Evaluation of plasticity and consolidation characteristics of migmatite–gneiss-derived laterite soils

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Abstract

Information on plasticity and consolidation characteristics of soil materials have been found to be profoundly important for preliminary structural planning and designs since these properties influence soils' compressibility and settlement characteristics and, by extension, the performance of any engineering structure on the soils. The dependency or relationship of consolidation characteristics with plasticity characteristics of remolded migmatite–gneiss-derived laterite soils from southwestern Nigeria was statistically evaluated. A total of eight (8) bulk disturbed soil samples were subjected to Atterberg limits tests and one-dimensional consolidation tests following British Standard BS 1377 methods. Further, the results obtained were subjected to regression analysis. The plasticity index (PI), linear shrinkage, and shrinkage index values ranged from 8.0 to 33.65, 4.3 to 10.7, and 19.0 to 50.2, respectively. The average coefficient of consolidation (C_v) and compression index (C_c) values ranged from 0.02184 to 0.03290 mm²/min and 0.0203 to 0.0812, respectively. The correlation coefficient of compression index values with plasticity index and shrinkage index values is 0.90 and 0.72, respectively. The coefficient of correlation (r) of the relationship between consolidation coefficient values and consolidation pressure (AP) values of 20–160 kPa (loading session only) is 0.97. The coefficients of correlation (r) of average consolidation coefficient values with linear shrinkage, shrinkage index, and plasticity index values are 0.60, 0.73, and 0.88, respectively. Hence, coefficient of consolidation and compression index have better correlations with plasticity index over shrinkage index and linear shrinkage. Further, the correlation coefficient of plasticity Index (PI) with all the consolidation coefficient values, derived at each stage of effective vertical consolidation pressures (AP) of 20–160 kPa (loading and unloading), is 0.79. Based on these results, correlation equations for predicting consolidation coefficient and compression index were proposed. This evaluation has aided better understanding of the relationship between consolidation and plasticity characteristics of migmatite–gneiss-derived laterite soils and can be applied to several other basement terrains.

Keywords Consolidation characteristics · Plasticity characteristics · Migmatite–gneiss-derived laterite soils · Correlation equation

1 Introduction

The safety, reliability, and overall stiffness of structures are affected by heterogeneity and, by extension, the differential settlements of the soil [1]. This was evident in the coastal areas of India where foundations of buildings settled from 10 to 100 cm/s. This alarming settlement rate was traced to several reasons such as consolidation,

creep failure due to excessive loading, volume reduction in soil due to shrinkage, and settlement due to reduction in water content [2]. Shanyoung et al. [3] found that as the amount of fines in weathered granite increases, the permeability decreases due to a reduction in void ratio. However, they reported that the coefficient of consolidation increases with higher fines content. With increasing clay-size fraction, the soil becomes more plastic, and its

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swelling and shrinkage potential increases and so does its compressibility [4]. Therefore, induced settlement of soil is a function of the increase in pore water pressure caused by the loading, the reduction in pressure over time, and permeability of the in situ soils. Otoko [5] studied the dependence of shear strength and compressibility on clay content of some tropical laterite soils and established that compressibility has a direct proportionality with clay content. From the above considerations, clayey soils generally possess low void ratio, and, under saturated condition and increased pore water pressure caused by loading, they settle. Hence, plasticity index, compression index, and void ratio have profound influence on compressibility and settlement characteristics of soils and, by extension, the performance of any engineering structure.

To avoid settlement, routinely one-dimensional consolidation test is usually carried out to determine the settlement parameters of soils, namely compression index (C_c), consolidation coefficient of volume compressibility (M_v), and swelling index (C_s). This complex but important test requires overwhelming experimental time and cost. There is therefore a need to understand the variability of plasticity and consolidation characteristics of soils upon loading and unloading of consolidation pressures. This is important since consolidation test requires continuous addition of vertical effective consolidation pressure which gradually affects the rate of settlement of soil with time.

The parent rock factor determines the engineering properties and behavior of residual soils [6]. For instance, biotite, feldspar, and hornblende in migmatite–gneiss would make the derived soil more plastic and hydrophilic [7]. The high amount of fine-grained particles, especially silt-sized micaceous particles in the migmatite–gneiss-derived soils, has been attributed to the presence of micas that constitute bulk of the minerals in the parent rock [8]. Migmatite–gneiss-derived soils are well graded with low to slightly high plasticity [9]. This is supported by the Casagrande chart classification of the migmatite–gneiss-derived soils studied by [7] which indicated high plasticity.

