

## **CHAPTER 2**

### **THEORETICAL BASIS**

#### **2.1. SLOPE STABILITY ANALYSIS USING GEOTEXTILE (*REFERENCE*)**

*Ismanti (2012)*, conducted a study on Embankment Behavior Analysis using Analytical Calculations and using the PLAXIS V8.2 Program to analyze the stability and subgrade settlement based on embankment loads, traffic and earthquakes for conditions without and with geosynthetic reinforcement. The geosynthetic reinforcement used consists of non-woven geotextiles, woven geotextiles and geogrids. Based on the analysis calculation, the subgrade consolidation process during the gradual filling until the consolidation ends take 278.76 days while based on the PLAXIS numerical analysis it takes 2760 days. The magnitude of the total subgrade subsidence until the final consolidation is completed as a result of analytical calculations obtained values of 0.31 meters and 0.25 meters as the result of PLAXIS numerical analysis. The safe value of the PLAXIS numerical analysis for the unreinforced embankment structure is 1.27. This value does not meet the requirements for the embankment structure, which is 1.30. The results of the analysis of the safe number for the embankment structure with non-woven geotextile reinforcement of 1.28, with woven geotextile reinforcement of 1.35 and with geogrid reinforcement of 1.31 where the safety value values have met the requirements of the embankment structure. From the results of the analysis of safety figures, the most effective and optimal geosynthetic reinforcement and able to be used as a solution during the construction of the road embankment structure in this study is the woven geotextile type.

*Pamungkas, et al. (2015)* conducted research on “*Slope Stability Analysis Using Geotextile Reinforcement with Software Assistance which contained landslide events that occurred in Trenggalek district*”. The slope has a height of between 8 m to 8.5 m with a retaining wall length of 375 m and experienced a collapse in the structure of 90 m. Analyzed using the SLOPE/W software on the slope, it was found that the safety number was only 0.660 so that landslides occurred. The slope was redesigned using geotextile reinforcement with 5 layers, tensile capacity 400 kN/m, cohesion 0 kN/m and shear angle to the soil 38°, vertical distance 1 m. By analysis using SLOPE/W, the safety number is 1.893.

*Prasetyo (2016)* conducted research on Slope Stability Analysis using Geotextile Reinforcement with the help of the PLAXIS version 8.2 software program with the finite element method. The purpose of this study was to determine the level of safety of a slope used as road infrastructure and to plan a safe slope reinforcement with geotextile reinforcement using PLAXIS software version 8.2. The conclusions obtained from this study include that the condition of the slope before the reinforcement is less stable because the Meyerhoff shear angle approach is 1.2221 so that according to Bowless safety the safe number is below the Bowless safety number and landslides can occur because without reinforcement, it is necessary to have reinforcement. From the results of the analysis with geotextile reinforcement, it was obtained that the design was able to withstand landslides with a safety rating of 1.25 so that landslides occurred.

*Nurul (2017)* conducted research entitled “*Analysis of Road Embankment Stability Based on Geotechnical Instruments in the Surabaya-Gempol Toll Road Relocation Development Project*”. The study used data from geotechnical instruments (inclinometer, pneumatic

piezometer, and settlement plate) and retrofit planning using sheet piles and micropiles with the help of the XSTABL program. Based on the results of the geotechnical instrument analysis carried out, the compression of the subgrade under the package 3A embankment can be said to have been completed with a degree of consolidation of more than 90%; so the condition of the embankment in package 3A can be said to be stable and there is no danger of landslides. However, the results of the embankment stability analysis using the auxiliary program showed an SF value of 0.898 which means less than the design SF or in an unsafe condition. Therefore, the embankment in package 3A is planned to be reinforced using 5 pieces of sheet pile type W-500-A-1000 as many as 13 m deep or 5 pieces of 600 mm diameter micropile with a depth of 13 m.

*Budiasto (2018)* conducted a study entitled “*Stability Analysis of Road Body Embankments with Geotextile Reinforcement using the PLAXIS application*”. The case study being researched is the solo – kertosono toll road project, STA 118+700–139 +760. This study aims to determine the safety factor of embankment and soil subsidence for 200 days. The embankment modeling uses variations in height of 2 m, 4 m, 6 m, and 8 m. In addition, modeling variations are distinguished in three conditions, namely, original soil embankment, embankment with replacement soil, and replacement soil embankment reinforced with geotextiles. From the analysis of the PLAXIS program, we get a safe number that is greater than the required safety number 1.4 and the magnitude of the decrease is in the 2 m embankment original soil condition with geotextiles 1.785 during construction, 1.452 during post construction and settlement -0.038 m, original soil replacement 0, 5 m with geotextile 1,859 during construction, 1,529 during post construction and -0.038 m settlement, original land replacement 1 m with geotextile

2,065 during construction, 1,716 during post construction and settlement -0.043 m. On the 4 m embankment the original soil condition was 1 m replacement with geotextile 1.645 during construction, 1.512 during post construction and -0.005 m settlement. On the 6 m embankment the original soil condition was 1 m replacement with a geotextile of 1,457 during construction, 1,410 during post construction and a settlement of 0.045 m. On the 8 m embankment the original soil condition was 1 m replacement with geotextile and counterweight 1,504 during construction, 1,501 during post construction, the settlement was 0,471m.

*Annisa (2018)* conducted research on the “*Analysis of the Stability of Retaining Walls and Slope Reinforcement using Geotextiles*”. The research took place on the White Elephant River. The research was conducted because of the slope that experienced a landslide even though it had been given DPT. The purpose of this study was to determine the safety factor on slopes that have been given retaining walls and to plan safe reinforcement on the slopes using geotextiles. The method used is the finite element method with the help of the PLAXIS program. Slope reinforcement planning using geotextiles used variations of the 1-level and 2-tiered slope models. In this study, the analysis was carried out at normal water levels and flood water levels by taking into account the effects of uneven pedestrian loads and earthquake loads. The safe value for masonry walls under normal water level conditions with pedestrian and earthquake loads is 1.232 and 1.016, while flood water levels are 1.235 and 1.015, respectively. The safe figure indicates that the river slope with the masonry wall is critical and unstable so that it collapses. The results of the analysis of the stability of the retaining wall at normal water levels have a safe number of stability against shearing, overturning, and the bearing capacity of the soil of 4.346, respectively; 7,520; and 4,288. In the condition of the flood water level

of 3,885; 6,923; and 3,590; while the PLAXIS program obtained safe numbers with pedestrian loads and earthquake loads at normal water levels of 2,949 and 1,563, for flood water levels of 3,027 and 1,564, respectively. These results indicate that the retaining wall is safe and stable. In planning for slope reinforcement with geotextiles for slope variation 1, the safe value values for normal water levels are 2.433 and 1.579 and for flood water levels are 2.494 and 1.574. The safe numbers for slope variation 2 at normal water levels are 2.665 and 1.569 and at flood water levels are 2.733 and 1.567. These results indicate that the design of slope reinforcement with geotextiles is safe and stable and can be used as an alternative to reinforcement on the slopes of the Gajah Putih riverbank.

### 2.1.1. Comparison of Past Research with Current Research

**Tabel 2.1** Comparison of Past Research with Current Research

No	Researcher	Title of Research	Method	Purpose	Result	Research Differences
1	<i>Chasanah (2012)</i>	<i>Slope Stability Analysis with Geotextile Reinforcement Using Geoslope</i>	Analysis with manual calculations, namely internal and external stability and calculations using <i>Geoslope</i> software for slope stability.	To find out the safe value on slopes with geotextile reinforcement using the <i>Geoslope</i> program.	From the results of the analysis with geotextile reinforcement using the <i>Geoslope</i> program, the average SF value increases in length, slope, vertical distance between geotextiles.	The program used is different, namely <i>Geoslope</i> , while the researcher uses <i>PLAXIS</i> .  Not counting land subsidence
2	<i>Pamungkas, et al. (2015)</i>	<i>Slope Stability Analysis Using Geotextile Reinforcement with SLOPE/W Software (Case Study on Sungai Parit Raya)</i>	<ul style="list-style-type: none"> <li>➤ Perform slope stability analysis using geotextile reinforcement on river trenches</li> <li>➤ Calculating the value of the safety factor in 2 ways,</li> </ul>	Knowing the comparison of manual calculations, and comparisons on slope stability analysis using geotextile reinforcement on the river ditch.	Knowing the comparison of manual calculations, and slope stability analysis using geotextile reinforcement on the river trench.	Case studies are different from current research. The program used is <i>SLOPE/W</i> while currently using <i>PLAXIS</i> .  Not Counting

			<p>namely: Manual calculations and computational calculations using the <i>Geoslope</i> Program</p> <p>➤ Doing comparisons</p>			the rate of land subsidence
3	<i>Prasetyo (2016)</i>	<i>Stability Analysis of Multilevel Slope with Geotextile Reinforcement Using Finite Element Method</i>	Analysis using PLAXIS software with the finite element method for slope stability.	To find out the value of a safe number using the finite element method, the <i>Bowless method</i> .	From the results of the analysis using PLAXIS obtained a safety number of 1.25 where the results are above the Bowless safety number so that landslides rarely occur.	Do not use the <i>Felenius method</i> in manual calculations. The slope safety rating refers to the bowless safety rating
4	<i>Adi Budiasto (2018)</i>	<i>Analysis of Embankment Stability on Road Agencies with Geotextile Reinforcement of the PLAXIS program on the</i>	➤ Stability analysis using PLAXIS software to get the SF value. Meanwhile, the collapsed embankment uses manual	To find out the safe value and the amount of land subsidence on road embankments with variations in embankment	The original soil embankment has a safety factor that is more than the required one, namely 1.4. However, the land subsidence is very large, so it needs	<p>The case study locations are different.</p> <p>Using soil data during construction</p>

		<i>Solo-Kertosono Toll Road Project</i>	<p>calculations, namely the Felenius method.</p> <p>➤ Variation of embankment height is 2 m, 4 m, 6 m, and 8 m. The soil conditions analyzed are the original soil embankment, replacement soil embankment, and replacement soil embankment with geotextile reinforcement.</p>	height of 2 m, 4 m, 6 m, and 8 m.	strengthening. After being reinforced with replacement soil and geotextiles, soil subsidence can be reduced.	
5	<i>Fuanda (2018)</i>	<i>Slope Stability Analysis Using Geotextile Reinforcement Using Software on the Solo - Kertosono Toll</i>	Analysis with geotextile reinforcement using PLAXIS software for slope stability.	Analysis with geotextile reinforcement using PLAXIS software for slope stability.	From the analysis results with geotextile reinforcement using the PLAXIS 8.6 program, the resulting SF value that meets the addition of	<p>The case study locations are different.</p> <p>Different embankment height variations.</p>

		<i>Road Project Section I.</i>			geotextile reinforcement can prevent landslides from occurring.	
6	<b>Researcher (2022)</b>	<i>Slope Stability Analysis using Geotextile with PLAXIS computer program in the Relocation Development Project of Porong-Gempol Toll Road, Package 3A STA 41+570</i>	<ul style="list-style-type: none"> <li>➤ Stability analysis using PLAXIS V20 software to get the SF value and consolidation, the comparison of SF value and consolidation, between unreinforced embankment and reinforced embankment.</li> <li>➤ Uses manual calculations, namely the Felenius method.</li> <li>➤ Variation of embankment height is 2 m, 4 m, and 6 m.</li> </ul>	To find and comparison out the safe value on slopes unreinforced embankment and reinforced embankment using the PLAXIS V20 program.	The results of the analysis embankment slope with the highest safety factor, and consolidation values is a embakment height of 2 m, from embankment height 2 m, 4 m, 6 m, and 7 m. So for embankment height of 7 m after reinforced with geotextile, is still less than the required SF (Safety Factor) $\geq 1,25$ ; so not recommended for embankment heights of 7 m.	

