International Journal of Geology and Earth Sciences

ISSN 2395-647X www.ijges.com
Vol. 4, No. 1, March 2018

Research Paper

GEOTECHNICAL CHARACTERIZATION OF GEOLOGICAL FORMATION AT SLUMP SITES WITHIN SOUTH-WESTERN OUTSKIRTS OF ZUNGERU, NORTH CENTRAL NIGERIA

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Received on: 9th January, 2018 Accepted on: 25th February, 2018

Slumping is destroying farmlands on the south-western outskirts of Zungeru. Sieve analysis and Atterberg limit tests were conducted on samples of geological formation from the slump and stable sites to ascertain the geotechnical attributes that make the area susceptible to slumping. Surface geological reconnaissance revealed that the area is underlain by schist, amphibolite and granite. The schist unconformably underlay Doko member of Bida Formation, which is the lithostratigraphic unit undergoing slumping. Coefficient of Uniformity (C_U) ranges from 0.57 to 3.48 at the slump sites. This indicates that the slump sites' geological formation is poorly graded. Formation C_U at stable site is 5, which indicates fair particle size grading. Natural Moisture Content (NMC) is 1.9% at the stable site. The value tripled (2.2 to 6.6%) at the slump sites. Atterberg limits' value is similar at all the sites. Their liquid limit is less than 40%. Their plastic limit and plastic index are less than 20% and 7% respectively. The low Atterberg limits' value indicates that clay shrinkage and swelling is not responsible for observed slumping. Poor formation particle size grading and high NMC caused slumping in the area. Retaining walls with drain pipes, and vegetation will arrest observed slumping.

Keywords: Slumping, Farmlands coefficient of uniformity, Atterberg limits

INTRODUCTION

Slumping of geological formations can be regarded to be gravity driven downslope movement of a nearly homogeneous cohesive geological material when the slope fails by shearing (Rahn, 1996). The upper part of geological formations commonly contains organic matter which supports vegetation. Consequently, food and cash crops are susceptible to being destroyed by slumping. Inter community road links are also destroyed.

Slumping occurs when factors that drive downslope movement of geological materials overcome those that resist movement. The downslope movement resisting factors include (1) friction between a slope and loose materials

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along its surface (2) strength and cohesiveness of the material comprising the slope. These factors prevent slope shearing and material slippage. Counteracting these resistive factors are steep slope, lack of vegetation cover and material's water content.

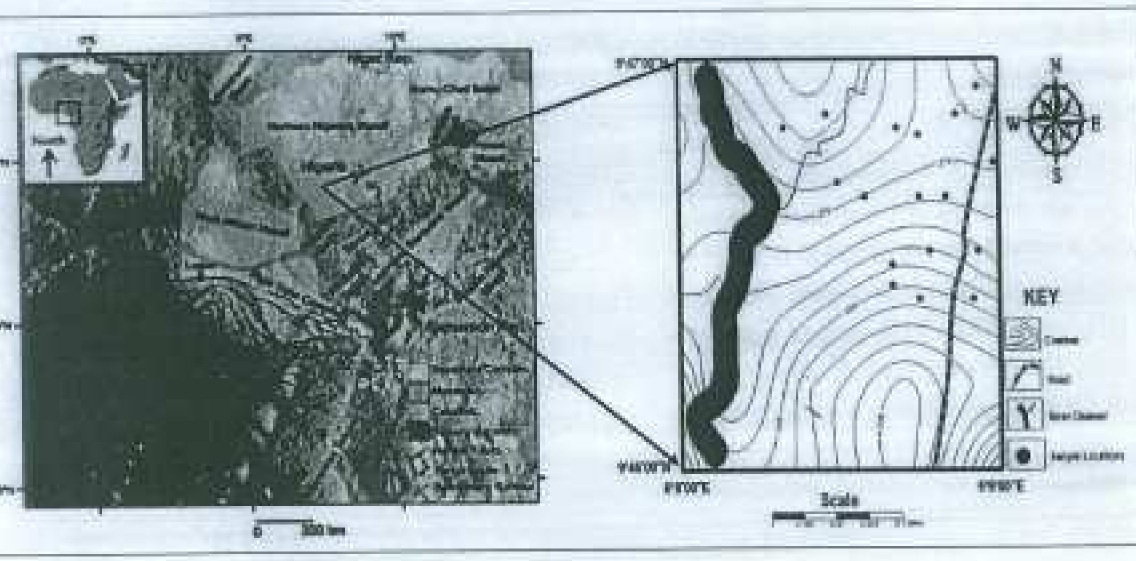
Slumping can be hindered by increasing stability of geological materials through: (1) building retaining walls with orthogonal drainage pipes (to reduce water content) across the slope face and (2) planting fast growing vegetation that develop extensive, deep root network that cohere materials(www.soest.hawaii.edu/GG/FACULTY).

