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Characterization of Building Foundation Using Geophysical and Geotechnical Techinques: A Case Study of Wollega University Main Campus, Nekemte, Oromia, Ethiopia

Birhanu Gonfa, Fekadu Tamiru and Benti Tesema

Wollega Uinversity, Collegue of Natural and Computional Sciences,
Department of Earth Sciences, Nekemte, Ethiopia

Abstract: A foundation study was conducted at construction site of Wollega University of Nekemte main Campus using integrated geophysical and geotechnical methods. The site is located north of Nekemte city in western Ethiopia, about 328 km from Addis Ababa, the capital city of Ethiopia. The purpose of study was to evaluate the competence of the near surface formations as building foundation materials. Magnetic survey was employed for the geophysical investigations along three profiles and secondary data was used for geotechnical study. The foundation soils data were characterized and classified based on laboratory test result and visual interpretation. Magnetic field data were collected along the profiles were processed using Oasis montaj software in which the total magnetic anomaly and upward continuation maps were produced. The soil samples were tested for attenberg limits, swelling potential, specific gravity, natural moisture content, grain size distribution. The liquid limit, plastic limit and plasticity index of the soils from the study area ranged between 39 - 47%, 23 - 32% and 8 -16% respectively. Thus 87.5% are medium and 12.5% are low expansive soil. It posses low plasticity clay that showed good engineering property. The higher plasticity index causes greater amount of fines and engineering problems associated with such soil for buildings foundation. Natural moisture content varied from 26 to 36 % and further, grain size analysis indicated that the dominant particle size in the soils. Further, grain size analysis indicates that the dominant particle size in the soils from the study area is claygravelsand and gravelclaysand and the mixture of silts fractions are observed. Magnetic anomaly map exhibits good magnetic anomaly contrast interpreted as fractured and fresh igneous rocks. The low magnetic anomaly contrasts were resulted due to weak zones through southern of total magnetic anomaly map that needs special design for heavy structures and large infrastructures.

Key words: Magnetic field · Weak zone · Geotechnical · Clay and gravel soil

INTRODUCTION

Geophysical and geotechnical techniques are important in evaluating/characterizing the physical properties of subsurface in terms of its soil type, soil porosity, depth to bed rock and lithological sequences. Geophysical investigation is basic for the construction site to reveal possible feature of subsurface problems and proffer possible solutions before erection of building [1]. It is also applicable to investigate, detect and determine soil properties, inhomogenities of the subsurface, cavities, ancient relics and generally any underlying structures or bodies that have different physical properties from their geological surroundings [2].

Geophysical techniques are based on the detection of contrasts of different physical properties of materials like magnetic susceptibility, electrical resistivity and density [3]. Therefore, the purpose of a construction site investigation is for the evaluation of foundation material for the proposed structure. Ground investigation is usually required to determine the variation in thickness and nature of the rocks and engineering soils within the zone of influence of the proposed structure [4].

The magnetic method of geophysics measures variations in the Earth's magnetic field to determine the variations of subsurface features. This technique has numerous applications in engineering and environmental studies, including the location of lithological contacts,

Corresponding Author: Birhanu Gonfa, Wollega Uinversity, Collegue of Natural and Computional Sciences, Department of Earth Sciences, Nekemte, Ethiopia.

near-surface faults, dikes and buried ferromagnetic objects based on the differences in their magnetic susceptibility relative to their surrounding Earth materials [5].

Practically all civil engineering works are built on soils or from the soils, detailed understanding of the type, nature and characteristics of the soil is most valuable to civil engineers. Quite different types of soils exist, owing to varied climate, geomorphology and geology, wind load, self-weight of the building, earth quake that determine the building foundations. Buildings need to be safely designed and founded over more suitable Earth materials. Soils of various engineering property, electrical resistivity and magnetic susceptibility have different bearing capacity [6].

Geotechnical investigations provide information on the physical properties of soils underlying a site to evaluate soil conditions that may affect the safety, cost effectiveness and design of a proposed structure. The need for adequate and reliable geotechnical characterization of sub-soils is very important. This is because the impact of the imposed load is exacerbated by the thickness and consistency of the compressible layer [7]. This, in addition to other intrinsic factors contributes to the failure of civil engineering structures [8, 9]. If the foundation studies are not conducted properly, it may affect the performance of the structure and economy of the owner. Any irregularities of the subsurface revealed during excavation of building foundations might change the design of foundation column.