Various researchers have attempted to correlate index properties with consolidation characteristics of soils [5, 10–16]. Owoyemi and Adeyemi [17] recommended detailed sampling, statistical analysis, and geological considerations as a basis for the determination of parameters often utilized for foundation design. Solanki and Desai [18] showed that plasticity index correlates with coefficient of consolidation with coefficient of correlation of 0.97 (Eq. 1).

$$C_v = 7.7525 * I_p^{-3.1025} \quad (1)$$

where C_v = coefficient of consolidation in cm^2/s and I_p is plasticity index.

Sridharan and Nagaraj [12] proposed a better correlation equation for predicting coefficient of consolidation in terms of shrinkage index rather than plasticity index for the natural soils and kaolinites (Eq. 2).

$$C_v = \frac{3}{100(I_s)^{3.54}} \quad (2)$$

where C_v = coefficient of consolidation in m^2/s , with coefficient of correlation (r) = 0.94.

Devi et al. [15] observed that better correlation exists between coefficient of consolidation and liquid limit than for plasticity index and shrinkage index of the five (5) clayey soils (Eq. 3).

$$C_v = -4 \times 10^{-9} W_L + 4 \times 10^{-7} \quad (3)$$

where C_v = coefficient of consolidation in m^2/s and W_L = liquid limit, with coefficient of determination (R^2) = 0.8298.

Sridharan and Nagaraj [11] found that shrinkage index better correlates with compression index of the studied soils rather than plasticity index or liquid limit (Eq. 4) with correlation coefficient of 0.96.

$$C_s = 0.007(I_s + 18) \quad (4)$$

where C_s = compression index and I_s = shrinkage index.

Adepoju et al. [19] stressed that compressibility of soils is a function of reduced initial volume of void and increased hydraulic conductivity of soils. In order to avoid the overwhelming experimental time and cost involved in determining the complex but important one-dimensional consolidation test on soils, researchers have established some correlations between coefficient of consolidation and varying plasticity properties of clayey soils. Most consolidation–plasticity property correlations done in the past usually exempt linear shrinkage property (e.g., [10–12, 14–16]). Also, a little emphasis has been paid to generating correlation models for variation in index properties with consolidation properties of migmatite–gneiss-derived laterite soils (e.g., [5, 10, 12, 13]). This study, therefore, incorporates linear shrinkage property with other plasticity properties, namely plasticity index and shrinkage index, in the determination of which plasticity property correlates best with coefficient of consolidation. Further, it attempts to generate correlation models for determining coefficient of consolidation.

2 Geological setting and test methods

The study area is located in the southwestern part of Akure metropolis within latitudes $7^\circ 12' \text{N}$ and $7^\circ 14' \text{N}$ and longitudes $5^\circ 09' \text{E}$ and $5^\circ 11' \text{E}$ (Fig. 1). It is part of the tropical rain forest zone of Nigeria with temperature

Fig. 1 Topographic map of Akure environs (Federal Surveys, Nigeria, [22])

subjective to rain-bearing southwest monsoon winds from the ocean and dry northwest winds from the Sahara desert. The annual rainfall is estimated at about 2000 mm [20], with relative humidity of about 80%. The mean monthly temperature varies between 25.7 and 30.2 °C [21]. The topography of the area can be described as having high rising or inselberg outcrops in the eastern part of the study area, while low-lying outcrops occupy the other parts. The area studied is drained by Ogburugburu River which runs in the east–west direction in a dendritic pattern (Fig. 1).