## **2.2. SOIL**

### **2.2.1. General Definition**

Soil is a collection of minerals from organic (plants) or inorganic (volcanic) materials and are relatively loose deposits, which are located above the bedrock (*Hardiyatmo, 2002*). Soil is formed from the weathering of rocks into smaller particles due to mechanical and chemical processes. Soil formation from the parent rock can be a physical or chemical process. The process of physical soil formation that changes rock into smaller particles, occurs due to the influence of erosion, water, ice, people, or simply soil particles due to changes in temperature or weather. The particles may be spherical, jagged, or in some form in between. Generally, weathering due to chemical processes can occur under the influence of oxygen, carbon dioxide, water (especially those containing acids or alkalis) and other chemical processes. If the weathering results are still in their original place, then this soil is called residual soil and if the soil changes its place is called transported soil.

### **2.2.2. Soil Classification**

Soil classification system is a system of arranging several types of soil but having similar properties into groups and subgroups based on their use. The classification system provides an easy language to briefly describe the general properties of highly variable soils without going into detail (*Das, 1995*).

Soil classification system was created with the aim of providing information on the characteristics and physical properties of the soil. Because the nature and behavior of soils are so diverse, classification systems classify soils into general categories where

soils have similar physical properties. Soil classification is also useful for detailed studies of the state of the soil and the need for testers to determine the technical properties of the soil such as compaction characteristics, soil strength, density and so on (Bowles, 1989).

1. *AASHTO Classification System* is generally useful for determining the quality of soil for road works, namely subbase and subgrade. This system is based on the following criteria:

a. Soil Grain

- Gravel: the part of the soil that passes through a 75 mm diameter sieve and is retained on a 2 mm diameter sieve (No.10).
- Sand: the part of the soil that passes through a 2 mm diameter sieve and is retained on a 0.0075 mm, diameter sieve (No. 200).
- Silt and Clay: the part of the soil that passes the sieve with a diameter of 0.0075 mm no 200.

b. Silty soil plastics are used when the finer parts of the soil have a Plasticity Index (*IP*) of 10 or less. The name loam is used when the finer parts of the soil have a plasticity index of 11 or more.

c. If rocks larger than 75 mm are found in the soil sample to be tested, these rocks must be removed first, but the percentage of rock removed must be recorded.

The *AASHTO* classification system divides into 7 major groups, namely A-1 to A-7. Grained soils where 35% or less of the grain size passes through the No. 200 sieve are classified into groups A-1, A-2, and A3. Grained soils where more than

35% of the soil grains pass the No. 200 sieve are classified into groups A-4, A-5, A-6, and A-7. The grains in groups A-4 to A-7 are mostly silt and clay. To classify soils based on the *AASHTO* classification system, the data obtained from the results of laboratory tests are matched with the numbers given in *Table 2.2* regarding the soil classification system based on *AASHTO* below:

**Table 2.2** Soil Classification System Based on AASHTO

**TABLE 3-6** Classification of Soils and Soil-Aggregate Mixtures\*

General Classification	Granular Materials (35% or less passing 0.075 mm)							Silt-Clay Materials (More than 35% passing 0.075 mm)			
	A-1		A-3	A-2				A-4	A-5	A-6	A-7
Group classification	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5
Sieve analysis, percent passing:											
2.00 mm (No. 10)	50 max.	—	—	—	—	—	—	—	—	—	—
0.425 mm (No. 40)	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
0.075 mm (No. 200)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing 0.425 mm (No. 40):											
Liquid limit	—	—	—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.	—	NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to Poor			

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† Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30 (see Fig. 3.5).

(Source: Bowles, 1993)

2. In the *Unified system*, the soil is classified into coarse-grained soil (gravel and sand) if less than 50% passes sieve number 200, and 14 as fine-grained soil (silt/clay) if more than 50% passes sieve number 200, the symbols used are:

G = gravel

S = sand

C = clay

M	= silt
O	= silt or organic clay
Pt	= peat and highly organic soil
W	= well-graded
P	= poor gradation
H	= high plasticity
L	= low plasticity

The following is *Table 2.3* regarding the *Unified Classification system*:

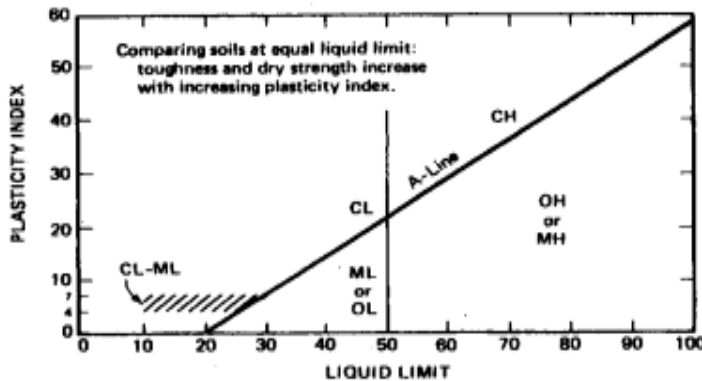
**Table 2.3** Soil Classification System Based on Unified

UNIFIED SOIL CLASSIFICATION SYSTEM			GROUP SYMBOLS	DESCRIPTIONS
MAJOR DIVISIONS				
COARSE GRAINED SOILS More Than Half Retained on 200 Sieve	GRAVELS More Than Half Coarse Fraction Retained on No. 4 Sieve	Clean Gravels (Little or no Fines)	GW	Well Graded Gravels, Gravel - Sand Mixtures, Little or no Fines
			GP	Poorly Graded Gravels, Gravel - Sand Mixtures, Little or no Fines
		Gravels With Fines (Appreciable Fines)	GM	Silty Gravels, Gravel-Sand-Silt Mixtures
			GC	Clayey Gravels, Gravel-Sand-Clay Mixtures
	SANDS More Than Half Coarse Fraction Passes a No. 4 Sieve	Clean Sands (Little or no Fines)	SW	Well Graded Sands, Gravelly Sands, Little or no Fines
			SP	Poorly Graded Sands, Gravelly Sands, Little or no Fines
		Sands With Fines (Appreciable Fines)	SM	Silty Sands, Sand - Silt Mixtures
			SC	Clayey Sands, Sand - Clay Mixtures
FINE GRAINED SOILS More Than Half Passes 200 Sieve	SILTS and CLAYS Liquid Limit Less Than 50		ML	Inorganic Silts & Very Fine Sands, Silty or Clayey Fine Sands, Clayey Silts
			CL	Inorganic Clays of Low to Medium Plasticity, Lean Clays
			OL	Organic Silts & Organic Silty Clays of Low Plasticity
	SILTS and CLAYS Liquid Limit Greater Than 50		MH	Inorganic Silts, Fine Sand or Silty Soils, Elastic Silts
			CH	Inorganic Clays of High Plasticity, Fat Clays
			OH	Organic Clays of Medium to High Plasticity, Organic Silts
Highly Organic Soils			PT	Peat and Other Highly Organic Soils

(Source: Bowles, 1993)

The following is a soil classification based on the *USCS* system, which is shown in *Table 2.4*:

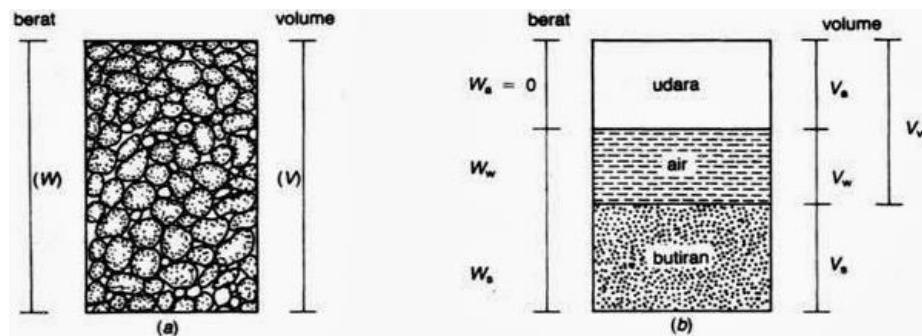
**Table 2.4** USCS Classification System

Laboratory Classification Criteria		
<p style="writing-mode: vertical-rl; transform: rotate(180deg);">Use grain size curve in identifying the fractions as given under field identification.</p> <p style="writing-mode: vertical-rl; transform: rotate(180deg);">Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows:                      Less than 5%: GW, GP, SW, SP                      More than 12%: GM, GC, SM, SC                      5% to 12%: <u>Borderline cases requiring use of dual symbols.</u></p>	6	
	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4 (See Sec. 2-5) $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3 Not meeting all gradation requirements for GW	
	Atterberg limits below A line, or PI less than 4 Atterberg limits above A line with PI greater than 7 Above A-line with PI between 4 and 7 are <u>borderline cases</u> requiring use of dual symbols.	
	$C_u = \frac{D_{60}}{D_{10}}$ greater than 6 (See Sec. 2-5) $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3 Not meeting all gradation requirements for SW	
	Atterberg limits below A line, or PI less than 4 Atterberg limits above A-line with PI greater than 7 Limits plotting in hatched zone with PI between 4 and 7 are <u>borderline cases</u> requiring use of dual symbols.	
	Plasticity Chart For laboratory classification of fine-grained soils	
		

(Source: Bowles, 1993)

### 2.2.3. Land Property

Soil consists of two or three parts, namely soil grains, air and air. Soil in a dry state only has two parts of the soil, namely soil grains and air pores. In saturated soil, there are only two parts, namely soil grains and pore water. While in unsaturated conditions the soil consists of three parts, namely soil grains, air pores, and pore water. The relationship between the parts of the soil is depicted in the form of a phase diagram, which can be seen in *Figure 2.1* below:



**Figure 2.1** Ground Phase Diagram

Based on *Figure 2.1* above, a soil has three elements in each grain. There is air, water, and solids. Each element has its own volume and weight. Referring to the ground phase diagram, the following equations can be seen *Equation 2.1* for 2.3:

$$W = W_s + W_w \quad \dots(2.1)$$

With,

$$V = V_s + V_w + V_a \quad \dots(2.2)$$

$$V_v = V_w + V_a \quad \dots(2.3)$$

And then,

$$W = \text{total weight}$$

$$W_s = \text{weight of solid granules}$$

- $W_w$  = weight of water  
 $V$  = total volume  
 $V_s$  = volume of solid granules  
 $V_w$  = volume of water  
 $V_a$  = volume of air  
 $V_v$  = cavity volume

### 1. Solid Granule Volume Weight ( $\gamma_s$ )

The weight of dry soil grains in one unit volume of soil grains or the ratio between the weight of solid grains ( $W_s$ ) and the volume of solid grains ( $V_s$ ) can be expressed in *Equation 2.4*.

$$\gamma_s = \frac{W_s}{V_s} \quad \dots(2.4)$$

### 2. Weight of soil volume in a saturated state ( $S=1$ )

The volume weight of the soil in a saturated state can be expressed in *Equation 2.5*.

$$\gamma_{sat} = \frac{\gamma_w(G_s + e)}{1 + e} \quad \dots(2.5)$$

### 3. Relationship between degree of saturation, void ratio, moisture content, and specific gravity

The relationship between the degree of saturation, void ratio, moisture content and specific gravity can be expressed in *Equation 2.6*.

$$S e = w G \quad \dots(2.6)$$

The correlation to determine soil density ( $\gamma$ ) and saturated soil density ( $\gamma_{sat}$ ) can be seen in *Table 2.5*.

