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Geotechnical Conditions and Stability Analysis of Landslide Prone Area: A Case Study in Bonga Town, South-Western Ethiopia

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Abstract—There were several slides and associated ground subsidence which brought significant impact on cracking of walls and floor of several private and governmental buildings in Bonga Town. The principal and secondary roads were also affected by subsidence with vertical displacement up to 1m which hampered the traffic in the town. Water pipelines along the road were disturbed by the sliding which were later repaired. Cracking of the walls and floor of more than 120 private residences and more than 10 government buildings were recorded. The main highway that connects Bonga-Tepi- Masha via Alamo and Gatiba has been disrupted at four locations. This resulted in hampering in traffic for several days. This research aimed to evaluate the cause and failure mechanism as well as the stability condition of the landslides. The study involved the investigation of the Geotechnical parameters of soil and the terrain characteristics to be used for the stability analysis of the slope, including distribution and characteristics of soils, the groundwater table, and the depth and geometry of the failures. The Slope stability analysis is supplemented by using Geo-studio 2004 software. Soil samples were collected, and were tested for grain size analysis, distribution analysis (sieve & hydrometer) plastic limit, liquid limit, plasticity index, water content, unit weight of soil, specific gravity and shear strength parameters following the ASTM procedures. Based on the findings, the landslides were triggered by heavy rainfall. Therefore, the main factors controlling the stability of slope are soil type and characteristics, slope angle, water (surface and groundwater), and slope steepness. The design of retaining wall is recommended to mitigate the impact of landslides in the study area.

Index Terms—Geotechnical parameters; Groundwater table, Landslides; Mitigation measures, Retaining wall, Slope stability analysis.

1 Introduction

The termed landslide includes all varieties of mass movements of hill slopes and can be defined as the downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or combination of all these materials along surfaces of separation of falling, sliding and flowing, either slowly or quickly from one place to another [1]. Although the landslides are primarily associated with mountainous terrains, these can also occur in areas where an activity such as surface excavations for highways, buildings and open pit mines takes place.

Natural hazards can be divided into three main categories: atmospheric, endogenic and exogenic hazards. Atmospheric hazards are caused by processes of atmospheric nature, such as, tropical storms, hail storms, hurricanes and droughts. Endogenic hazards are results from internal earth processes, such as volcanoes and earthquakes. Exogenic hazards are caused by the operation of natural earth surface processes, including flooding, coastal erosion, mass movement and soil erosion. It is important to realize that natural hazards cannot always be categorized into one of these segments listed above. In many cases, the natural hazard could actually be a combination of two different types of the categorized hazards above. For example, a landslide is often triggered off by an atmospheric hazard, such as a tropical storm and an endogenic hazard such as an earthquake. However, this is a good method of separating the hazards into basic categories, making a differentiation between the geological hazards (endogenic and exogenic) and the atmospheric hazards [1].

Natural slope instability is a major concern in hilly terrain where failures might cause catastrophic destruction of the surrounding area. The failures might be triggered by internal or external factors that cause imbalance of natural forces. An internal triggering factor is the factor that causes failure due to internal changes, such as increasing pore water pressure and or imbalanced forces developed due to external load [2].

Landslide occurrence is on the increase worldwide the consequences of which can be loss of life, loss of livestock, damaging or destroying residential and industrial developments, villages or even entire towns, destroying agricultural and forest land and negatively influencing the quality of water in rivers and streams [3].

Geologic factors have also been found to cause mass movements on the slopes and these include shallow soils over hard, impermeable rocks or glacial till, soft, clay-rich rocks that produce thick plastic soil mantles, alignment of lineaments parallel to the ground slope and planar rock structures, unconsolidated or weakly consolidated deposits. (Sidle, R.et al, 1985).

A close relationship exists between landslide activity and the amount of precipitation. The amount of rainfall has considerable influence on the moisture content and the pore water pressure in soils. Slope steepness is also a significant factor and the greater the height, steepness and concavity of slopes, the greater the volumes of the landslides [3].

The landslide in the study area was known to have the greatest impact on the Town due to damage to buildings and roads linking four different directions from the town. This prompted the researcher to investigate the causes of the landslide.

1.1. Objectives of the Study

1.1.1 General Objective

The general objective of the research was to characterize the Geotechnical conditions of the site and analyze the stability of the landslide in Bonga town.

1.1.2 Specific Objectives

- To evaluate the Geotechnical properties of soil/rocks in the landslide affected area.
- To investigate the main causes, triggering factors for the occurrence of landslides in the study area.
- To analyze slope stability of the affected areas and determine the factor of safety of the slopes using GeoStudio Software.
- To recommend possible remedial measures in order to minimize risks from landslide in the area.

1.2 Research Questions

The research questions that the researcher had sought to be answered as follows:

1. What are the Geotechnical soil/rocks parameters that controls the initiations of the landslides and its failure mechanisms?
2. What are the main causes, triggering factors for the occurrence of landslides in the study area?
3. How the slope of the affected area's response to the effect of surcharge and its corresponding factor of safety using GeoSlope Software?
4. What type of measures could be implemented in order to mitigate the landslide problems in Bonga town?