The study area is underlain by rocks of the migmatite–gneiss–quartzite complex of Nigeria (Fig. 2). Kayode and Akinwumi [23] reported that quartz, feldspar, biotite, hornblende, muscovite, and opaque minerals occupy 88% (by volume) of the migmatite rocks. The migmatite–gneisses have both melanocratic and leucocratic portions. The melanocratic component is composed of mafic minerals (containing more magnesium and iron). The leucocratic component ranges from fine-grained granitic gneisses to medium-grained banded gneisses [24] and is composed of relatively more felsic minerals (silicate minerals) which contain lighter elements, such as silicon, oxygen, aluminum, sodium, and potassium. Pegmatite and quartz vein occur as intrusions in nearly all the various rock types, and they cut across the different rocks concordantly or discordantly and sometimes occupy the joint spaces [24]. Texturally, the migmatite–gneisses are medium- to coarse-grained rock with light gray varying to pinkish rocks [25]. The differences in textural and mineralogical characteristics of parent rocks could be responsible

for significant differences in the engineering properties of the derived soils [26]. Therefore, parent rock factor is expected to have some significant influence on the engineering properties of laterite soils [27].

Eight disturbed representative bulk samples of migmatite–gneiss-derived laterite soil were collected at depth of 1.0 m each from eight trial pits within the study area. The soil samples were preserved in polythene bags and labeled S1 to S8. The soils were subjected to Atterberg limits test and one-dimensional consolidation test in accordance with the British Standard (BS 1377) [29] specifications. For the consolidation test, load increment stresses of 20, 40, 80, and 160 kPa were applied and then unloaded at predefined time intervals.

3 Results

The results of the geotechnical tests are presented in Tables 1, 2, and 3.

4 Discussion

4.1 Plasticity characteristics

The plasticity index values of the soil samples varied from 8.0 to 33.65, linear shrinkage values varied from 4.3 to 10.7, and shrinkage index values ranged from 19.0 to 50.2 (Table 1). According to Ola [30] who related plasticity index to swelling potential (Table 4), 25% of the soils

Fig. 2 Geological map of Akure area (Adapted from Nigeria Geological Survey Agency, [28])

Table 1 Results for Atterberg limits tests

Sample no.	MC (%)	LL (%)	PL (%)	PI	LS	SI
S1	13.5	31.5	23.5	8.00	4.3	19
S2	14.1	34.1	19.1	15.03	8.6	24.5
S3	18.1	49.4	21.4	28.00	7.1	38.8
S4	22.7	58.4	24.8	33.65	10.7	50.2
S5	16.6	40.8	20.1	20.70	7.9	30.7
S6	21.1	42.9	21.9	21.00	10.0	34.2
S7	11.1	33.8	20.0	13.80	7.1	23.2
S8	13.4	48.9	33.3	15.58	7.9	38.8

MC in situ moisture content; LL liquid limit; PL plastic limit; PI plasticity index; LS linear shrinkage; SI shrinkage index

possess low swelling potential, 25% of the soils possess medium swelling potential, and 50% of the soils possess high swelling potential. This result is consistent with Adeyemi [26] who noted that a great majority of samples of migmatite–gneiss-derived soil have high plasticity.

According to Bell [31] who classified plasticity using liquid limit values (Table 5), 37% of the soils possess low plasticity, 50% of the soils possess intermediate plasticity, and 13% of the soils possess high plasticity.

Table 2 Results for coefficient of consolidation, C_v , from the one-dimensional consolidation test

Pressure change (kPa)	Coefficient of consolidation (mm^2/min)							
	S1	S2	S3	S4	S5	S6	S7	S8
Loading								
20	0.033827	0.032355	0.027760	0.026820	0.027462	0.028111	0.033579	0.032896
40	0.033754	0.031841	0.025962	0.024778	0.025585	0.026405	0.033431	0.032543
80	0.034363	0.031735	0.023852	0.022307	0.023359	0.024435	0.033918	0.032696
160	0.032854	0.029563	0.019993	0.018182	0.019412	0.020682	0.032293	0.030761
Unloading								
80	0.032128	0.029264	0.020816	0.019189	0.020295	0.021431	0.031641	0.030309
40	0.031577	0.029119	0.021758	0.020317	0.021298	0.022301	0.031161	0.030018
20	0.031807	0.029524	0.022639	0.021280	0.022205	0.023150	0.031421	0.030360
Average	0.03290	0.03049	0.02325	0.02184	0.02280	0.02379	0.03249	0.03137

kPa kilopascal

Table 3 Results for coefficient of volume compressibility, M_v , and compression index, C_c