**Table 2.5** Soil Volume Weight Value

No.	Type of soil	$\gamma_{sat}$ (kN/ m <sup>3</sup> )	$\gamma_d$ (kN/ m <sup>3</sup> )
1	Gravel	20 -22	15 – 17
2	Sand	18 – 20	13 – 16
3	Silt	18 – 20	14 – 18
4	Clay	16 - 22	14 – 21

(Source: John Wiley & Sons, 2000)

#### 4. Permeability

Permeability is the property of a porous material that allows the flow of seepage from a liquid in the form of water or oil to flow through the pore cavity. The pores in the soil are connected to each other, so that water can flow from high pressure to lower pressure. In soils, permeability is defined as the nature of the soil that drains water through the soil pores. According to Das (1983) in the book *Soil Mechanics 1 Sixth Edition*, the range of permeability values for soil types can be seen in *Table 2.6* below.

**Tabel 2.6** Permeability Coefficient Value

No.	Type of soil	k (mm/second)
1.	Coarse Details	$10 - 10^3$
2.	Fine gravel, coarse grain mixed with medium sand	$10^{-2} - 10$
3.	Fine sand, loose silt	$10^{-4} - 10^{-2}$
4.	Solid silt, loamy silt	$10^{-5} - 10^{-4}$
5.	Silty clay, clay	$10^{-8} - 10^{-5}$

(Source: Hardiyatmo, 2013)

#### 5. Modulus of Elasticity

The modulus of elasticity is a value that shows the magnitude of the elasticity of the soil from the ratio between the stress that occurs to the strain. This estimated value can be determined from the soil type as shown in *Table 2.7* below.

**Tabel 2.7** Soil Elasticity Modulus Value

No.	Soil of Type	E (kN/m <sup>2</sup> )
1.	<i>Clay</i>	
	Very soft	300 - 3000
	Soft	2000 - 4000
	Medium	4500 - 9000
	Hard	7000 - 20000
	Sandy	30000 - 42500

	<i>Sand</i>	
2.	Silty	5000 - 20000
	Not dense	10000 - 250000
	Congested	50000 - 100000
	<i>Sand and gravel</i>	
3.	Solid	80000 - 200000
	Not solid	50000 - 140000
4.	<i>Slit</i>	2000 - 20000
5.	<i>Loses</i>	15000 - 60000
6.	<i>Rock</i>	140000 - 1400000

(Source: Bowles, 1977)

## 6. Poisson Ratio

The poisson ratio value is determined as the ratio of shaft compression to lateral expansion strain. This value can be determined based on the type of soil as shown in *Table 2.8*.

**Table 2.8** Relationship between Soil Type and Poisson's Number

No	Type of soil	<i>Poisson Ratio</i>
1.	Saturated clay	0,4 – 0,5
2.	Unsaturated clay	0,1 – 0,3
3.	Sandy loam	0,2 – 0,3
4.	Silt	0,3 – 0,35

5.	Solid Sand	0,2 – 0,4
6.	Sand is not solid	0,15
7.	Fine sand	0,25
8.	Stone	0,1 – 0,4
9.	Loess	0,1 – 0,3

(Source: Hardiyatmo, 2002)

### 2.3. PARAMETER OF SOIL SHEAR STRENGTH

Soil shear strength is the ability of the soil to resist the shear stresses that occur when the soil is loaded. Soil shear failure occurs not because of the destruction of the soil grains, but because it is caused by the relative motion between the soil grains (*Budi Santoso, 1998*). On the basis of this understanding, if the soil is subjected to loading it will be held back by *Hardiyatmo HC (2009)*:

1. Soil cohesion, which depends on the type of soil and its density, but does not depend on the normal stresses acting on the shear plane,
2. Friction between soil grains, whose magnitude is directly proportional to the normal stress in the shear plane.

There are several methods to determine the shear strength of soil, including:

1. Direct shear test,
2. Triaxial test
3. Unconfined compression test.

However, in this study, used to determine the shear strength of the soil is direct shear test and triaxial test.

The shear strength test is carried out to obtain the shear strength parameters, namely cohesion ( $c$ ) and internal shear angle ( $\phi$ ).

a) Cohesion ( $c$ )

Cohesion is the attraction between soil particles. Together with the internal shear angle, cohesion is a parameter of soil shear strength that determines the soil's resistance to deformation due to stresses acting on the soil, in this case in the form of lateral soil movements. This value is obtained from the triaxial test and direct shear test. In addition, the range of cohesion values can be determined based on the  $qc$  value in the sondir test as shown in *Table 2.9* below.

**Table 2.9** The relationship of soil consistency to cone pressure and cohesion

No.	Soil Concentration	Cone Pressure ( $qc$ ) (kg/cm <sup>2</sup> )	Cohesion Level <sup>o</sup>
1	Very soft	<2,50	<1,25
2	Soft	2,50 – 5,0	1,25 – 2,50
3	Medium Stiff	5,0 – 10,0	2,50 – 5,0
4	Stiff	10,0 – 20,0	5,0 – 10,0
5	Very Stiff	20,0 – 40,0	10,0 – 20,0
6	Hard	>40,0	20,0

(Source: Bowles, 1996)

### b) Internal Shear Angle

The internal shear angle along with cohesion determines the resistance of the soil due to the stress acting in the form of lateral soil pressure. This value is also obtained from the triaxial test and direct shear test. In addition, the range of internal shear angle values can be determined based on the soil type as shown in *Table 2.10*.

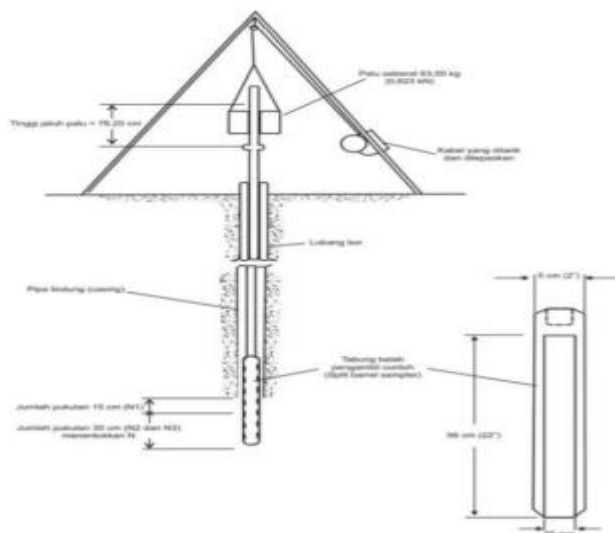
**Table 2.10** The Relationship between Shear Angle and Soil Type

<b>Type of soil</b>	<b>Internal Shear Angle</b>
Sandy pebbles	35 – 40
Pebbles	35 – 40
Solid sand	35 – 40
loose sand	30
Clay	25 – 30
Silt	20 - 25

(Source: DAS 1994)

## 2.4. STANDARD PENETRATION TEST (SPT)

Standard Penetration Test (SPT) is a test method that is carried out in conjunction with drilling to determine both the dynamic resistance of the soil and taking soil samples with the pulverizing technique. The test on the standard penetration test (SPT) method consists of a test of hitting a thick wall split tube into the ground and measuring the number of blows to insert the split tube as deep as 300 m vertically. In this method of falling load system, a hammer with a weight of 63.5 kg is used, and it is dropped repeatedly with a falling height of 0.76 m. The implementation of the SPT test can be divided into three stages of implementation and successively 150 mm thick for each stage of implementation. In the first stage, it is recorded as a holder, while the number of strokes to enter the second and third stages is added up to obtain the value of N strokes or SPT resistance (expressed in strokes/0.3 m). Details of the tools in the SPT process can be seen in *Figure 2.2* as follows.



**Figure 2.2** Penetration with SPT

(Source: SNI 4153-2008)

The testing parameter is obtained from the number of blows against cone penetration, which can be used to identify the soil layer in the field which is part of the foundation design.

This standard used can describe the principles of the field penetration test method using the SPT method including: a field penetration test equipment system consisting of cone equipment with the SPT method and other equipment, testing equipment requirements, test methods, test reports and test samples. This test method applies to soil types on generally (SNI 4153-2008).

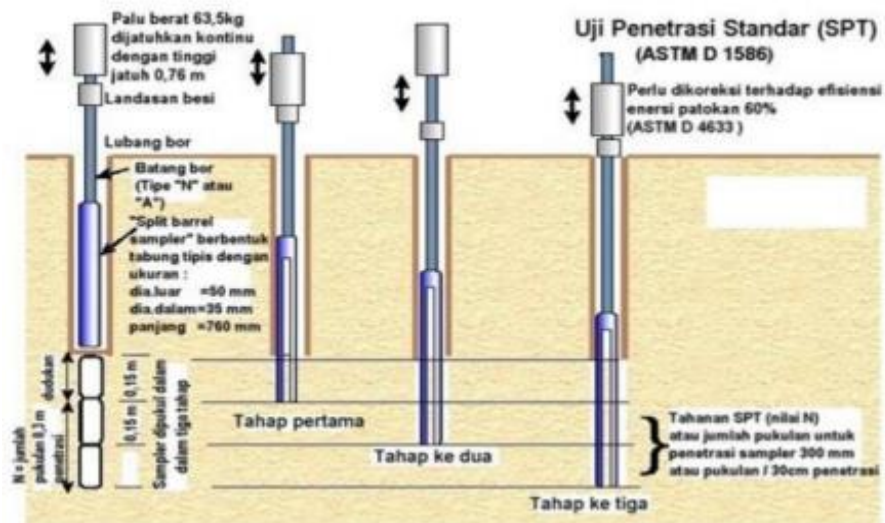


Figure 2.3 Standard Penetration Test (SPT) Testing Scheme

## 2.5. SLOPE STABILITY

### 2.5.1. General Definition

A slope is a land surface that is sloping and forms a certain angle to a horizontal plane. In a place where there are two land surfaces with different heights, there will be forces that push so that the higher ground tends to move downwards which is called the

gravitational potential force which causes landslides (*Tjokorda, et al, 2010*).