2 RESEARCH METHODOLOGY

2.1. Study Area

Bonga town is located in the Southwestern part of Ethiopia, Southern Nation Nationalities and Peoples Regional State (SNNPS). The town is an administrative center of Keffa zone. It is about 440 km from Addis Ababa passing through Jimma Town. The Eastern and Southeastern part of the town was always affected by the landslide phenomena. The affected area of the landslide is bounded by 7°15'25" -7°16'00" Latitude and 36°14'55" - 36°15'25" Longitude, which can be seen from Figure 1.

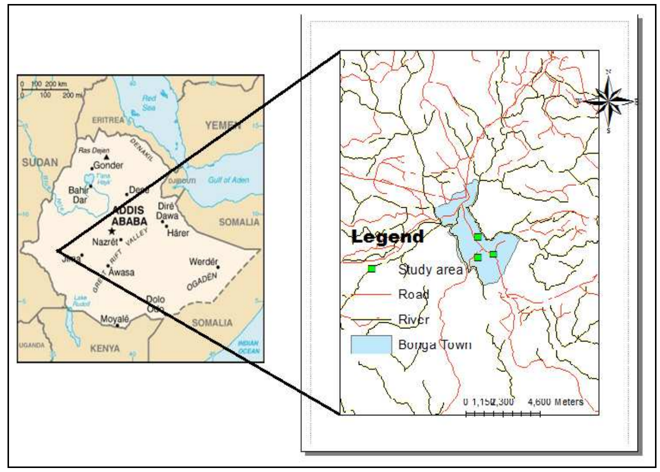

Figure 2.1: Map of the Study Area (Source: Google Map 2016)

2.2 Regional geological setting

On the geological map of Ethiopia, the study area belongs to the Jimma volcanic (upper sequence) that consists of trachite, ignimbrite, rhyolite, and tuff with minor basalt. Whereas in the recent 1:50,000 scale engineering, geological map of the area (EGS, 1999) as shown in Figure 2, compiled in relation to the current landslide problem, basic lava flow and Pyroclastic materials formed due to tertiary volcanism dominated the area. The basic lava flows are fine-grained and porphyritic basalts, while fine and coarse Tuff and agglomerate represent the pyroclastic eruptions. The recent quaternary deposits are recognized as alluvial, colluvial and residual soils. Faults trending NE-SW direction displaces the volcanic rock units with a distinct scarp zone at the eastern and southeastern of the Bonga Town [4].

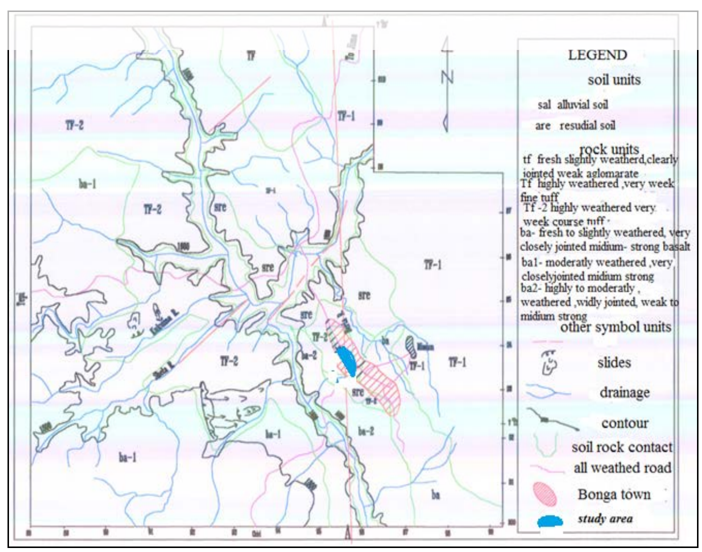

Figure 2.2: Engineering geological map of BONGA and its surrounding. (Source: EGS, 1999)

2.2. Regional Hydrogeology

On the 1:2,000,000 Hydrogeological map of Ethiopia the Bonga town and its surroundings are characterized by extensive aquifer, with fracture permeability of volcanic rocks (basalt, rhyolites, trachytes and ignimbrites) which are found in abundance. The water resource is widespread with moderate to large quantities of surface water and ground water. Most streams are perennial and cold springs are also common. The depth of the ground water varies from 0 to 100 meters, with a static water level around 1 to 4.5 meters. Rainfall is the main recharge of the groundwater, which reaches from 1000mm to 2000 mm annually, being one of the highest in the Ethiopia. While the recharge from runoff is relatively low and the discharge rate of groundwater is high.

2.3. Climate

Since the study area belongs to the Southwestern Ethiopian highlands, it is characterized by warm, humid and wet subtropical climatic conditions. According to the Bonga meteorological station, the mean annual rainfall of the area is 1628.8mm/year, i.e. for the years 1996-2013. Temperature during summer reaches up to 20°C.

Even though, there is a rainfall distribution throughout the year, two major seasons of rainfall are common in the area. The first one is from July to September and the other is from April to May which shows biomedical characteristics of the rainfall. Based on the summary of hydrometric discharge data of Shite and Dincha at Bonga, there is a seasonal variation of stream flow, which reflects seasonal of the rainfall. The main rainy season in all the area is during winter, with a secondary maximum in the spring. Therefore, the peak stream flows occurred during winter months.

It should be noted however that the duration of the rainfall and its distribution throughout the year can influence the conditions of surface runoff.

