ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 7, Issue 11 , November 2020

Geotechnical study of landslide at the Bamenda station escarpment

François NGAPGUE*, **Moses MBUH KUMA, APAH Desiderus AZHI**

Department of Civil Engineering FOTSO Victor University Institute of Technology
Department of Civil Engineering and Forestry Techniques, Higher Technical Teacher Training College, University of Bamenda, Bambili, Cameroon
Department of Civil Engineering and Forestry Techniques, Higher Technical Teacher Training College, University of Bamenda, Bambili, Cameroon

ABSTRACT: The Western Highlands of Cameroon are regions where during periods of heavy rainfall there occur mass movements and more frequently landslides. The study of the landslides occurrence along the Bamenda station escarpment has motivated the study of the geotechnical characterization of the soils and the measures to fight against this dangerous natural phenomenon. It has been established that the hydrostatic pressure generated by the heavy rainfall of more than 1500mm/year, the fluctuation of the water table level, likewise the intense anthropogenic action (agriculture, quarry, construction of infrastructures, etc.) have combined with geomorphologic and geotechnical factors to give raise to landslides along the escarpment of Bamenda.

The drainage of surface water, the planting of trees, the limitation, control of anthropogenic action, the modification of the profiles of the slopes in certain cases and the realization of retaining structures in other cases, are measures proposed to limit the risks of landslides along the escarpment of Bamenda. These measures must be accompanied by intensive sensitization of populations exploiting the risks zone.

KEYWORDS: highland, landslide, geotechnical factors, hydrostatic pressure and measure

I. INTRODUCTION

The rapid rate of urbanization and industrialization in the world today has led to the depletion of the ozone layer and consequent global warming which have resulted to a trend of steady increase in the annual rainfall in the world. The consequences of this observed phenomenon are natural hazards especially landslides and floods, resulting to numerous losses in human lives and properties in many part of the world and Cameroon in particular.

Most of the geologically related hazards (landslides and floods) in Cameroon are linked to the existence of the Cameroon Volcanic Line (CVL). Landslide is the movement of more or less consolidated mass of soil and rock fragments (Ndenecho E.N., 2007) and Yonghe et al. (1999) historical statistics recorded landslides in Cameroon which theyestimated that since 1988, at least five people are killed in Cameroon every year by landslide hazards with a huge effect on infrastructures and the economy in general. Some reported landslide casualties in Cameroon since 1988 include; Bakombo (Melong) landslide June 1988, Oyomabang (Yaoundé) landslide August 1990, Pinyin (Santa) landslide September 1992, Bafaka Balue (Ndian) landslide September 1995, Sho-Belo landslide September 1997, Guoata (Dschang) landslide September 1997, Baingoh, Belo landslide July 1998, Anjin, Belo landslide September 1998, Ron(Nwa) landslide September2001, Limbe landslide June 2001, Wabane landslide July 2003 and Bamenda station landslide September 2009.

The rapid growth of the Bamenda population has led to the colonization of some landslide prone zonesfor the construction of houses (settlement) and agriculture. As a result of this, the population is exposed to potential risk of landslides. Along the Bamenda station escarpment, while some areas are constantly affected by landslides, others appear to be potential landslide prone areas. These potential landslide prone areas (zones) therefore need special attention since the inhabitants are unaware of the risks they are exposed to, and as such, more vulnerable than those permanently at risk. In august 2009, at Sisia II quarter, two lives and lots of properties were lost along this escarpment as a result of landslides.

The heavy rainfall in the North West Region for the past two years has led to landslides, endangering human life, obstructing access roads into Bamenda town and destroying properties to the detriment of the population and the economic development of Bamenda. It is in the light of these predicaments that motivated the geotechnical study of landslide at the Bamenda station escarpment.

The main objective of this study is to carryout geotechnical analysis along the Bamenda station escarpment, with the view of determining mechanical and physical parameters of the soil, thereby scrutinizing their influence on landslides along this escarpment.