Slope landslide is the movement of soil rock mass in an upright, horizontal, or sloping direction from its original position as a result of the inability of the slope to withstand the shearing force acting on the boundary between the moving mass and the stable mass (*Skempton and Hutchinson, 1969 in Wicaksono, 2003*).

Slope stability is a very important factor in work related to excavation and stockpiling of soil, as well as rock and excavated materials, because it involves issues of human safety (workers), equipment security and smooth production. This situation relates to being in various types of work, for example in road construction, dams, digging canals, excavations for construction, mining and others.

In mining operations the problem of slope stability will be found in open pit excavations, dams for working water reserves, tailings disposal sites and stockyards. If the slopes that are formed as a result of the mining process (pit slope) or which are facilities supporting mining operations (such as dams and roads) are unstable, it will disrupt construction activities.

In a place where there are two land surfaces with different heights, there will be forces that work to push so that the higher ground tends to move downward which is called the gravitational potential force which causes landslides.

### 2.5.2. Cause of Landslide

According to *Hardiyatmo (2010)*, natural slope landslides can occur from the following things:

1. Adding load to the slope. Additional slope loads can be in the form of new buildings and additional water loads that enter the soil pores or those that float on the soil surface and dynamic loads by plants blown by the wind and others.
2. Excavations that sharpen the slope of the slope.
3. Excavating or cutting soil at the foot of the slope.
4. Changes in water level position quickly (rapid drawdown) on weirs, rivers and others.
5. Earthquakes.
6. The increase in lateral earth pressure by water (water filling the crack will push the soil laterally).
7. Decrease in shear resistance of slope-forming soil due to increase in water content, increase in pore water pressure, seepage pressure by standing water in the soil, soil on slopes containing clay that is easy to expand and shrink and others.

### 2.5.3. Landslide Effect

Based on *Hardiyatmo (2010)* several things affect landslides as follows.

#### 1. Climate Effect

According to *Hardiyatmo (2010)*, near the soil surface, the shear strength of the soil changes from time to time depending on the climate. Some types of soil float during the rainy season, and shrink during the dry season. In the rainy season, the shear strength of this soil is very low compared to the dry season. Therefore, the shear strength of the soil used in the slope

stability analysis must be based on the lowest soil shear strength, namely during the rainy season, or shear strength when the soil is saturated with water.

## 2. Effect of Water

Based on *Hardiyatmo (2010)* the influence on water flow or seepage is a very important factor in slope stability, but this influence is difficult to identify properly. It has been studied that the seepage of water that occurs in the soil will cause a seepage force that greatly affects the stability of the slope.

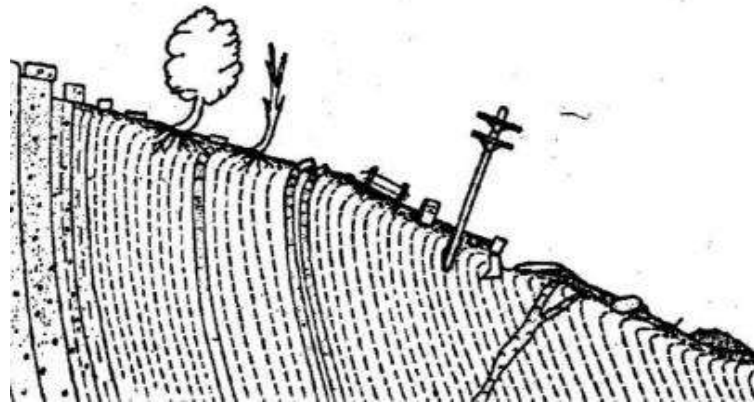
Erosion on the surface of the slope can cause erosion of the surface soil which can reduce the height of the slope, thus increasing the stability of the slope. On the other hand, erosion that cuts the toe of the slope can increase the height of the slope and reduce slope stability.

If on the slope there is a sudden drop in water level in the channel or near the slope, for example a sudden drop in the water level in a channel or river, there will be a reduction in the lifting force of the water on the soil mass and increase the load on the slope. The increase in load causes an increase in shear stress, which if the shear resistance of the soil is exceeded it will cause slope failure. This happens a lot on the slopes of the soil with low permeability.

## 3. Creep Effect

According to *Hardiyatmo (2010)*, near the sloping ground surface, the soil is affected by the swell-shrink cycle. This cycle can occur due to temperature changes, changes from the dry season to the rainy season, and in cold areas can be caused by

the effect of freezing water. As the soil expands, it rises against the forces of gravity. Meanwhile, when the soil shrinks, the soil descends assisted by gravity. The result of both movements is a gradual downward slope downward movement into the creep zone varying from a few centimeters to several meters depending on soil properties and climatic conditions. The appearance of the slope movement due to creep is illustrated by Taylor (1962) in Figure 2.4 below.



**Figure 2.4** View Slope due to the Effect of Creep

(Source: Taylor, 1962)

As shown in the image above, crawling can cause the following things:

- a. Moving rock blocks.
- b. The trees arched upwards.
- c. The bottom of the slope is curved and pulls the rock.
- d. Tower buildings, monuments, and others tilted.
- e. Retaining walls and foundations move and crack.
- f. Highways and railroads are out of line.
- g. Big stones rolling and so on

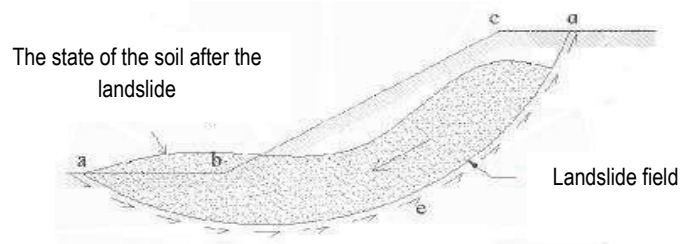
#### 2.5.4. Types of Landslides

A landslide is the movement of slope-forming material caused by shear failure, along with one or more areas of the landslide that occur. The total material displacement before the landslide depends on the amount of strain to reach the peak shear strength and on the thickness of the landslide zone (Hardiyatmo, 2010).

Landslides are natural disasters that often occur and are dangerous, especially during the rainy season. Landslides often occur due to soil movement in conditions of steep slopes, soil conditions that are not homogeneous, and do not have adhesion between layers of the soil.

Other factors that cause landslides are seepage, geological activities such as faults in the earth's plates, fractures and linearization. Local environmental conditions such as the shape and slope of the slopes, the strength of the material, the position of the water table and local drainage flow conditions are also quite important factors to cause landslides (Verhoef, 1985).

Landslides can be prevented if the thrust (the force causing the landslide) does not exceed the resistance force originating from the shear resistance of the soil along the plane of the landslide as shown in *Figure 2.5* below.



**Figure 2.5** Slope Slide

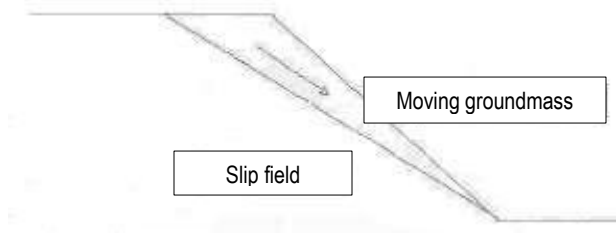
(Source: Hardiyatmo, 2010)

Based on *Hardiyatmo (2010)*, landslides that often occur so far are divided into several types of landslides, namely:

### 1. Translation Slide

This avalanche occurs because the mass of soil and rock moves on a flat or wavy inclined slip plane. A translational landslide is a movement along a discontinuous plane or weak plane that is approximately parallel to the slope surface so that the ground motion is translational as shown in *Figure 2.6* In clay conditions, translation occurs along a thin layer of sand or silt, especially if the weak plane is parallel to the existing slope.

Translational avalanches of clay containing layers of sand or silt can be caused by high pore water pressures in the sand or silt.



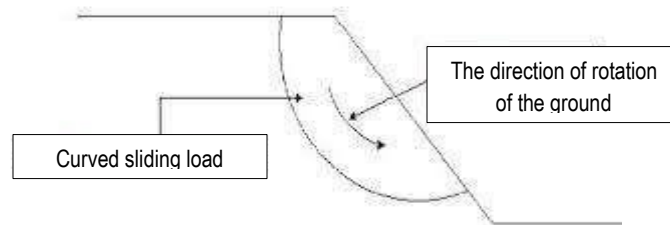
**Figure 2.6** Translation Slide

(Source: *Hardiyatmo, 2010*)

### 2. Rotational Slide

This avalanche can occur when the mass of soil and rock moves in a concave slip plane as shown in *Figure 2.7*. Rotational avalanches have an upward-curving landslide area and often occur in soil masses that move in a single unit.

Pure rotational avalanches (shumps) occur in relatively homogeneous materials such as artificial embankments (dykes).



**Figure 2.7** Rotational Slide

(Source: *Hardiyatmo, 2010*)

## 2.6. SLOPE STABILITY ANALYSIS

### 2.6.1. General Definition

In the non-horizontal position of the ground surface, the component of gravity tends to move the ground downwards. If the component of gravity is so large that the resistance to shear that can be exerted by the soil on the plane of the landslide is exceeded, a slope failure will occur. Stability analysis on a sloping ground surface is called slope stability analysis (*Hardiyatmo, 2010*).

Factors that can affect the stability of a slope are divided into two, namely external influences in the form of influences that cause an increase in the shear force without any change in the shear strength of the soil. While the internal influence is in the form of avalanches that occur without any change in external conditions or an earthquake (*Hardiyatmo, 2010*).

### 2.6.2. Slope Stability Analysis Theory

Based on *Hardiyatmo (2010)* the purpose of stability analysis is to determine the safety factor of potential landslide areas. In the analysis of slope stability, several ideas were made, which are as follows.

- 1) Slope slippage occurs along the surface of a certain landslide plane and can be considered a 2-dimensional plane problem.
- 2) The landslide mass is considered as a massive object.
- 3) The soil shear of the soil mass at each point along the landslide area does not depend on the orientation of the landslide surface, or in other words the shear strength of the soil is considered isotropic.
- 4) The safety factor is defined by showing the average shear stress along the potential landslide area, and the average soil shear strength along the surface of the landslide.

Slope stability analysis is generally based on the concept of boundary plastic balance. The parameter in the analysis of the stability of a slope is the safety factor of the landslide area which has the potential to cause a landslide.

The safety factor of a slope can be seen in *Table 2.11* and *Table 2.12* which are made according to the stability of a slope.