2.4. Physiography

The study area is characterized by rugged volcanic, mountainous terrain comprising of high to low relief hills. Bonga town is located at moderately to gently sloping and undulating topography. Elevation ranges from 1590 to 1880m above average sea level.

2.5. Land use and settlement

Bonga town is situated on the gentle and moderately steep to undulating slope of Sobra mountain. Recent settlements are still undertaking along the hill slopes. The main plantation around Bonga town is the coffee and maize, which cover the mid to lower hill slopes. The higher elevated areas are covered by dense tropical forest, mainly Junipers, Oak and Olive trees.

2.6. Research Design

The research was conducted by using both Experimental and Analytical methods as well as qualitative and quantitative study were employed in this study. Qualitative study forwards impression of the findings, whereas the quantitative study was used to describe the numerical aspects of the findings.

2.7. Parameters for slope stability evaluation

The parameters used in this study are grain size, specific gravity, permeability and shear strengthen (i.e. Cohesion, angle of internal friction and unit weight of soil), thickness of sliding mass, size of slide (i.e. Lengthen, depth and width).

2.8. Field sampling and laboratory test preparation

Soil samples collected to determine physical characteristics. Core sampling carried out using standard procedures of ASTM. For each sampling pit, undisturbed and disturbed samples collected Two sets of samples (one disturbed and one undisturbed) extracted at depths of 1.7m to 5.4m.

The sampling pits (sites) were taken randomly in areas where landslides had occurred, specifically at the sides of the scar. Samples were collected at their moist condition using plastic bags. The plastic bags were tied to reduce loss of moisture. In-situ moisture contents were determined immediately. The samples were brought to the laboratory for testing using oven temperatures of 105°C for every test. Each sample was dried in oven until continuous weighing gives constant weight. Soil samples from 9 test pits were taken at various depths and analyzed to know the properties like cohesion, angle of friction, unit weight of soil, water content, liquid limit, plastic limit and plasticity index, specific gravity and grain size analysis (sieve and hydrometer). Then these properties were used in classification of soil and Slope stability analysis of landslide. The analysis was conducted through Numerical modeling software package GeoStudio-Slope/W 2004. Soil samples collected from the study area were brought to a Jimma University soil laboratory to substantiate the model provided by GeoSlope.

2.9. Data collection procedures

The research approach included: (a) review of previous studies and literatures on the subject matter; (b) Geotechnical investigation of soils, rocks and water pressure within slopes; (c) measurement of landslide features which includes (length, width, and depth) and failure mechanism; and (d) selection of appropriate slope stability analysis methods.

2.10. Slope Stability analysis

Modern limit equilibrium software such as Slope\W is making it possible to handle ever-increasing complexity in the analysis. Using the limit equilibrium, SLOPE/W could model homogeneous to heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable pore-water pressure conditions using a large selection of soil models. Slope stability analyses can be performed using

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deterministic or probabilistic input parameters. Stresses computed by a finite element stress analysis may be used in addition to the limit equilibrium computations, for the most complete slope stability analysis available. Therefore, GeoSlope Slope\W is one of the powerful tools of this integrated approach that opens the door to types of analyses of a much wider and more complex spectrum of problems, including the use of finite element computed pore-water pressures and stresses in a stability analysis. Not only does an integrated approach widen the analysis possibilities, it can help overcome some limitations of the purely limit equilibrium formulations [2].

The conventional Limit Equilibrium method is used to analyze the high embankment slope stability Program Geo-Studio (SLOPE/W) was formulated in terms of a moment and force equilibrium factor of safety equations. The Analysis provides a factor of safety, defined as a ratio of available shear resistance (capacity) to that required for equilibrium [5]. The limit equilibrium procedure for calculating the factor of safety involves comparing the available shear strength along the sliding surface with the force required to maintain the slope in equilibrium.

3 RESULTS AND DISCUSSION

3.1. Water content of the soil

A test was conducted to determine the water (moisture) content of soils. The water content is the ratio, expressed as a percentage of the mass of "pore" or "free" water in a given mass of soil to the mass of the dry soil solids. Water content tests were carried out on three samples. Table 3.1 shows the water content of the soils varying from 38.09%-38.92%.

Table 3.1. The water content of the soils from landslide affected areas

Slope profile	Depth of sample taken (m)	Water content in %
SIBH1	1.9-2.4	38.77
S2BH2	1.8-2.6	38.09
S3BH3	1.7-2	38.92

3.2 Specific gravity of soil

The specific gravity, Gs, is used in the determination of hydrometer analysis. In residual soils the specific gravity may be unusually high or unusually low. The laboratory performed to determine the specific gravity of the soil by using a Pycnometer. Specific gravity is the ratio of the mass of a unit volume of soil at a stated temperature of the mass of the same volume of gas-free distilled water at a stated temperature. Specific gravity tests were also run on all samples and results of the test is summarized in Table 3.2. The soils were found to have specific gravity, which ranges from 2.68 to 2.7.