II. LOCATION OF THE STUDY AREA AND LITERATURE REVIEW

Bamenda (Fig. 1) is situated in Northwest Region and is located between latitudes 5° 56" and 5° 58" North of the equator and longitudes 10° 09" and 10° 11" East of the Greenwich Meridian (Neba, 1999). This town falls along the Cameroon Volcanic Line and is implanted on two distinct environments; that is, the High Lava plateau (Up Station) with an altitude of about 1400m and the Lower plateau (Down Town) with an average altitude of 1100m above sea level. The study area therefore includes the steep slopes of the escarpment of Bamenda which constitute the landslide prone zones (Fig. 1, 2 and 3) and stretches along parts of Sisia IV, through Sisia II, New Layout, Ntambang, Atuazire, Ntaghem to Abangoh.

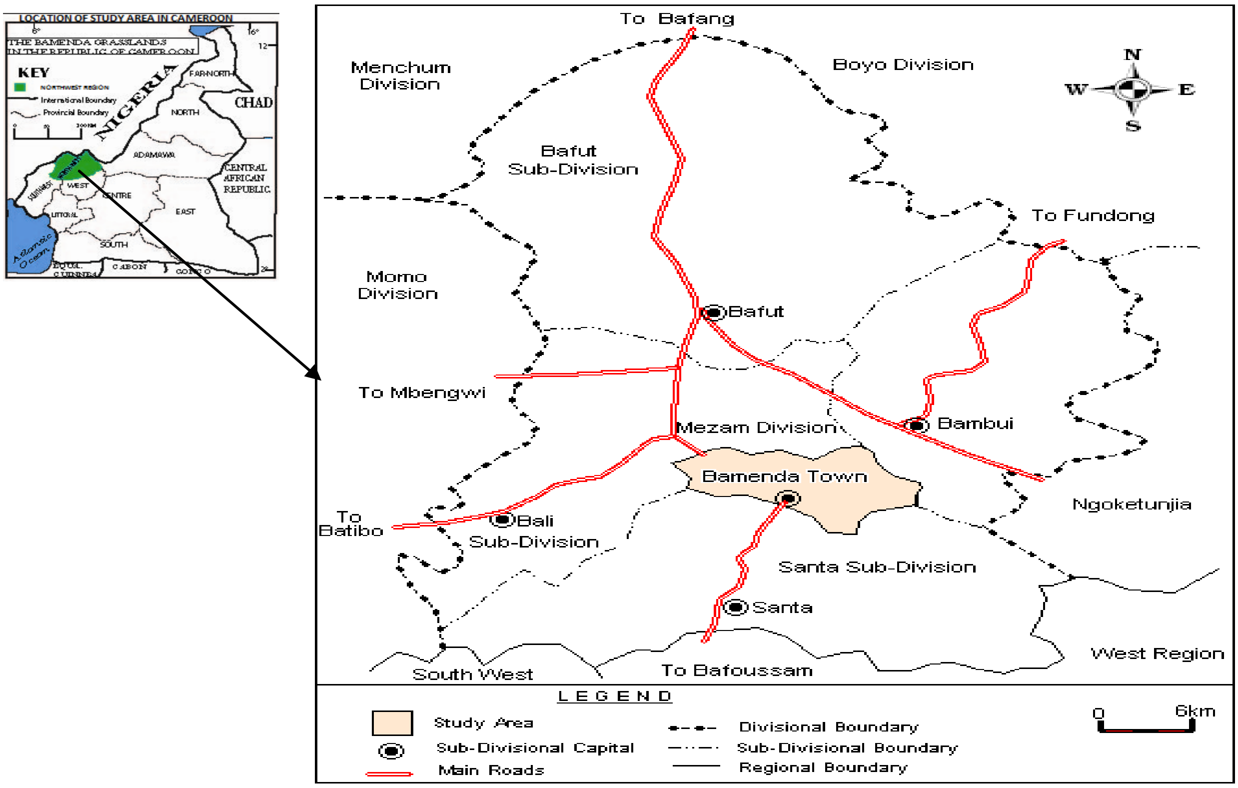

Fig.1: Location of Bamenda in North West Region of Cameroon
Source: CAMGIS, (2008)