**Table 2.11** Relationship of Safety Factor Value with Landslide Intensity

<b>Safety Factor Value</b>	<b>Possible Landslide</b>
$SF \leq 1,07$	Landslides occur regularly/frequently (labile slopes)
$1,07 \leq SF \leq 1,25$	The landslide has occurred (critical slope)
$SF \geq 1,25$	Landslides are rare (slopes are relatively stable)

(Source: Bowles, 1989)

**Table 2.12** Value of Safety Factor for Slope Design

<b>Safety Factor</b>	<b>Slope State</b>
SF ≤ 1,00	Slope in unstable condition (labile slope)
1,00 ≤ SF ≤ 1,20	The slope is in doubtful steady state
1,30 ≤ SF ≤ 1,40	Slope in satisfactory condition
1,50 ≤ SF ≤ 1,70	Slope is in steady condition (slope is stable)

(Source: Sosrodarsono, 2003)

The stability of a slope depends on the value of cohesion ( $c$ ) and the angle of friction in the soil ( $\phi$ ). Soils with drier conditions generally have a high safety factor. On the other hand, the more saturated soil conditions generally the value of the safety factor is getting smaller. One of the causes of slope instability is the rising groundwater level which increases the degree of saturation and pore water pressure thereby reducing the effective stress and shear strength of the soil.

The influence of the stability of a slope is divided into two by Terzaghi in the book (*Hardiyatmo, 2010*) namely external influences in the form of influences that cause an increase in shear force without any change in the shear strength of the soil. Meanwhile, the internal influence is in the form of avalanches that occur without any change in external conditions or an earthquake. The safety factor for slope stability is defined as the ratio between the resisting force and the driving force as in *Equation 2.7* below.

$$SF = \frac{\tau}{\tau_d} \quad \dots(2.7)$$

Description:

$\tau$  = Maximum shear resistance

$\tau d$  = Shear stress, that occurs due to the gravity of the soil  
that will slide

$F$  = Safety factor

According to *Mohr Columb*, the maximum shear resistance is the shear resistance that the soil can exert along the sliding plane. While the value of the shear stress that occurs can be defined as a result of soil loads and other loads on the landslide field.

### 2.6.3. Slope Stability Analysis Method

To analyze the stability of this slope there are several methods, which are often used among others as follows.

#### 1. Fellenius Method

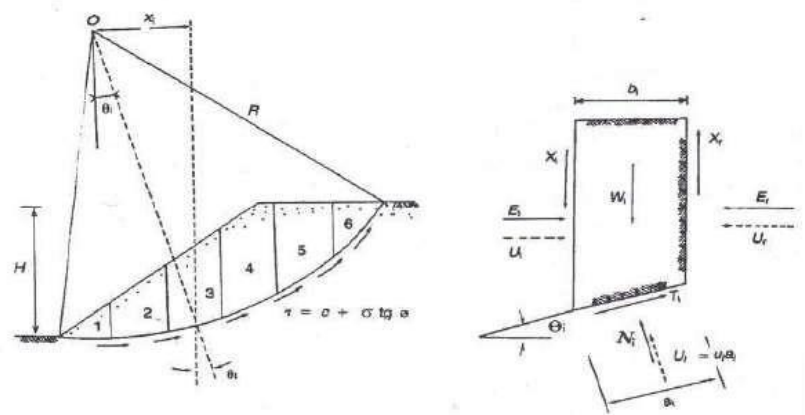
The Fellenius method (Ordinary Method of Slice) was first introduced by *Fellenius (1927, 1936)* assuming the forces acting on the right-left side of any slice have zero resultant in the direction perpendicular to the landslide plane.

Fellenius proposed his method by stating the assumption that failure occurs through the rotation of a block of soil on a circular (circular) landslide surface with point O as the center of rotation. This method also assumes that the normal force P acts in the middle of the slice. It is also assumed that the resultant forces between the slices at each slice are equal to zero, or it can also be stated that the resultant forces between the slices are ignored.

So the total assumptions made by this method are:

- The position of the normal force  $P$  lies in the center of the base of the wedge:  $n$
- The resultant force between the slices is zero:  $n - 1$

An illustration of the fellenius method modeling can be seen in the following figure



**Figure 2.8** Forces That Work on Slices

(Source: Hardiyatmo, 2010)

With these assumptions, it is possible to test the moment balance equation for all slices about the center of rotation and obtain a value of the factor of safety. With this assumption, the balance of the vertical direction and the working forces is:

$$N_i + U_i = W_i \cos \theta_i \quad \dots(2.8)$$

Or else,

$$\begin{aligned} N_i &= W_i \cos \theta_i - U_i \\ &= W_i \cos \theta_i - u_i a_i \end{aligned} \quad \dots(2.9)$$

The safety factor is defined as,

$$F = \frac{\text{(Number of moments of shear resistance along the sliding plane)}}{\text{(Number of moments of mass weight of the landslide)}}$$

$$= \frac{Z Mr}{Z Md}$$

The moment arm of the weight of the soil mass per slice is  $R \sin \theta$ , then:

$$\sum Md = R \sum_{n=1}^{i=n} W_i \sin \theta; \quad \dots(2.10)$$

Description:

$R$  = The radius of the avalanche circle.

$n$  = Several slices.

$W_i$  = The weight of the mass of the soil mass of the -i slice.

$N_i$  = The resultant of the effective normal force acting along the base of the wedge.

$\theta_i$  = Defined angle

In the same way, the moment that resists the soil from sliding is:

$$\sum Md = R \sum_{n=1}^{i=n} (ca; + N; tg \varphi) \quad \dots(2.11)$$

Then the equation for the safety factor becomes,

$$F = \frac{\sum_{n=1}^{i=n} (ca; + N; tg \varphi)}{\sum_{n=1}^{i=n} W_i \sin \theta;} \quad \dots(2.12)$$

If there is water on the slope, then the pore water pressure in the landslide area does not increase the moment due to the soil that will slide ( $Md$ ), because the resultant force due to the pore water pressure is the center of the circle.

$$F = \frac{\sum_{n=1}^{i=n} cai; +(Wi; \cos \theta; -ui; a_i) tg \varphi}{\sum_{n=1}^{i=n} W; \sin \varphi;} \dots(2.13)$$

Description:

$F$  = Safe factor

$c$  = Soil cohesion (kN/m<sup>2</sup>)

$\varphi$  = The angle of friction in the ground (°)

$a_i$  = The length of the arc of the circle at the- $i$  intersection (m)

$W_i$  = Weight of the  $i$ th soil slice (kN)

$u_i$  = Pore water pressure at the- $i$  slice (kN/m<sup>2</sup>)

$\theta$  = Defined angle

If when there are forces other than the weight of the soil itself, such as a building on a slope, then the effect of this load is calculated as  $Md$ .

## 2. Slice Method

Stability analysis using the wedge method is more suitable for inhomogeneous soil conditions and erratic water flow. The normal force of a point in the circle of the landslide area is affected by the weight of the soil above that point. In this method, the soil that is likely to experience landslides is divided into several vertical slices. Then the balance in each slice is considered.

The factor of safety is the ratio of the existing shear strength ( $\tau$ ) to the shear strength ( $\tau_m$ ) that must be applied to maintain the equilibrium boundary conditions. To calculate the safety factor, the following Equation 2.14 can be used.

$$SF = \frac{\tau}{\tau_m} \quad \dots(2.14)$$

Considering the moment about point O, the sum of the moments due to the shearing forces on the failure arc AC must be equal to the moment due to the soil mass ABCD. For each slice, the moment arm  $W \cdot r \cdot \sin \alpha$  so that Equation 2.15, Equation 2.16, and Equation 2.17 can be formed below.

$$\sum Tr = \sum W \cdot r \cdot \sin \alpha \quad \dots(2.15)$$

$$T = \frac{c}{cm} \cdot l \quad \dots(2.16)$$

$$SF = \frac{Z c \cdot l}{Z W \cdot \sin \alpha} \quad \dots(2.17)$$

To analyze those using effective stress, the following Equation 2.18 can be used.

$$SF = \frac{c^F \cdot La - \tan \theta Z N'}{Z W \cdot \sin \alpha} \quad \dots(2.18)$$

### 3. Bishop Method

Bishop assumes that the resultant force on the side of the intersection is horizontal, is  $X1-X2 = 0$ . By solving the forces in the vertical direction, Equation 2.19 is obtained below.

$$W = N' \cdot \cos \alpha + u \cdot \cos \alpha - \frac{c'}{SF} \cdot \sin \alpha - \frac{N'}{SF} \cdot \tan \phi' \cdot \sin \alpha \quad \dots(2.19)$$

By substituting the value  $1 = b \cdot \sec \alpha$ , then Equation 2.20 is obtained for the factor of safety as follows.

$$SF = \frac{1}{Z W \cdot \sin \alpha} \sum \left[ (c' + W) n \varphi \right] x \frac{\sec \alpha}{1 - \frac{\tan \alpha \cdot \tan \varphi F}{SF}} \quad (2.20)$$

Description:

$N'$  = Effective normal style

$W$  = Total weight of slice

$\alpha$  = The angle of the shear tangent to each slice

$u$  = Pore water pressure at the center of the base

$l$  = Base length

$\varphi$  = Inner friction angle

$c'$  = Effective soil cohesion

## 2.7. SLOPE REINFORCEMENT

### 2.7.1. General Definition

Slope reinforcement (revetments) is a building that is placed on the surface of a slope to protect a river channel cliff or the surface of the embankment slope and as a whole plays a role in increasing the stability of the river channel or the body of the embankment it protects. There has been a very advanced development of the construction, one of the most vital river buildings and it is now possible to choose one of the most suitable constructions, materials, and construction methods adapted to various local conditions. However, slope reinforcement construction is continuously being developed and perfected.

### 2.7.2. Slope Safety Factor

In the analysis of the stability of the slope with a sliding surface that is assumed to be a circular curvature, the force that pushes the soil mass above the circular curvature so that it slips must be compared with the shear force along the circular curvature that resists the slide. Because the thrust and the resistance are different from the position and the radius of curvature of the circle, it is necessary to carry out an analysis by changing the position and the radius of curvature of the circle to some values using assumptions. Various methods are proposed for the comparison between the thrust and the resisting forces so that the safe number is: the force that derails the resisting force  $SF =$  If the safety factor is 1, it means that the slope is almost in danger of slope collapse/slide. As a result, to get the specified slope, the safety factor (SF) 1.0. In the book *Mechanics of Soil I* by Hardiyatmo H.C., 2009, Bowles J.E. (1989) explained that the condition of the slope based on the value of its safety factor (SF) can be seen in Table 3.11 below.