Table 3.2. The specific gravity of the soils from landslide affected areas

Slope profile	Depth of sample taken (m)	The average specific gravity
SIBH1	1.9-2.4	2.7
S2BH2	1.8-2.6	2.68
S3BH3	1.7-2	2.69

3.3 Unit weight of soils

In-place density was determined for undisturbed soil obtained by pushing or drilling a thin-walled cylinder. The bulk density is the ratio of mass of moist soil to the volume of the soil sample, and the dry density is the ratio of the mass of the dry soil of the volume the soil sample. The dry unit weight of natural, undisturbed samples ranges between 11.77 and 12 kN/m^3 and moist samples ranges between 16.68 and 16.97kN/m^3, respectively. All of the tests were performed on samples according to ASTM standards.

Table 3.3: Unit weight of the soils from landslide affected areas

Slope profile	Depth of sample taken (m)	The average specific gravity
SIBH1	1.9-2.4	2.7
S2BH2	1.8-2.6	2.68
S3BH3	1.7-2	2.69

3.4 Grain size analysis result

Soil sampling is the most important part in analyzing a landslide behavior. By knowing the properties of the soil of the landslide, a great deal of information can be obtained to determine the triggering mechanisms of the landslide. Soil tests ideal for the landslide analysis were particle size distribution and hydrometer analysis.

There were three slope profiles that had been selected along the landslide area and a total of nine samples were collected with three samples from each slope profile. There were designated as Samples S1BH1, S1BH2, and S1BH3, of which all of these extracted from slope profile one at the depth of 2.4m, 2.1m and 1.9m, respectively. On the other hand, the Samples S2BH1, S2BH2, and S2BH3, were all taken from the slope profile to at respective depth of 2.6m, 2.5m and 1.8m. For Samples S3BH1, S3BH2, and S3BH3, were taken from the slope profile three at the depth of 1.9m, 2.0m and 1.7m, respectively.

Table 3.4: Grain size analysis of the soils from landslide affected areas

Slope profile	Depth at which sample taken (m)	Percent of gravel	Percent of sand (%)	Percent of fines (silt and clay) (%)
SIBH1	2.4	0.22	39.5	60.49
SIBH2	2.1	0.37	42.8	57.24
SIBH3	1.9	1.25	40.1	59.87
S2BH1	2.6	0.32	42.8	57.24
S2BH2	2.5	0.89	35.7	64.31
S2BH3	1.8	0.64	35.2	64.85
S3BH1	2	0.21	39	61
S3BH2	1.9	0.75	34.5	65.52
S3BH3	1.7	1.64	31.3	68.73

3.5 Liquid Limit, Plastic Limit, and Plasticity Index of the soils

The Atterberg's limits determined to establish the structural strength of the soils. Liquid limit tests were carried out to determine the water content of the soils required to lose its cohesion and flow as a liquid. On the other hand, plastic limit tests were carried out to determine the water content required before the soils split or crumble. The plasticity index was calculated from liquid and plastic limits (Table 3.5) to give the range over which the soils in the study area remain plastic before deformation.

The results are presented for a multiple comparison test for liquid limit, plastic limit, and plasticity index, which were given in the table for the liquid limit (LL) and plastic limit (PL) of the soil masses varying between 35.64–39% and 32.34%–35.67%, respectively.

Table 3.5: Atterberg's limit of the soils from landslide areas

Soil properties	Slope 1	Slope 2	Slope 3
Water content (%)	38.77	38.09	38.92
Unit weight (kN/m³)	16.68	16.77	16.97
Specific gravity (G_s)	2.70	2.69	2.68
Liquid limit (%)	35.90	39.00	35.64
Plastic limit (%)	33.72	35.67	32.34
Plasticity index (%)	2.18	3.33	3.26
Percent of fines (silt &clay)	59.2	62.15	65.08
Sand (%)	40.20	37.45	34.05
Gravel (%)	0.61	0.63	0.87
Class of soil	CL-ML	CL-ML	CL-ML
Angle of internal friction (φ) °	13	9.9	10
Cohesion (c)(KN/m²)	13.9	9	10

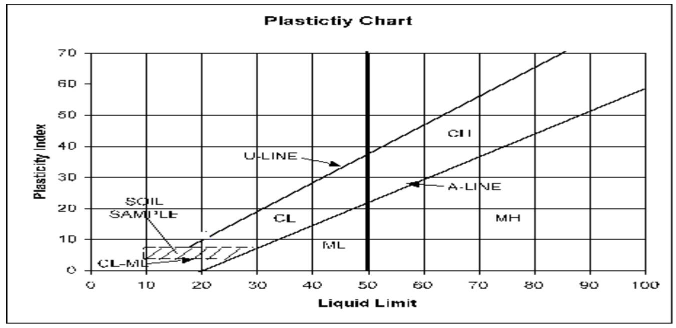

Figure 3.1. Liquid limit versus plasticity index, ASTM standards.

3.6 Shear strength parameter determination

Determination of shear strength parameters (angle of internal friction and cohesion of soil) is the key parameters in slope stability analysis at the Bonga landslide. The result from direct shear test (Table 3.6) indicates that the internal friction angle of soil materials from slope profile 1, slope profile 2 and slope profile 3 are 13.9°, 9.9° and 10 ° respectively. While the cohesion of the soils from slope profile 1, slope profile 2, and the slope profile were found to have 13KN/m², 9KN/m² and 10KN/m².