Samples no.	M_v (mPa^{-1})	M_v in percentage (%)	Compression index
S1	0.102713209	5.28973053	0.0203
S2	0.158424615	8.158868043	0.0327
S3	0.347769828	17.91014701	0.0714
S4	0.389824279	20.07595132	0.0812
S5	0.36099494	18.59124033	0.0748
S6	0.332404444	17.11882967	0.0618
S7	0.111934009	5.764601741	0.0229
S8	0.137682156	7.090631365	0.028

 M_v coefficient of volume compressibility (mPa^{-1})**Table 4** Relationship between plasticity index and swelling potential (Ola [30])

Plasticity index	Swelling potentials	Results (%)
0–15	Low	25
15–25	Medium	25
25–35	High	50
> 35	Very high	

Table 5 Classification of plasticity characteristics using liquid limit values (Bell [31])

Plasticity	Range of liquid limit (%)	Results (%)
Low plasticity	< 35	37
Intermediate plasticity	35–50	50
High plasticity	50–70	13
Very high plasticity	70–90	
Extra high plasticity	> 90	

The plasticity results were plotted on the Casagrande [32] chart classification, and 88% of the soils plot within the field of inorganic clay, while 12% of the soils plot within the field of inorganic silt (Fig. 3). Detailed classification reveals that 37% of the soils plot within clay of low plasticity (CL) and clay of medium plasticity (CI) each, while 13% of the soils plot within clay of high plasticity (CH) and silt of medium plasticity (MI) each (Fig. 3). According to Casagrande [32], soil samples with low, medium, and high plasticity will have low, medium, and high compressibility, respectively.

4.2 Consolidation characteristics

There is corresponding variation in the distribution of liquid limit values with the coefficient of volume compressibility values of the soil samples (Table 3 and Fig. 4a). The average values of the coefficient of consolidation for each pressure change varied from 0.02184 to 0.03290 mm^2/min (Table 2). Lambe and Whitman [33] correlated rate of consolidation with coefficient of consolidation. Based on the latter, all the studied soils are classified as being of very low rate of consolidation. Head et al. [34] implied that soils with coefficient of volume compressibility value between 0.1 and 0.3 mPa^{-1} have medium compressibility, while those having coefficient of volume compressibility value between 0.3 and 1.5 mPa^{-1} are typical of soils of high compressibility (Table 6). Fifty percentage (50%) of the soil samples possess medium compressibility, while the other 50% possess high compressibility following Head's coefficient of volume compressibility classification.

The compression index values which ranged from 0.0203 to 0.0812 are observed to relate better with plasticity index with correlation coefficient of 0.90 as compared with shrinkage index with correlation coefficients of 0.72

Fig. 3 Plots of the soil samples on Casagrande [32] chart classification

and linear shrinkage with correlation coefficient of 0.60 (Fig. 4b; Eqs. 5–7 in mm^2/min).

$$C_c = 0.0028(PI) - 0.0052 \quad (5)$$

$$C_c = 0.0018(SI) - 0.0091 \quad (6)$$

$$C_c = 0.0079(LS) - 0.013 \quad (7)$$

where C_c is compression index, PI is plasticity index, SI is shrinkage index, and LS is linear shrinkage.

This result is consistent with Carrier [35] who concluded that compression index is directly related to plasticity index based on an empirical study and also Sridharan and Nagaraj [11] whose correlation coefficient from the plot of compression index against plasticity index is 0.91. Further, the result is consistent with that of Jain et al. [16] whose compression index–PI plot's correlation coefficient is 0.95, respectively.

The coefficient of consolidation values were plotted against the index parameters. This was done to determine the variation in the index properties with coefficient of consolidation. The coefficient of consolidation was plotted against increasing consolidation pressures (20–160 kPa) for two soil samples having the same linear shrinkage values but different plasticity index and shrinkage index values (Fig. 4c). Soil sample 3 (S3) has higher plasticity index (28.0) and shrinkage index (38.8) values than the plasticity index (13.8) and shrinkage index (23.2) values of soil sample 7 (S7). Even though both soils have the same linear shrinkage values, their coefficient of consolidation–pressure increment relationship differs. The soils having higher plasticity index and shrinkage index displayed a lower range of coefficient of consolidation–consolidation pressure relationship, while soils with lower plasticity index and shrinkage

limit values displayed a higher range of coefficient of consolidation–pressure increment relationship. This plot shows that linear shrinkage does not determine the relationship between coefficient of consolidation and consolidation pressure and, hence, does not have direct relationship with coefficient of consolidation as against plasticity index on the one hand and shrinkage index on the other hand.