The study area is within the southwestern outskirts of Zungeru, where farmlands are being destroyed by slumping of exposed geological formation. The slumping is also gradually etching out the main rural road linking neighbouring communities. The geographical coordinates of the study area are Longitudes E6°8'0" to E6°8'10" and Latitudes N9°49'0" to N9°49'15" (Figure 1).

The geotechnical characterization of the geological formation of the study area was conducted in order to ascertain geological issues underlying the slumping and proffer possible solutions to arrest it. Geological formation that can be excavated without blasting is termed soil in civil engineering. It typically disintegrates in water (Venkatramaiah, 2008).

Jaddal *et al.* (2001) and Wati *et al.* (2010) employed soil particle distribution curves to reveal fine textured nature of soils. They remarked that fine particle fraction of soils have small pores which liberate water slowly and consequently results in high water content that makes them susceptible to slumping. Baynes (2008) include expansive soft clays and collapsible and dispersive soils among problem soils that are prone to slumping. Kitutu *et al.* (2009) observed that soils with fines fraction greater than 10% threshold exhibit extreme expansive potential and are therefore susceptible to slumping. Mugagga *et al.* (2011) employed particle size distribution, Atterberg Limits, shear strength and factor of safety to test the hypothesis that soils at slump sites are problem soils. They found that liquid

Figure 1: Location of the Study Area



limits greater than 53% and plastic index of about 53% characterize soils at slump sites.

MATERIALS AND METHODS

Surface geological field reconnaissance was carried out to ascertain the rock types in the study area. Samples of the geological formation were collected from the slumping sites and from a stable site (for controlled and comparative interpretation) to determine the geological formation's geotechnical attributes comprising particle size distribution, moisture content, and Atterberg's limits(Liquid Limit, Plastic Limit and Plasticity Index). The surface geological field reconnaissance was conducted using Global Positioning System (GPS) and compass clinometer. Instruments employed for geotechnical attributes determination are weighing balance, mechanical sieve shaker, sets of sieves, mortar and pestle, thermostatically regulated oven, and a cone penetrometer (Dutch cone penetrometer type). The attributes were determined at soil mechanics laboratory of Civil Engineering Department of the Federal University of Technology, Minna. The sieve shaker is gyratory electrically operated shaker SM1-190 and the oven is laboratory electric oven SM 118. Both were manufactured by SM scientific industries in India.

Sieve Analysis

About 300 g of formation samples were washed in 75 mm B.B. sieve to remove clay, and dried at 100 °C for 24 hours in an oven. This was weighed again and sieve analyzed in a set of sieves shaken by an electrically powered mechanical shaker, which shook the set of sieves for 40 minutes. Percentage Mass Retained (PMR) on each sieve was obtained, using:

Individual mass retained on each sievemass of total dry sample ×100 ...(1)

The Cumulative PMR (CPMR) for each sieve was obtained by adding up PMR on the sieve to PMR on all sieves above it. Percentage Mass Passing (PMP) at each sieve was obtained by subtracting the CPMR for each sieve from 100. The PMP was plotted against grain-size on a semi-log graph sheet, using Microsoft excel. The coefficient of uniformity C_U was obtained using:

$$C_U = \frac{D_{60}}{D_{10}} \quad ...(2)$$

where D_{60} and D_{10} are respectively sieve size in mm for D_{60} % PMP and D_{10} % PMP.

The coefficient of curvature (C_c) was obtained using:

$$C_c = \frac{D_{30}^2}{D_{60}} \times D_{10} \quad ...(3)$$

The C_U and C_C were employed in classifying the samples using AASHTO (American Association of State Highway and Transportation Official, 2006) criteria given in Table 1.

Hydraulic Conductivity, Porosity, Moisture Content and Atterberg's Limits

Hydraulic conductivity (K) for the samples was estimated using Hazen's equation:

$$K = CD_{10}^2 \quad ...(4)$$

where D_{10} is grain size corresponding to 10% PMP, and C = 1 if K is in cms^{-1}

Porosity (η) was obtained from C_U, using equation of Vukovic Soiv (1923):

$$\eta = 0.255(1 + 0.83C_U) \quad ...(5)$$

K was employed to classify the samples in terms of degree of permeability using Table 2, of Sehgal (1967).

Moisture content (M_c) was determined as follows:

$$M_c = W_2 - W_1 W_2 \times 100 \quad ...(6)$$

where W_2 is weight of fresh sample, W_1 is weight of dry sample (weight of sample dried for 24 hours in an oven at 100 °C).