Table 3.6 Summary Shear strengthens parameter of soils from landslide area

Slope profile	Depth at which sample is taken (m)	Cohesion of soil (kN/m²)	Angle of internal friction (°)
SIBH2	2.1	13.9	13
S2BH2	2.5	9.9	9
S3BH2	1.9	10	10

3.7 Causes of landslides and Triggering factors for the instability of the affected area

3.7.1. Groundwater condition

The ultimate source of groundwater in the study area is rainfall. It is supposed that portion of rainfall evaporates and lost through transpiration of plants. Another portion of the flow was surface runoff, and the remaining portion recharges the ground system. The largest source of groundwater in the area was observed coming from the surrounding upland areas. However, the degree to which it contributed to the surface runoff or recharge to the ground water depends on many factors such as depth to water permeability of the formation vegetation and slopes as well as distribution and intensity of the rainfall. In the study area, it was found out the depth of the water table was shallow which can influence recharge and surface runoff. It can be assumed that the higher the water table, the thinner the unsaturated zone and sooner it becomes wet enough to shed excess water. From field observations and sub-surface investigations: (a) the failure surface for the Bonga town landslide is mainly at the contact between the soil and the underlying weathered volcanic rock, (b) the groundwater table in the hand-dug wells and test-pit excavations varied from 1.5m to 4.5m.

Figure 3.2. Ground water as observed on the surface.

The thickness of the sliding mass of the study area obtained from existing two hand dug well with the residents in areas affected by landslide and from additional two tests-pits excavated during site investigation. The depth to bedrock from existing hand dug well were obtained at 6m and 5.5m. The depth to the bedrock was obtained at 6.2m (downstream of the road) and 5.4m (upstream of the road) from excavated test pit during site investigation. The study area observed that was characterized by quaternary sediments which composed of gravel, sand, silt and clay. The researcher considered to be an extensive, but moderately productive aquifer of inter-granular porosity. At the observed site springs are composed of emerging topographic breaks, at the contact between soils and underlying rocks. The discharge of spring varied from 0.1to 0.5 l/Sec. According from local people, said spring does not dry throughout the year, except some fluctuations on the discharge. During heavy rainfall the discharge of the spring increases due to the reason the pore water pressure rises and the mass of the soil tends to slide.

3.7.2. The effect of water content/rainfall on the landslide

From the result of laboratory tests of water contents, the percentage of water ranges from 38% to 39%, which was taken at the depth of 2m, and 2.4m, respectively. This indicates that as the depth from the ground increases the water content increases. It is believed that heavy winter, high intensity and long duration rainfall results in the saturation of topsoil and raises the groundwater level. These changes affect the weight, volume, internal water pressure and internal cohesion of the soil particles. The shallow ground water condition and high rainfall resulted in an increase of the water content that triggers the sliding by reducing the shear strength of soil cohesion and angle of internal friction of the soil mass. Saturation of the soils added to the total weight. A combination of these different factors leads to the condition whereby shear stress was greater than the shear strength which leads to downslide movement of the soil mass.

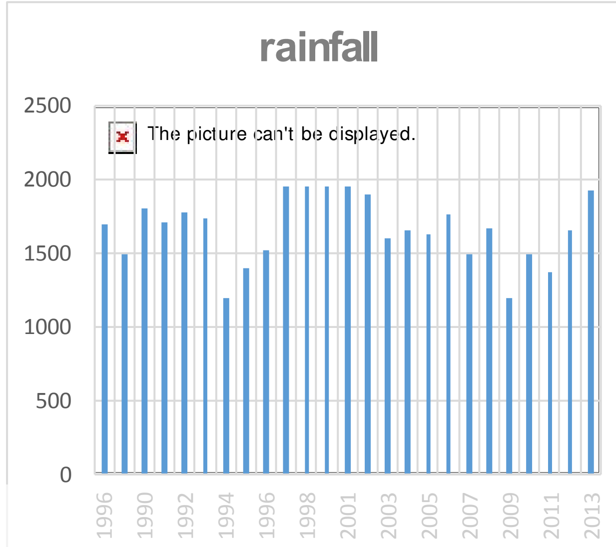

Figure 3.3. Rainfall versus time graph in the Study Area

Figure 3.3 was taken from the meteorological station in the years 1996-2013 (Data from the Ethiopian National Meteorology Agency Bonga station). Considering annual average rainfall of the individual years of the Bonga meteorological station, heavy rainfall amount was recorded in 1997, which was 1956.1mm. This high rainfall triggered the landslide in this year. The other landslide had occurred in September, 2013 after heavy rainfall of 1923.6mm in the study area.

3.7.3 Influence of slope steepness and gravity

The most important relief characteristic was the steepest, which affects the mechanism as well as the intensity of the landslides. The greater the height and steepness of slopes, the greater the volumes of the landslides. On the slope, the force of gravity can be resolved into two components, one acting perpendicular to the slope and another acting tangentially to the slope. The perpendicular component of gravity helps to hold the object in place on the slope. The tangential component of gravity causes a shear stress parallel to the slope that pulls the object in the down-slope direction parallel to the slope.

Table 3.7. Input data for slope stability analysis

Section		Input data			
		Unit weight of soil(KN/M³)	Cohesion (KN/M²)	Angle of internal friction in degree	Ground water conditions
Slope 1	SIBH1	16.68	13.9	13	Great depth
	S1BH2	16.68	13.9	13	4.5m
	S1BH3	16.68	13.9	13	Surface
Slope 2	S2BH1	16.77	9	9.9	Great depth
	S2BH2	16.77	9	9.9	2.5m
	S2BH3	16.77	9	9.9	Surface
Slope 3	S3BH1	16.97	10	10	Great depth
	S3BH2	16.97	10	10	4m
	S3BH3	16.97	10	10	surface

From slope stability analysis along the three slope profile (slope one, two and slope three), the resisting force/moment and activating force/moment are summarized in Table 9 below.