According to [10] foundation is an important part of every building, which interfaces the superstructures to the adjacent soil or rock below it. The construction site locally is covered by thick soils that overlie alluvium deposit (mainly composed of the clay soil) at the most top part and volcanic rocks particularly massive basalt and weathered and fractured basalt. The weathered volcanic igneous rocks, black basaltic rocks are exposed along river, road and surface of surrounding study area. The area is composed of alluvium deposit (mainly composed of the clay soil) at the most top part and volcanic rocks particularly massive basalt and weathered and fractured basalt. The clay seems developed from the in-situ weathering of the underlying basalt and sediments of soil from another area. At many sites it has reddish to black color and variable thickness. The most abundant and dominant volcanic rock unit which composed of mostly basalt is fine grained, black to grayish in color and strongly subjected to weathering.

The integration of geophysical and geotechnical investigation has been carried out to give a meaningful geological interpretation and classify the construction site for its suitability for the sitting of building foundation. The geotechnical surveys give results that are discontinuous (from randomly selected areas), are confined to small areas and are of limited depth.

Geophysical surveys provide continuous subsurface information to identify in-homogeneity and/or discontinuities that affect the building foundation of the proposed structures, where as geotechnical tests such as pit tests and boreholes would probably miss the information. Properly conducted surface geophysical surveys can provide information over relatively large areas on overburden depths and critical geologic structures. Therefore it is in this intention that the integrated geophysical and geotechnical methods were chosen for investigations building foundation for future construction site of the University.

MATERIALS AND METHODS

In this study two integrated methods were applied, namely the magnetic method of geophysics and geotechnical methods. Magnetic method was employed to study the geological structures that affect the building foundation by measuring the magnetic field of the earth whereas the secondary data was used for geotechnical studies to identify the property of subsurface materials.

Geological setting of the Study Area: The study area is characterized by volcanic rocks and thick residual deposits soils, mainly composed of alluvium deposit (mainly composed of the clay soil) at the most top part and volcanic rocks particularly massive basalt, weathered and fractured basalt. The clay seems developed from the in-situ weathering of the underlying basalt. At many sites it has reddish to black color and variable thickness. The most abundant and dominant volcanic rock unit which composed of mostly basalt is fine grained, black to grayish in color and strongly subjected to weathering and varies degree of fracturing. The lithological units of the area was described as clay, highly weathered and fractured basalt, coarse-grained sand and gravel, agglomerate and medium grained sands volcanic rocks like Black basaltic rocks and residual soils.

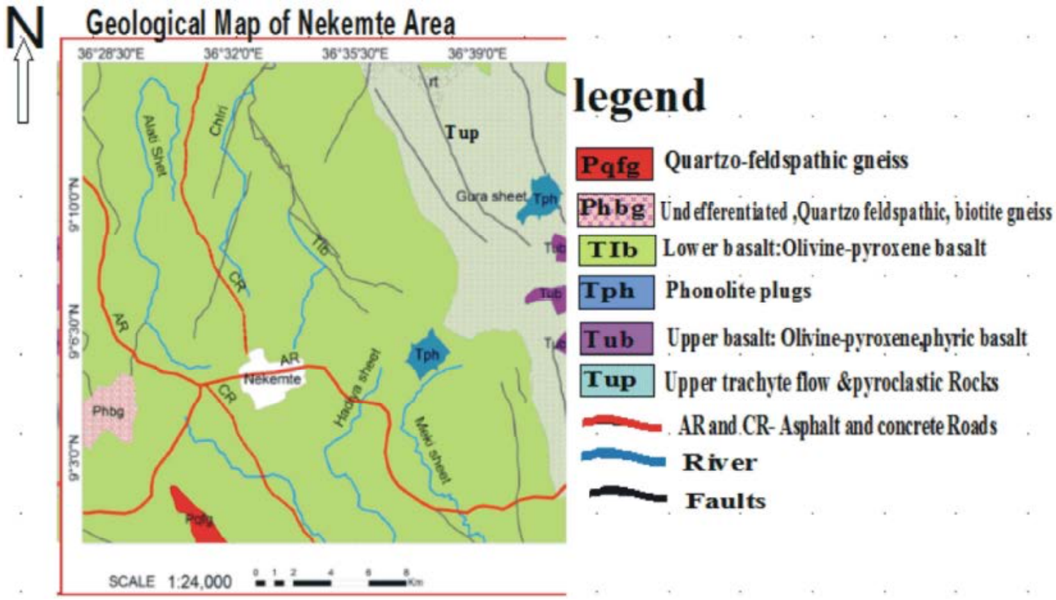

Fig. 1: Geological Map of Nekemte areas

Fig. 2: (a) Top red black clay soil (b) Brown clay soil to 4m depth (c) Columnar joints around study area