Atterberg's limits determined were Liquid Limit (LL) and Plastic Limit (PL). The LL was determined using cone penetrometer. Some of the samples were air dried for 9 hours. They were then pulverized and sieved using sieve mesh 425 μ. 200 mg of the sieved sample were mixed thoroughly with some water to form a thick paste. Penetration depth, in 5 seconds, of the pentrometer's cone was determined for some of the paste. The procedure was repeated for five more times with different amount of water employed to form the paste. Moisture content for each paste was determined. Depth of penetration was plotted against corresponding moisture content. The moisture content for 190 mm penetration depth was obtained from the graph. This moisture content is LL. This was determined for samples from all the sites. Some of the samples for the LL tests were rolled to about 3mm thickness on a plastic board to the point where the sample begins to break. The corresponding moisture content is the PL. Plasticity index was obtained as follows:

$$PI = LL - PL \quad ...(7)$$

Table 1: Classification of Soil Gradation

Gradation	Gravel	Sand
Well graded	$Cu \geq 4$ and $1<Cc<3$	$Cu \geq 6$ and $1<Cc<3$
Poorly graded	$Cu<4$ and $1<Cc<3$	$Cu<6$ and $1<Cc<3$
Gap graded	Cc not between 1 and 3	Cc not between 1 and 3

Source: AASHTO (2006)

Table 2: Classification of K in Terms of Degree of Permeability

Soil Description	K(mm^{-1})	Degree of Permeability (Terzaghi and Peck, 1948)
Coarse gravel	>1	High
Fine gravel-fine sand, silt-sand admixtures	$1-10^{-2}$	Medium
Dense silt, clay-silt admixtures	$10^{-2}-10^{-4}$	Low
Non-homogenous clays	$10^{-4}-10^{-6}$	Very low
Homogenous clays	$<10^{-6}$	Almost impervious

RESULTS AND DISCUSSION

Figures 2, 3, 4 and 5 are some slumping sites revealed during surface geological reconnaissance. Vegetation is being destroyed in the sites (apart from site 3), and the road linking neighbouring communities is gradually etching away. The reconnaissance also revealed amphibolite and schist outcrops intruded by granites. These basement rocks are overlain by thick massive to vaguely bedded sandstone that belongs to Doko member of Bida Formation. The Doko member is the slumping lithostratigraphic unit. It consists of clay matrix conglomerates at its base, and a vaguely bedded fining upward sequence of medium-fine sand, siltstone and mudstone.

Table 3 is the sieve analysis result for slump site 1. Figure 6 is the plot of Percentage Mass Passing (PMP) versus sieve grain size for samples from slump site 1. Figure 7 is a bar representation of grain sizes in samples slump site1. The graph shows that the formation is mostly fine sand, with subordinate medium to coarse sand, fine gravel and coarse silt. Values of C_u and C_c are 2.85 and 0.764 respectively.

Figure 2: Slumping Site 1, Latitude N9°46'50'' Longitude E6°8'32''

Figure 3: Slumping Site 2, Latitude 9°46'45'' Longitude 6°8'30''

Figure 4: Slumping Site 3 (Stable Site), Latitude 9°46'55'' Longitude 6°8'30''

This indicates that the geological formation is poorly graded at this slump site. Table 4 is the sieve analysis result for slump site 2.

Figure 5: Slumping Site 4, Latitude 9°46'30'' Longitude 6°8'20''

Figure 6: Plot of Mass Passing (PMP) versus Sieve Grain Size (Slump Site 1)

