EVALUATION OF EMBANKMENT STABILITY FOR NEW DIVERSION CHANNEL UNDER VARIOUS LOADING CONDITIONS

by

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TABLE OF CONTENTS

CHAPTER 1 - INTRODUCTION

CHAPTER 2 – LITERATURE REVIEW

CHAPTER 3 - METHODOLOGY

CHAPTER 4 – RESULTS AND DISCUSSION

CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF SYMBOLS

S_u	undrained shear strength
σ_p	pre-consolidation pressure
C_c	compression index
m_v	coefficient of volume change
C_v	coefficient of consolidation
σ'	effective stress
σ	total stress
u	pore water pressure
$\mathrm{M_R}$	resisting moment
$\mathrm{M_D}$	driving moment
α	reinforcement tensile force angle with respect to the horizontal
$\mathrm{T_{allow}}$	maximum allowable reinforcement tensile strength
E	elastic modulus
v	Poisson’s ratio
ϕ	friction angle
c	cohesion
γ	unit weight of each material
z	thickness of each material layer
σ_v	total vertical stress
σ'_v	effective vertical stress
σ'_h	effective horizontal stress
K_0	coefficient of lateral earth pressure at rest
H	total hydraulic head
k_x	saturated hydraulic conductivities in x direction
k_y	saturated hydraulic conductivities in y direction
m_w	slope of the storage curve
γ_w	unit weight of water
t	time
n	porosity
s	degree of saturation
M_v	coefficient of volume compressibility

θ_r	residual volumetric water content
θ_s	saturated volumetric water content
ψ	negative pore water pressure
k_s	saturated hydraulic conductivity
Θ_p	volumetric water content at the halfway point of the volumetric water content function
ψ_p	matric suction at the same point
c'	effective cohesion
ϕ'	effective friction angle
σ_n	total normal stress
u_a	pore air pressure
u_w	pore water pressure
ϕ^b	angle defining the increase in shear strength for an increase in suction
Π_a	strain energy
EA	axial rigidity
L	length of reinforcement
u	axial displacement along the reinforcement
x'	distance along reinforcement

LIST OF ABBREVIATIONS

DID	Department of Irrigation and Drainage Malaysia
USCS	Unified Soil Classification System
IGS	International Geosynthetics Society
PVC	Polyvinyl chloride
HDPE	High density polyethylene
GCL	Geosynthetic clay liners
FOS	Factor of safety
FEM	Finite element method
SPT	Standard penetration test
USDA	United States Department of Agriculture
AASHTO	American Association of State Highway and Transportation Officials
BS	British Standards
UU	Triaxial unconsolidated undrained test
AEV	Air entry value
USACE	United States Army Corps of Engineers

PENILAIAN KESTABILAN TEBING LENCONGAN SUNGAI BARU DI BAWAH PELBAGAI KEADAAN PEMBEBANAN

Abstrak

Kajian ini dijalankan untuk menilai kestabilan tebing sebatang sungai lencongan baru yang dinamakan ‘Sungai Baru Diversion’ yang terletak di negeri Kedah, Malaysia. Kestabilan tebing telah dikaji menggunakan pelbagai jenis tanah pembinaan seperti tanah liat, liat berkelodak, loam liat berkelodak dan loam serta keadaan pembebanan yang berbeza iaitu selepas pembinaan tebing, semasa keadaan mantap, semasa banjir dan selepas surutan pantas paras air sungai. Siasatan tapak telah dijalankan di lapangan dan data terkumpul telah digunakan dalam simulasi dan analisis pelbagai keadaan pembebanan seperti yang dinyatakan dengan menggunakan perisian SEEP/W, SIGMA/W dan SLOPE/W. Tebing tanah liat menghasilkan faktor keselamatan yang terendah berbanding dengan jenis tanah yang lain. Faktor keselamatan yang diperolehi untuk cerun tebing tanah liat ialah 1.39 selepas pembinaan tebing, 3.75 semasa keadaan mantap, 3.7 semasa banjir dan 1.33 semasa surutan pantas air. Analisis juga menunjukkan bahawa ubah bentuk yang tinggi berlaku di lapisan asas tanah liat selepas pembinaan tebing di mana enapan sebanyak 164 mm dan pengembangan sebanyak 72 mm telah dianggar berlaku di kawasan tengah dan kaki tebing. 9 kaedah penstabilan tebing menggunakan geotekstil bukan tenun telah dicadangkan serta dianalisis dan didapati bahawa kaedah konvensional yang menggunakan geotekstil bukan tenun berukuran 3 m adalah kaedah yang paling sesuai untuk meningkatkan kestabilan dan mengurangkan ubah bentuk tebing sungai. Kajian ini telah membuktikan bahawa pemodelan tebing sungai yang realistik dan komprehensif boleh dilaksanakan untuk menilai kestabilan di bawah pelbagai keadaan pembebanan agar kaedah penstabilan yang paling sesuai dapat dicadangkan.

EVALUATION OF EMBANKMENT STABILITY FOR NEW DIVERSION CHANNEL UNDER VARIOUS LOADING CONDITIONS

ABSTRACT

This study investigates the stability of the channel embankment associated with a flood mitigation project known as Sungai Baru Diversion channel located in Kedah, Malaysia. The stability of the channel embankment were investigated for different type of soil such as clay, silty clay, silty clay loam and loam; and different loading conditions namely at the end of construction, during steady state, during flooding, and after rapid drawdown. A site investigation was carried out at the site and the data gathered were utilized to model and analyze the embankment stability at various loading conditions using softwares namely SEEP/W, SIGMA/W and SLOPE/W. Embankment constructed with clay produced the lowest factor of safety when compared to embankment made of other soils. For clay embankment, the factor of safeties obtained were 1.39 at the end of construction, 3.75 during steady state, 3.7 during flooding, and 1.33 during rapid drawdown. At the end of construction, clay embankment also possessed the highest deformation for the surface of the foundation as compared to embankment constructed with other soils. Based on the analysis, a settlement of 164 mm and heave of 72 mm were anticipated at the central position and near the toe area of the embankment respectively. 9 reinforcement methods using non woven geotextile have been proposed and analyzed. It was found that the reinforcement method of conventional configuration using 3 m length of non woven geotextile gives the best result in terms of stability and deformation. In conclusion, this study proved that a realistic and comprehensive modeling for a channel embankment could be carried out in order to assess stability under various loading conditions for selecting the most appropriate stability enhancement method.