Magnetic Field Data Acquisition: The Geometrics G-859 portable proton-precision Magnetometer was used to measure the the variation of the magnetic field of the earth. The Magnetometer measures the total Earth's magnetic field with an accuracy of $\pm 10nT$ and a resolution 0.1nT. During the field work a single base station was established in the survey area. The reading at the base station was made by reoccupying every 30 minute to correct the noises that resulted from diurnal variation. The total magnetic field data were collected along three traverses. Each traverse has a length about 900m to 1000m and the traverse spaced 30m apart from each other. The magnetic reading, time at which reading was made and the location of the data points were recorded at every 30m spacing along the profiles in discrete mode. A total of 83 magnetic data were collected along all the profiles in the study area.

Magnetic Data Processing: The effect of diurnal variation was corrected from the magnetic data using the base station data. After the effect of diurnal variation has removed, the residual magnetic anomaly data was obtained from the difference of diurnal corrected magnetic field and International Geomagnetic Reference Field (IGRF) data. Finally, the upward continuation of data processing was applied to the magnetic anomaly.

Geotechnical Method: Secondary data was used for the geotechnical method where the laboratory test of the soil samples was analyzed by Allonso Geotechnical Service. The soils of the study area were classified on the basis of their engineering and geological properties according to Unified Soil Classification Systems (USCS) and classification proposed by International Association of Engineering Geologists [5]. The analysis includes atterberg limits, swelling potential, specific gravity, natural moisture content, grain size distribution, visual interpretation, vertical geological cross section and different laboratory tests. Four test pits were tested for atterberg limits and swelling potential whereas, among 4 test pits, eight samples were tested for natural moisture content and grain size distribution.

RESULTS AND DISCUSSIONS

Result and Discussion for Magnetic method: Nowadays, the method is used for engineering and environmental applications to locating contacts between rock units, near-surface faults, dikes and buried ferromagnetic objects (storage drums, pipes, etc) based on the differences in magnetic susceptibility between these and the host rocks [11].One of the applications of magnetic method in engineering study is to locate boundaries between different lithologic units and geological structures that produce magnetic anomaly contrasts. The magnetic field data were presented in the total and residual magnetic anomaly map interpretation to study subsurface structure as shown in Figure 4.1. The north western and south eastern part of the study area was described with high magnetic anomaly whereas the south western part showed low magnetic anomaly. All traverses almost lies on high magnetic response.

As indicated from local geology of Figure 2, there is basalt developing fracturing and this might brought a contrast in the magnetic field anomaly at northern and North Western of the study area. This also may be interpreted as dike intrusion at north western part from shallow to deep depth and which has an extension to south eastern part the study area.

Upward Continuation: Figure 4 show the upward continuation maps of the magnetic field up to 50m, 100m, 200m and 400m respectively. It was observed from the map that the trend of possible structure oriented was from northwestern to southeastern. The high magnetic response in the northwestern part of the map might be due weak structures followed by some basaltic intrusion in the area. The fracturing developed following the intrusion was observed to be extended in the southeastern to northwestern orientation that might has also depth.

Result and Discussion for Geotechnical Method

Soil Description: The study area was covered by recent deposit which was formed from the in-situ weathering of volcanic rocks. This was observed from the Standard penetration Test (SPT) of disturbed and undisturbed soils and observation view of excavated area for selected soil for building construction. The type of soil was