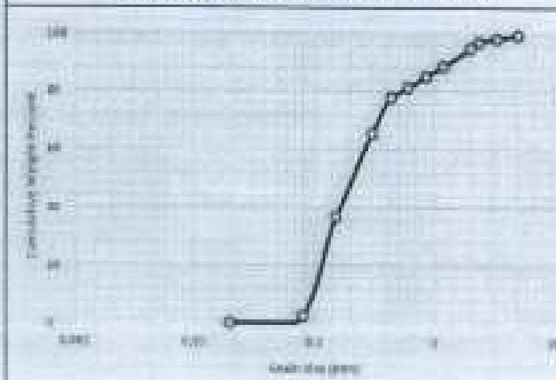


Figure 7: Bar Chart Representation of Grain Sizes in Samples Slump Site 1

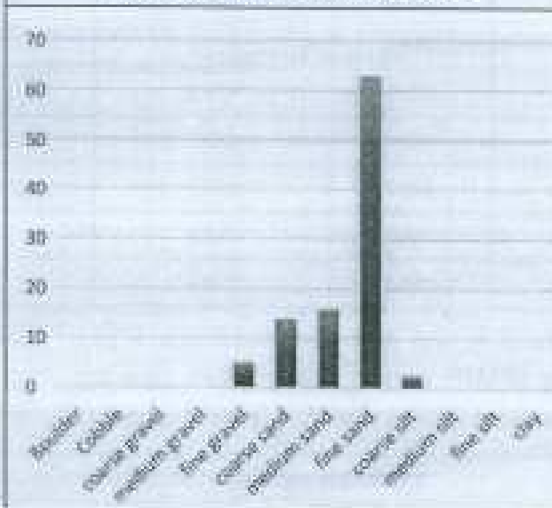


Table 3: Sieve Analysis Result for Slump Site 1

Sieve Size (mm)	Weight of Sieve	Weight of Sieve and Soil	Weight of Soil Retained	% Retained	Cum. Retained	% Passing
5	476	476.6	0.6	0.59	0.59	99.41
3.35	468.2	469.3	1.1	1.09	1.68	98.32
2.36	426.7	428	1.3	1.29	2.97	97.03
2	418	420	2	1.99	4.96	95.04
1.18	385.7	392.1	6.4	6.36	11.32	88.68
0.85	353.8	357.4	3.6	3.57	14.89	85.11
0.6	470.1	474	3.9	3.87	18.79	81.24
0.43	435.3	442.8	7.5	7.45	26.21	77.79
0.3	313	321.4	8.4	8.34	34.55	65.45
0.15	420.7	444.6	28.9	28.69	63.24	36.76
0.08	380	414.5	34.5	34.26	97.5	2.5
0.02	298.5	301	2.5	2.48	100	0

Table 4: Sieve Analysis Result for Slump Site 2

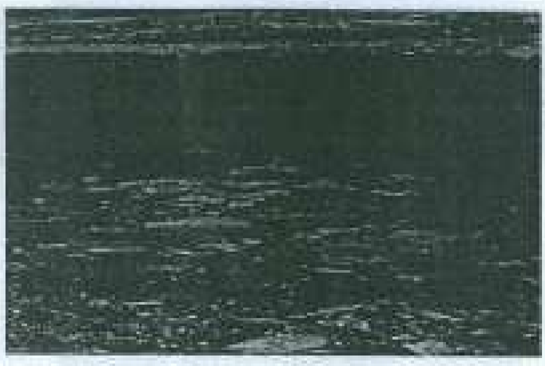
Sieve Size (mm)	Weight of Sieve	Weight of Sieve and Soil	Weight of Soil Retained	% Retained	Cum. Retained	% Passing
5	476	482.8	6.8	3.22	3.22	96.8
3.35	468.2	472.2	4	1.89	5.11	94.9
2.36	426.7	431.8	5	2.42	7.53	94.7
2	418	420.6	6.6	1.23	8.76	91.2
1.18	385.7	402.7	17	8.06	16.82	83.2
0.85	353.8	369.6	15.8	7.49	24.31	75.7
0.6	470.1	300.1	30	14.22	38.53	61.5
0.43	435.3	477.8	42.5	20.15	58.68	41.3
0.3	313	347.9	34.9	16.55	75.23	24.8
1.15	420.7	457.3	36.6	17.55	92.58	7.4
0.08	380	394.5	14.5	6.88	99.46	0.5
0.02	298.5	299.6	1.1	0.52	100	0

Figure 8 is the plot of Percentage Mass Passing (PMP) versus sieve grain size for samples from slump site 2. Figure 9 is a bar chart representation of the particle sizes. The graphs revealed that the sample consists mainly of medium to coarse sand with some

Figure 2: Slumping Site 1, Latitude N9°46'50'' Longitude E6°8'32''

Figure 3: Slumping Site 2, Latitude 9°46'45'' Longitude 6°8'30''

Figure 4: Slumping Site 3 (Stable Site), Latitude 9°46'55'' Longitude 6°8'30''



This indicates that the geological formation is poorly graded at this slump site. Table 4 is the sieve analysis result for slump site 2.

Figure 5: Slumping Site 4, Latitude 9°46'30'' Longitude 6°8'20''

Figure 6: Plot of Mass Passing (PMP) versus Sieve Grain Size (Slump Site 1)

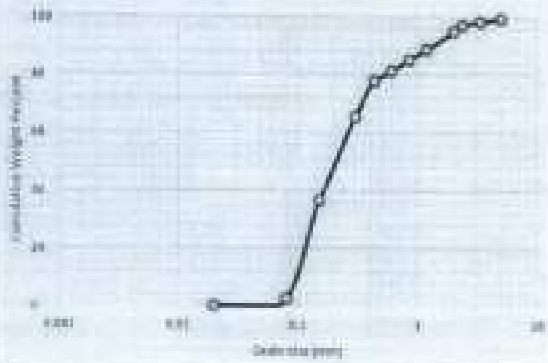


Figure 7: Bar Chart Representation of Grain Sizes in Samples Slump Site 1

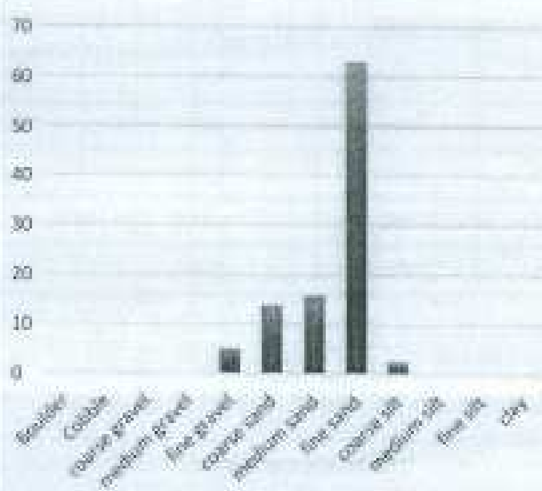


Figure 8: Plot of Percentage Mass Passing (PMP) versus Sieve Size (Slump Site 2)