Table 3.8: Total resisting force/moment and total activating force/moment with water table below failure plane.

Profile	Methods	Total resisting force/moment (KN/KNm)	Total activating force/moment (KN/KNm)
Slope 1	Morgensrn –price	393.64/7662.4	297.27/5439.4
	Ordinary	-/7216.4	-/6625
	Bishop	-/7466.8	-/5551.4
	janbu	396.03/-	263.66/-
Slope 2	Morgensrn –price	324.3/7493.1	458.46/10502
	Ordinary	-/7260.5	-/10502
	Bishop	-/7502.9	-/10502
	janbu	323.2/-	471.6/-
Slope 3	Morgensrn –price	269.81/5462.2	335.39/6755.8
	Ordinary	-/5296.3	-/6755.8
	Bishop	-/5479.4	-/6755.8
	janbu	268.06/-	350.62/-

3.7.4 Slope Stability Analysis

Stability analysis is a check process by making a calculation to determine the safety of slopes. This check involves determining and comparing the ratio of resisting forces or moment to the sliding forces or moment along the most likely rupture surface. The most likely rupture surface is the critical plane that has the minimum factor of safety. The stability analysis of a slope is not an easy task. Evaluations of important variables such as the soil stratification and its in-place shear strength parameters are the main elements in slope stability analysis. The stability analysis is carried out with the following basic assumptions [17]:

a. Failure is along a slip surface or failure surface which may be plane or curved and the problem will be solved as a two-dimensional plane problem
b. Soil strength properties are isotropic
c. The safety factor is determined by the limit equilibrium method.

The analysis supplemented by using software called GeoStudio 2004 (Slope/W) with input parameters indicated from Table 3.8 (above).

The software was generated considering the input parameters which provide the results. Figure 3.4 shows the Slope stability analysis of slope, vertical profile 2 with water level below the failure plane. While, Figure 3.5 was a free body diagram force of slice number 12 from Morganstrn-Price from the parameters indicated in Figure. 3.3. In Figure 3.6 was the summary of output from slope stability analysis for slope, vertical profile with water level at different groundwater level. Table 13 indicates the summary of the results of the analysis.

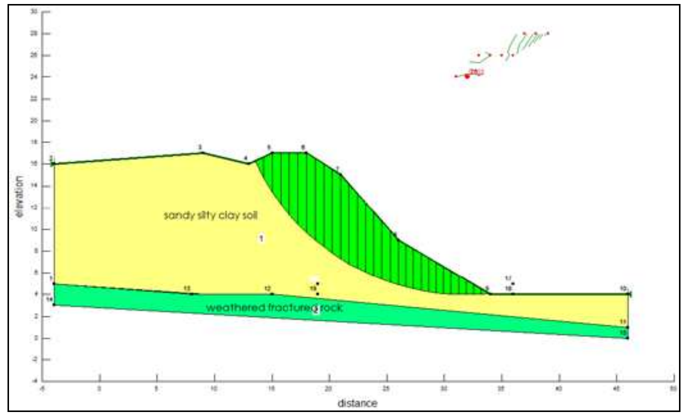

Figure 3.4: Slope stability analysis of slope profile 2 (with water level below failure plane).

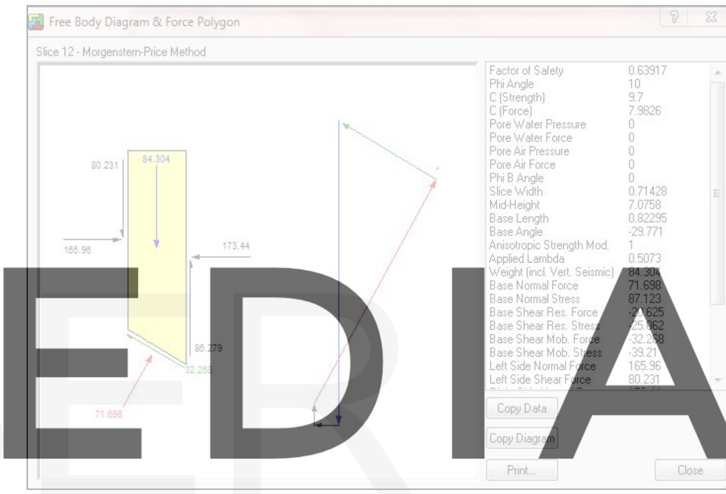

Figure 3.5: Free body diagram force of slice number 12 from Morganstrn- Price from Fig. 3.3

