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EVALUATION OF PHYSICAL AND GEOTECHNICAL CHARACTERISTIC OF RESIDUAL PROFILE WITH DEPTH OF THREE DIFFERENT BASEMENT COMPLEXES IN NIGER STATE

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ABSTRACT
Disturbed soil samples were collected from three different trial pit at depths of 0.5m interval, to bedrock or 5.0m. at three different basement complexes of (Granite, Schist and Gneiss) physical and geotechnical properties test were carried out on the disturbed samples, test carried out includes index properties, compaction and California Bearing Ratio (CBR), the compaction and California Bearing Ratio (CBR) test of all the soil samples were prepared using British Standard Heavy (BSH) .Evaluation of the variation of physical and geotechnical properties of the weathered basement profiles with depth were made. The result shows that soil sample of Granite and Schist has intermediate plasticity, while that of Gneiss has a low plasticity. The compaction properties of Granite, Schist and Gneiss has maximum dry density (MDD) of 1.9701kg/cm3,2.430kg/cm3 and 2.450kg/cm3 respectively and the Optimum Moisture Content (OMC) of 15.40%, 18.00% and 9.80% accordingly. While that of the California Bearing Ratio (CBR) for both Granite, Schist and Gneiss has the maximum values of 40.42%, 25.85% and 21.60% respectively.

Keywords: *Basement complex, California Bearing Ratio (CBR), Geotechnical, Gneiss, Schist, Residual profile.*

1 INTRODUCTION

Soils are aggregates of mineral particles, and together with air and/or water in the void spaces, they form three-phase systems. A large portion of the earth's surface is covered by soils, and they are widely used as construction and foundation materials. (Braja, 2007). To civil engineers 'soil' means, the loose unconsolidated inorganic material on the earth's crust produced by the disintegration of rocks, overlying hard rock with or without organic matter. Foundations of all structures have to be placed on or in such soil, which is the primary reason for our interest as Civil Engineers in its engineering behavior (Venkatramaiah 2006). Many soil workers in Nigeria may treat laterite weathering products and other residual soils as uniform with depth. This is the main reason why single or few soil test results carried out on soil from trial pit at the beginning of excavation is used to represent soils at deeper depth. The composite and complex nature of the weathering materials and the variation in the morphological, geotechnical, mineralogical and chemical properties of the materials with depth of the weathering profile is usually not taken into consideration. (Adekoya, 1987).

Soils as construction materials are completely different from materials of structural mechanics. The reason is that soils are aggregation of particles, formed by the weathering of rocks, and the behavior of soils is a legacy of natural processes, from their origin to the actual state. This gives soils a character of inhomogeneity and anisotropy, and basic parameters, such as strength, stiffness and hydraulic conductivity, need to be measured instead of being specified and may vary over a wide range. The discrete particles that make up soils are not strongly bounded together, they are free to move relatively among themselves and, when a soil element deforms, the overall deformation is essentially the result of relative sliding between particles and rotation of particles. Therefore, it is not surprising that soil behavior is highly non-linear and irreversible.

Furthermore, it must be realized that the voids or pores between particles are filled with water, or there may be more than one fluid, typically water and air at near surface depths, but there could be water and liquid and gaseous hydrocarbon in certain circumstances. It follows that soils are multi-phase materials, their behavior being influenced by the interaction between solids and fluids (Lancellotta 2009).

Soil is any uncemented or weakly cemented accumulation of mineral particles formed by the weathering of rocks, the void space between the particles containing water and/or air. Weak cementation can be due to carbonates or oxides precipitated between the particles or due to organic matter. If the products of weathering remain at their original location, they constitute a residual soil. If the products are transported and deposited in a different location they constitute a transported soil, the agents of transportation being gravity, wind, water and glaciers (Craig 2004).

Soils which are formed by weathering of rocks may remain in position at the place of region. In that case these are 'Residual Soils'. These may get transported from the place of origin by various agencies such as wind, water, ice, gravity, etc. In this case these are termed ‘‘Transported soil’’. Residual soils differ very much from transported soils in their characteristics and engineering behavior. The degree of disintegration may vary greatly throughout a residual soil mass and hence, only a gradual transition into rock is to be expected. An important characteristic of these soils is that the sizes of grains are not definite because of the partially disintegrated condition. The grains may break into smaller grains with the application of a little pressure.