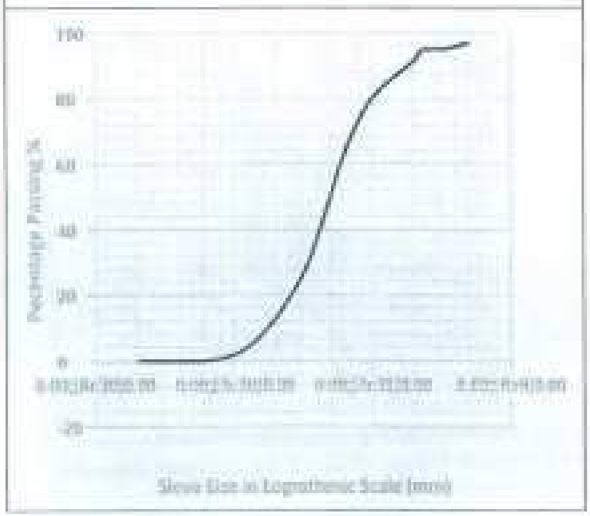
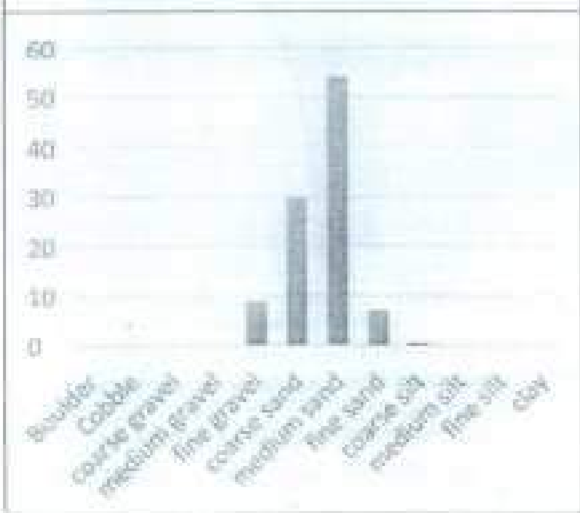


Figure 9: Bar Chart Representation of Grain Sizes in Samples Slump Site 2



fine sand, coarse silt and fine gravel. Estimated values of C_u and C_c are 0.57 and 0.148 respectively, which indicates it is poorly graded. Table 5 is the sieve analysis result for slump site 3.

Figure 10 is the plot of Percentage Mass Passing (PMP) versus sieve grain size for samples from slump site 3. Figure 11 is its bar chart representation. The graphs revealed that

Figure 10: Plot of Percentage Mass Passing (PMP) versus Sieve Grain Size (Slump Site 3)

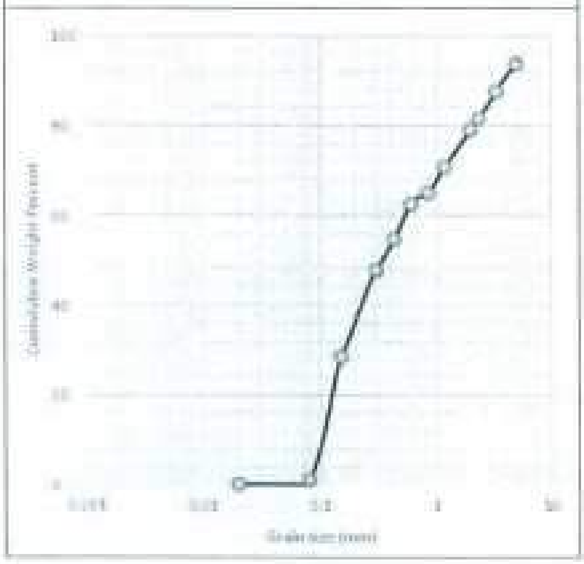
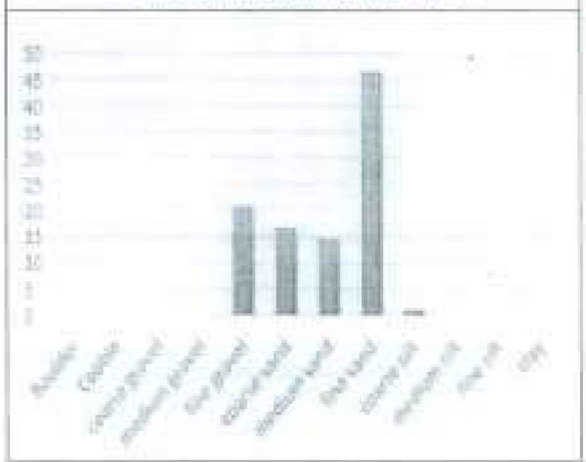


Figure 11: Bar Chart Representation of Grain Sizes in Samples Slump Site 3



the sample contains high amounts of fine sand, medium to coarse sand and fine gravel. Estimated values of C_u and C_c are 5.31 and 0.711 respectively. The C_u reflects substantial amount of gravel, and is fairly graded.