The coefficient of consolidation values were plotted against consolidation pressure for two soils having the same shrinkage index values but different plasticity index values (Fig. 5a). Soil sample 3 (S3) has higher plasticity index value (28.0) than the plasticity index value (15.6) of soil sample 8 (S8). Even though both soils have the same shrinkage index values, their coefficient of consolidation versus pressure increment relationship differs. The soils having higher plasticity index displayed a lower range of coefficient of consolidation–pressure increment relationship, while the soils with lower plasticity index displayed a higher range of coefficient of consolidation–pressure increment relationship. This plot shows that shrinkage index does not have absolute direct relationship or control on coefficient of consolidation. On the other hand, plasticity index was observed to have better and direct relationship or control on the coefficient of consolidation value (Fig. 5b).

The coefficient of consolidation–consolidation pressure increment behavior differs for soils of opposite ranges of plasticity index values (Fig. 5b). Soil samples S1, S2, S7, and S8 have lower range of plasticity index, while soil samples S3, S4, S5, and S6 have higher ranges of plasticity index. Evidently, soils with lower plasticity index display higher range of coefficient of consolidation–consolidation

Fig. 4 **a** Plot variation in liquid limit (%) with percentage coefficient of volume compressibility (mPa^{-1}). **b** Plots of compression index against linear shrinkage, plasticity index, and shrinkage index. **c**

Plot of coefficient of consolidation versus consolidation pressure increment (20–40–80–160 kPa) for two soils having the same linear shrinkage values

Table 6 Typical values for coefficient of volume compressibility (M_v) (Head et al. [34])

Coefficient of volume compressibility (m^2/MN)	Compressibility	Results (%)
< 0.05	Very low	
0.05–0.1	Low	
0.1–0.3	Medium	50
0.3–1.5	High	50
> 1.5	Very high	

pressure increment behavior, while soils with higher plasticity index display lower range of coefficient of consolidation–consolidation pressure increment behavior. This result is consistent with Sridharan and Nagaraj [12] and Carrier [35] who noted that the coefficient of consolidation values are comparatively higher for less plastic soils than for more plastic soils and that plasticity index is inversely proportional to coefficient of consolidation. Further, soil samples with higher plasticity indices (S3, S4, S5, and S6) indicate a decreasing trend in consolidation coefficient with the increase in applied consolidation pressure as compared with soils of lower plasticity indices (S1, S2, S7, and S8) (Fig. 5b). Hence, the relationship between

Fig. 5 **a** Plot of coefficient of consolidation versus consolidation pressure (20–160 kPa) for two soils having the same shrinkage index values. **b** Plot of coefficient of consolidation versus effective vertical consolidation pressure increments (20–160 kPa) for the

eight soils having the low and high ranges of plasticity index but different ranges of shrinkage index values. **c** Plot of coefficient of consolidation against applied consolidation pressure

coefficient of consolidation and applied consolidation pressure is expressed in (8) with a coefficient of correlation, $r = 0.97$ (Fig. 5c).

$$C_v = -5.503 * (10^{-5})AP + 0.028 \quad (8)$$

where AP is effective vertical consolidation pressure and C_v is coefficient of consolidation (in mm^2/min).

The shrinkage index values also fairly correspond with this result with an exception of soil sample 8, which possesses low plasticity index value but higher shrinkage index relative to others. Sridharan and Nagaraj [12]

Fig. 6 Relationship between average coefficient of consolidation values and plasticity index, shrinkage index, linear values

observed that for soils having the same liquid limit values, those with lesser shrinkage or plasticity index demonstrate an increasing trend of coefficient of consolidation. Hence, the variation in the plot of coefficient of consolidation against vertical effective consolidation pressure is much dependent on variation in plasticity index of the studied soils.

