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Laboratory Studies on Soil Characterization of Earth Slope Failure at Dessie South Wollo Ethiopia- A Case Study

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Abstract

In the densely populated highlands and almost all slope area of the country Ethiopia, where altitudes more than 1750m, increasing the number and size of landslides from past more than 30years is causing considerable damages and losses among the society and the government. Since from 1993 to present, about more than 300 people lives are lost, more than 200 houses damaged, more than 150km of roads are damaged. Landslide is one of the major natural hazards for the underdeveloped countries viz urbanization and infrastructures of country Ethiopia. Besides it is observed that the slope failure is located on the sides of Dessie- Kombolcha road, which is the only access road connecting the two nearby cities. The detailed characterization of the soil mass will be carried out by using laboratory studies to back analysing the observed slope failure. The main purpose of this detail laboratory studies is to identify the causes of the slope failure in the area and provide appropriate remedial measures.

Keywords: Soil, Failure, Landslides, Slope, Stability.

Introduction

The slopes are surfaces rising and falling [1]. A soil slope is unsupported, inclined at a certain angle surface of a soil mass or rock mass. Failure of rock or soil mass located below a slope is called as landslide [2]. The landslides involve a movement of soil or rock mass in downward direction due to any external and internal forces and the failure takes place [3, 4]. Mainly the failure of soil slope or rock mass may take place due to following factors such as forces due to gravity, percolation of water in to the soil and Erosion of soil particles [5, 6]. The failure may take place suddenly or long-time [7]. The seepage is the flow of water in to the soil under hydraulic gradient [8, 9]. The resistance to soil failure or slide is the shear strength of soil, shear strength of soil is depending on the type of soil and interparticle gradation of soil when the water enters the soil the shear strength of the soil will decrease and the soil leads to failure [10]. The detail knowledge of shear strength of soil is needed for the solution of any problems concerning to stability analysis of earth slopes [11, 12, 13].

The shear strength of soil can be determining in the Laboratory by Direct shear test, Unconfine compressive test and Triaxial test depending on the type of soil [14]. In the case of clay soil require undrained and drained shear strength parameters soil testing. Determination of shear strength parameters by direct shear test cost effective for residual soils [15, 16].

1.1. Failure of Slopes

Basically, there different types of slope failures but these failures are common in slope failure as shown in figure.

1. Rotational slide
2. Failure of slope in high strength soil
3. Failure of Toe in case of homogeneous soil
4. Failure of base in soft soil

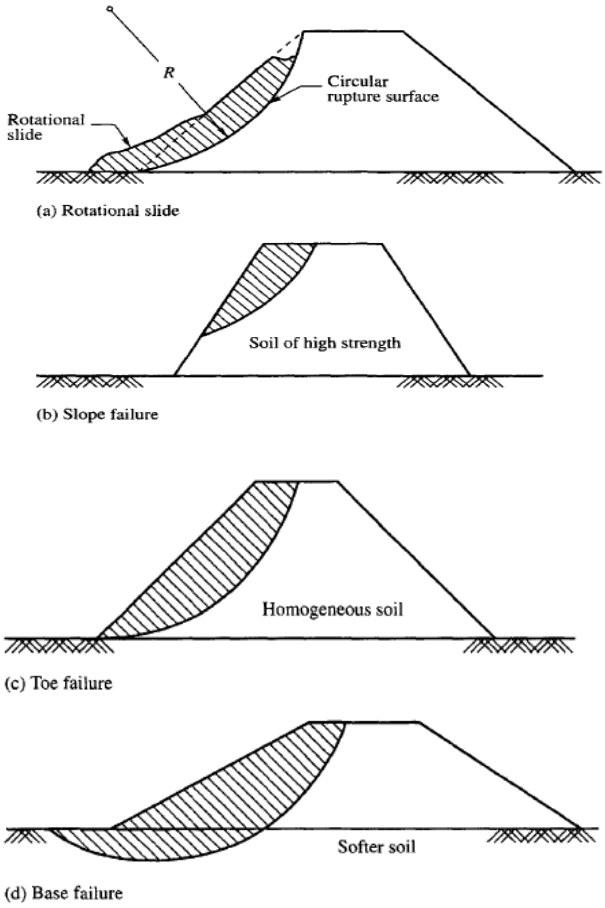

Fig. 1. Types of slope failure

The slope failure in cohesive or black cotton soil is tend to occur rotational slip and appears large tension cracks as shown in figure 2.