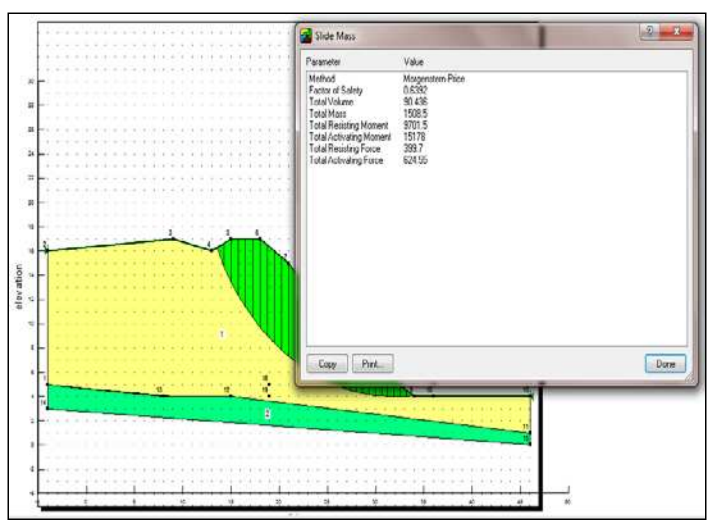

Figure 3.6: Summary of output from slope stability analysis for slope profile (with water level at different groundwater level)

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Table 3.9: Results of slope stability analysis for the three selected slope at different water level

Section name	Depth of water level (m)	Methods	Minimum FOS	Notes
Slope 1	Great depth	Morgensrn	1.409	Stable slope
		Ordinary	1.089	Stable slope
		Bishop	1.345	Stable slope
		Janbu	1.502	Stable slope
	4.5	Morgensrn	1.242	Stable slope
		Ordinary	1.225	Stable slope
		Bishop	1.242	Stable slope
		Janbu	1.226	Stable slope
	Surface	Morgensrn	1.01	Slightly stable
		Ordinary	0.9685	Unstable slope
		Bishop	1.012	Slightly stable
		Janbu	0.9587	Unstable slope
Slope 2	Great depth	Morgensrn	0.7135	Unstable slope
		Ordinary	0.6913	Unstable slope
		Bishop	0.7144	Unstable slope
		Janbu	0.6853	Unstable slope
	4.5m	Morgensrn	0.6056	Unstable slope
		Ordinary	0.5855	Unstable slope
		Bishop	0.6057	Unstable slope
		Janbu	0.6083	Unstable slope
	Water level at surface	Morgensrn	0.3816	Unstable slope
		Ordinary	0.3474	Unstable slope
		Bishop	0.3813	Unstable slope
		Janbu	0.3744	Unstable slope
Slope 3	Great depth	Morgensrn	0.8085	Unstable slope
		Ordinary	0.784	Unstable slope
		Bishop	0.8111	Unstable slope
		Janbu	0.7645	Unstable slope
	4.5m	Morgensrn	0.6627	Unstable slope
		Ordinary	0.6444	Unstable slope
		Bishop	0.6465	Unstable slope
		Janbu	0.6445	Unstable slope
	Water level at the surface	Morgensrn	0.4948	Unstable slope
		Ordinary	0.4712	Unstable slope
		Bishop	0.4953	Unstable slope
		Janbu	0.4779	Unstable slope

3.7.5 Recommended methods to minimize effect of landslide

3.7.5.1 Design of ditches/surface drainage

Groundwater was probably one of the most important contributors to landslide initiation in the study area. From slope stability analysis summarized in Table 13, the numerical value of factor of safety decreases while the groundwater level increases. Therefore, adequate drainage of water is the most important element of a slope stabilization scheme and can control the rise of ground water, for both existing and potential landslides. Drainage is effective because it increases the stability of the soil and reduces the weight of the sliding mass. Drainage can be either surface or subsurface. Surface drainage measures require minimal design and costs and have substantial stability benefits. They are recommended to any potential or existing slide. Surface drainage can be through either surface ditches or shallow subsurface drains. Surface drainage is especially important at the head of the slide, where a system of cutoff ditches that cross the headwall of the slide, and lateral drains to lead runoff around the edge of the slide are effective. Ditch gradient should be at least 2 percent in order to ensure rapid outflow of surface runoff from the unstable area.

3.7.5.2 Retaining wall design for slope one

A retaining wall was designed to withstand lateral earth and water pressures, the effects of surcharge loads, and the self-weight of the wall, in accordance with the general principles specified in Ethiopian building construction standards (EBCS 7-7). Selection of appropriate wall type is based on an assessment of the design loading, depth of adequate foundation support, physical constraints of the site, and cost. The gravel was selected as the backfill material it was proposed in order to use as the filtering material. The wall was designed to retain earth and by considering at a worst condition that is when ground water reached at ground surface. The weep hole provided at least 30cm above the downstream wall from the backfill material. At the upstream section of the weep hole the filtering material covered with geo-synthetic material. According to the 7-7 EBCS the weep hole is provided at 3m interval throughout the span of the retaining wall.

