks, such as the extent of the area covered is generally small and manual overlay of thematic maps is tedious and has poor integration capability (Saha *et al*., 2002).

With the advent of remote sensing and GIS technology, a computer system for capturing, storing, querying, analyzing, and displaying geographic data (Chang, 2002), it has become possible to efficiently collect, manipulate and integrate a variety of spatial data such as geology, structure, surface cover, and slope characteristics of an area which can be used for landslide hazard zonation (van Westen 2000, Gupta and Joshi 1990, and Gupta *et al.,* 1999). Dikau *et al.* (1996) argued that compared with manual map production GIS technology has clear advantages because the modeling procedures and the graphical output can be handled in the same GIS environment. The use of GIS has enhanced the possibilities of systematic mapping of large regions and increased significantly the productivity of mapping procedures (Corominas *et al.*, 2003). GIS has also strong capability in spatial data processing and geostatistical analysis. Therefore, it is useful and popular for the assessment of natural disasters (Shou *et al.*, 2005).

GIS technology has been used virtually everywhere in the world, including both developed and developing countries. Since the mid 1980s, GIS becomes a very popular technology used in calculating and managing natural hazards, including landslides (Saha *et al.*, 2002,). GIS is used by many (e.g. Guzzetti *et al.*, 1999; Moss, 2000; Suzen *et al.*, 2004; Fall *et al.*, 2006; Guinau *et al.*, 2005; Cevik *et al.*, 2003; Perotto-Baldiviezo *et al.*, 2004; Shou *et al.*, 2005; Chau *et al.*, 2004; Tangestani, 2003; Komac, 2006; Chalermpong, 2002; Rautela *et al.*, 2000; Lee *et al.*, 2002; Ramakrishnan *et al.*, 2002; and Duman *et al.*, 2005) in different parts of the world to assess landslide hazard and risk. Thus the use of computer or information technology is crucial to the success of such analysis given the fact that all aspects of hazard and risk analysis due to landslides involve the handling and interpreting a large amount of spatial data.