The average value of coefficients of consolidation at the loading of each consecutive pressure (20–160 kPa) and unloading (160–20 kPa) is plotted against the plasticity index, shrinkage index, and linear shrinkage values (Fig. 6). As seen, the distribution of the plasticity index plot is less scattered relative to the plot of shrinkage index and linear shrinkage. Hence, the coefficient of consolidation has a better coefficient of correlation with plasticity index (0.88) as compared with shrinkage index (0.73) and linear shrinkage (0.60). Solanki and Desai [18] and Sridharan and Nagaraj [12] proposed coefficients of correlation of 0.95 and 0.80, respectively, in their C_v –PI plots which are in close range with the C_v –PI plots results of this study.

Having determined that plasticity index is better correlated with the coefficient of consolidation, the coefficient of consolidation values derived at each stage of effective vertical consolidation pressures of 20–160 kPa (loading and unloading) were plotted against plasticity index values (Fig. 7). The correlation equations for predicting coefficient of consolidation based on plasticity index values are then proposed (Eq. 9).

The correlation equation for the prediction of coefficient of consolidation based on plasticity index values of the remolded migmatite–gneiss-derived laterite soils is given as:

Fig. 7 Coefficient of consolidation versus plasticity index values for complete gradual loading and unloading cycles of applied vertical pressures of 20–160 kPa

$$C_v = 1 \times 10^{-9} \text{ PI}^{-0.357} \text{ (in m}^2/\text{s)} \quad (9)$$

where C_v is coefficient of consolidation (mm^2/min), PI is plasticity index (%), coefficient of determination (R^2) is 0.62, and the coefficient of correlation (r) is 0.79 (Fig. 7).

As seen from (6), coefficient of consolidation decreases with the increase in plasticity index. This result is consistent with Devi et al. [15] whose coefficient of correlation for plot of C_v against PI is 0.77, Sridharan and Nagaraj [12] whose coefficient of correlation for plot of C_v against PI is 0.81, and Carter and Bentley [36] who determined that remolded soils are generally of very low hydraulic conductivity. Therefore, it is expected that since all the studied soils are remolded, they will all possess low hydraulic conductivity, low interconnected void space, poor drainage, and decreasing rate of consolidation—characteristics typical of soils of high plasticity. However, the studied soils ranged from low plasticity to high plasticity. (PI ranged from 8.0 to 33.65%). The compressibility behavior of soils with dissimilar plasticity is depended on mechanical or physicochemical factors [37]. When a less plastic soil displays increasing rate of compressibility with load, it is due to the mechanical factor. On the other hand, when a more plastic soil displays decreasing rate of compressibility with load, it is due to the physicochemical factors. This is the case with the studied soils. The soils with low plasticity possess low amount of fine particles, high effective pore size (interconnected void space), high hydraulic conductivity, thinner diffuse double layer, and hence, high rate of

compression upon increased gravitational force (effective vertical consolidation pressure). Contrastingly, the soils with high plasticity possess high fine particles, low effective pore size, low hydraulic conductivity, thicker diffuse double layer, and hence, low rate of compression upon increased gravitational force (effective vertical consolidation pressure). This explains the reason for the variation in coefficient of consolidation with plasticity characteristics of the studied soils. From this study, it could be inferred that migmatite–gneiss-derived soils, although clayey and/or plastic soil, will display decreasing compressibility rate under load.

5 Conclusion

This study correlated index properties, namely, linear shrinkage, plasticity index, and shrinkage index with consolidation characteristics of remolded migmatite–gneiss-derived laterite soils under a maximum effective vertical consolidation pressure of 160 kPa. The relationships between these parameters were evaluated using correlation equations which generated coefficient of correlation (r) values. Coefficient of consolidation varies significantly with applied consolidation pressure with a coefficient of correlation value of 0.97. Further, soils that possess relatively higher plasticity indices exhibited significant decreasing trend in coefficient of consolidation with increasing applied consolidation pressure as compared with soils of lower plasticity indices. The compression index values also relate better with plasticity index values with a coefficient of correlation (r) value of 0.90 as compared with shrinkage index and linear shrinkage values with coefficient of correlation (r) of 0.72 and 0.60, respectively. The relationship between average coefficient of consolidation values and plasticity index, linear shrinkage, and shrinkage index values gave coefficients of correlation of 0.88, 0.60, and 0.73, respectively. This indicates that plasticity index better correlates with coefficient of consolidation as compared with linear shrinkage and shrinkage index values. Further, the correlation of plasticity index (PI) values with all the derived coefficient of consolidation (C_v) values showed positive strong correlation coefficient (r) of 0.79. Further, there was strong positive correlation, i.e., coefficient of correlation of 0.79, in the relationship between coefficient of consolidation and plasticity index values for the studied remolded migmatite–gneiss-derived laterite soils based on the coefficient of consolidation (C_v) values derived at each stage of vertical consolidation pressures (AP) that were loaded and unloaded. Hence, the correlation equations generated by this study can be applied to predict coefficient of consolidation and compression index values from plasticity index