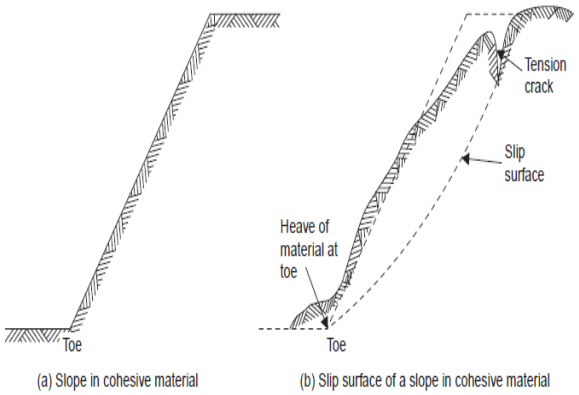

Fig. 2. Failure of Slope in cohesive or clay soil

1.2. Landslides

The landslides are now days is very common serious problem in the world, it causes huge loss in the society. [16]. Landslide is a natural disaster or by human activities it disturbs the soil or rock mass slope stability. The phenomenon of landslides different to the shape and size of movement of displacement of soil or rock and its failure mechanism [17].

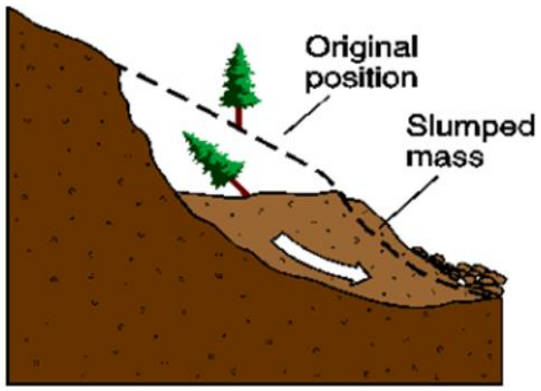

Fig.3. Landslides in earth slope

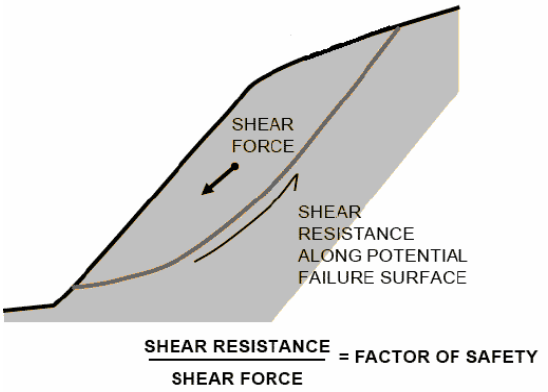

Fig. 4. Shear resistance to shear force

The landslides may be possible on any part of the steep terrain or slope of soil mass with respect to water content and the slope angle with respect to horizontal surface [18]. It is a natural process of the earth's surface geology and geomorphology; it serves to separate the soil particles and soil sediments in a process that can leads collapses or in slow gradual slides in soil mass [19]. Before landslides some features might be notice in soil or

rock such as unusual new cracks, heave in the ground and swelling and shrinkage in the soil or volume of soil increases or decreases [20, 21]. In the case of lower factor of safety, the failure potential of soil or rock will be more and in the case of higher factor of safety the chances of slope failure are very less [22] as shown in figure 4.

2. STATEMENT OF THE PROBLEM

The slope failure presented in this work has been observed around "Menberetsehay" on the way from Dessie to Kombolcha highway road. It was clear that the existing road width was obtained by cutting the adjacent steep ridge. However, the toe cut for the road way has triggered several shallow failures in that area. Apart from this during the construction of the road, the existing spring water with significant flow rate has been buried close to the toe part without providing any drainage system. The local communities are still believing the main reason to the failure are the construction of the road in such loose soil mass and secondly the influence of the water pressure present in the pores trigger failure to the loose soil material. The movement covers almost half of the compound of Menberetsehay School and adjacent residence areas. The presence of several damaged class rooms, offices, nearby houses, trees clearly give witness to the presence of unstable movement of soil mass. Current active failures are reinitiated as a consequence of heavy rainfall. Some remedial measures like masonry retaining walls, piles were provided previously to reduce the slope movement. But, none of the adopted remedial measures were effective as observed during the site visit. The impact load of the moving soil mass has also caused failure of the retaining wall. Currently, the transported soil mass has blocked full of the road width affecting the function of this important route public transportation as shown in figure 5 and large cracks in the soil have occurred as shown in figure 6.