The residual soil profile may be divided into three zones: (i) the upper zone in which there is a high degree of weathering and removal of material; (ii) the intermediate zone in which there is some degree of weathering in the top portion and some deposition in the bottom portion; and (iii) the partially weathered zone where there is the transition from the weathered material to the unweathered parent rock. Residual soils tend to be more abundant in humid and warm zones where conditions are favorable to chemical weathering of rocks and have sufficient vegetation to keep the products of weathering from being easily transported as sediments (Venkatramaiah 2006).

1.1. Residual Soils and Transported Soils

Residual soils are formed by the in-situ physical and chemical weathering of underlying rock, while sedimentary soils are formed by a process of erosion and transportation followed by deposition and consolidation under their own weight. In addition, the latter may undergo further alteration after deposition due to processes such as secondary consolidation, leaching and thixotropic effects (Bjerrum 1967a). Unloading processes may produce over consolidated clay's. Sedimentary soils may also be subjected to the development of inter particle bonds as well as other post deposited effects (Bjerrum 1967 b). As bonds develop with time in residual soils, hardening occurs. The reverse will be normal trend, as bonds and cementation are broken down by the weathering process.

The behavior of a soil, weather residual or sedimentary, can be considered to depend on two factors; firstly, the nature of the soil particles themselves (i.e., their size, shape, and mineralogical compositions); and, secondly, the particular state in which these particles exists in the soil in its undisturbed condition. For convenience, these factors will be referred to respectively as composition and structure. The term structure will be used here to refer to those aspects of the soil that are peculiar to the soil in its undisturbed state, such as inter particle bonding or cementation, and that are eliminated or destroyed by remolding the soil. With residual soils, the structure results directly from whatever in-situ physical and chemical processes have taken place in altering the parent rock to become a residual soil. With sedimentary soils, the picture appears more complex, as a variety of factors have been involved in the formation of the final structure covering the deposition process, the loading and unloading history, and the post-depositional processes mentioned. The important factors, however, generally lead to a degree of homogeneity and predictability with sedimentary soils that is absent in residual soils (Vaughan, 1988). These are:

a) The sorting process that takes place during erosion, transportation and deposition of sedimentary soils tends to produce homogeneous deposits.

b) Stress history is generally a dominant factor in influencing the behavior of sedimentary soils, and leads to the well-known division of these soils to normally consolidated, and over consolidated materials. The absence of these factors with residual soils means that, in practice, structural effects may be generally more complex and important with residual soils than sedimentary soils. In addition to structural effects, the behavior of residual soil may be markedly influenced by the presence of clay minerals not found in sedimentary soils. Halloysite and allophane in particular are common in volcanic residual soils and have quite different properties from the minerals normally found in sedimentary soils. Hence, both composition and structure should be taken into account in seeking to explain the distinctive aspects of residual soil behavior. The above discussion terms out that there are clear differences between the factors influencing the transported and residual soils. In transported soils the particles are "pre-formed, delivered by some transporting agency and deposited in a certain way.

The soil is then subjected to an increase in effective stress due to increasing burial (normal consolidation) and, sometimes, a subsequent decrease due to removal of overburden (over-consolidation). In the special case of clay deposited from suspension En water, this stress history wholly determines porosity and particle packing. Classical soil mechanics has been developed for particular materials with properties wholly arising from initial porosity and subsequent stress history (Vaughan, 1988).

According to Zonn (1986), all tropical and subtropical soils can be grouped in terms of their profile as:

Soils whose profile depends on textural or structural differentiation.

Soils whose profile are mainly differentiated by texture and

Soil that can further be differentiated by the morphology of the individual generic horizons.

1.2. Soil Formation

Soil are formed by disintegration (technically called weathering), of rocks. The disintegrated or weathered materials may either be found deposited at its own place of origin, or may get transported by agents like water, wind ,ice etc. before deposition . In the first case, the resultant soil is called residual soil; and in the second case is called transported soil. More over depending upon whether the sediments are transported y water, ice, or wind, the soil are called alluvial, glacial, or aeolin respectively. Mechanical weathering disintegrate a pre-existing rock into smaller fragment, while chemical weathering act on this small fragments, rearranged the element into new minerals and thus decomposed them.(Garg 2012).