values, as the dependent variable, of other derived soils in the migmatite–gneiss basement areas. However, since this study was conducted on migmatite–gneiss-derived laterite soils only, further studies need to be carried out to evaluate the relationships between consolidation and plasticity characteristics of several other derived residual laterite soils of the basement terrain.

Compliance with ethical standards

Conflicts of interest The authors declare no conflict of interest.

References

1. Frantziskonis G, Breysse D (2003) Influence of soil variability on differential settlements of structures. *Comput Geotech* 30:217–230
2. Chummar AV (1984) Excessive settlement in buildings. In: International conference on case histories in geotechnical engineering, vol 17
3. Shanyoung W, Chan D, Lam KC (2009) Experimental study of the fines content on dynamic compaction grouting in completely decomposed granite of Hong Kong. *Constr Build Mater* 23:1249–1264
4. Dimitrova RS, Yanful EK (2012) Factors affecting the shear strength of mine tailings/clay mixtures with varying clay content and clay mineralogy. *Eng Geol* 125:11–25
5. Otokoto GR (2014) Dependence of shear strength and compressibility of tropical lateritic soils on clay content. *Int J Eng Technol Res* 2(2):1–9
6. Okunlola IA, Idris-Nda A, Dindey AO, Kolawole LL (2014) Geotechnical and geochemical properties of lateritic profile on migmatite gneiss along Ogbomosho—Ilorin Highway, Southwestern Nigeria. *Afr J Geogr Sci* 1(1):01–06
7. Adeyemi GO, Afolagboye LO (2013) Mechanical stabilization of a migmatite gneiss-derived lateritic soil from Southwestern Nigeria. *IJGE* 18:1847–1858
8. Adeoye AS, Alo BA, Abdu-Raheem YA (2018) Assessment of geotechnical properties of migmatite-derived residual lateritic soil from Ado-Ekiti South Western Nigeria as barrier in sanitary landfill. *IJIRSET*. <https://doi.org/10.15680/ijirset.2018.0706115>
9. Adebisi NO, Osammor J (2017) Assessment of geotechnical properties of soils derived from basement and sedimentary rocks in Southwestern Nigeria. *Afr J Sci Nat* 4:39–48
10. Adebisi N (2012) Assessment of plasticity and compressibility of engineering soils in Ibadan, Southwestern Nigeria. *Miner Wealth* 163(2012):17–24
11. Sridharan A, Nagaraj HB (2000) Compressibility behaviour of remoulded, fine-grained soils and correlation with index properties. *Can Geotech J* 37(2):712–722
12. Sridharan A, Nagaraj HB (2004) Coefficient of consolidation and its correlation with index properties of remolded soils. *Geotech Test J* 27(5):1–6
13. Jadhav G (2016) Establishing relationship between coefficient of consolidation and index properties/indices of remoulded soil samples. In: 5th international conference on recent trends in engineering science and management, Parvatibai Genba College of Engineering, Wagholi, Pune, pp 1109–1119