The sieve analysis results for sample from slump site 4 is Table 6. Its plot of percentage mass passing (PMP) versus sieve grain size is Figure 12. The bar chart representation of its

Figure 12 : Plot of Percentage Mass Passing (PMP) versus Siev Grain Size (Slump Site 4)

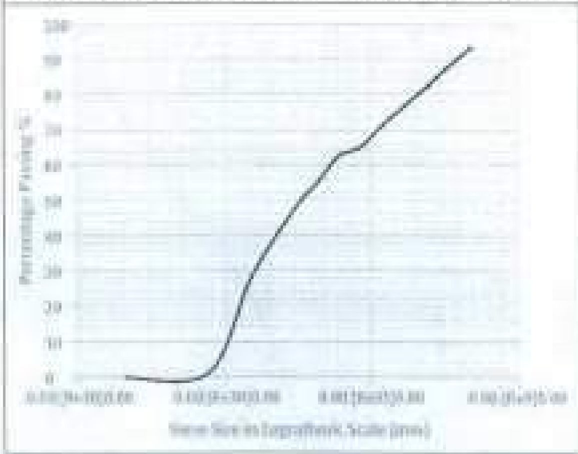


Figure 13: Bar Chart Representation of Grain Sizes in Samples Slump Site 4

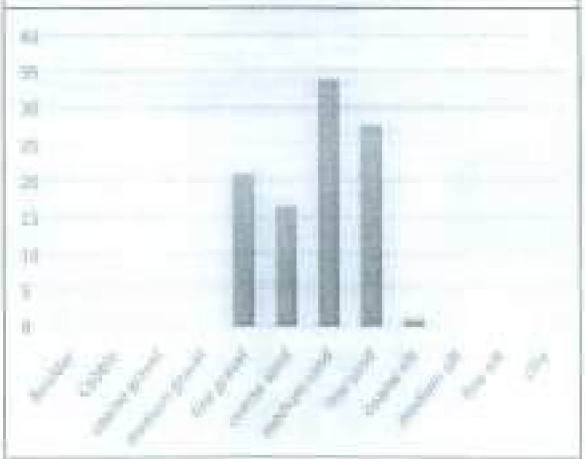


Figure 14: Plot of Percentage Mass Passing (PMP) versus Sieve Grain Size (Slump Site 5)

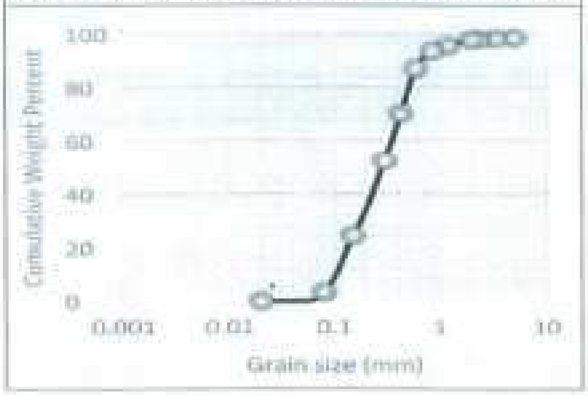


Figure 15: Bar Chart Representation of Grain Sizes in Samples Slump Site 5

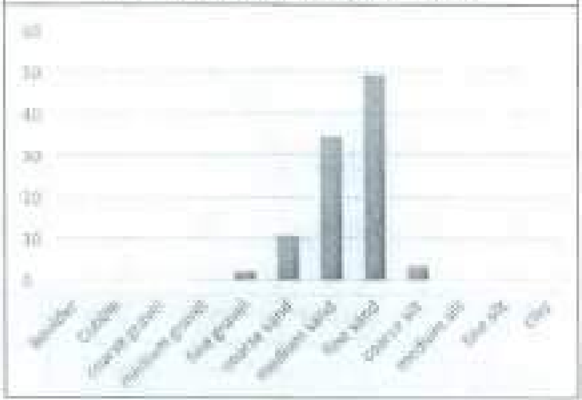


Figure 16: Plot of Percentage Mass Passing (PMP) versus Sieve Grain Size (Slump Site 6)