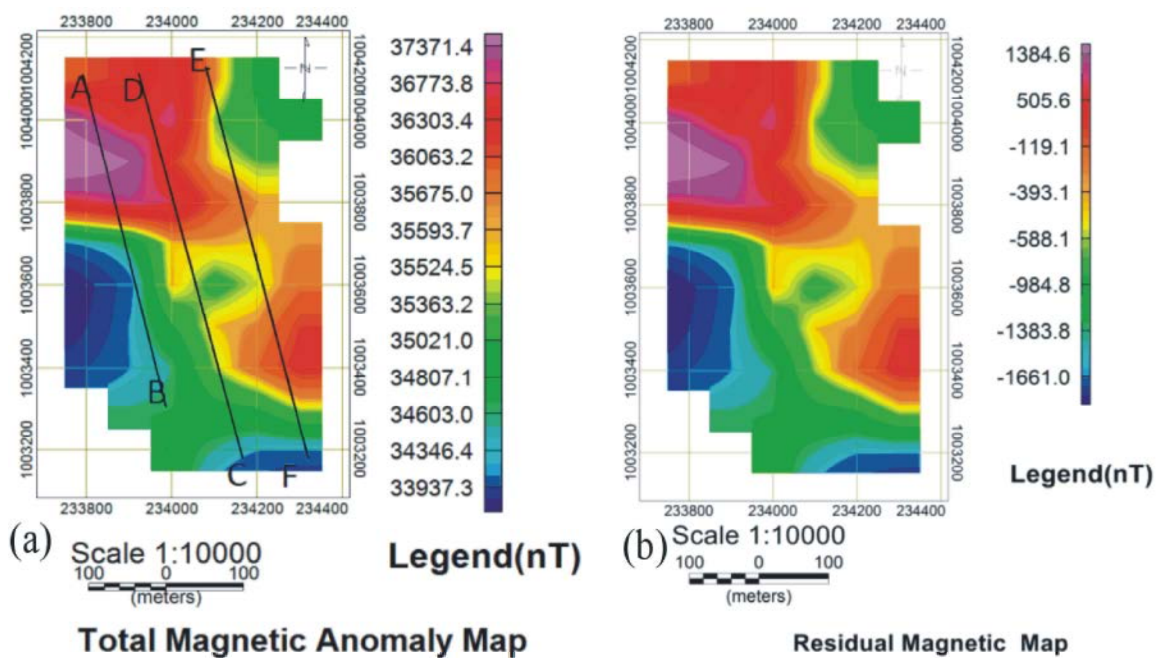

Fig. 3: (a) Total Magnetic Anomaly Map (b) Residual Magnetic Map.