Soil is defined as a natural aggregate of mineral grains, with or without organic constituents that can be separated by gentle mechanical means such as agitation in water. By contrast rock is considered to be a natural aggregate of mineral grains connected by strong and permanent cohesive forces. The process of weathering of the rock decreases the cohesive forces binding the mineral grains and leads to the disintegration of bigger masses to smaller and smaller particles. Soils are formed by the process of weathering of the parent rock. The weathering of the rocks might be by mechanical disintegration, and/or chemical decomposition. In mechanical weathering the expansive forces of freezing water in fissures, due to sudden changes of temperature or due to the abrasion of rock by moving water or glaciers. Temperature changes of sufficient amplitude and frequency bring about changes in the volume of the rocks in the superficial layers of the earth's crust in terms of expansion and contraction. Such a volume change sets up tensile and shear stresses in the rock ultimately leading to the fracture of even large rocks. This type of rock weathering takes place in a very significant manner in arid climates where free, extreme atmospheric radiation brings about considerable variation in temperature at sunrise and sun set, and the chemical weathering (Murthy 2012).

Composition, structure and properties of a natural soil element are the result of its geological history. This history includes weathering, transportation, deposition and post-depositional changes. The actual state of homogeneity and anisotropy of any soil deposit is related to this formational history and to subsequent changes, summarized in Figure 1.1 and discussed in detail in the sequel (Lancellotta 2009).

This work is therefore aimed at determining the variation of the physical and geotechnical properties of residual soils derived from three different basement complexes of weathered schist, granite and gneiss at Tudun Fulani dam site and Birgi village all in Minna and Kateregi mining village in Kacha local government area all in Niger state respectively.

2 MATERIALS AND METHODS

Three locations were identified on the basement complexes of weathered schist, granite and gneiss origin. Three trial pits were then dug manually on each of the identified location. Both disturbed and undisturbed soil samples were collected from 0.5m to bedrock or 5.0m depth at interval of 0.5m and profile inspected manually. The sample were carefully labeled in sample bags and then taken to the laboratory in sealed polythene bags to prevent contamination and loss of moisture.

Physical properties tests including, natural moisture content (NMC), sieve analysis, liquid limit, plastic limit, specific gravity (S.G) were conducted while the geotechnical properties tests include compaction – British standard heavy (BSH) and California bearing ratio(CBR) which was conducted at a predetermined optimum moisture content (OMC) and maximum dry density (MDD). All these tests were conducted according to the procedure highlighted in BS8110 (1990) with some modifications where necessary.

3 DISCUSSION AND RESULTS

3.1. Physical properties

The physical properties of studied sample are shown in table 1, 2 and 3, the natural moisture content (NMC) of granite basement increased between 10.30%, 16.90%, 20.50%, 24.10% at 0.5m to 2.0m where it decreased again between 22.40%, 21.80%, 22.60%, and 22.70% at 2.5m to 4.0m and subsequently increased to 25.90% and 26.30% at 4.5m and 5.0m, with that of weathered gneiss ranges from 9.70%, 10.81%, 13.78% at 0.5m -1.5m then decreased to 12.97%,11.49% 8.31% and 7.62% at 2.0m-3.5m and increased to 7.90% at 4.0m, while that of weathered rock from schist from 5.96% to 5.57% at 0.5m -1.0m and increased to 8.88% at 1.5m then decreased to 6.35%, at 2.0m increase to 8.22%, at 2.5m before decreasing to 4.60% and 4.44% at 3.0m and 3.5m respectively. Natural moisture content is the function of void ratios and the specific gravity of the samples. Although it is not a constant property of soils. This values are consistent with the fine content of the clays (Ademila *et al.*, 2017).