14. Zaman W, Hossain R, Shahin H, Alam AA (2016) A study on correlation between consolidation properties of soil with liquid limit, in situ water content, void ratio and plasticity index. *Geotechnics for Sustainable Infrastructure Development*, pp 899–902
15. Devi SP, Devi KR, Prasad DSV, Raju GVRP (2015) Study on consolidation and correlation with index properties of different soils in Manipur valley. *Int J Eng Res Dev* 11(05):57–63
16. Jain VK, Dixit M, Chitra R (2015) Correlation of plasticity index and compression index of soil. *Int J Innov Eng Technol (IJET)* 5(3):263–270
17. Owoyemi OO, Adeyemi GO (2017) Variability in the highway geotechnical properties of two residual lateritic soils from central Nigeria. *J Geol Geophys* 6:290. <https://doi.org/10.4172/2381-8719.1000290>
18. Solanki CH, Desai MD (2008) Role of Atterberg limits on time rate settlement of alluvial deposits. *J Eng Technol, Sardar Patel University* 21:12–15
19. Adepoju O, Asiwaju-Bello YA, Malomo S (2018) Compressibility characteristics of remoulded residual soils under loading. *IOSR J Appl Geol Geophys* 6(1 Ver. I):52–57
20. Ondo State Ministry of Economic Planning and Budget (2010) The Publication of Facts and Figure of Ondo State of Nigeria, Research and Statistics Department, pp 7–9, in Asiwaju-Bello YA, Ololade JO (2013) Groundwater potential of basement aquifers in part of Southwestern Nigeria. *Am Int J Contemp Res* 3(3):124–141
21. Ondo State Ministry of Lands, Housing and Environment (2000) *Ecological report and engineering design for flood and erosion control works in Idanre Township*, Ministry of Lands, Housing and Environment, Akure, Ondo State, Nigeria, p 104, in Asiwaju-Bello YA, Ololade JO (2013) Groundwater potential of basement aquifers in part of Southwestern Nigeria. *Am Int J Contemp Res* 3(3):124–141
22. Federal Surveys, Nigeria (1966) Topographic Sheet, 1:50,000, Akure S.W. Sheet 264 S.W
23. Kayode OT, Akinwumi II (2017) Residual soils derived from charnockite and migmatite as road pavement layer materials. *J Mater Environ Sci* 8(2):657–665
24. Adeola AJ (2015) Mineralogy and geochemistry of residual clay occurrences in Idi-Ayunre and Akure areas, Southwestern Nigeria. *J Geogr Geol* 7(4):23–32
25. Olabode OF, Asiwaju-Bello YA (2018) Insights from the engineering geological mapping of four basement rocks derived soils. *Sustain Geosci Geotour* 2:16–34
26. Adeyemi GO (1995) The influence of parent rock factor on some engineering index properties of three residual lateritic soils in Southwestern Nigeria. *Bull Int Assoc Eng Geol* 52:3–8
27. Owoseni JO, Aro SO (2018) Effect of parent rock on liquid limits and compaction characteristics of residual lateritic soils. *Iconic Res Eng J* 2(6):69–74
28. Nigeria Geological Survey Agency (2006) Geological and Mineral Resources Map of Ondo State. Published by the Authority of the Federal Republic of Nigeria, Nigeria
29. BS 1377 (1990) Methods of test for soils for civil engineering purposes. British Standards Institution, London
30. Ola SA (1981) Expansive clays in engineering construction, in Lekmang IC, Daku SS, Yenne EY, Wazoh HN, Goyit MP (2016) Geotechnical investigations for infrastructural development: a case study of Daki Biyu District, Federal Capital Territory, Abuja, Central Nigeria. *J Geol Min Res* 8(3):28–39
31. Bell FG (2007) Engineering geology, 2nd edn. Butterworth-Heinemann Publishers, Oxford
32. Casagrande A (1947) Classification and identification of soils. *Am Soc Civ Eng* 113:901–930
33. Lambe TW, Whitman RV (1979) Soil mechanics. In: Head KH, Epps RJ (eds) Manual of soil laboratory testing. Vol. II: permeability, shear strength and compressibility tests, 3rd edn. Whittles Publishing, Scotland
34. Head KH, Epps RJ (2011) Manual of soil laboratory testing. Vol. II: permeability, shear strength and compressibility tests, 3rd edn. Whittles Publishing, Scotland
35. Carrier WD III (1985) Consolidation parameters derived from index tests, in Sridharan A, Nagaraj HB (2004) Coefficient of consolidation and its correlation with index properties of remolded soils. *Geotech Test J* 27(5):1–6
36. Carter M, Bentley SP (1991) Correlations of soil properties, in Adepoju O, Asiwaju-Bello YA, Malomo S (2018) Compressibility characteristics of remoulded residual soils under loading. *IOSR J Appl Geol Geophys* 6(1 Ver. I):52–57
37. Robinson RG, Allam MM (1998) Effect of clay mineralogy on coefficient of consolidation. *Clays Clay Miner* 46(5):596–600

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