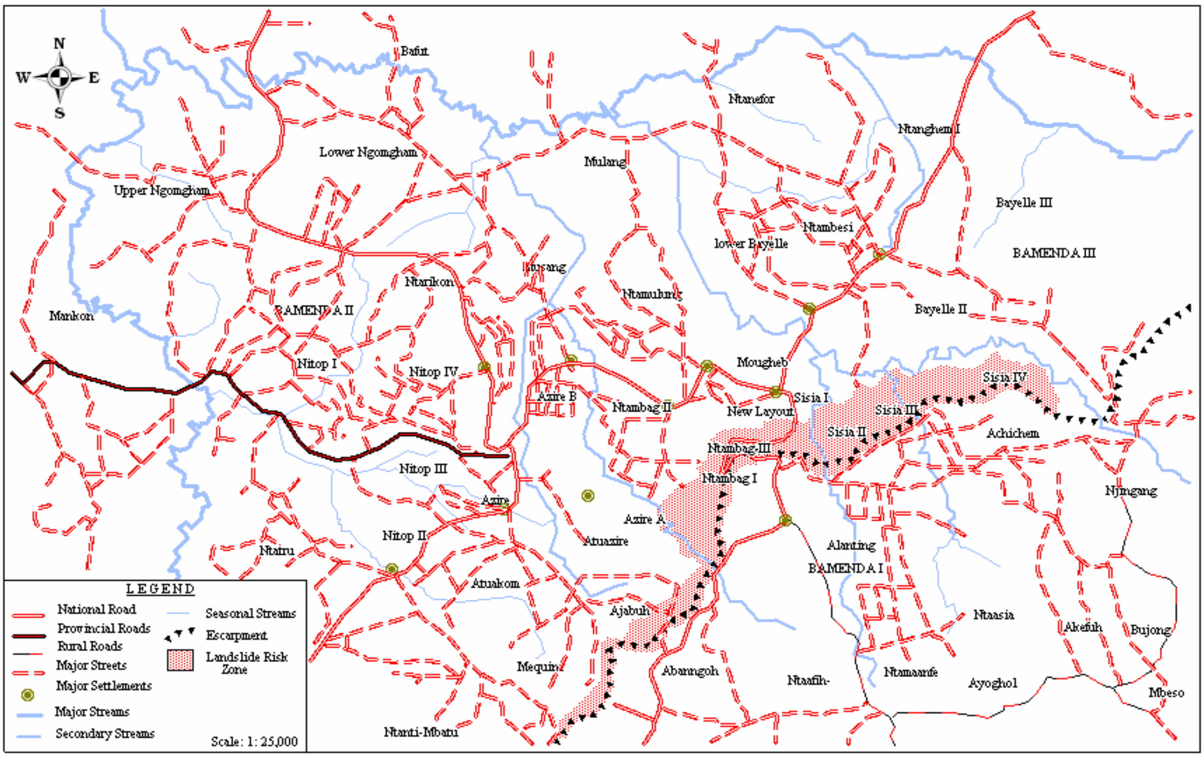

Fig. 2: Location of Escarpment and landslide risk zone in Mezam
Source: Bamenda City Council

Fig. 3: A partial view of the Bamenda station Escarpment
Source: Apah, 2010

Many researchers and authors have carried out studies on landslides in Cameroon, Africa and the world as a whole. However, only a few were interested in the prevalence of landslides at the Bamenda station escarpment in the

Northwest Region of Cameroon. The studies carried out on landslides ranges from unpublished dissertations, textbooks, thesis and journals.

The history of landslides in Bamenda is rich given its high altitude, the steep slopes, the nature of the underlying lithology and structure (geology) of the escarpment, the heavy precipitation and the high degree of chemical weathering (Lambi 2004). According to him, while the physical environment is rife for catastrophic landslides, the anthropic factors only come to make matters worse. Therefore anthropic intervention has been manifested by the artificially steepened road-site cuts. As a matter of fact, of the 10 landslide scars which he studied, only one appears to be partially out of reach of human influence. He thus recommended that, wider rock benches should be created at the foot of the artificial slopes which should serve as a talus or soil trap.

Kouayep (2003) in his dissertation entitled "*the contribution of the study of mass movement in the massive of Bana; case study of the locality of toungou*" laid more emphasis on the geotechnical studies of mass movement. He equally examines some geological aspects which serve as a guide to the present study. He identified some major causes of landslides and gave some recommendation to prevent future occurrence.