CHAPTER 1
INTRODUCTION

1.1 General

Embankments are also known as flood banks, levees, bunds, or dikes. The primary function of a channel embankment is to constrain and direct the passage of flood water along a water course subsequently protecting the land from inundation. With growing population and urbanization, failure of embankment is very disastrous that can result in extensive damage such as loss of lives and properties. Therefore, till today embankment remains as one of the most important flood protection structure since the 1950s.

The fill material of embankment is normally obtained from shallow pits or from channel excavated adjacent to the embankment. Hence, the properties of the material used will directly affect the stability of the embankment. Aside from this, the stability of an embankment varies according to the condition that it is encountered. This different in condition is mainly cause by the events that yield different loading to the embankment. Nevertheless, there are still many factors that must be considered in designing a channel embankment. These factors may vary from project to project and thus no specific procedure in designing a channel embankment can be established.

1.2 Problem statement

The basic cause of flooding is the large concentration of runoff due to heavy rainfall that exceeds the river capacity. Flooding that occurs in Malaysia is very severe especially during the monsoon season. One of the most costly flood events in Malaysian history occurred at Johor in the year 2006-2007 due to a couple of unnatural heavy rainfall events. This disaster required a total estimated cost of RM 1.5 billion. During the flood, a death toll of 18 persons was recorded and around 110000 people were brought to shelter in relief centres. Moreover, the recent flood in Kedah in November 2010 has cause 50000 people being evacuated and left at least 4 people dead. This disaster has result in the closure of all major transport routes into the states leaving helicopters as the only mode of aerial transport.

Channel embankment is different from earth dam embankment because it is subjected to a shorter duration of water loading particularly during flooding. The embankment is generally in unsaturated condition for most of their design life. This condition generates low hydraulic gradients with water levels towards the base of the embankment. However, these conditions can change rapidly within a matter of hours during flood event. The embankment can be exposed to high flood water levels leading to overtopping of the crest and high hydraulic gradients within the body of the embankment. This extreme condition can result in failure of the embankment due to the variety of different mechanisms. The failure mechanisms are often very difficult to be identified that can lead to abrupt and violent failure of the embankment.

This research focuses on the technique to evaluate the stability of channel embankment under various loading conditions. Various reinforcement configuration methods by using non woven geotextile to stabilize the embankment will be proposed and analyzed. The method that produces the best results will be selected as the best configuration for ensuring the stability. Furthermore, the advantages of using this configuration can be identified and applied to other similar projects.

1.3 Objectives

A case study has been conducted on the basis of the diversion channel Sungai Anak Bukit/Sungai Baru located in Kedah. The main objectives of this study are:

i. To investigate the stability of the embankment under different loading conditions, namely, the end of construction, flood events, steady state, and rapid drawdown;

ii. To determine the stability of the embankment for each loading condition by factor of safety; and

iii. To propose the best reinforcement configuration for ensuring the stability of the embankment using non woven geotextile.

1.4 Significance of the study

Embankment failures or collapse that occurred will cause the surrounding areas losing the flood protection structure. In designing a stable embankment for this study, the safety of the population around the area, where life and properties may be threatened, are ensured. Reconstructing a collapsed embankment can be very costly compared with adopting a preventive method that can ensure the stability of the embankment throughout its service life. Therefore, analyzing and designing a stable embankment is essential to avoid future problems. The benefits that can be obtained from this study are:

i. the comparison of various types of reinforcement configurations that can ensure embankment stability; and

ii. the application of numerical analysis in modeling the stability of channel embankment.

1.5 Thesis outline

The outline of this thesis is shown in Figure 1.1:

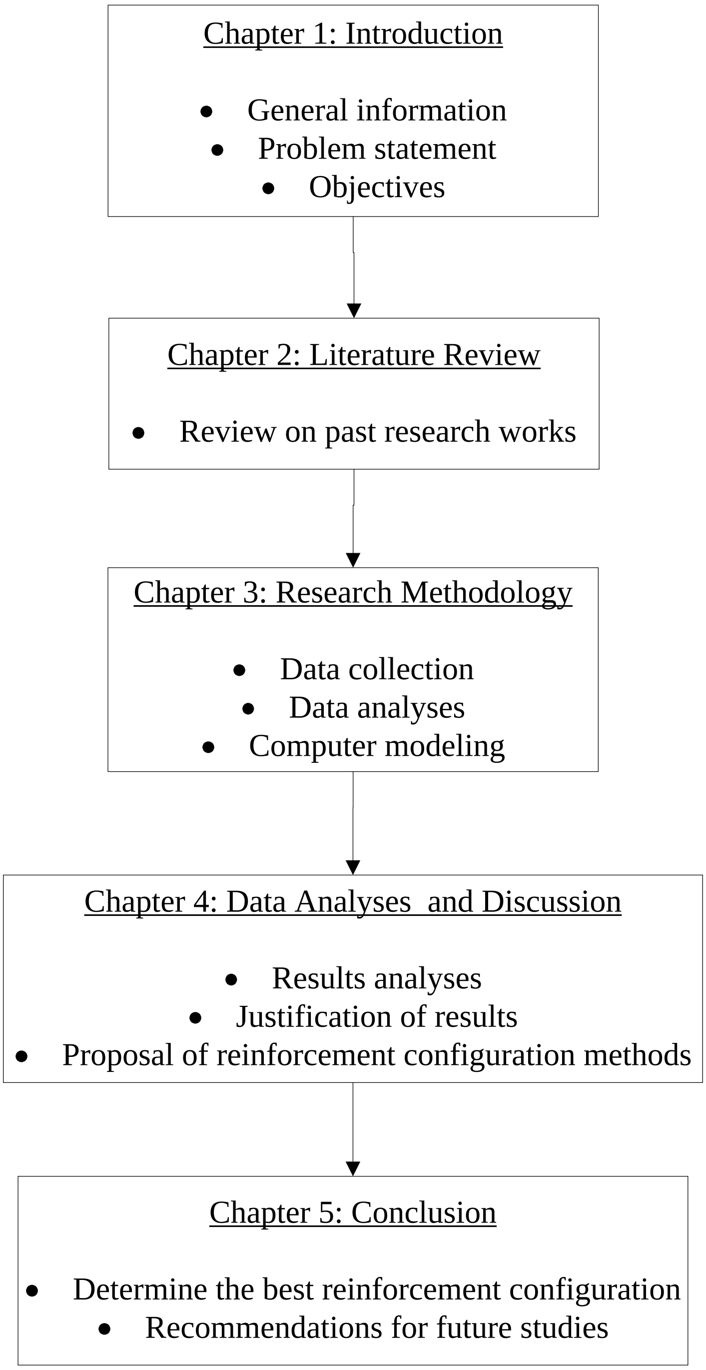


Figure 1.1: Thesis outline

In Chapter 2, a review of past research works regarding the types of embankment failure and causes are first presented. It is then followed by the general review of geosynthetics’ classifications, functions and geosynthetics’ applications to channel embankment. Method to analyze the stability of channel embankment slope using limit equilibrium and finite element method are also compared. Finally, a review of reinforced embankment analysis carried out by other researchers is presented.

In Chapter 3, the methods to gather data were described. The simulation of this study through conducting numerical modeling is carried out. The numerical modeling is performed in four different loading conditions that mainly affect the stability of the embankment which are at the end of construction, flooding, rapid drawdown and steady state.

In Chapter 4, the results of the numerical modeling are presented. Comparison of the results with USACE Engineer Manual for Design and Construction of Levees is made to ensure the obtained results fulfill the required factor of safety. Different reinforcement configuration methods to enhance the stability and to minimize deformation of embankment are proposed.

In Chapter 5, conclusions of the research study are summarized. The best reinforcement configuration to stabilize the embankment is identified. Recommendations for further research are also given.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The basic requirements of an embankment are (1) it must not overflow (2) an embankment should be impervious; seepage through, below, and around the embankment should be safely controlled and maintained at a very low level (3) an embankment should be stable during the lifetime of the project, which means that the settlement of its body or deformation of its slopes must not exceed the magnitude stated in the guidelines.

A typical embankment consists primarily of the following components and is shown in Figure 2.1:

i. an embankment body, which provides mass obstruction against flood water;
ii. the toe of the embankment on both the outward and inward embankment faces;
iii. the outward face of the embankment, which is directly exposed to flood water;
iv. the inward face on the landward side, which is not directly exposed to water;
v. the crest at the top of the embankment, which is typically flat and several meters wide;
vi. an optional drainage ditch excavated close to the inward toe of the embankment;
vii. surface protection or revetment in the form of vegetation (grass), man-made material (concrete), or a combination of different materials.

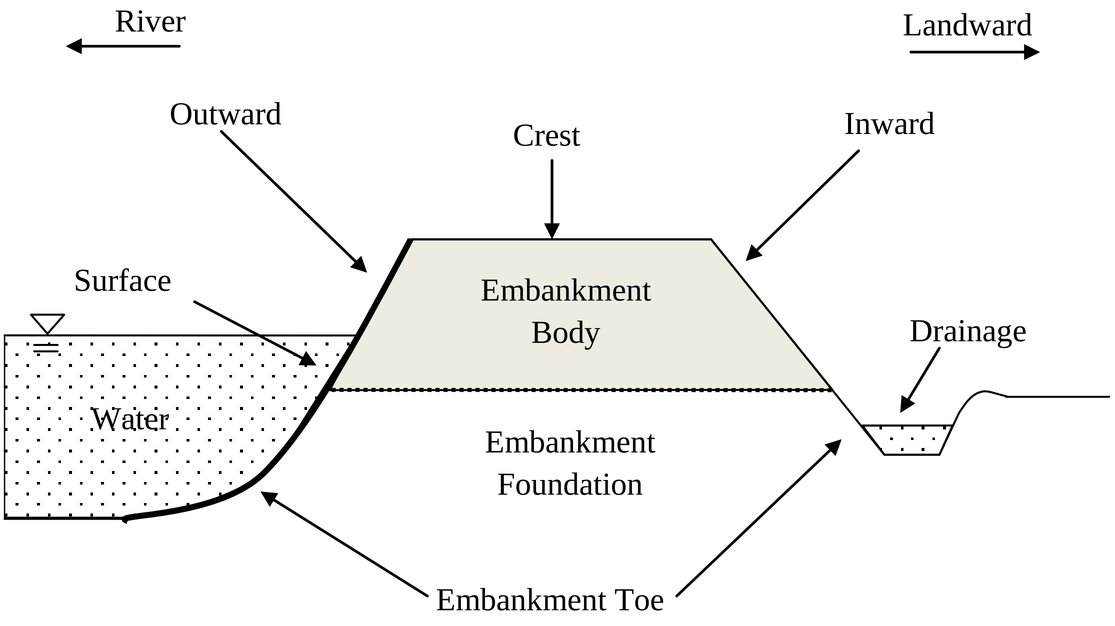


Figure 2.1: Typical embankment components

Razvan (1989) emphasis on the two main types of embankments which are:

i. homogeneous embankments made of a single kind of material; and
ii. zoned embankments that consist of a central impervious core flanked by prisms of pervious materials.

2.1.1 Homogeneous embankment

A homogeneous embankment can be categorized into embankment of impervious materials and pervious materials.

2.1.1.1 Embankment of impervious materials

The materials used in this type of embankment consist of clay, silt, and a mixture of coarse-grained soils with 10% of the particles smaller than 0.074 mm (no. 200 sieve). However, dispersive clays must be avoided in the construction of this embankment because of the loss of the finest fractions of such materials. In constructing an impervious embankment, identifying the site where the sources are abundant is important. The principle of the design for this type of embankment is the control over pore water pressure using drains and filters.