The liquid limit for Granite basement increased from 46.02% at o.5m to 50.50% at 2.0m depth from where it decreased to 46.20% at 2.5m and increased to 48.80% at 3.5m and falls to 46.00% at 4.0m and increased to 48.20% at 4.5m before finally decreased to 46.20% at 5.0m, with that of gneiss basement increased from 29.0% at 0.5m to 30.80% at 1.0m and continuous decreasing from 30.50% at 1.5m 30.00% 2.0m, 29.00%, at 2.5m, 27.80% at 3.0m, and increased to 28.60% and 30.80% at 3.5m and 4.0m. While that of rock from schist basement decreased from 36.005 at 0.5m to 35.01% at 1.0m and increased from 35.50% to 40.00% at 1.5m and 2.0m then falls to 39.10% at 2.5m decreased to 39.00% at 3.0m and finally increased to 39.90% at 3.5m. Liquid limit less than 30% indicate low plasticity, between 35% and 50% are intermediate plasticity. Between 50% and 70% high plasticity, between 70% and 90% indicates very high. plasticity and greater than 90% indicates extremely high plasticity (R. Whitlow 1995).

On this basis the granite and schist basement are termed to be of intermediate plasticity, while that of gneiss basement show low plasticity. Liquid limit of soil use for barriers lining should be less than 90% (Declan *et al.*, 2003). Therefore, all the samples studied can be used as barriers liners hence they are less than 90%. Plastic limit for granite basement decreased from 37.75% at 3.5m depth to 27.75% at 0.5m depth and that of gneiss basement varies from 0.00% at 0.5m to 27.37% at 2.5m. While that of schist basement was 0.00% for all depths. This shows that the granite basement is suitable for production of ceramic clay (Grimsha, 1971) prescribed a range of 10-60% for clay used in ceramic production.

The value of plasticity index (an indicator of soil plasticity) of granite basement ranged from 18.26% at 0.5m depth and 9.24% at 5.0m depth and that of gneiss basement ranged from 30.80% at 5.0m and 4.74% at 1.5m while that of schist basement ranges from 40.00% at 2.0m depth and 35.01% at 1.0m depth. The schist basement has the highest plasticity index of 40.0% and gneiss having the lowest plasticity index, the schist basement has a high swelling and high compressibility characteristics. The difference in the plasticity index may be due to the presence of clay minerals in the mineralogy of the soil samples (Rowe et al., 1995).

Specific gravity for granite basement ranged from 2.77 at 1.5m depth to 2.54 at 2.5m depth and that of gneiss basement ranged from 2.92 at 0.5m depth to 2.58 at 2.0m depth, while that of schist basement ranged from 2.66 at 3.5m depth and 2.58 at 0.5m depth. Specific gravity is an important property in the identification and evaluation of aggregate parameters for construction purposes. The higher the specific gravity of the soil, the better it is for construction purposes (Ademila *et al., 2017).*

TABLE I: PHYSICAL PROPERTIES OF WEATHERED GRANITE WITH DEPTH

BIRGI SAMPLES										
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**
Natural moisture content (%)	10.30	16.90	20.50	24.10	22.40	21.80	22.60	22.70	25.90	26.30
Specific gravity Gs	2.71	2.64	2.77	2.68	2.54	2.59	2.66	2.69	2.68	2.66
Liquid limit ''LL" (%)	46.02	49.20	49.60	50.50	46.20	46.00	48.80	46.00	48.20	46.20
Plastic limit "PL"(%)	27.70	28.54	36.5	36.07	36.07	35.02	37.75	35.71	36.93	36.96
Plasticity Index "PI" (%)	18.26	20.66	13.10	14.43	10.13	10.98	11.05	10.29	11.27	9.24
Percentage passing sieve No. 200 (0.075mm)	35.47	53.40	56.97	52.00	48.10	49.30	47.90	53.37	62.60	63.70
AASHTO classification	A-7-6	A-7-6	A-7-6	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5	A-7-5
Plasticity	CI	CI	CI	CI	MI	MI	MI	MI	MI	MI