Kometa (2005) posits that natural processes can by themselves generate landslides irrespective of human activities. But experience from Cameroon and other parts of the world have proven that anthropogenic activities such as real estate construction, farming on steep slopes or on unconsolidated scoria or deeply weathered regolith, engineering structures such as road building, deforestation of watersheds, overgrazing of deeply weathered and over steepened slopes are common human factors which sometimes combine with the natural and the underlying geological structure to bring about massive slope failure.

Some natural hazards that appear initially to be natural may actually owe their origin to anthropogenic cause. That is, human interference with the natural environment (Pickering *et al*., 1995). Landslides according to them may be the result of badly damaged land, deforestation, or construction works. Such landslides according to them are particularly common on tropical mountain areas as in the Himalayas and the countries of South East Asia where high population growth rates force the teaming numbers of people to extend their activities unto otherwise marginal lands.

Ndenecho et *al*.; (2004), the irregular and ripening growth of the town brings pressure on land, water, vegetation and fauna. Swamps and flood prone zones and landslide-prone zones are rapidly being colonized by squatters with various environmental and health consequences. Besides, the lack of urban planning in Bamenda constitutes another serious problem. In fact houses are randomly built along streets, steep slopes and swampy areas. They recommended that tree planting should be an integral part of the town because it will prevent erosion and landslides. Besides sensitization, creation of awareness through environmental education, the resettlement of squatters away from risk prone sites should be the focus of landslide management plans in this mountainous ecosystem.

It is therefore seen that many authors and researchers have written about the landslides at the station escarpment of Bamenda but none of them has come closer to the geotechnical aspects of the landslides, which the present study seeks to investigate.

III. MATERIALS AND METHODS

A. Field work and soil sampling

The field work consisted of visiting the study area for general observations, location of sampling points and for soil sampling. To obtain samples for soil analysis, after the visual description of the nature of the soil and the alteration profiles of various sampling points, thick plastic cylinders of 16cm diameter and 25cm of height were used to collect five intact samples along the slopes of the escarpment. Once the extraction of each soil sample using the plastic cylinder done, paraffin was used to seal each sample to maintain its natural conditions. Reworked samples were equally collected in plastic bags at each sampling spot. The intact and reworked samples were carefully labelled with respect to the sampling locations. For instance Sisia4 and Sisia2 designate two samples collected at Sisia4 and Sisia2 quarters respectively. It should be noted that these five samples were collected with respect to the different soil types along the escarpment within the landslide zone.

B. GEOTECHNICAL ANALYSIS

The natural water content was determined by drying in an oven at 105°C for 24 hours according to NF P 94-050 (1995) Standard. The specific density was determined using thepycnometer method according to the French Standard Norm NF P 94-054 (1991) and the bulkdensity was performing according to NF P 94-059 (2000). The, dry density, porosity, compacity, voidratio and the saturation ratio were determined using according to the formulas 1, 2, 3, 4 and 5 respectively.

$$\gamma_d = \frac{\gamma}{1-w} \tag{1}$$

$$n = 1 - \frac{\gamma_d}{\gamma_s} \tag{2}$$

$$C = \frac{\gamma_d}{\gamma_s} \tag{3}$$

$$e = \frac{\gamma_s}{\gamma_d} - 1 \tag{4}$$

$$Sr(\%) = \frac{W_w \times \gamma_d \times \gamma_s}{(\gamma_s - \gamma_d)W_d} \times 100 \tag{5}$$

The grain size distribution was determined following the NF P 94-056 standard. P 94-056 The Atterberg's limits (liquid and plastic limits, plastic index) were determined according to the French Standard Norm NF P 94-051 (1991).The liquid limit(WL) was determined using the Casagrande method while the plastic limit (WP) was identified on the rods of 10 cm lengthand about 3 mm of thickness. Those limitswere used to determine the plasticity index (IP) using the formula 6.

$$IP = WL - WP \tag{6}$$

Finally, the shear strength (mechanical) parameters of the intact soil samples were obtained using the French Standard Norm N P 94-071 (1994).

IV. RESULTS AND DISCUSSION

A. Soil profiles characteristics

Soil sampling of alteration products were done at five different points along the escarpment specifically on the slopes of the escarpment which are the landslide prone zone and the sampling profiles present the following characteristics.