2.1.1.2 Embankment of pervious materials

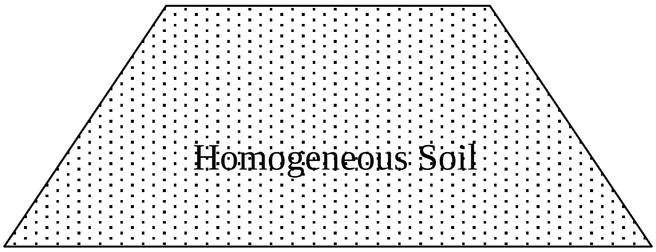
Pervious materials usually consist of sand and gravel, which are abundantly available. However, impervious soils are scarce near the site of the river diversion. An embankment built with pervious materials must be provided with watertight elements that can be divided into the following:

i. impervious membranes placed on the upstream slope, and
ii. an impervious core built inside the embankment.

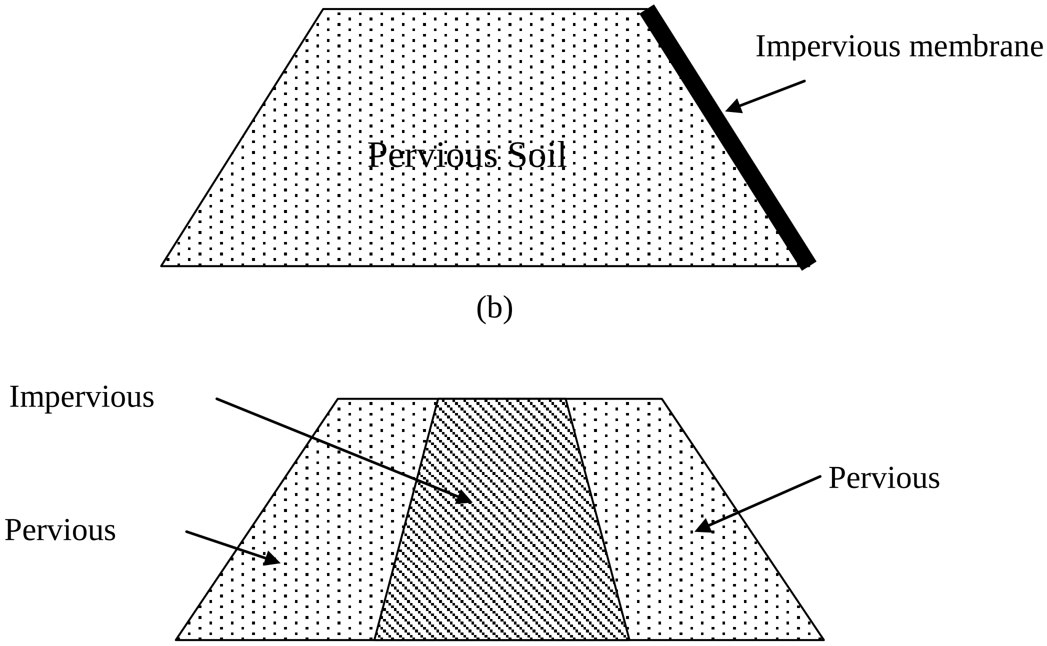
Examples of impervious materials used are impervious soils and manufactured elements such as reinforced concrete, geomembrane, or sheet pile walls.

2.1.2 Zoned embankment

In a zoned embankment, an impervious core is added and flanked on either side by pervious materials, which enclose, support, and protect the core. Generally, the upstream zone provides stability against rapid drawdown and controls seepage. Figure 2.2 shows the different types of embankment.



(a)



(b)

(c)

Figure 2.2: A typical type of embankment a) Homogeneous b) Pervious material with impervious membrane c) Zoned

2.2 Types of embankment failures

Information regarding the conditions or events that cause embankment failure can be determined through observation. According to Hemphill and Bramley (1989), the common types of embankment failures are shallow slough, shallow rotational (toe), deep rotational (base), and wedge or block failures. The detail of these failures will be discussed in the following section.

2.2.1 Shallow slough failure

This type of failure occurs mostly at an embankment that has a shallow angle and non-cohesive soil caused by erosion as shown in Figure 2.3. The failure surface is approximately parallel to the slope angle. For instance, Arno River in central Italy has been experiencing an increase of bank instability due to intense erosion

(Dapporto et al., 2003). This kind of failure can typically be overcome by using vegetation to stabilize the slope.

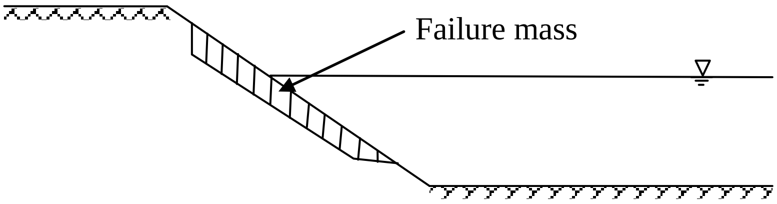


Figure 2.3: Shallow slough failure

2.2.2 Shallow rotational (toe) failure

This type of failure as shown in Figure 2.4 occurs when the failure surface passes through the toe of an embankment, and usually involves cohesive material on a moderately high or steep embankment. The presence of tension cracks is an early indication of embankment failure. If these tension cracks are filled with water, the hydrostatic pressure will reduce the stability of the embankment. Toe failure is also affected significantly by the position of the water level.

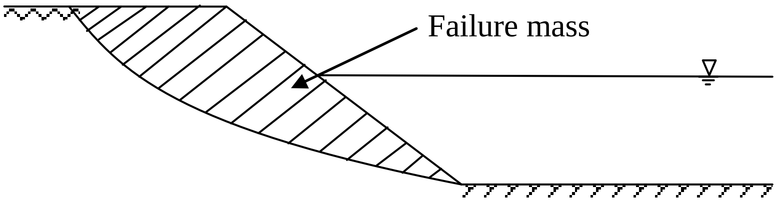


Figure 2.4: Shallow rotational (toe) failure

2.2.3 Deep rotational (base) failure

As shown in Figure 2.5 deep rotational failure involves a larger volume of slipped material compared with toe failure as the failure surface is extended beyond the toe or is deep seated. Tension cracks are also early signs of potential collapse as the failure surface normally follows such cracks. This type of failure is also affected by weak foundation material and the position of the water table.