Figure 17: Bar Chart Representation of Grain Sizes in Samples Slump Site 6

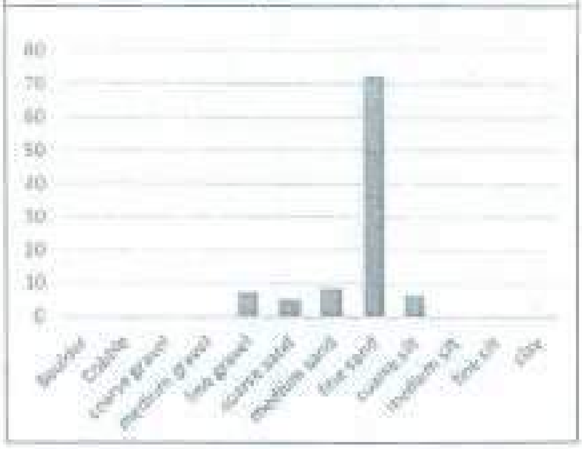


Table 5: Sieve Analysis Result for Slump Site 3

Sieve Size (mm)	Weight of Sieve	Weight of Sieve and Soil	Weight of Soil Retained	% Retained	Cum. Retained	% Passing
5	476	483	7	6.34	6.34	93.7
3.35	468.2	474.9	6.7	6.07	12.41	87.6
2.36	426.7	433.3	6.6	5.98	18.39	81.6
2	418	420.8	2.8	2.54	20.93	79.1
1.18	385.7	394.8	9.1	8.24	29.17	70.8
0.85	353.8	360.2	6.4	5.79	34.96	65
0.6	470.1	472.9	2.8	2.54	37.5	62.5
0.43	435.3	443.9	8.6	7.79	45.29	54.7
0.3	313	320.6	7.6	6.88	52.17	47.8
0.15	420.7	441.9	21.2	19.2	71.37	28.6
0.08	380	410.4	30.4	27.54	98.91	1.1
0.02	298.5	299.7	1.2	1.87	100	0

Table 6: Sieve Analysis Result for Slump Site 4

Sieve Size (mm)	Weight of Sieve	Weight of Sieve and Soil	Weight of Soil Retained	% Retained	Cum. Retained	% Passing
5	476	483	7	6.34	6.34	93.66
3.35	468.2	474.9	6.7	6.07	12.41	87.59
2.36	426.7	433.3	6.6	5.98	18.39	81.61
2	418	420.8	2.8	2.54	20.93	79.07
1.18	385.7	394.8	9.1	8.24	29.17	70.83
0.85	353.8	360.2	6.4	5.8	34.97	65.03
0.6	470.1	472.9	2.8	2.54	37.51	62.49
0.43	435.3	443.9	8.6	7.79	45.3	54.7
0.3	313	320.6	7.6	6.88	52.18	47.82
1.15	420.7	441.9	21.2	19.2	71.38	28.62
0.08	380	410.4	30.4	27.54	98.92	1.08
0.02	298.5	299.7	1.2	1.08	100	0

particle grain size is Figure 13. The graphs reveal very high amount of fine sand and considerable significant coarse silt. Proportion of medium to coarse sand and fine gravel is high as well. Its C_u and C_c are 1.280 and 0.10 respectively, which indicates poor grading.

Table 7: Sieve Analysis Result for Slump Site 5

Sieve Size (mm)	Weight of Sieve	Weight of Sieve and Soil	Weight of Soil Retained	% Retained	Cum. Retained	% Passing
5	476	477.8	1.8	1.38	13.8	98.62
3.35	468.2	468.6	0.4	0.31	1.69	98.31
2.36	426.7	426.9	0.2	0.15	1.84	98.16
2	418	418.3	0.3	0.23	2.07	97.93
1.18	385.7	387.6	2.9	2.23	4.3	95.7
0.85	353.8	356.4	2.6	1.99	6.29	93.71
0.6	470.1	478.5	8.4	6.45	12.74	87.26
0.43	435.3	457.4	22.1	16.97	29.71	70.29
0.3	313	337.9	22.9	17.59	47.3	52.7
0.15	420.7	457.3	36.6	28.11	75.41	24.59
0.08	380	408.2	27.5	21.12	96.53	3.47
0.02	298.5	303	4.5	3.46	99.96	0.04

Table 8: Sieve Analysis Result for Slump Site 6

Sieve Size (mm)	Weight of Sieve	Weight of Sieve and Soil	Weight of Soil Retained	% Retained	Cum. Retained	% Passing
5	476	476.8	0.8	0.97	0.97	99
3.35	468.2	470.7	2.5	3.02	3.99	96
2.36	426.7	428.8	2.1	2.53	6.52	93.5
2	418	418.7	0.7	0.84	7.36	92.5
1.18	385.7	387.9	2.2	2.65	10.01	89.9
0.85	353.8	355.3	1.5	1.81	11.82	88.2
0.6	470.1	470.8	0.7	0.84	12.66	87.3
0.43	435.3	438.3	3	3.62	16.28	83.7
0.3	313	316.9	3.9	4.7	20.98	79
0.15	420.7	437.3	16.6	20.02	41	59
0.08	380	423.3	43.3	52.23	93.23	6.8
0.02	298.5	304.1	5.6	6.76	100	0

Table 7 is the sieve analysis result for slump site 5. Figure 14 is the plot of Percentage Mass Passing (PMP) versus sieve grain size for samples from slump site 5. The bar chart representation of its particle grain size is Figure 15. The chart reveals much fine to coarse sand.