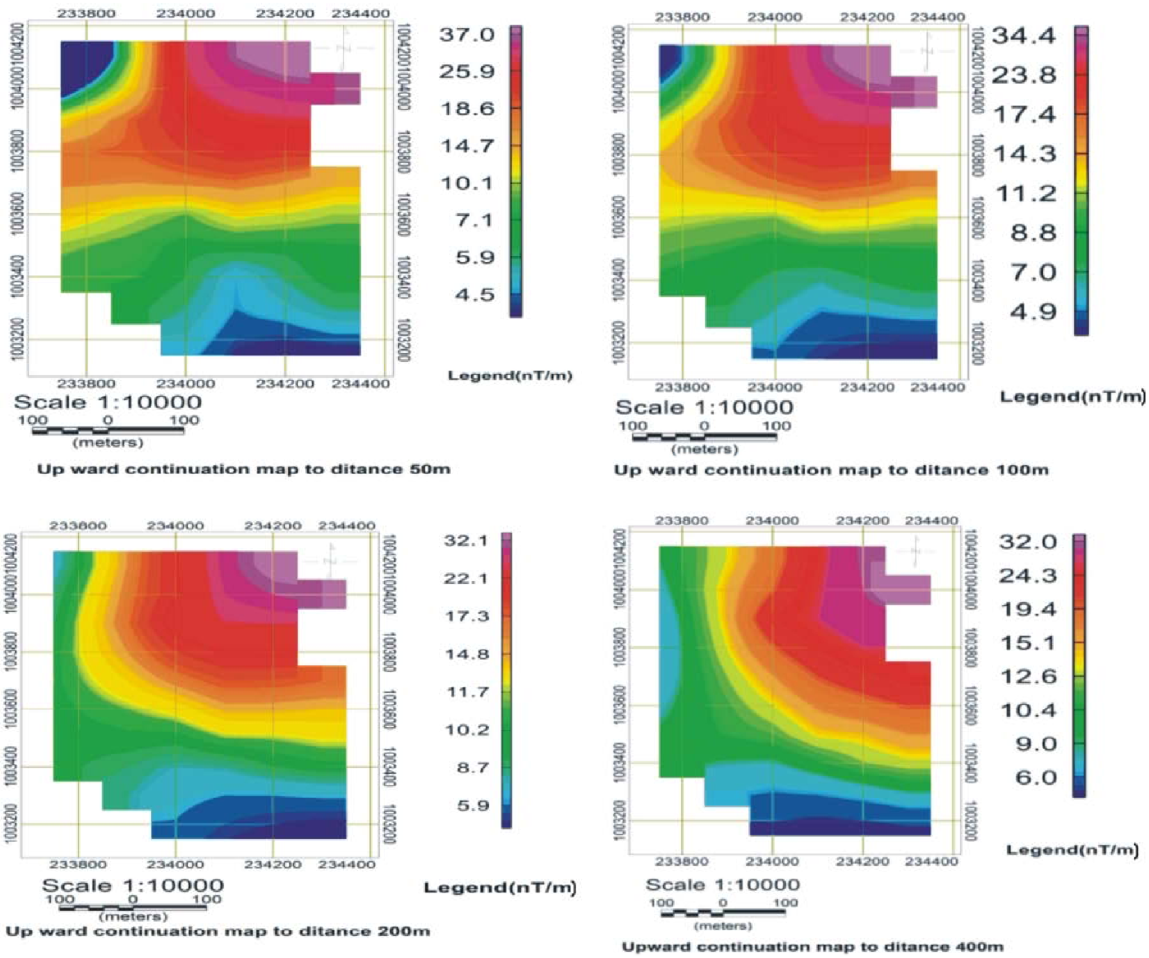

Fig. 4: Upward Continuation (50m, 100m, 200m and 400m distance) of the Magnetic field

differentiated up to 12m by geotechnical method and observation of surrounding rocks at Wollega University, Nekemte Campus. From the sections and close examination of the materials, the soil of the study area grouped into clay and soft rock with clay as shown in table laboratory test result.

From Table 1 the sub-surface geology of the area is almost similar with observed four bore holes. Visual description of samples was made following widely used and practiced international procedures (such as AASHTO, ASTM 2488-93 and BS5930:1981). The surface geology of the proposed construction area for all bore holes posse medium relative density.

Clay Soil: This layer covers clay soils with different rocks and depth in four bore holes. The top part of the entire study area with a general thickness increase from zero to 12m. Its index properties are used to classify the engineering properties of the soils of the study area for the suitability of building foundation, laboratory test were conducted on the 8 samples of representative test pits. The results and descriptions of different index properties are obtainable in the following section.

Natural Moisture Content (NMC): Moisture content can have the significant effect on the behavioral properties of soils when used for the construction purposes and building foundation. Moisture content affects the settlement (consolidation) condition, shear strength and suitability of soil for compaction. Moreover, the swelling-shrinkage condition and consistency of fine grained soil depends on the moisture content. From the laboratory results, the natural moisture content of the soils were determined for the representative soil samples from the study area and thus described in tabular form Table 3. The average natural moisture content of the study area soil was found to be 31.125%, with ranging 26 to 36 %.

Table 1: Standard Penetration Test result from Bore Holes.

S.no	BH No	Top (m)	Base (m)	Material Description	Measured SPT value Depth (m)	SPTvalue@15cm/30cm/45cm	SPTN-Value/ 300mm
1	BH-1	0.00	2.50	Red Clay Soil	-	-	-
		2.50	7.80	Light yellow			
				Claygravel	5.00	5/9/14	23
		7.80	10.50	Deep red clay	8.00	4/10/13	23
		10.50	12.00	Light yellow			
				Claygravel	-	-	-
2	BH-2	0.00	7.90	Red clay soil	4.5	5/14/16	30
		7.90	10.60	Light yellow			
				Claygravel	8.5	5/8/10	18
		10.60	12.00	Light yellow			
				Claygravel	10.00	5/6/10	16
3	BH-3	0.00	3.60	Red clay soil			
		3.60	11.05	Light yellow	4.50	4/7/11	18
				Claygravel	8.00	4/5/8	13
		11.05	11.55	Light yellow	11.00	4/4/9	13
				Claygravel			
		11.55	12.00	Light yellow			
				Claygravel			
4	BH-4	0.00	3.50	Red clay			
		3.50	10.20	Light yellow	4.00	5/6/10	16
				Claygravel	8.00	4/8/11	19
		10.20	10.50	Light yellow			
				Claygravel	11.00	4/7/7	14
		10.50	12.00	Light yellow			
				Claygravel			