Fig. 5. Failure of earth slope covered almost half of the existing Kombolcha to Dessie Road

Fig. 6. Large Tension cracks appeared in earth slope failure

3. METHODOLOGY

3.1. Laboratory Soil Testing required for Slope Failure Analysis

Specific information on laboratory testing, including standard tests performed and associated AASHTO methods. Geotechnical Guidelines for Sample Handling, testing and Data Reporting. Consolidated-undrained (C_U) and consolidation testing shall be conducted for each major cohesive soil layer in order to reliably characterize each layer's soil strength parameters.

1) Moisture Content

2) Particle Size Analysis and Soil Classification

3) Wet unit weight soil and Dry density by core cutter method

4) Atterberg Limits and Soil behaviour

   a) Plastic limit – plasticity index

   b) Liquid limit- Liquidity index

   c) Shrinkage Limit

5) Swelling test

6) Specific Gravity test

7) Compaction test

8) Permeability test

9) Unconfined compressive test

10) Direct shear test

4. RESULT AND DISCUSSION

There are from four soil samples have been collected from different places from test pits of different depths and laboratory studies have been conducted and the test results have been obtained as shown in below table 1.

Table.1. Soil Test Results at Slope Failure Site

Soil Test	**Sample -1**	**Sample-2**	**Sample-3**	**Sample-4**	**Average Value**
Bulk Unit Weight (g/cm^3)	1.86	1.91	1.87	1.94	1.895
Dry Unit Weight (g/cm^3)	1.38	1.51	1.43	1.55	1.467
OMC (%)	34.70	26.6	31.50	25.00	29.45
Liquid Limit (LL)	81.10	76.44	57.27	61.80	69.15
Plastic Limit (PL)	31.45	29.56	30.47	32.36	30.96
Plasticity Index (Ip)	49.7	46.9	26.8	29.4	38.20
Specific gravity (G)	2.38	2.31	2.38	2.55	2.405

Free swell	50	20	54.6	28.6	38.30
Permeability K (cm/s)	$1.48E^{-5}$	$5.64E^{-8}$	$6.73E^{-6}$	$1.31E^{-7}$	$7.29E^{-5}$
Cohesive C_u (kPa)	17.2	19.2	21.2	20.0	19.40
Angle of internal friction of the soil (φ^o)	18.4	25.8	17.7	23.4	21.32
Unit weight of soil γ (kN/m^3)	17	17.2	16.8	17	17
Gravel (%)	14.4	0	0	2.02	14.90
Coarse Sand (%)	4.28	0.13	8.29	3.75	4.112
Fine Sand (%)	17.31	2.56	38.10	9.20	16.792
Silt and Clay (%)	64.03	97.30	53.61	85.03	74.992

Table. 2. Identification of type of Soil at Slope failure site

Particle Size in mm	Soil Grade (%)	Test Sample			
		I	II	III	IV
80 - 4.75	Gravel	14.4	0	0	2.02
4.75 - 0.075	Sand	21.59	2.69	46.39	12.95
0.075 - 0.002 Less than 0.002 mm	Silt & Clay	64.03	97.30	53.61	85.03
Type of soil @ Test pits		c & ø Soil	c & ø Soil	c & ø Soil	c & ø Soil
Overall type of soil @ slope failure site		Black cotton soft soil mixed with sand particles			

The type of soil which is present in the slope failure site is black cotton soil mixed with sand particles as shown in table 2. Gibbs and Holtz in 1956 demonstrated that plasticity index of soil and liquid limit, W_L are very useful parameters for obtaining the characteristics swelling of most clayssoil mixed with sand particles. The liquid limit & the swelling of clays soil both are depends on the amount of water absorbs the clay soil to its natural state. The relation between the plasticity index & swelling potential of clay soil are established as given in Table 3.

Table. 3. Relation between swelling potential and plasticity index, I_p

Plasticity Index Ip (%) Range	Swelling potential Range	Plasticity Index Ip of soil @ Test pit of Slope Failure	Swelling Potential	Swelling Potential

		Test Sample	*Ip (%)*		Result
0-15 15-20 25-30 35 and above	Low Medium High Very High	I	49.7	Very High	Very High
		II	46.9	Very High	
		III	26.8	High	
		IV	29.4	High	

Table. 4. Identification of plasticity nature of Soil based on the plasticity index of the Soil

Plasticity Index Ip Range	Plasticity nature of soil	Plasticity Index Ip of soil @ Test pit of Slope Failure		Description	Plasticity Index Ip Result
		Test Sample	*Ip (%)*		
0	Non-plastic	I	49.7	Very High	Very High
1-5	Slightly plastic	II	46.9	Very High	
5-10	Low	III	26.8	High	
10-20	Medium	IV	29.4	High	
20-40	High				
Above 40	Very High				

Soil colloids particles are very minute and have a large surface per unit area of mass of soil. Colloids are also carrying the electrostatic +ve and -ve charges that are balanced by the adsorbed anions and cations. Therefore, there is a direct relationship between the swelling nature and soil collides as shown in figure 7. For a given clay type of soil, the amount of swelling in soil will increases with the increase in percentage of clay soil particles. The clay mineral which is present the slope failure soil is identified as commercial illite or bentonite, this type of soil usual has more swelling and shrinkage characteristics as shown in table 5.