Table 9: Summary of the Geotechnical Attributes

Slump Site	NMC (%)	C_U	C_C	K Cms^{-1}	η (%)	Atterberg Limits		
						LL	PL	PI
1	6.6	2.85	0.764	0.909×10^{-2}	0.4	32	14.5	17.5
2	3.1	0.57	0.148	0.202×10^{-1}	0.484	28	19.9	8.1
3	1.9	5.31	0.711	0.105×10^{-1}	0.34	25	19.9	5.1
4	5.8	1.28	0.1	0.105×10^{-1}	0.456	26	19.5	6.5
5	2.2	3.48	0.999	0.10×10^{-1}	0.39	24	17.3	6.7
6	2.2	1.87	0.912	0.718×10^{-2}	0.43	21.9	13.8	8.1

There is significant amount of coarse sand, fine gravel and coarse silt. C_U and C_C for samples from site 5 are 3.480 and 0.999 respectively, and these indicate poor particle size grading.

Table 8 is sieve analysis results for sample from slump site 6. Figure 16 is the plot of Percentage Mass Passing (PMP) versus sieve grain size for samples from slump site 6. The histogram representation of the grain components is Figure 17. The sample comprises fine sand, medium grained sand, coarse sand and fine gravel. C_U and C_C for samples from site 6 are 1.87 and 0.912 respectively, and these indicate poor particle size grading.

The entire geotechnical attributes at the slump sites are summarized in Table 9. Obtained values of Atterberg limits are similar in magnitude for samples from all the sites. The LL values are less than 40%. Such low LL values are indicative of low clay content. The PL are lower than 20% and this indicates little silt and clay content. Values of PI are less than 7%, which is an indication that the particles are non-plastic to plastic. These obtained values of Atterberg limits imply that slumping in the sites is unlikely to be caused by clay shrinking and swelling. The NMC value obtained from sieve analysis results of samples from site 3 is 1.9%. The NMC value of sample from site 1 (6.6%) and site 4 (5.8%) are larger than the value of site 1 samples. The values for site 2 samples (3.1%) and site 5 samples (2.2%) are higher than the value of site 1 sample. This variation in NMC values indicates that natural moisture content significantly affects slumping in the area. As NMC increases, the internal cohesion that holds the formation particles together is reduced, and this initiates slumping (www.soest.hawai.edu/GG/FACULTY). Well graded formation has a wide spectrum of particle sizes. The presence of many particles of different sizes resists mass movement by promoting internal friction, and therefore internal cohesion. Values of C_U obtained from sieve analysis results for the samples are less than 5%, except at site 3 where C_U value is 5.31%. This implies that samples from the samples are poorly graded, except samples from site 3 which are fairly graded. Such poorly graded sites are susceptible to slumping, as observed at sites except site 3. The NMC test and C_U from sieve analysis show that the slump sites are characterized by high values of NMC poor particle size grading, and consequently low internal cohesion. Any steps taken to increase Internal would therefore arrest slumping at the sites. Some of such steps are the following:

1. Building concrete retaining walls with orthogonal steel drain pipes across exposed slump surfaces. The walls will stabilise the slump surfaces, while the pipes will drain water away from the formation. The result is increased internal cohesion and inhibited slumping.
2. Spraying environmentally friendly formation particles stabilising solution into the formation would improve internal cohesion. One of such solutions is GRT 7000, which largely increases particles cohesion strength and impermeability (thereby preventing increase in NMC).
3. Planting fast growing vegetation will improve particle cohesion, as roots of the vegetation bind formation particles together.

CONCLUSION

Surface geological reconnaissance revealed that the geological formation undergoing slumping is Doko member of the Bida Formation. Its petrographic attributes comprise clay-matrix conglomerate at its base, combined with its vaguely bedded fining upward sequence of medium-fine sand, siltstone and mudstone. Atterberg limits of the formation samples from slumping sites and stable site have similar values. The LL values are low, being less 40%. The low values indicate low clay content. The PL values are less than 20% and they indicate very low silt and clay content. The PI values are lesser than 7%, thus indicating that the formation particles are non-plastic to slightly plastic. These low Atterberg limit values suggest that clay swelling and shrinking is very minimal to absent at the slump sites, and unlikely to be responsible for the observed slumping. Values of C_u indicate that the samples at the dump sites are poorly graded, while the sample at site 3 (where the formation is stable) is fairly graded.

Values of NMC at slump sites vary between 2.2% and 6.6%. These are sometimes triple the value at the stable site, which is 1.9%. The C_u and NMC attributes indicate that poor formation particle size grading and high natural moisture content are responsible for slumping at the slump sites. Since poor formation particle size grading and high NMC diminish internal cohesion and promote slumping, steps that reduce NMC and promote internal cohesion would arrest slumping at the sites. Some of such steps are building concrete retaining walls with steel drainage pipes across the slump surfaces, spraying environment friendly formation particles stabilising solution into the formation, and planting fast growing vegetation on the slump surfaces.

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