TABLE II: PHYSICAL PROPERTIES OF WEATHERED GNEISS WITH DEPTH

KATEREGI SAMPLES								
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Natural moisture content (%)	9.70	10.81	13.78	12.97	11.49	8.31	7.62	7.90
Specific gravity Gs	2.92	2.68	2.62	2.58	2.69	2.68	2.71	2.71
Liquid limit ''LL" (%)	29.00	30.80	30.50	30.00	29.00	27.80	28.60	30.80
Plastic limit "PL"(%)	0.00	21.12	25.76	24.19	27.37	0.00	0.00	0.00
Plasticity Index "PI" (%)	29.00	9.68	4.74	5.81	1.63	27.80	28.60	30.80
Percentage passing sieve No. 200 (0.075mm)	27.87	34.00	29.30	30.80	28.87	24.57	27.63	24.67
AASHTO classification	A-6	A-5	A-4	A-4	A-4	A-6	A-6	A-2-6
Plasticity	CL	ML	ML	ML	ML	CL	CL	CL

TABLE III: PHYSICAL PROPERTIES OF WEATHERED SCHIST WITH DEPTH

TUDUN FULANI							
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**
Natural moisture content (%)	5.96	5.57	8.88	6.35	8.22	4.60	4.44
Specific gravity Gs	2.58	2.62	2.60	2.65	2.62	2.57	2.66
Liquid limit ''LL" (%)	36.00	35.01	35.50	40.00	39.10	39.00	39.90
Plastic limit "PL"(%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plasticity Index "PI" (%)	36.00	35.01	35.50	40.00	39.10	39.00	39.90
Percentage passing sieve No. 200 (0.075mm)	40.77	34.80	22.17	30.73	37.23	32.23	29.90
AASHTO classification	A-6	A-2-6	A-2-6	A-2-6	A-6	A-6	A-2-6
Plasticity	CI	CI	CI	CI	CI	CI	CI

3.2. Geotechnical properties

3.2.1. Compaction

The maximum dry density (MDD) for granite weathered basement varied between 1.9701 Kg/ cm3 and 1.8753 Kg/cm3 at depth 3.5m and 5.0m.while the optimum moisture content (OMC) ranged between 15.40% and 8.54% at depth of 1.5m and 4.0m (Table 1. Also the maximum dry density (MDD) for gneiss basement varied between2.450kg/cm3 and 2.260kg/cm3 at depth of 3.5m and 1.0m while the optimum moisture content (OMC) ranged between 9.80% and 7.00% at depth of 1.0m to 4.0m. (Table ii. Also that of schist basement varied between2.430kg/cm3 and 1.910kg/cm3 at depth 2.0m and 3.5m and the optimal moisture content varied from 18.00% to 9.00% at 1.0m and 3.0m depth. Table iii. The observed results for all the samples show that the higher the MDD, the lower the OMC. The results of the MDD and OMC show that the samples can be used as filling and embankment materials because they fall within the specification (FMW&H.2000).

TABLE I: GEOTECHNICAL PROPERTIES OF WEATHERED GRANITE WITH DEPTH

BIRGI SAMPLES										
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**
Maximum dry density (kg/cm3)	1.954	1.927	1.875	1.902	1.950	1.950	1.970	1.969	1.929	1.892
Optimum moisture content (%)	12.54	14.16	15.40	12.94	12.10	12.10	10.32	8.54	10.46	11.83
California bearing ratio (CBR)	31.63	25.5	40.42	29.92	25.61	32.02	14.43	27.10	19.50	15.80

TABLE II: GEOTECHNICAL PROPERTIES OF WEATHERED GNEISS WITH DEPTH

KATEREGI SAMPLES								
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Maximum dry density (kg/cm3)	2.274	2.260	2.360	2.350	2.340	2.450	2.450	2.400
Optimum moisture content (%)	9.68	9.80	7.60	8.40	9.70	7.40	7.40	7.00
California bearing ratio (CBR)	5.2	0.40	0.62	4.48	12.4	20.5	16.2	21.60

TABLE III: GEOTECHNICAL PROPERTIES OF WEATHERED SCHIST WITH DEPTH

TUDUN FULANI SAMPLES							
Depth (m)	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**
Maximum dry density (kg/cm3)	2.108	2.080	2.080	1.910	2.100	2.090	2.430
Optimum moisture content (%)	10.20	18.00	17.50	17.00	11.00	9.00	11.50
California bearing ratio (CBR)	6.08	0.51	5.50	0.80	17.90	25.85	24.00