**Table 2.13** Relationship of Safety Factor Value with Landslide Intensity

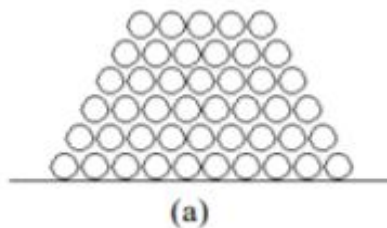
<b>Safety Factor Value</b>	<b>Possible Landslide</b>
$SF \leq 1,07$	Landslides occur regularly/frequently (labile slopes)
$1,07 \leq S F \leq 1,25$	The landslide has occurred (critical slope)
$SF \geq 1,25$	Landslides are rare (slopes are relatively stable)

(Source: Bowles, 1989)

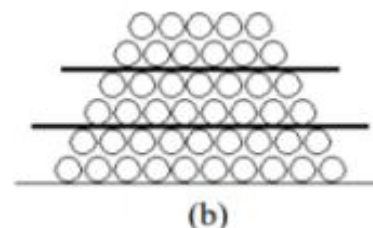
The unstable slope is a slope that often occurs in landslides, characterized by the value of the safety factor ( $SF$ ) below 1.07. Critical slope is a slope that has experienced landslides, characterized by a safety factor value ( $SF$ ) between 1.07 to 1.25.

## 2.8. SLOPE STRENGTH USING GEOTEXTILE

A French engineer, *Henri Vidal* in 1966 conducted a study. From his research, Henri can conclude that natural sand embankments which have a certain original slope angle can be stable with a larger slope angle and if given a flexible material that is able to withstand the pull in the sand embankment. The difference between the soil with the original slope angle and the reinforced soil can be seen in *Figure 2.9* and *Figure 2.10* below:



**Figure 2.9** Sand Embankment with Original Slope



**Figure 2.10** Sand Embankment with Reinforced Slope

Soil in the field is generally loose, easily compressed, has high permeability and other properties that are not suitable for a development project, so the soil must be strengthened. Soil reinforcement techniques that have developed to date use materials that have relatively high flexibility properties (*Purwanto, 2012*). The collapse or slide that occurs is not due to the pull or pressure between the soil grains.

However, it is caused by the overturning or slipping of soil grains. By knowing the type of failure that occurred, soil reinforcement can be applied to the landslide area by placing soil reinforcement material, anchoring (soil nailing) and so on.

### **2.8.1. Geotextile**

Geotextile, which is a geosynthetic material that resembles textile materials in general, but consists of synthetic fibers so that apart from being flexible, there is also no shrinkage problem as in materials from natural fibers such as wool, cotton or silk. The definition provided *by ASTM* states that geotextiles are materials that are not impermeable to water. In this case, the geotextile functions as a separation layer, filtration layer, drainage, soil reinforcement and moisture barrier.

In the geotextile manufacturing process, textile elements such as fibers or yarn strands are combined into a sheet textile structure. These elements can be in the form of filaments (continuous fibers) in the form of thin and long polymer threads or staple fibers in the form of short filaments with a length of between 20-150 mm. The textile element can also be made by cutting a sheet of plastic or film to form a flat, thin ribbon. In filaments and slit films, the process of ejection or pulling will elongate the polymer in the direction of pulling thereby increasing the strength of the filament.

The selection of geotextiles for reinforcement is influenced by two factors, namely internal and external factors. The internal factors of geotextile consist of geotextile tensile strength, creep properties, geotextile structure, and resistance to environmental factors, while external factors are the type of embankment material that interacts with the geotextile. The loading time also

reduces the strength of the geotextile because there will be degradation of the geotextile by fatigue and aging factors. To cover this shortcoming, not all the available geotextile tensile strength can be utilized in the planning of retrofitting construction (Djarwadi, 2006).

According to Holtz (1998), in Hardiyatmo (2007), slope design with geotextile reinforcement can be done using two methods, namely the trial, and error method and the direct method. In the trial design, the calculation is done by making a cross-section of the slope with a geotextile arrangement on a trial basis, then analyzed with a computer program.

In direct calculations, slope stability calculations are carried out with a computer program and manual calculations are carried out in calculating geotextile requirements.

The types of geotextiles are then divided according to the method used to combine the filaments or ribbons into the sheet structure. The main types of geotextiles are non-woven and woven.

#### 2.8.1.1. Woven Geotextile

Woven geotextile is a geosynthetic material in the form of a woven made of polypropylene (PP) or polyester (PET) raw materials with high technology and strict quality control to produce quality geotextile products with very high tensile strength.

Woven geotextiles are made from monofilament, multifilament, fibrillated yarns or from strips of film and ribbon. The weaving process for woven geosynthetics is the same as for ordinary textile manufacture.

To make visualization easier, this Woven Geotextile is similar to a rice sack (not made of burlap) but is black.



**Figure 2.11** Woven Geotextile

The function of woven geotextiles is as a material to increase the stability of the subgrade (especially soft subgrade), because this type of geotextile has a higher tensile strength value than non-woven geotextiles. It also has good water absorption (permeability), resistance to chemicals and organics. (*Isparmo, 2010*).

Some advantages of woven geotextile materials are that they are regular in shape and woven so that they have a high tensile strength compared to non-woven geotextiles, so they are very suitable as materials used in pavement layers. And also its Permeable (permeable to water) so it can also be used as a filter layer. The disadvantages of woven geotextiles are that they are not resistant to sunlight, this is because sunlight contains ultraviolet rays, which can cause rapid degradation and are susceptible to sharp object punctures.

### 2.8.1.2. Non-Woven Geotextile

Non-woven geotextiles are sheets made of polyester fibers and some are made of polypropylene, which are processed by needle punch with high technology and strict quality control to produce quality geotextile products. Non-woven geotextiles are made with advanced technology wherein polymer fibers or filaments are pushed out and twisted continuously, blown or placed on a conveyor belt.

Then the filament or fiber mass is joined by a mechanical process with the puncture of tiny needles or heated together, where the fiber is "welded" by heat and/or pressure at the point of contact of the fiber with the non-woven textile mass.

The non-woven geotextile has a lower tensile strength than the woven geotextile, but the non-woven geotextile has good permeability properties. In accordance with its physical characteristics, non-woven geotextiles are mostly used as a filter (filtration) and as a drain (drainage). As a tool to facilitate the process of flowing water, the function of the non-woven type of geotextile will function as a diverter as well as a filter, namely filtering soil particles so that they are not carried away by the flow of water.



**Figure 2.12** Non-woven Geotextile

In addition, the presence of this type of geotextile also facilitates the compaction process of the pavement system. It can also function on high embankments or slopes, where the soil pressure of the infill material is high enough to cause sliding or lateral strain in the fill material, geotextiles can provide resistance in the horizontal direction to increase the stability of the embankment.

### **2.8.2. Function of Geotextile**

Based on *Isparmo (2010)* the function of geotextile consists of a function as a separating material and a function as a geotechnical reinforcement material as follows.

- a) Separation function is required when placed between two different types of materials, to avoid contamination and mixing that may occur between the two materials. An example is the use of geotextiles in road construction to separate aggregate from a subgrade layer that has a weak bearing capacity as shown in *Figure 2.13* below.



**Figure 2.13** Geotextile for Separator

*(Source: Isparmo, 2010)*

- b) The next function is soil reinforcement because the soil has the strength to withstand compression, but cannot withstand tension. This weakness to tension is met by geotextiles. Geotextiles have the ability to withstand strong tensile strength, so the function of geotextiles in this geotechnic is the same as the function of reinforcement in concrete. This material can be placed under embankment which is built on soft soil, can also be used to build retaining walls, and can also be used to strengthen road pavement and subgrade materials as shown in *Figure 2.14* below.



**Figure 2.14** Geotextile for Reinforcement

*(Source: Isparmo, 2010)*

### 2.8.3. Interface Value Geotekstil

Based on *Hardiyatmo (2010)* the properties of the soil to be strong to withstand this tension are the result of the interaction between the soil and its reinforcement. With this friction, the soil transfers the forces acting on it to the reinforcement. The interaction of soil with geotextiles is influenced by the interface. The interface value can be obtained from the shear test and tensile test. Several interface values have been proposed by several researchers and are also included in the technical offer of geotextile products. The following is the interface value for the type of cohesive soil with the proposed geotextile along with a description of the assumptions and types of materials reviewed in *Table 2.14* below.

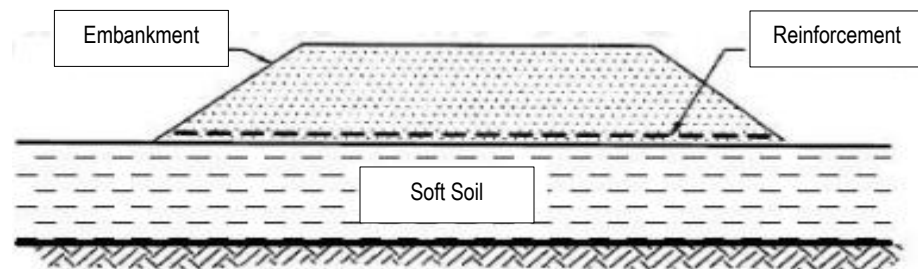
**Table 2.14** Interface Value of Cohesive Soil with Geotextile

Reference Source	Interface Value	
	Geotekstil <i>non woven</i>	Geotekstil woven
<i>Suryokekono (2000)</i>	0,67	
	Practical assumptions in the field	
<i>Brinkgreeve (2002)</i>	-	
	Practical assumptions for PLAXIS numerical analysis	
<i>Kamon (2008)</i>	-	0,85
		Polypropylen woven
<i>Rifa'l (2009)</i>	0,84 – 1,3	0,78 – 0,95
	TS600 – R206	BW250
<i>Mariapan (2011)</i>	-	0,85
		Polypropylen woven
<i>Produsen Geotekstil (2001)</i>	0,92	0,84
	Geosynthetic Clay (GCL)	

(Source: *Ismanti, 2012*)

#### 2.8.4. Embankment Stability Analysis Using Geotextile

The important effect of using geotextiles for embankment reinforcement is that it functions primarily as a separator and also functions as reinforcement or reinforcement that increases the bearing capacity of the subgrade by the strength of the soil composite with the geotextile. Embankments built on soft soil have a tendency to move laterally, due to the horizontal earth pressure acting on the embankment. This pressure causes a shear stress at the base of the embankment which must be supported by the soft foundation soil so that it does not collapse. Therefore, at the base of the embankment, geotextiles with high tensile strength can be installed which are useful for increasing the stability of the embankment, as shown in *Figure 2.15* below.