The first soil sample SIS4 was collected at Sisia IV quarter from a pit of three layers. The top layer was dark brown in colour 20 cm. The alloterite was brownish in colour and spotted with yellowish, reddish, pinkish and greenish colours 30 cm. The isalterite was yellowish in colour and contains properties of the main rock 25 cm.

The second soil sample was collected at Sisia II quarter and denoted SIS2.The sampling pit consisted of two layers of soil having fine grains. The top layer was dark brown in colour and 25cm thick. The alloterite was multi-coloured with dominant colour yellow and 35cm thick.

Third sample pit (SBE3)

The third soil sample was collected at "S" bend below the governor's former residence and denoted SBE3.The top soil was dark brown in colour and 20cm thick. The alloterite was reddish brown with very few yellowish fine particles and 55cm thick.

Fourth sample pit (ABA4)

The fourth soil sample was collected above Abangoh quarter at the beginning of the quarter and denoted ABA4. The sampling pit consisted of two layers and contains fine particles of low plasticity. The top soil was dark brown in colour and 25cm thick. The alloterite layer was yellowish brown in colour and 35cm thick.

Fifth sample pit (ABA5)

The fifth soil sample was collected at Abangoh, at the end of the escarpment and denoted ABA5.The sampling pit consisted of two layers of variable thickness and contained fine grain of average plasticity. The top soil was dark in colour and 20cm thick. The alloterite was reddish brown in colour and spotted with yellowish-brown particles of rocks and 37cmthick.

B. Geotechnical characteristics

B.1 Specific and bulk density

The values of specific density obtained at the different sampled points differ from each other, ranging from 2.20 to 2.58 t.m^{-3} with an average value of 2.36 t.m^{-3}. The value of the ABA4 and SBE3 sampled points are slightly bigger when compare to other sampled points. The values of the bulk density obtained vary slightly from each other, ranging from 1.32 to 1.59 t.m^{-3}with an average value of 1.49 t.m^{-3}for the five samples. The values of specific density and those of bulk density are presented in the table 1 below.

Table 1: Specific and bulk density

Sample	γ_s (t.m^{-3})	γ(t.m^{-3})
SIS4	2.23	1.45
SIS2	2.20	1.52
SBE3	2.52	1.59
ABA4	2.58	1.32
ABA5	2.27	1.56

From the table 1, we observe that the specific density present values that ranges from 2.20 to 2.58 which are below normal range of specific densities of average dense soils that ranges from 2.64 – 2.72 (McRoberts, 1957).The low values of the specific density are due to the nature of the weathered rocks which form less dense and less cohesive soils, thereby giving rise to landslides when there is any light modification of their natural conditions.

The values of the bulk density fluctuate slightly in all the sampling positions but the values remain close to each other. This variation is due to the different water content at different sampling points. Moreover, it is also due to changes that takes place in soils near the ground surface as a result of rainfall and temperature.

B.2 Water content, void ratio, Porosity, compacity and saturation ratio

Taking into consideration the water content (w), void ratio (e), porosity (n), compacity (c) and the saturation ratio (Sr), Table 2 below presents the values of the above mentioned properties.

Table 2: Water content, void ratio, Porosity, compacity and saturation ratio

Sample	w(%)	e	N (%)	C	Sr (%)
SIS4	33.57	1.032	50.81	0.49	71.89
SIS2	39.52	1.040	50.98	0.49	84.8
SBE3	28.79	1.045	51.11	0.49	69.99
ABA4	43.17	1.567	61.05	0.39	65.6
ABA5	31.57	0.909	47.63	0.52	78.86

From the result obtained, we observe that the water content values ranges from 28.79 to 43.17% with an average value of 35.32%.The values of the void ratio vary from 0.909 to 1.567 with an average value of 1.11. The values of the porosity ranges from 47.63% to 61.05% with an average value of 52.32%, and slightly higher at ABA4.The compacity has an average value of 0.472 and ranges from 0.48 to 0.49. The values of the degree of saturation vary from 65.60 to 78.86% with an average value of 74.22%.