3.3. California bearing ratio (CBR)

The California bearing ratio (CBR) is often used in estimation of the bearing capacity of soil, which are used as highway sub-base, sub-grade and base course materials, the result obtained from these work shows the unsoaked CBR value for granite basement rock ranged from 40.42% at 1.5m and 14.43% at 3.5m depth, while that of gneiss basement rock ranged between 21.60% at 4.0m and 0.40% at 1.0m, also the schist basement rock CBR values ranged between 25.85% at 3.0m and 0.51% at 1.0m with these results none of the samples have meet the required value of 80% for unsoaked and 30% for soaked samples as recommended for highway sub-base and sub grade materials by federal ministry of works and housing (FMW&H, 2000).

4 CONCLUSION

It was observed that all the soil samples studied possess liquid limits within the range considered suitable for use in landfill liner systems. The compaction values of all the soils are considered good, if 100% of the MDD and OMC are attained during field compaction. The relatively good values of compaction properties possessed by these soils makes them good for engineering construction materials.

The CBR test shows that the entire studied soil did not meet up with the general specification requirement for roads and bridges recommended by federal ministry of works, which is 80% for unsoaked and 30% for soaked but can be used as filling materials.

The granite and schist basement samples are granular materials with plasticity index greater than 12% which may be considered suitable for barrier as notable increase in permeability is not expected, and can be used to make structural blocks, bricks.

It is observed that all physical properties of residual soils studied varied with depth and results obtained for soils at one layer should not be used to represent the result of soils at other layers for the avoidance of in accurate design of soil structures which may lead to its failure on application of the first load.

REFERENCE

Adekoya, J.A. (1987). “Preliminary Geological and Geotechnical Study of Lateritic Weathering Profiles Derived from Banded Gneiss in the

Ibadan Area, S.W Nigeria", *Proceedings of 9th Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Lagos, Nigeria, 21*-30 doi/ 10.22606/gr.2017.22006

Ademila, O. & Adebanjo, O.J. (2017). Geotechnical and Mineralogical characterization of clay deposit in part of south western Nigeria. *A journal of a Geoscience research* 2(2), 127-137

Bjerrum, L. (1967b). Progressive failure in slopes of over consolidated plastic clay and clay shales. Soil mech. and found. Engg. Div., SCE, 93(5), 3-49.

Braja, M.D. (2006). Principle of geotechnical engineering fifth edition published by Hemisphere publishing corporation and McGraw-Hill.

Craig, R.F. (1974) Soil mechanics seventh edition. Spon press, New York, ISBN.12

Declan, O. & Paul, Q. (2003). "Geotechnical engineering and environmental aspects of clay liners for landfill projects," *Technical paper 3*, Fehily Timoney and Co. and IGSL limited

Federal Ministry of Works and Housing, (2000) "Specification for roads and bridges," 2:137-275

Garg.S.K (2012) Soil mechanics and foundation engineering 8th revised edition Khanna publishers New Delhi-110002

Grimshaw, R.W. (1971). The Chemistry and Physics of clays and allied ceramic materials," 3rd Edition, *Ernest Benn Limited*, 801-802

Leroueil, S. & Vaughan, P.P. (1990). The general congruent effect of the structure natural and weak rocks. Geotechnics 40(3), 467-488.

Murthy, V.N.S (2002). Geotechnical Engineering: Principle and practice of soil mechanics and foundation Engineering, Marcel Dekker Inc. New York, published by CRC press. 8,

Renota, L. (1995) Geotechnical engineering second edition published by Taylor and Francis

Rowe, R. K., Quigley, R. M. & Booker, J. R. (1995). Clayey barrier systems for waste disposal facilities," *E and FN Spon*, London,

Venkatramaiah, C. (2006). Geotechnical Engineering, Revised Third Edition, New Age International (P) Limited, Publishers, Ansari Road, Daryaganj, New Delhi – 110002, 6

Whitlow, R. (1995). Basic soil mechanics," *3rd Edition Addison Wesley Longman Limited,* Edinburgh gate

Zonn, S.V. (1986) Tropical and subtropical soil science. Mir publishers, Moscow, USSR, 31-32