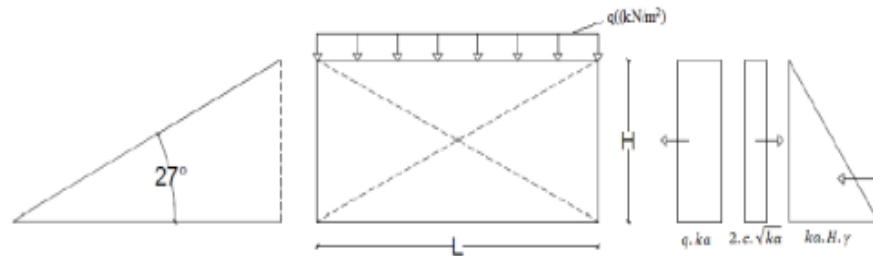


**Figure 2.15** Embankment on Soft Soil

(Source: Hardiyatmo, 2008)

Planning for geotextile reinforcement has stability forces that need to be taken into account. Slope stability analysis with reinforcement consists of several analyzes of external stability and internal stability. External stability consists of stability against shear, overturning, eccentricity, and bearing capacity of the soil. Internal stability in the form of stability to the forces and the effective length of the geotextile.

The distribution diagram of the lateral soil pressure on the slope can be seen in *Figure 2.16* below.



**Figure 2.16** Lateral Soil Pressure Distribution Diagram

(Source: Purwanto, 2012)

Analysis of the forces acting for stability against internal forces used stress analysis as in retaining walls using the classical theory of Rankine and Coulomb.

The working principle of Geotextile in the stress that occurs by friction in the contact area is stated in *Equation 2.21* below.

$$\tau = c + \sigma_v \operatorname{tg} \varphi \quad \dots(2.21)$$

Description:

- $\tau$  = Shear stress acting on the plane surface contact between reinforcement and soil particles (kN/m<sup>2</sup>).
- $c$  = Cohesion (kN/m<sup>2</sup>).
- $\sigma_v$  = Normal stress at the ground interface reinforcement (kN/m<sup>2</sup>).
- $\varphi$  = The friction angle between the soil and reinforcement (°).

The tensile forces that will act on the geotextile can be expressed in the following *Equation 2.22*

$$T_a = \tau \times b \times L \times \operatorname{tg} \varphi \quad \dots(2.22)$$

Description:

$T_a$  = Tensile force on reinforcement (kN/m).

$b$  = Reinforcement width (m).

$L$  = Reinforcement length (m).

To get the vertical distance between layers of geotextile ( $S_v$ ) can be done by *Equation 2.23* to *Equation 2.25* below.

$$K_a = \tan\left(45 - \frac{\varphi}{2}\right) \quad \dots(2.23)$$

$$\sigma_{hc} = (q \times K_a) + (K_a \times H \times \gamma b) - (2 \times c \times \sqrt{K_a}) \quad \dots(2.24)$$

$$S_v = \frac{T_a}{\sigma_{hc} \times SF} \quad \dots(2.25)$$

Description:

$K_a$  = Active soil coefficient.

$\sigma_{hc}$  = Average horizontal pressure on the fold (kN/m<sup>2</sup>).

$q$  = Even load (kN/m<sup>2</sup>).

$SF$  = Safety factor.

$S_v$  = Distance of the reinforcement in the vertical direction (m).

$\gamma$  = Soil volume weight (kN/m<sup>3</sup>).

$c$  = Cohesion (kN/m<sup>2</sup>)

$T_a$  = The tensile strength of geotextile is allowable.

## 1. External Stability

### a) Stability Against Shear

$$SF = \frac{(q \cdot \tan \delta \cdot L) + (H \cdot \gamma b \cdot \tan \delta \cdot L)}{(q \cdot K_a \cdot H) + (0,5 \cdot K_a \cdot \gamma b \cdot H^2) - (2 \cdot c \cdot \sqrt{K_a} \cdot H)} \quad \dots(2.26)$$

Description:

- $SF$  = Safety factor.  
 $\Phi$  = The friction angle between the soil and the geotextile ( $^{\circ}$ ).  
 $L$  = Geotextile length (m).  
 $H$  = Soil layer height (m).  
 $\gamma b$  = Soil volume weight ( $\text{kN/m}^3$ ).  
 $ka$  = Active soil coefficient.  
 $c$  = Cohesion ( $\text{kN/m}^2$ ).  
 $q$  = Even load ( $\text{kN/m}^2$ ).

#### b) Stability Against Rolling

The safety factor against overturning can be expressed in *Equation 2.27* below.

$$SF = \frac{\sum MD}{\sum MR} = \frac{\text{Holding Moment}}{\text{Rolling Moment}} \quad \dots(2.27)$$

$$\sum MR = (q \cdot Ka \cdot H) + \left(\frac{1}{2} \cdot Ka \cdot \gamma b \cdot H^2\right) - (2 \cdot c \cdot \sqrt{Ka} \cdot H)$$

$$\sum MD = (q \cdot L) + (H \cdot \gamma b \cdot L)$$

$$SF = \frac{(q \cdot L) + (H \cdot \gamma b \cdot L)}{(q \cdot Ka \cdot H) + \left(\frac{1}{2} \cdot Ka \cdot \gamma b \cdot H^2\right) - (2 \cdot c \cdot \sqrt{Ka} \cdot H)}$$

Description:

- $SF$  = Safety factor.  
 $L$  = Geotextile length (m).  
 $H$  = Soil layer height (m).  
 $\gamma b$  = Soil volume weight ( $\text{kN/m}^3$ ).  
 $c$  = Cohesion ( $\text{kN/m}^2$ ).

### c) Stability Against Eccentricity

The value of  $\frac{1}{6} L$  must be greater than the eccentricity value stated in *Equation 2.28* and *Equation 2.29* below:

$$\frac{1}{6} L \geq e \quad \dots(2.28)$$

$$\frac{1}{6} > \frac{(q.Ka.H)+(0,5.Ka.\gamma b.H^2)-(2.c.\sqrt{Ka}.H)}{(q.L)+(H.\gamma b .L)} \quad \dots(2.29)$$

Description:

$e$  = Soil eccentricity value (m).

$L$  = Geotextile length (m).

$H$  = Soil layer height (m).

$\gamma b$  = Soil volume weight (kN/m<sup>3</sup>).

$ka$  = Active soil coefficient.

$c$  = Cohesion (kN/m<sup>2</sup>).

$q$  = Even load (kN/m<sup>2</sup>).

### d) Stability of Soil Bearing Capacity

The factor of safety on the bearing capacity of the soil is expressed in *Equation 2.30* to *Equation 2.32* below:

$$L \leq \frac{\sigma_{ult}}{(H \times \gamma b) + q} \quad \dots(2.30)$$

$$\sigma_{ult} = [(c \times Nc) + (q + Nq) + (0,5 \times L \times \gamma b \times N\gamma)] \times SF$$

(Source: Bowless, 1989)

.....(2.31-32)

## 2. Internal Stability

### a) Length of Overlapping Geotextile

The length of the overlapping geotextile can be expressed in *Equation 2.33* below.

$$L_o = \frac{\sigma_{hc} \times SV \times SF}{2 \times \gamma b \times H \times \tan \varphi} \quad \dots(2.33)$$

Description:

$L_o$  = Overlapping length (m).

$\sigma_{hc}$  = Ultimate stress (kN/m<sup>2</sup>).

$SV$  = Reinforcement distance vertical direction (m).

$\gamma b$  = Soil volume weight (kN/m<sup>3</sup>).

$SF$  = Safety factor.

$\varphi$  = The friction angle between the soil and the geotextile (°).

### b) Effective Length of Geotextile

The length of reinforcement behind the slip plane ( $L_{ef}$ ) at the end of the geotextile can be calculated in *Equation 2.34* below.

$$L_{ef} = \frac{SF \times SV \times K_a \times \gamma b \times H}{2 \times \gamma b \times H \times \tan \varphi} \quad \dots(2.34)$$

Description:

$L_{ef}$  = The effective length of geotextile (m).

$K_a$  = Active soil coefficient

$SV$  = The distance of the reinforcement in the vertical direction (m).

$\gamma b$  = Soil volume weight (kN/m<sup>3</sup>).

$SF$  = Safety factor.

$\varphi$  = The friction angle between the soil and the geotextile ( $^{\circ}$ ).

## 2.9. LAND SUBSIDANCE

### 2.9.1. General Definition

If the soil layer is loaded, the soil will experience strain or settlement. The strain that occurs in the soil is caused by changes in the composition of the soil or by a reduction in the pore/water cavities in the soil. The sum of the strains over the layer depth represents the total settlement of the soil. Impairment due to load is the sum of the immediate settlement and consolidated settlement.

### 2.9.2. Primary Consolidation Primer

The addition of a load on a saturated soil layer causes the pore water pressure to increase and causes water to try to flow out of the soil pores so that its volume will decrease. This land subsidence is known as consolidation settlement or primary settlement. The amount of consolidation settlement for soft soil types is highly dependent on the geological history of the soil. The soil at a certain depth has experienced pre-consolidation effective stress, which is the greatest effective stress ever experienced before. The effective pre-consolidation stress can be less than or equal to the current effective overburden stress. Normally consolidated, the current effective overburden stress is the largest (maximum) stress experienced by the soil. Calculations to find the value of the normally consolidated decline can be done with the following *Equation 2.35*.

$$S_c = H \frac{C_c}{1 + e_o} \log \frac{P_o + \Delta p}{P_o} \dots(2.35)$$

Description:

- $S_c$  = Primary drop (m)  
 $C_c$  = Soil compression index  
 $P_o$  = Effective overbunden pressure (kN/m<sup>2</sup>).  
 $\Delta p$  = Vertical stress change (kN/m<sup>2</sup>)  
 $e_o$  = Pore number  
 $H$  = Soil thickness (m)

### 2.9.3. Parameters of Calculation of Land subsidence

In calculating the amount of subsidence of a soil layer, several parameters are needed. The following are parameters for calculating primary consolidation settlement as follows.

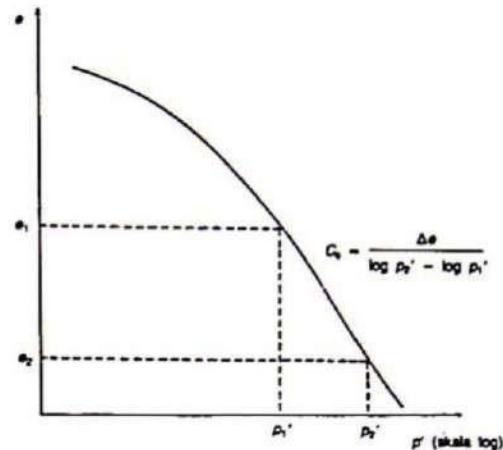
#### 1. Soil Compression Index ( $C_c$ )

*Terzaghi and Peck (1967) in Barimbing (2017)* suggest the use of empirical equations to calculate the compression index in clays whose soil structure is disturbed or undisturbed. Calculations are carried out using the following *Equation 2.36*

$$C_c = 0,009 (LL - 10) \dots(2.36)$$

Where LL is the liquid limit. This equation is used for inorganic clays that have low to moderate sensitivity with an error of 30% (this equation should not be used if the sensitivity is greater than 4). *Terzaghi and Peck* also propose *.....(2.37)* relationship with remolded clay as in *Equation 2.37* and the graph of the  $C_c$  compression index graph relationship can be seen in *Figure 2.16* below.

$$Cc = 0,007 (LL - 100)$$



**Figure 2.16** Compression index,  $C_c$

(Source: Hardiyatmo, 2003)

Some  $C_c$  values based on soil properties at certain places given by Azzous (1976) can be seen in Equations 2.38 to 2.41 below.

$$C_c = 0,01 \, w_n \quad (\text{for Chicago clay}) \quad \dots(2.38)$$

$$C_c = 0,0046 (LL - 9) \quad (\text{for Brazilian clay}) \quad \dots(2.39)$$

$$C_c = 0,208e_o + 0,0083 \quad (\text{for Chicago clay}) \quad \dots(2.40)$$

$$C_c = 0,0115 \, w_n \quad (\text{for organic soil}) \quad \dots(2.41)$$

Where  $w_n$  is the original water content in the field in (%) and  $e_o$  is the void ratio.