Table 2: Undisturbed sample from SPT soil field description

BH.No	Sample No.	Depth(m)	Description
BH-1	S_1	7.85-7.95	Light yellow, claygravel
	S_2	8.50-8.65	Red clay soil
BH-2	S_3	4.00-4.15	Red clay soil
	S_4	6.50-6.70	Red clay soil
BH-3	S_5	4.00-4.30	Light yellow, claygravel
	S_6	6.25- 6.50	Light yellow, claygravel
BH-4	S_7	4.30-4.60	Light yellow, claygravel
	S_8	7.50-7.65	Light yellow, claygravel

Table 3: Density and Moisture Test Result

Bore Hole	Sampling depth (m)	Moisture Content (%)	Dry Density (g/cm^3)	Wet Density (g/cm^3)
BH-1	7.85-7.95	34	15.93	21.35
	8.50-8.65	36	10.48	14.25
BH-2	4.00-4.15	28	8.45	12.82
	6.50-6.70	31	8.26	10.82
BH-3	4.00-4.30	31	17.15	22.46
	6.25-6.50	26	18.19	22.92
BH-4	4.30-4.60	30	15.66	20.36
	7.50-7.65	33	15.74	20.93

Table 4: Sieve Analysis of Test Result

S.No	Sieve size (mm)	Passed Grain Size in percent (%) BH_1S_2	BH_2S_3	BH_2S_4	BH_3S_5	BH_3S_6	BH_4S_7	BH_4S_8
1	75	100	100	100	100	100	100	100
2	63.5	100	100	100	100	100	100	100
3	50	100	100	100	100	100	100	100
4	37.5	100	100	100	90.56	92.68	100	100
5	25	100	100	100	82.34	79.21	94.32	95.68
6	19	100	100	100	69.05	68.29	89.64	83.79
7	12.5	100	100	100	56.08	56.35	77.92	75.52
8	9.5	86.52	95.23	94.08	49.25	51.64	65.02	63.29
9	4.8	72.58	85.12	84.93	33.86	36.71	52.64	54.97
10	2	59.32	72.69	76.31	25.14	24.92	38.67	45.62
11	0.425	46.41	58.64	62.54	19.88	17.36	27.89	35.26
12	0.075	39.92	43.56	47.23	14.39	9.24	14.25	21.47

Table 5: Consistency limits for the soil from the study area.

BH NO	Depth (m)	Description	Soil type	Free swell	(%) Content Moisture content	Wet unit (g/cm^2)	Direct shear C Kpa	Φ (deg)	Attemberg Limit LL	PL	PI
1	7.85-7.95	Light yellow premature soft rock with clay	A-2-7	18%	34	2.14	35	21	41	28	13
	8.5-8.65	Deep red clay	A-6	19%	36	1.43	-	-	39	27	12
2	4.00 -4.15	Red clay soil	A-7-6(1)	19%	28	1.08	39	25	47	32	15
	6.50-6.70	Red clay soil	A-7-6(1)	20%	31	1.08	-	-	44	31	13
3	4.00-4.30	Light yellow claygravel	A-2-6	18%	31	2.25	37	16	39	27	12
	6.25-6.50	Light yellow claygravel	A-2-4	19%	26	2.3	-	-	39	29	10
4	4.30-4.60	Light yellow claygravel	A-2-4	20%	30	2.04	35	16	39	31	8
	7.50-7.65	Light yellow Claygravel	A-2-6	20%	33	2.1	-	-	39	23	16

Particle size analysis: Grain size analysis results for soil samples from the study area are presented in Table 4. The study soil comprises12.5% gravel and 87.5% clay. From the results, the dominant particle size in the soil from the study area is stiff soil (gravel) and clay. A combined sieve and sedimentation procedure enable continuous particle size distribution curve for the given soil sample. Thus, during the present study combined sieve and sedimentation procedure enabled to prepare grain size distribution curve for the soil samples to indicate the proportion of clay, silt and sand fraction.