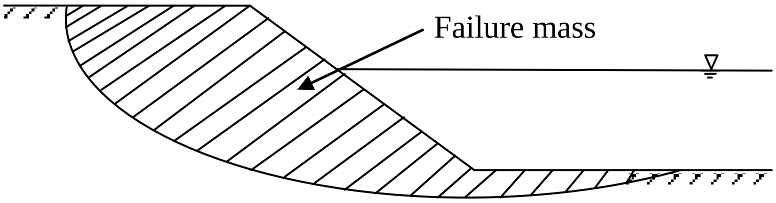


Figure 2.5: Deep rotational (base) failure

2.2.4 Wedge or block failure

This type of failure often occurs when the soil mass falls either by sliding or toppling in block form as shown in Figure 2.6. It is normally associated with non-cohesive soils, where deep tension cracks have developed prior to failure. Groundwater table imposes only a minor influence on this type of failure. Breaches had occurred at Borth Estuary in Wales where the embankments constructed from peat cause large translational block movement (Dyer and Gardener, 1996).

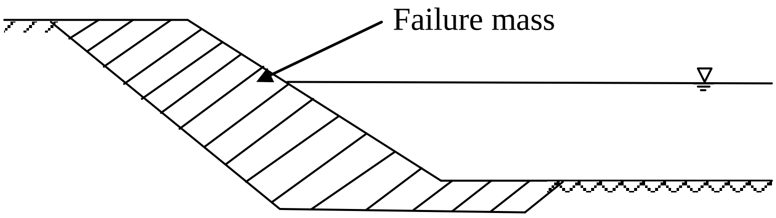


Figure 2.6: Wedge or block failure

2.3 Causes of mass embankment failure

Embankment failure is usually caused by a process that increases the shear stress or decreases the shear strength of the soil (Abramson, 2002). Processes or events that frequently occur and mainly contribute to embankment failure are overtopping, surcharge, seepage, erosion, and piping.

2.3.1 Overtopping

Overtopping occurs when flood water exceeds the crest of the embankment as shown in Figure 2.7. This event is mainly caused by the inability of the embankment to cater the discharge. In addition, the massive temporary load of water that the embankment is subjected to during flooding can cause the flood protection structure to burst. Overtopping is catastrophic to the area when the flood water can no longer be contained within the channel. An example of severe overtopping event that caused channel embankment failure occurred when hurricane Katrina devastated New Orleans on 29 August 2005; a death toll of about 1500 people was reported, and almost 80% of the city was submerged in water (Seed et al., 2005).

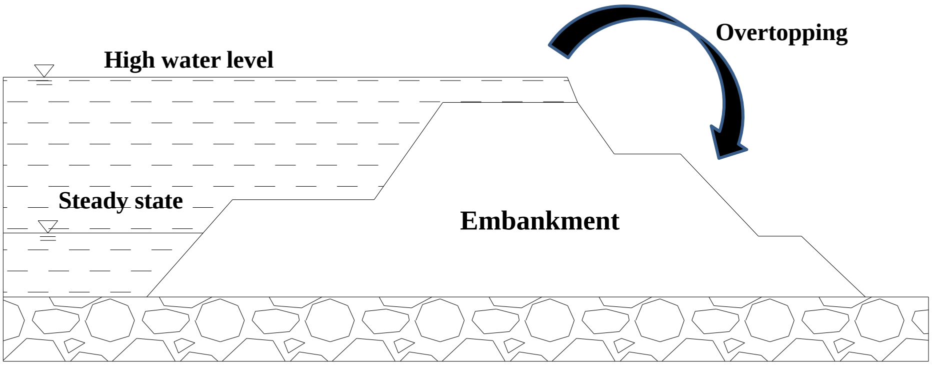


Figure 2.7: Overtopping of channel embankment (Kwangseok, 2005)

2.3.2 Surcharge

In addition, external forces such as permanent or temporary loading on top of a bank will increase its susceptibility to mass failure. Surcharge loading increases the shear stresses within an embankment. If this stress exceeds the shear resistance of the material, failure will occur. Embankment failure due to surcharge loading throughout its service life is very rare because an embankment is designed with consideration of the probable load that will be applied to it, such as transportation loading (Hemphill and Bramley, 1989). However, the saturated or partially saturated embankment conditions during and at the end of construction have to be addressed carefully because this type of temporary loading will generate excess pore water pressure. If the drainage system does not function properly, instability of the embankment eventually will occur.

2.3.3 Seepage

Seepage is a process of the flow of fluid through soil pores (Das, 2010). Surface water and rainwater infiltrate into the embankment through cracks and voids, thereby inducing a seepage process that results in the development of pore water pressure as shown in Figure 2.8. The velocity of seepage depends primarily on the hydraulic gradient and permeability of the soil. Moreover, unsteady seepage is commonly encountered in a channel embankment because of the fluctuations in the water level. The decrease in pore water pressure near the bank surface due to drawdown is considerable and will cause a high pressure gradient. Therefore, this phenomenon often triggers failure when the reduction of soil strength combines with the unit weight of the embankment (Hemphill and Bramley, 1989).

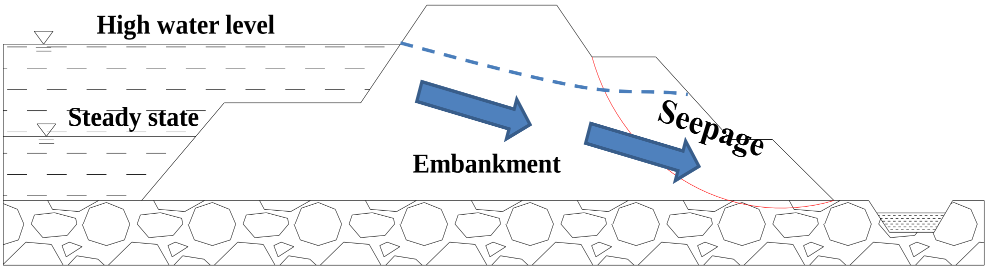


Figure 2.8: Seepage of channel embankment (Kwangseok, 2005)

2.3.4 Erosion

Surface water that acts externally on the embankment also stimulates the hydraulic erosion process, which causes an increase in shear stresses of the embankment. Erosion is often responsible for destabilizing an embankment and promoting mass failure. It is normally triggered by surface water and is essentially a two-part process. The first part is the loosening of soil particles, which can be caused by river flow, raindrop impact, freezing-and-thawing, and the wetting-drying cycles. The second part is the process of soil particle transportation by flowing water. According to Wishmeier et al (1971), the susceptibility of a soil to be eroded or affected by erosion is defined as soil erodibility. Generally, soils with faster infiltration rates, higher levels of organic matter and good structure, have greater resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand, and clay textured soils (Joanne et al., 2008).