From the results presented in table 3-3, we can observe that the void ratios present very high values that range from 0.91 to 1.57.These values are very important with respect to the soil compressibility. Typical values of void ratio ranges from 0.4 to 1.0 in the case of sand and 0.3 to 1.5 for clay. McRoberts (1957) experimented that typical void ratios might be 0.3 for a dense, well graded granular soil and 1.5 for soft clay. Therefore the clay soils identified in the study area is pretty soft and as such, the soils are prone to sudden collapse. Since the void ratio values are very high, this portrays the fact that the soils contain much voids and when these voids are filled with water after rainfall, the weight of the soils increases.

Moreover clay soils particles are slippery and sticky when wet, therefore the tendency of sliding is very high. This justified the reason why most of the landslides in the study area occur after heavy or prolonged rainfall.

Degree of saturation of various soils samples are reasonably high, which ranges from 65.60 to 84.81% as compare to 100% for a completely saturated soil. This property is very important with respect to the shear strength of clay soils, since the higher the degree of saturation, the lower the shear strength of the soil. This justify the fact that as it rains, the amount of water clay soils absorb increases the volume and therefore the volume of voids will also increase and so, the degree of saturation remain at one hundred percent (Sr = 1) while the actual volume of water is increasing, thereby increasing the weight of soil and decrease the shear strength properties of the soil. The decrease in shear strength leads to the increase of the driving force of gravity which eventually results to landslides. These account for some of the landslides along the escarpment (study area).

The porosity values obtained are averagely high and indicate the rate of permeability of the soils in the study area. Therefore, when it rains, water easily penetrate into the soil causing lubrication of the soil grains and decreases the cohesion and friction between particles which eventually lead to slippery surface of weakness in the soils, thus the end result is landslides. This actually account for the water oozing from some of the landslides scars in the study area. For instance, the landslides scar at S-bend (fig.3.6).

The water content fluctuates in all the sampled points with an average value of 35.32%. However the proportion of clay mineral flakes in a fine soil affects its current state, particularly its tendency to swell and shrink with changes in water content as such the soils may be prone to sudden failure.

B.3 Grain size distribution

The grains size distributions are presented on figure 4.

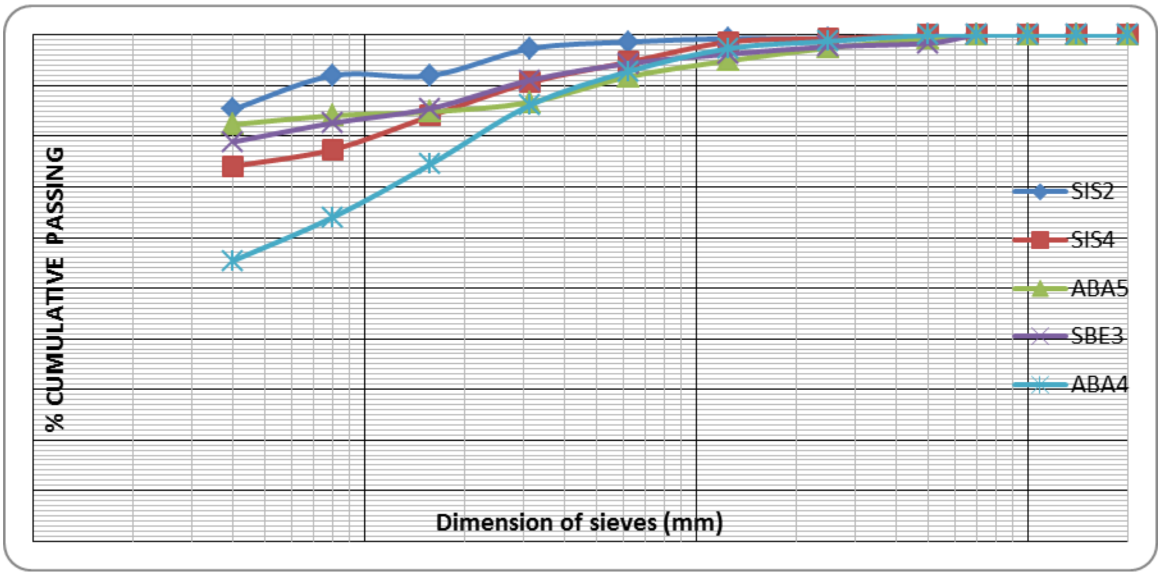

Fig. 4: grains size distribution graphs

The grain size distribution presented on figure 4 show that for all the samples analyzed, majority of the samples are made up of silt, sand with few gravel. The water content of various sample are 33.00% , 32.91% , 29.00%, 43.00% , 26.62% for SIS2,SIS4, SB3, ABA4 and ABA5 respectively.