3.7.5.3 Design of subsurface drainage for slope one and two

3.7.5.3.1 Pipes for field and collector drain

The function of field drains is to collect excess groundwater and to convey it to collector drain. The pipes are permeable (perforated) or require openings at the joints of pipe section so that water can enter into the collector drain. The perforation or openings of the pipes should be as large as to limit the entry of water. This is to prevent the soil particles surrounding the pipes entering the pipe as a result of mobilization by water flow. If soil particles enter the pipe they will sediment in the pipe and obstruct the flow. Since the soil type of the study area is fine grained soil, these particles may enter into the pipes, to prevent the entrance of these particles installing envelope around perforated pipe. Perforated plastic pipe (PVC or HDPE) was selected because the easiest and most secure pipe type of for installation, the plastic material is inert and is not affected by soil chemicals. Corrugated plastic pipes are available in diameters ranging from 40 to 600mm. 150mm diameter PVC pipes coiled to the length of 50m with 100m intervals. Collector drain pipes are usually installed for the purpose of conveying the excess water to an outlet. These pipes are closed, the joints are sealed and there are no perforations, thus the groundwater only enters through the junctions with field drains. Collector drains are generally similar to field drain pipes, only the diameters tend to be larger. The diameter of collector drain selected are 200mm with a 50m distance interval. The pipes are installed to drain water at the depth of 1.5m- 2.5m

3.5.5.3.2 Granular envelope

The preparation of granular envelopes can be done by sieving out particles of undesirable size from natural or crushed base material or by mixing particles of specific size ranges.

The first criteria, proposed by Terzaghi (US Army Corps of Engineers, 1941) for what he termed a 'filter', are:

1) The particle diameter of the 15 percent size of the filter material ($D15$) should be at least four times as large as the diameter of the 15 percent size of the soil material ($d15$):

$$D15 \leq 4\ d15$$

This requirement would make the filter material roughly more than ten times as permeable as the soil.

2) The 15 percent size of the filter material ($D15$) should not be more than four times as large as the 85 percent size of the soil material ($d85$):

$$D15 \leq 4\ d85$$

This requirement would prevent the fine soil particles from washing through the filter material. D15 for filter material is 2mm. Therefore, D15 (2mm) ≤ 4d15 (0.008mm), it means the soil particle could not wash through the filter material because D15 (2mm) ≤ 4d85 (0.6*4) = 2.4mm.

4 CONCLUSION

Based on the laboratory tests, all the soil samples collected from the study area, (samples S1BH1, S1BH2, S1BH3, S2BH1, S2BH2, S2BH3 and S3BH1, S3BH2, and S3BH3), the soils have similar properties which indicate more or less homogenous. The soil samples have (a) gravel content between 0.1 and 1.7 percent, (b) coarse sand content between 5 and 21 percent, (c) medium sand content between 12 to 32percent, (d) fine sand content between 14 and 35 percent, and (e) fine content between 57 to 70 percent. Using these numbers and ATSM Code D422, a soil classification was made using the Unified Classification System. The results of the study show that the amount of the fine soil comprised greater than 50 percent and hence the soil is, considered as fine grained soil. Results from ASTM classification, the soil of the study area classified as CL-ML— sandy silty clay.

From the gain-size distribution analysis of the soils, the percentage of fine fractions in the soil samples from sliding mass was found to be ≥50 due to this high proportion of fines significant influence is expected on the properties of soil. Therefore, when the soil gets fully saturated, the frictional properties of the soil could be reduced, which leads to sliding of soil masses. Based site investigation and laboratory test results, the triggering factors are the presence of heavy rainfall coupled with the construction activity which avoided drainage of water and changes in groundwater level. The main causes are: slope angle, thickness of the soils, permeability deference in the subsurface, and properties of soils.

The findings found out that the soil type of study area is composed of more than 80% particles smaller than 2mm (the upper size limit of the sand). Therefore, the research study established that the type of landslide in Bonga town was earth slide and flow. From slope stability analysis, as the level of groundwater fluctuates the numerical value of factor of safety decreases. This indicates that when the soil becomes saturated, the cohesion, angle of internal friction and unit weight of soil decreases as a result of the tendency of sliding mass.

On the other hand, the increasing in slope steepness from slope one profile (steeper) to slope three profiles (less-steeper) were due to increasing minimum factors of safety. Therefore, as the slope steepness increases the shear stress or tangential component of gravity increases and the perpendicular component of gravity decreases. In addition, the force of gravity and slope steepness was the major driving force for the instability of the slope.

The value of the minimum factor of safety decreases as the ground water level increases and the instability of the slope were observed as the level of water increases. This is because when the material becomes saturated, the angle between particles is reduced to very small values and the material tends to flow like a fluid. At the same time when the groundwater level increases, the uplift pressure developed to the weight of the sliding mass as a result the tendency to increase in sliding volume. Surface and subsurface drainage and Stone masonry gravity retaining wall is selected because of the cost and availability of construction material within 50m distance in the study area. The design of retaining wall was made in order to withstand the sliding (activating) force ranges from 490KN/m2 – 675KN/m2 which is obtained from slope stability analysis results. Based on the design and analysis, it is safe against overturning, sliding and subsidence.

Recommendation

1. River Berta which is situated at the toe of the sliding area and a contributory factor of the movement of material above on it. Therefore, in order to prevent the removal of supporting material, provide gabion structure to minimize the erosion of the embankment and to stabilize the soil slope.
2. Smoothing the topography of the slide surface should be done to prevent surface water from ponding.
3. Provide afforestation (green economy) to the study area such as Vetiver grass and long root plants which reinforce the soil and to prevent further erosion of the soil.

4. Relocate the affected residential areas and avoid settling in areas of high hazard which would add extra load on the sliding area. This would aggravate the area, increasing the shear stress on the sliding mass.
5. Local government must record the direct and indirect impacts which relate with disruptions of the economic activities, social, educational, delay in travel time due to landslide hazard.

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