Hanson and Cook (2004) utilized Equation 2.1 to estimate erosion rates, E_r:

$$E_r = k_d(\tau_e - \tau_c) \qquad \text{Equation 2.1}$$

where E_r = erosion rate (m/s), k_d = soil erodibility (m^3/N-s), τ_e = effective stress (Pa), and τ_c = critical shear stress (Pa). Soil erodibility reflects the rate at which erosion occurs while the critical shear stress is the stress at which erosion starts (Wynn et al., 2007). The effective stress is the hydraulic force applied to the soil of the embankment, per unit area and can also be referred to as the particle or grain shear stress. Although the embankment is classified as having low erodibility, this does not mean that the embankment is stable and vice versa. Therefore, this study does not include the effect of erosion in the stability of the channel embankment.

2.3.5 Piping

Aside from the surface of the riverbank, erosion can also occur below the soil surface. This phenomenon is known as piping. As soil is removed by piping, its strength also diminishes, thereby promoting failure (Lachouette et al., 2008). An embankment that consists of non-cohesive sandy silts tends to experience piping because of steady seepage. However, piping rarely occurs in embankments composed of gravel or coarse-medium sand because the lift forces rarely exceed the submerged unit weight of the material. Figure 2.9 shows both the erosion and piping processes on channel embankment.

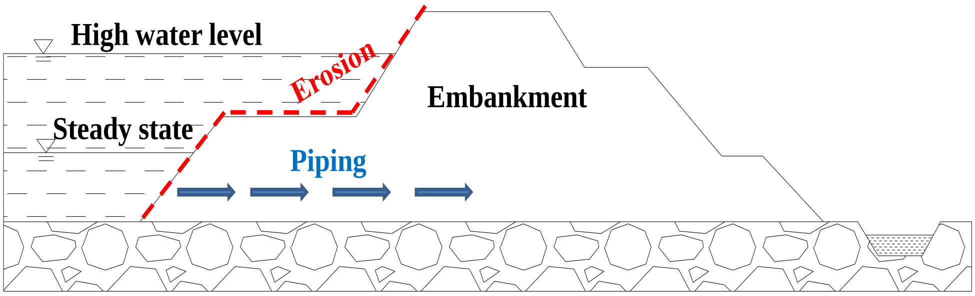


Figure 2.9: Erosion and piping processes on channel embankment (Kwangseok, 2005)

Besides the main processes discussed, other causes that have a minor contribution to embankment failure are human and animal activities (Dyer, 2004). For instance, burrowing animals can remove a considerable amount of embankment material, consequently reducing bulk strength; human activities such as trampling the embankment surface or destruction of surface vegetation can leave the bank more susceptible to failure.

2.4 Characteristics of soft soil

The material used for constructing an embankment may also affect its stability. However, constructing an embankment on a foundation of soft soil cannot be avoided because of the insufficiency of land that can accommodate infrastructure development.

Soft soils are normally produced through weathering processes and hydrothermal activities. According to the Unified Soil Classification System (USCS), soft soil is classified as fine grain soil if more than 50% can pass through a no. 200 sieve (0.075 mm). Numerous studies and field trials have been carried out to determine the characteristics of soft soil. The general characteristics of soft soil are low strength, high deformability, and low permeability (Borges and Cardoso, 2001). With low permeability, the soil compresses much more slowly because of the gradual expulsion of water from the small soil pores. Given its plasticity properties, soft soil can creep under constant load over time and expand when wet or shrink when dry. Hence, the ultimate volume decrease and settlement of the soil may not occur until it is being loaded.

Construction work associated with soft soil is a huge challenge for engineers because this type of soil exhibits undesirable properties such as insufficient bearing capacity, excessive post-construction settlement, and instability of excavation and embankment formation. Numerous remedial methods can be used to solve these problems: soft soil replacement, prefabricated vertical drains, stone columns, and geosynthetics, among others (Borges, 2004). However, the application of these methods depends on the construction cost, project feasibility, space and time constraints, and preferences of clients.

Soft soil is commonly found in wet areas, such as rivers. Therefore, determining the classifications and characteristics of the existing soil prior to designing an embankment is important. The parameters that represent the characteristics of the soil are:

i. Atterberg limits
ii. moisture content
iii. undrained shear strength (S_u)
iv. pre-consolidation pressure (σ_p)
v. compression index (C_c) and coefficient of volume change (m_v)
vi. coefficient of consolidation (C_v)

From all the causes described, the stability of an embankment depends on:

i. geometry – embankment height, crest width, slope steepness;
ii. soil properties – foundation and fill soil;
iii. internal forces – pore water pressure;
iv. external forces – surcharge loading and surface water.

The geometry and soil properties can be designed based on analyses, while the internal and external forces are hardly controlled or monitored. Therefore, this unknown condition must be understood and investigated because it may affect embankment stability.

2.5 Total stress and effective stress

Soil mass is typically divided into two phases: soil skeleton and pores. The soil skeleton transmits the normal and shear stresses at the particle contact points while the pores that are filled with water can exert only hydrostatic pressure at all directions. Effective stress is the stress sustained by the soil skeleton, while the hydrostatic pressure in the voids is known as pore water pressure. Thus, effective stress is the parameter that governs the behavior of the soil. This is defined as

$$\sigma' = \sigma - u \qquad \text{Equation 2.2}$$

σ = total stress

u = pore water pressure

Total stress can be defined as the total force per unit area acting on the plane, while pore water pressure can be determined from groundwater conditions. As indicated in Equation (2.2), the effective stress can only be calculated when the pore water pressure is known. Then, effective stress analysis can be performed using drained strength parameters to determine the long-term stability of the embankment. Under some conditions, however, determining pore water pressure is difficult. Hence, total stress analysis using undrained strength parameters should be employed (Abramson et al., 2002).