The grain size distribution curve for the soil samples from 4 test pits in the study area is presented as the following Table 4. From this table 4 BH1,S2 has13.94% gravel, 26.17% sand 6.49% silt and the left 53.4% clay soil; BH2,S3 has10.11% gravel, 26.48% sand, 15.08% silt and the left 48.33% clay soil; BH2,S4 has 9.15% gravel, 22.39% sand, 16.31% silt and the left 53.15% clay soil; BH3,S5 has 56.7% gravel, 13.98% sand, 5.49% silt and the left 23.83% clay soil; BH3,S6 has 55.97% gravel, 19.35% sand, 8.12% silt and the left 16.56% clay soil; BH4,S7 has 41.68% gravel, 24.75% sand, 13.64% silt and the left 80.07% clay soil; BH4,S8 has 40% gravel, 19.71% sand, 13.79% silt and the left 26.5% clay soil. Since clay gravel, gravel clay and the mixture of silty and sand soil of the study area are suitable for huge building construction.

Atterberg Limits: Atterberg limits are important in classifying fine-grained soils. To classify engineering properties of soils, Atterberg limit of selected soil samples were determined in the laboratory. From the results of plastic limit and liquid limit an important parameter, plasticity index is less than 35% indicates the soil possess low plasticity. The liquid limit is a good indicator for the compressibility of the soils.

The larger liquid limit, the greater will be engineering problems associated with using this soil as an engineering material for the foundation support, residential building

Table 6: Moisture Contents (Atterberg limits) of a soil samples

			Attemberg Limit			
BH NO	Depth (m)	Description	LL	PL	PI	Swelling Potential
1	7.85-7.95	Light yellow Claygravel	41	28	13	Medium
	8.5-8.65	Deep red clay	39	27	12	Medium
2	4.0 -4.15	Red clay soil	47	32	15	Medium
	6.50-6.70	Red clay soil	44	31	13	Medium
3	4.00-4.30	Light yellow Claygravel	39	27	12	Medium
	6.25-6.50	Light yellow Claygravel	39	29	10	Medium
4	4.30-4.60	Light yellow Claygravel	39	31	8	Low
	7.50-7.65	Light yellow Claygravel	39	23	16	Medium

and road sub grades. Furthermore, the comparison of liquid and plastic limits with the natural moisture content helps to know the state of soils during the time of sampling. The natural moisture content values are less than the plastic limit values, the soils were in the solid or semisolid state during sampling. Because of their natural moisture contents less than their liquid limits, as a result of this, the soil samples were not show the viscous flow behavior during sampling.

The liquid limit, plastic limit and plasticity index of the soils from the study area ranges from 39 - 47%, 23 - 32% and 8 -16% respectively. The higher plasticity index causes greater amount of fines and engineering problems associated with such soil particularly if such soils forms the foundation for buildings. About 100% of soils from the study area low plasticity clay soils. Since it posses low plasticity clay show good engineering property.

Soils of the study area are fine grained soils. The engineering properties of fine grained soils are mainly depending on the Atterberg limits rather than grain size. Because of this, the classification was done based on the liquid limit and plasticity index.

Swelling Index: Swelling potential can be evaluated by indirect methods of swell classification, which involves the use of soil properties and classification schemes to estimate swell potential, are based on the plasticity index and liquid limit approach [12]. They are useful indices for determining the swelling characteristics of most study area soil. Since the liquid limit and swelling of soils both depend on the amount of water a soil tries to absorb. The change in moisture contents (Atterberg limits) of a soil sample can be used to indicate the degree for potential swell as shown in Table 6.

Based on the indirect approach results of plasticity index, the soils of the study area revealed that 12.5% low and 87.5% medium swelling potential. The free swell test conducted on the collected samples shows that the soil has low to medium swelling capacity

From Table 6 plasticity index exist between 10-35 possess the property of medium expansive soil that have not an effect on building foundation and from bore hole 4 at depth 4.3m to 4.6m light yellow premature soft rock with clay has low plasticity it needs special foundation design.

Shear Strength Test: The shear strength and stiffness of soil determines whether soil will be stable or not. Knowledge of soil strength is necessary to determine slope stability of the building foundation. The soil that has high shear strength possesses better bearing capacity for the building foundation. Furthermore, sampling was done to conduct shear strength test on soil samples to know its shear strength of the study area soil. Direct shear strength test results are presented in Table 4.10.