## 2. Effective Overburden Stress ( $P_o$ )

Winner (2017) in Satindra (2018) states that the effective overburden stress is the effective vertical stress of the original soil due to the load or soil layer above the original soil point under consideration.

The effective overburden stress can be calculated by the following *Equation 2.42*

$$P_o = \gamma' x H' \quad \dots(2.42)$$

Description:

$P_o$  = Effective overburden stress

$\gamma'$  = Effective soil volume

$H$  = The thickness of the soil layer

### 3. Ground Stress Distribution ( $\Delta p$ )

The addition of soil stress is due to the influence of the load on the soil in terms of the midpoint of each layer of soil. The calculation of the addition of stress is defined as in *Equation 2.43* below.

$$\Delta p = q x l \quad \dots(2.43)$$

With the value of q defined in the equation,

$$q = \gamma_{embankment} x H \quad \dots(2.44)$$

Description:

$\Delta p$  = Vertical stress change

$q$  = Embankment load

$H$  = Layer thickness land

$\gamma_{embankment}$  = Volume weight of the embankment

$l$  = Influence factor

## 2.10. PLAXIS

PLAXIS is the chosen geotechnical analysis program because it can analyze soil stability using the finite element method, which is able to perform analyzes that are close to the actual behavior. PLAXIS provides various analyzes of displacement, soil stresses, slope safety factor and others. The conditions in the field that are simulated with the PLAXIS program aim to be applied from program work to implementation stages in the field. So that the results of the program make it easier for data processing which is expected to save time, but the results are in accordance with manual calculations.

The actual condition can be modeled in plane-strain or asymmetrically. This program implements a graphical interface model that is quite easy to use, users can create geometric and mesh models based on cross sections of the conditions to be analyzed. This program consists of four sub-programs, namely input calculations, outputs, and curves.

The model that will be used in this research is the *Mohr-Coulomb* model. This model is an elastic – plastic model which consists of five parameters, namely  $E$  and  $\nu$  to model soil elasticity, and  $c$  to model soil plasticity, and  $\phi$  as dilatation angle. The Mohr-Coulomb model is a “first-order” approximation of soil or rock behavior. This model is recommended to be used in the initial analysis of the problems encountered. Each layer will be modeled with a constant average stiffness value. Because of the constant stiffness, calculations tend to be fast and an initial estimate of the deformation shape of the model can be obtained. Besides the five parameters of the model, the initial stress conditions of the soil play an important role in almost all soil deformation problems. The initial horizontal stress of the soil must be determined first by determining the correct value of  $k_0$  (*Brinkgreve, 2007*).

The field conditions that are simulated into the PLAXIS program aim to implement the implementation stages in the field into the work stages of the program, with the hope that field implementation can be as close as possible to the program, so that the response generated from the program can be assumed to be a reflection of the actual conditions that occur in the field.

At the analysis stage using the *Bentley PLAXIS 2D V20* program there are several steps that must be taken, including the following.

a) Data Entry

At the data input stage, modeling is carried out in the form of retaining wall geometry and slope data to be analyzed, soil material, loading, meshing, and initial conditions. So that the resulting model can describe the real conditions that exist in the field.

b) Calculation

When the modeling has been carried out at the input stage, the next stage is the calculation stage. At this stage, the analysis is carried out according to the needs of the model that has been defined in the input data. There are several types of calculations provided, namely plastic-type, consolidation,  $\phi/c$  reduction, and dynamic analysis.

c) Output

After completing the analysis, the results of the analysis in the previous calculation stage can be seen in the output stage. The results of the analysis of the output stage can be displayed in the form of numbers, images, and curves. The outputs produced and will be reviewed in this study are total displacement, slide, safety factor, and total stress.

d) Curve

Besides being able to be seen from the output, the results of the analysis can also be in the form of a curve. The curve describes the

results of all calculation stages and displays 2 parameters to see the comparison of each calculation stage. The curve that will be taken as a comparison in this study is the curve of the safety factor and the vertical displacement curve.

#### **2.10.1. Slope Stability Analysis using *Bentley PLAXIS 2D V20* Program**

From the existing data then processed by entering data from the slopes for data processing by the program, it will be known whether the slopes need to be reinforced. With this program, it is also possible to control the safety factor (SF) of slopes with geotextile reinforcement. In operating the *Bentley PLAXIS 2D V20* program, the following steps are required:

- 1) Open the PLAXIS program then enter the dimension data and the title of the program to be created
- 2) Draw a cross-section of the slope to be analyzed, then click Standard Fixities.
- 3) Create the type of material properties that will be used on the slope, and fill in the slope data such as  $\gamma_d$ ,  $\gamma_b$ ,  $\varphi$ , and so on. Then apply the material that has been made to each layer of soil.
- 4) Then change the mesh generating setup according to the mesh and then generate
- 5) Create a groundwater table in the cross-section using the initial conditions.
- 6) Then do the calculations and the contents of each phase to be analyzed.
- 7) Then create a displacement curve, and then calculate it.
- 8) After the calculation process is complete.

From the steps that have been carried out by the *Bentley PLAXIS 2D V20* program, it is obtained in the form of a displacement curve and also the SF value. The output can be seen whether the slope is safe from sliding or is safe so that no additional reinforcement is needed. If the slope is not safe against landslides, then a re-analysis will be carried out using geotextile reinforcement and a new Safety Factor will be obtained after being reinforced. The way to add geotextile reinforcement to *Bentley PLAXIS 2D V20* is as follows:

- 1) Open the *Bentley PLAXIS 2D V20* program then enter the dimension data and the title of the program to be created
- 2) Draw a cross-section of the slope to be analyzed, then click Standard Fixities.
- 3) Create the type of material properties that will be used on the slope, and fill in the slope data such as  $\gamma_d$ ,  $\gamma_b$ ,  $\phi$ . Then then apply the material that has been made to each layer of soil.
- 4) Create a geotextile profile according to the required specifications by clicking the geometry button, then selecting the geogrid option
- 5) Then change the mesh generating setup according to the mesh and then generate.
- 6) Create a groundwater table in the cross-section using the initial conditions.
- 7) Then do the calculations and the contents of each phase to be analyzed.
- 8) Then create a displacement curve, and then calculate
- 9) After the calculation process is complete.

# CHAPTER 3

## RESEARCH METHODOLOGY

### 3.1. RESEARCH FLOWCHART

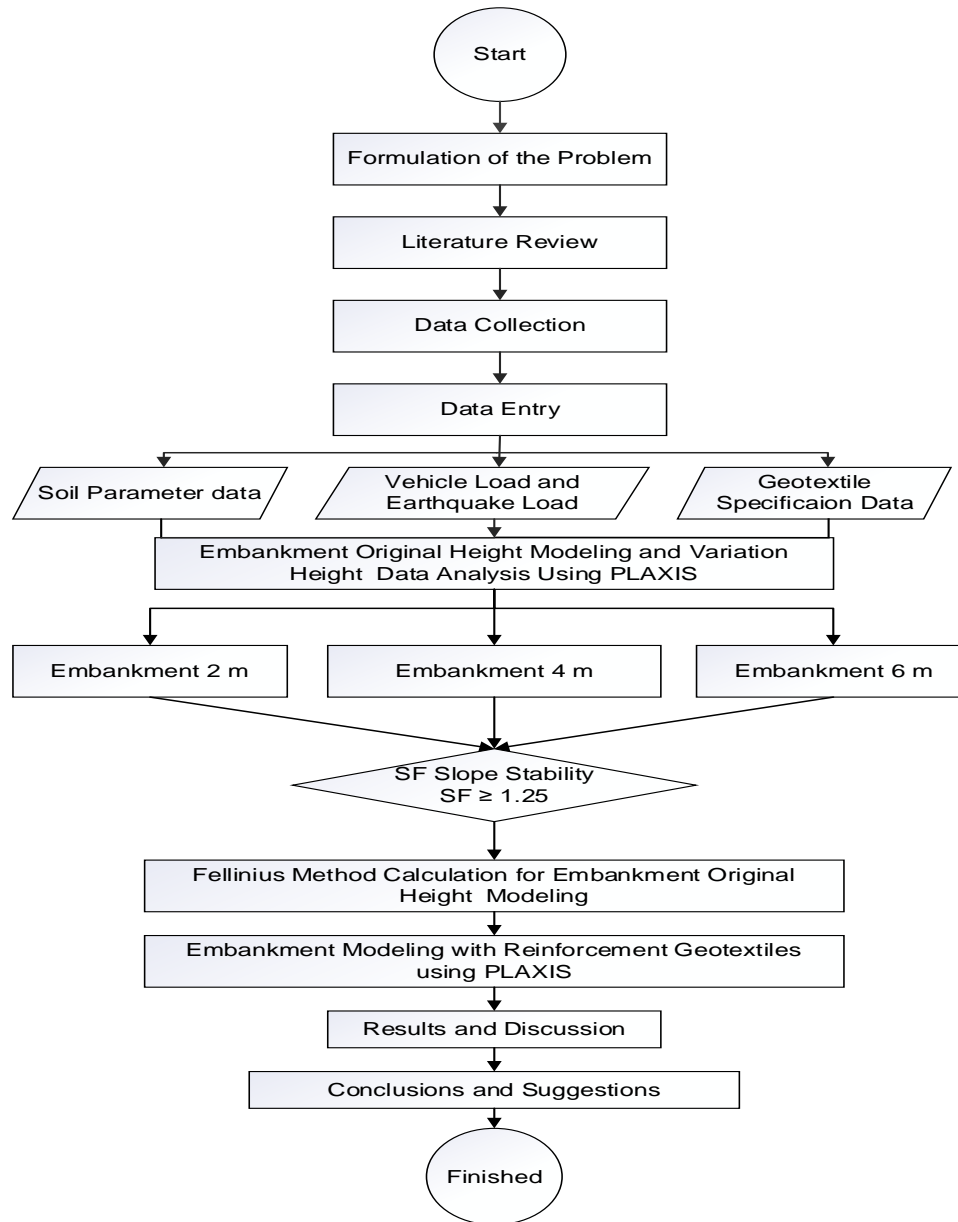


Figure 3.1 Research Flowchart