The grains size distribution graphs represent poorly graded soils, since they contain mostly fine particles. This implies that the range of particle-size distribution has an influence on the stability of a soil mass. This is due to grains packing, reflecting the soil structure. The presence of moisture has great influence on the structure of clay identified in the study area. Thus, a lot of water may be held as adsorbed water within clay mass, thereby increasing the weight of the soils and since clay soils particles are slippery and sticky when wet, this can eventually lead to landslides.

B.4 Atterberg's limits

The values of the liquid limit (WL) and plastic limit (WP) are presented in table 3. The values of the liquid limit ranges from 55.71% to 74.20% with an average value of 65.21% while the values of the plastic limit ranges from 36.70% to 46.22% with an average value of 40.77% for the five samples.

The different values of the liquidity index, plasticity index and consistency index are presented in table 3 and vary as follows; - 44.79% to 14.83% for liquidity index, 18.30% to 32.48% for plasticity index and 0.85 to 1.45 for consistency index.

Table 3: Atterberg's limits

Sample	WL (%)	WP (%)	I_L(%)	I_P (%)	(I_C)
SIS4	74.20	41.72	-25.09	32,48	1.25
SIS2	55.71	36.70	14.83	19.01	0.85
SBE3	68.94	41.21	- 44.79	27.73	1.45
ABA4	72.92	46.22	-11.42	26.70	1.11
ABA5	56.30	38.00	- 35.14	18.30	1.35

The liquid limits have an average value of 65.21% which correspond to a soil of high plasticity as indicated on plasticity table. The high liquid limits values are due to much water content of the soils which can easily flow under self-weight causing landslides.

The values of the plastic limits are considerably high with an average value of 40.77% greater than 40% hence the soils have very high plasticity. The high plasticity justifies the fact that if small quantity of water is added to the soil, it passes to liquid state and at this state the soils have high tendency to slide or flow thereby causing landslides.

The Plasticity index ranges from 18.3 to 32.48%. The plasticity index is an indicator of how much water the soil particles can absorb. Clay soils have flaky particles to which water adheres, thus imparting the property of plasticity.

B.5 Cohesion and angle of internal friction

The mechanical characteristics obtained from the direct shear box test are presented in table 4 below. The values of cohesion differ slightly from each other, but for the value of ABA4 which is two times higher than other values. The cohesion of the soils ranges from 28.5 to 73.4 KPa.

The values of the angles of internal friction of soils differ slightly from each other and ranges from 23.5° to 28°. The SBE3 sampled point presents the highest value of 28° and ABA5 sampled point has the smallest value of 26 °.

Table 4: Mechanical characteristics

Samples	Internal angle friction, φ_u (°)	Cohesion, c_u (KPa)
SIS2	27	2.60
SIS4	25,5	3.10
SBE3	28	3.20
ABA4	23,5	7.20
ABA5	26	3.60

The cohesions of the soils on table 4 above are very low and vary from 28.5 to 73.4 KPa. This is due to the texture of the clay soils and the high water content of the clay soils as a result of the heavy rainfall in the Northwest region. This low cohesive nature of the soils indicates the poor adhesion between the soil particles or low contact among the particles of the soil along the escarpment slopes and consequently low frictional resistance.

As a result of the low cohesive forces holding the particles together, the particles of the soils have high tendency to separate and move or flow down-slope, especially when it rains and the soil is saturated. The angle of internal friction reduces and the materials of the slope tend to move or flow like a fluid down slope thereby resulting to landslides. This is because the presence of water eliminates grain to grain frictional contact and hence, reduces the cohesive forces of the soils particles thereby, reducing the shear strength of the soil and increasing the shearing stress that eventually leads to landslides. This equally justify the reason why many landslides occurs after prolong or heavy rains at the station escarpment of Bamenda.