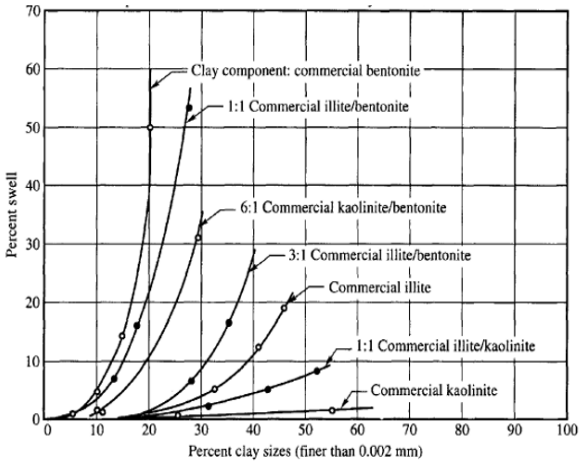

Fig. 7. Percent swell v/s Percent clay sizes

Table.5. Identification of clay mineral of soil

Test Sample	Free swell	Percentage of clay size	Mineral present in soil
I	50	64.03	1:1 Commercial illite/ Bentonite
II	20	97.30	Commercial illite
III	54.6	53.61	1:1 Commercial illite/ Bentonite
IV	28.6	85.03	3:1 Commercial illite/ Bentonite

4.1. Major problems faced during the soil slope failure are as follows

a. Very low bearing capacity

b. High settlements (the rate of settlement is very slow and settlement may continue for several years)

c. Instability of deep excavations or Slopes

d. Deep seated slip failure

e. Lateral flow under surface loading leading to settlement

f. Large cracks appearance

g. More swelling potential

4.2. Causes of Landslides

It is very important to know the causes of landslides or earth slope failures for the detail analysis, the following causes are identified for landslides are as follows,

a) The slope is too high

b) The soil present in the failure site is weak to hold the soil slope.

c) The shear strength of the soil is very less because of seepage of water in to the soil.

d) Due to gravitational force.

e) Due to external forces for example applied loads from structures.

f) The factor of safety provided is very less at the road side

g) The present soil is not a natural soil; it is transported and deposited soil from the above hill slope area.

h) Due to presence of spring water at failure site, the water enters in the soil hence the shear strength soil will be less and expansion of soil taken place, since the slope is failed.

4.3. Earth Slope Failure Mechanism

The failure mechanism of earth slope influencing due to seasonal variation in the environmental, during summer season due to hotter climate the soil shrinks in its volume and during winter and rainy season the soil will increase its volume so due to increase and decrease in its soil volume large crack in the soil will appear and soil mass may lead to failure. In rainy season the rain water will percolates in the soil mass through voids and the soil will become saturation and the shear strength of the soil will decrease and soil slope may slide or failure take place. This failure mechanism may take place in the presence of black cotton soil. The soil in landslide site investigated 75% black cotton soil and the plasticity index of the soil is very high so large cracks in the soil is appeared. The factor of safety is very important to protect the slope without failure. It is very important to know the failure mechanism for the analysis and design of retaining structure for the failure slope.

5. CONCLUSION

From the above experimental demonstration, it is concluded that, the type soil present in the soil slope failure is identified as black cotton soft soil mixed with sand particles almost 75% of soil is silt and soft clay, therefore it is concluded that the swelling potential of the soil is very high. From plasticity index chart it is observed that the plasticity index Ip of the soil is very high, therefore large cracks are appeared on the surface the soil. The clay mineral which is present in the soil is identified as commercial illite/bentonite. The main causes of soil slope failure are identified as the presence of spring water in the soil slope, the factor of safety provided is very less hence resistance to slope failure is less. The shearing strength of the soil is very less and low bearing capacity, bulk unit weight of the soil is less. Huge amount of soil is transported by storm water and deposited in slope form before many years. The remedial measure provided and suggested a reinforced concrete cantilever retaining wall.

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