2.6 Soil stabilization methods

To prevent embankment failure, various studies have been carried out to determine an appropriate method for guaranteeing embankment stability. The method adopted may vary from project to project because the site conditions differ. However, the primary objective of soil stabilization remains consistent; that is, to increase the stability of the embankment by increasing resistance or decreasing driving forces. Therefore, selecting the best method that suits a particular project is important; successful projects can also be used as reference. According to Chen and Lim (2005), the common methods used to achieve this purpose are the geometrical method, drainage method, and use of reinforcement and structural components.

i. Geometrical method

This method uses changes in the embankment geometry, especially by reducing the steepness of the embankment slope. This can be done by cutting the slope, removing external loading on top of the slope, or backfilling the toe of the slope. The advantages of this method are its simplicity and cost efficiency. Nevertheless, it is limited to the availability of space on a site.

ii. Drainage method

One of the causes of embankment failure is the internal forces exerted by pore water pressure on the embankment. Pore water pressure develops as the embankment soil is saturated when the water level of the channel rises. With a drainage system provided, therefore, the development of pore water pressure can be minimized. According to Cai et al. (1998), horizontal drains can effectively lower the ground water level and increase the slope stability under rainfall. However, surface drainage is easier to maintain but sub-surface drainage is difficult to preserve. Thus, the drainage method is typically used in combination with other methods to overcome this weakness.

iii. Use of reinforcement and structural components

This method is commonly used in a constrained site because of the flexibility that it offers. The principle adopted for this method is to provide resistance to the downward force of the soil mass. Components that facilitate this principle are retaining walls, sheet piles, ground anchors, soil nails, and geosynthetics.

Among all the remedial methods that are commonly used, geosynthetics can be divided into various types that present multiple functions such as reinforcement, drainage, separation, and filtration. Geosynthetics for soil reinforcement have been well accepted worldwide, and the market for them has grown rapidly since 1970. Many studies have also confirmed the numerous advantages and uses of the application of geosynthetics to channel embankment.

2.7 Geosynthetics for channel embankment

Geosynthetics are defined as planar or polymeric materials used in contact with soil, rock, or any other geotechnical material in civil engineering applications such as roads and railways, embankments, foundations, slopes, and retaining walls (IGS, 1998). The usage of geosynthetic materials benefits all the stakeholders of a project (Giroud, 1986). Significant savings can be achieved for the construction and maintenance of geosynthetic-reinforced soil compared with conventional soil stabilization methods. The construction process can also be executed more rapidly and less influence by the weather when utilizing geosynthetic materials. Aside from this, the volume of earthworks is reduced and the possibility of using poorer quality material is decreased. In addition, geosynthetic materials have uniform properties that conveniently help to achieve greater reliability and control. This material is easy to place on the soil and can also mitigate local soil defects.

The important advantages of using geosynthetics that are applicable to channel embankment are summarized as follows:

i. Geosynthetics produce equivalent performance compared with conventional soil stabilization methods because they are engineered for optimal performance in the desired application.
ii. Geosynthetics enable the construction of higher embankments and steeper side slopes. These materials can be placed in layers during construction to intercept and stabilize potential failure planes.
iii. Geosynthetics are lighter in weight. It is more easily transported and handled on site, which eventually reduces construction time, space, and cost.

The only limitation to the application of geosynthetics in channel embankment is insufficient local guidelines or standards that can assist engineers in designing a geosynthetic-reinforced channel embankment. However, this limitation can be overcome by gaining more experience in similar projects and by carrying out proper modeling to investigate the behavior of the geosynthetic material when incorporated into the channel embankment. Modeling the reinforced channel embankment prior to usage is essential because this predicts the stability of the embankment and determines the effective approach to utilizing the geosynthetic material.

2.7.1 Functions of geosynthetics

Geosynthetic applications are very diverse. They are consciously designed to perform the required functions by considering their different properties. The primary functions of geosynthetics are separation, reinforcement, filtration, drainage, barrier, and protection.

2.7.1.1 Reinforcement

Integrating geosynthetics in soil mass can provide a reinforcement function through the development of tensile forces as shown in Figure 2.10. This function eventually contributes to the stability of the composite system. Geosynthetic materials are commonly used in reinforcing steep slopes, thereby increasing the overall factor of safety against sliding or rotation. It is also used to improve the load bearing capacity of weak soil, avoiding excessive settlement.

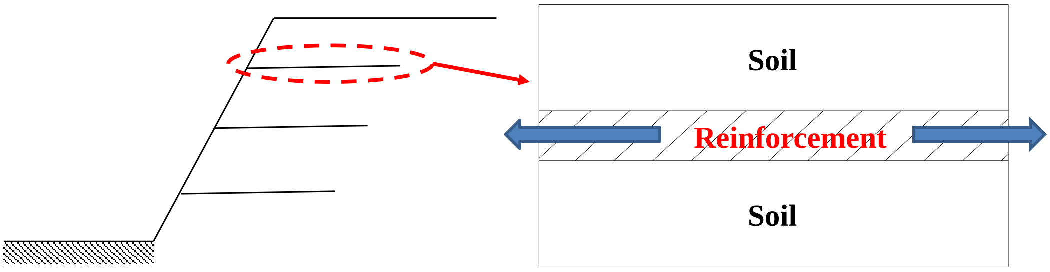


Figure 2.10: Geosynthetic as slope reinforcement (Geofabric, 2011)

2.7.1.2 Drainage

Geosynthetic materials act like a drain in transmitting liquid within the plane of their structure as shown in Figure 2.11. The drainage function allows for adequate liquid flow with limited soil loss over a service lifetime. Examples of applications for this function are the dissipation of pore water pressure on the road or embankment structure and the intercepting of drains in the slope.