On the other hand, the angles of internal friction or angles of shearing resistance of soils varies from 25.5^{o} to 28^{o} but not reasonably high enough to maintain the slopes of the escarpment stable since the inclined angle of the slopes are greater than the angles of internal friction of the soils (table 5). The fact that the angles of the slopes are greater than the angles of internal friction plays a very important part in the reduction of the slope stability. Hence, a slope is unstable when its angle is greater than the internal angel of friction of the soil of the slope. (Ntana, 2001). The elevated angle of the slopes increases the magnitude of the driving forces of gravity on slopes. Therefore, as the angle of the potential slip plane increases, the driving force also increases.The concept of slope evolution tends to reduce the angles of slopes to their angle of repose.

Table 5: Angles of internal friction and natural angles of slopes at various sampling points

samples	Angle of internal friction of the soils, φ_u (°)	Natural angle of the slopes of the escarpment (°)
SIS4	25,5	68.2
SIS2	27	51.34
SBE3	28	60.26
ABA4	23,5	30.47
ABA5	26	41.01

V. CONCLUSION AND RECOMMENDATIONS

A good number of factors were taken into consideration for the identification of landslides in the study area. However there exist three types of landslides; translational, rotational and compound or mixed landslide. The study area is characterized with scar of compound or mixed landslides and translational landslides. Thus, rotational landslides are not common in the area. However, there are no possibilities to completely eradicate this natural phenomenon. It is difficult and often expensive to prevents or minimize landslides. Nevertheless, preventive measures can be taken such as the modification of the profile of the natural slope in the form of steps profiles. To this effect, the height of the talus to be adopted must not exceed the critical heights as proposed in table 6. These critical heights were determined using the formula 7 (8)

$$Hc = 2.65 \times \frac{C}{\gamma} \tan(45 + \frac{\gamma}{2}) \quad (7)$$

Incase of a uniformly distributed load is to be placed on the top surface of the modified slope, the critical height should be determined using the formula 8.

$$Hc = 2.65 \times \frac{C}{\gamma} \tan(45 + \frac{\gamma}{2}) - \frac{2q}{\gamma} \quad (8)$$

Moreover, for assurance of good stability, the talus of the modified slope should be flatter to have an inclination.

Table 6: Determined critical height

Samples	Bulk density, γ(KN/m^3)	Cohesion, C_U(KPa)	Critical Height H_C(m)
SIS4	14.52	2.60	7.60
SIS2	15.25	3.10	6.77
SBE3	15.99	3.20	6.49
ABA4	13.27	7.20	18.65
ABA5	15.64	3.60	7.45

However, the slope should be reduced to have a gentle slope at the top to enable quick evacuation of surface water. The horizontal top distance should be greater or equal to 8m in the case of a uniformly distributed load and greater or equal to 2m when not loaded. The top surface should be concreted or grass should be planted over the whole surface to avoid erosion and infiltration of surface water.

REFERENCES

Ayonghe, S.N., Mafany, G.T., Ntasin, E., and Samalang, P. *Natural Hazards* Netherlands, Kluver Academic Publishers, 1999, 27 p.
Gruden, D. M. *Landslide Type and Processes*, Washington, National Academy Press, 1991, 236p.
Hutchinson J. N. *Mass Movement,* New York, Reinhold Book Corp, 1968, 688p.
Kouayep, Sylain. *Contribution to the study of mass movements in Bana Massif: Toungou,* Master's Thesis in earth science, University of Dschang, 2003, 70 p.
Lambi, Cornelius. *Revisit of the recurrent Landslides on the Bamenda Escarpment*, Buea, Journal of Applied Social Sciences, 2004, 25p.
McRoberts E.C. and Morgenstern, N.R.,The *stability of thawing slope*, Canadian, Geotechnical Journal, 1988, 469 p.
Ndenecho, Emmanuel. *Landslide and Torrent – Channel Problems of Mountain Slopes*, Bamenda, Unique Printers, 2007, 69 p.
Ngapgue, Francois. *Yaounde lateritic soils as foundation soils for buildings and structures.* PhD thesis, Kiev State Technical University of Construction and Architechture, 1997, 254 p.
Tamo Tateisse T., and Ngapgue F. *Physical characterization of Bafoussam (Cameroun) for the foundation*, J.P.journal of soils and structures, Pushpa publishing House, 2008, 52 p.