The result showed that under unconsolidated state the cohesion of the soil ranges from 35 to 39 KN/M^3 where as angle of friction ranges from 16 to 21°.The shear strength of study area soil from engineering suitability chart exhibit fair. Finally, angle of friction and cohesion of the study area soil shows good to fair workability for engineering design of the structures.

From Table 7 all bore holes possess angle of internal friction less than 28° have very loose relative density. In terms of engineering view combined foundation type recommended around such area.

Table 7: Engineering properties of the soil.

№	TP №	Sample	Depth (m)	Shear Strength	
				C (KN/M²)	Φ (Degree)
1	BH-1	S1	7.85-7.95	35	21
2	BH-2	S2	5.20-5.40	39	25
3	BH-3	S3	5.20-5.40	37	16
4	BH-4	S4	4.30-4.60	35	16

Bearing Capacity and Settlement Potential of the Study Area Soil: For the current study, an effort has been made to classify the study building foundation soils based on visual interpretation and index properties. Grain size analysis of the soils from the study area indicates that silt and clay size particles are the main portion and a reasonable amount of sand with premature soft rock are also present.

According to general engineering suitability the CL illustrates impervious permeability, medium compressibility, fair shear strength and good to fair workability. The ML soils exhibit semi-pervious to impervious permeability, medium compressibility, fair shear strength and good workability. The shear strength parameters cohesion ranges from 35kN/m^3 to 39kN/m^3 where as angle of friction ranges from 19° to 21°. By using Meyerhof equation the allowable shearing capacity of study area soil from engineering suitability of the soils exhibit between 288.12kpa and 419.13kpa. Finally, it was concluded that, according to the Ethiopian Building Code Standard EBCS-7, 1995 the construction site soils have good bearing capacity for shallow foundation column.

CONCLUSION

Based on the geophysical and geotechnical methods applied for Characterization of building foundation at Wollega University of Main campus, the study has shown that the higher plasticity index causes greater amount of fines and engineering problems associated with such soil for buildings foundation. The grain size analysis indicates that the dominant particle size in the soils from the study area was claygravelsand and gravelclaysand and the mixture of silts fractions were observed.

Magnetic anomaly map exhibits good magnetic anomaly contrast interpreted as fractured and fresh igneous rocks. The low magnetic anomaly contrasts were resulted due to weak zones through southern of total magnetic anomaly map that needs special design for heavy structures and large infrastructures.

REFERENCES

1. U.S Department of the Interior, 2001. Engineering Geology Field Manual. 2nd edition, 29-30
2. Sirles, P.C., 2006. Use of Geophysics for Transportation Projects. Transportation Research Board of the National Academies, Washington, D.C
3. Bell, F.G., 1983. Fundamentals of Engineering Geology. Butterworth and Co. Ltd., London, pp: 648.
4. Das, B.M., 1994. Principles of Geotechnical Engineering. 3rd Edition, PWS Kent Publishers.
5. IAEG, 1983. Rock and Soil Description and Classification for Engineering Geological Mapping. Report by IAEG Commission on Engineering Geological Mapping, Bull. Int. Assoc. Eng. Geol., 24: 235-274.
6. Anderson, N.L., 2006. Selection of Appropriate Geophysical Techniques: A Generalized Protocol Based on Engineering Objectives and Site Characteristics. Proc., Highway Geophysics-NDE Conference, pp: 29-47.
7. Oke, S.A. and A.N. Amadi, 2008. An Assessment of the Geotechnical Properties of the Subsoil of parts of Federal University of Technology, Minna, Gidan Kwano Campus, for Foundation Design and Construction. Journal of Science, Education and Technology, 1(2): 87-102.
8. Youdeowei, P.O. and H.O. Nwankwoala, 2013. Suitability of soils as bearing media at a freshwater swamp terrain in the Niger Delta. Journal of Geology and Mining Research, 5(3): k58-64.
9. Amadi, A.N., C.J. Eze, C.O. Igwe, I.A. Okunlola and N.O. Okoye, 2012. Architect's and geologist's view on the causes of building failures in Nigeria. Modern Applied Science, 6(6): 31-38.
10. Leow, J.H., 2005. A Study of Building Foundation in Malaysia.
11. Reynolds, J.M., 1998. An Introduction to Applied and Environmental Geophysics, Wiley and Sons.
12. Holtz, W.G. and H.J. Gibbs, 1956. Engineering Properties of Expansive Clays. Transactions. ASCE, 121: 641-677.