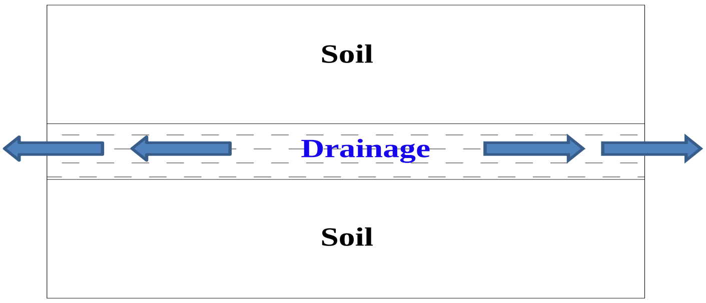


Figure 2.11: Drainage function of geosynthetic layer (Geofabric, 2011)

2.7.1.3 Protection

Geosynthetics can be used to protect or limit damage to an adjacent material. An example application is the use of geotextiles to protect against punctures of geomembranes in waste and liquid containment systems as shown in Figure 2.12. This protection provides resistance to both short- and long-term loading. Eventually, this enhances the service life and performance of the geosynthetics. Furthermore, geosynthetics can also be used to protect riverbanks from soil erosion that can trigger riverbank failure.

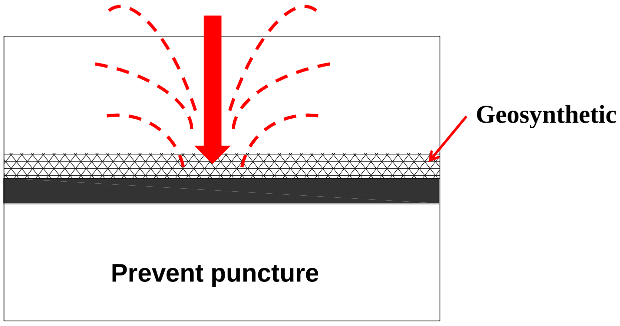


Figure 2.12: Geosynthetic layer functioning as protection (Geofabric, 2011)

2.7.1.4 Separation

This function pertains to the separation of two different materials but their functions remain intact or improved. For example as shown in Figure 2.13 for the application of road structure, road bases and sub-grade layers are separated using geosynthetics to maintain the designed thickness of the road. This maintenance is achieved through the prevention of the penetration of fine grain subgrade soil into a granular road base layer. Separation is normally used in combination with other primary functions.

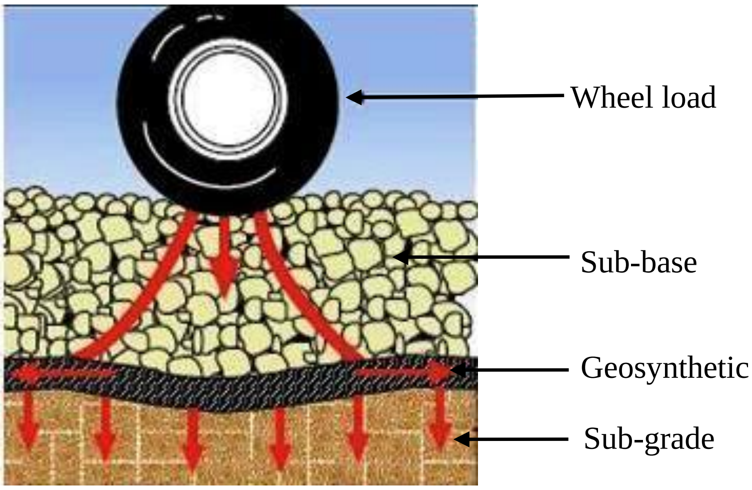


Figure 2.13: Separation function of geosynthetic layer in road structure (Mirafi, 2011)

2.7.1.5 Filtration

Figure 2.14 shows this function that enables the movement of liquid or gas through the geosynthetic material and at the same time, restrains the movement of soil on its upstream layer. The flow of fluid is perpendicular to the geosynthetic plane, while the filtration refers to cross plane hydraulic conductivity. Geosynthetic filtration is often partnered with separation, as in the application of coastal defense and wrapped drains.

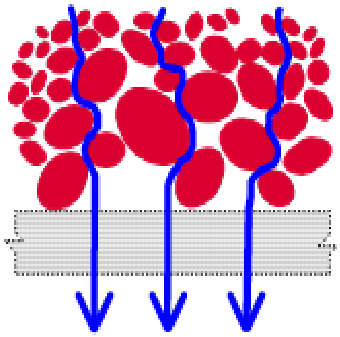


Figure 2.14: Filtration function of geosynthetic layer (Bathurst, 2005a)

2.7.1.6 Barrier

This function requires the geosynthetics to have low hydraulic conductivity for containment of liquid or gas. A geosynthetic infiltration barrier is a common application for base and cover liner systems of landfills. Base liners are placed below the waste to prevent leachate from contaminating the groundwater and underlying ground. Geosynthetics cover liner systems that are placed above the final waste configuration to prevent precipitation water from entering the waste and generating leachate as shown in Figure 2.15.

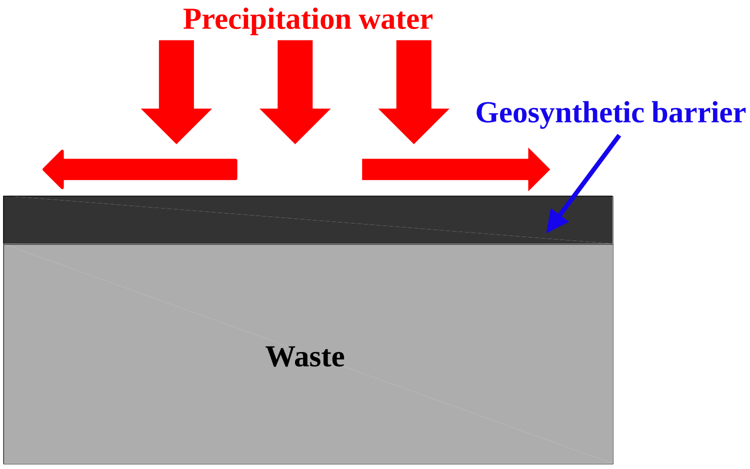


Figure 2.15: Barrier function of geosynthetic layer (Bathurst, 2005a)