Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.7, No.6, 2015

Engineering Behaviour of Cement-Treated Expansive Subgrade Soils from Awgu, Southeastern Nigeria

O.C. Okeke[1] C.O. Okogbue[2] O.I. Imasuen[3] O.P. Aghamelu[4]
1.Department of Geology, Federal University of Technology, Owerri Nigeria
2.Department of Geology, University of Nigeria, Nsukka, Enugu State, Nigeria
3.Department of Geology, University of Benin, Benin City, Nigeria
4.Department of Geology/Geophysics, Federal University, Ndufu-Alike/Ikwo, P.O. Box 1010, Abakaliki, Ebonyi State

Abstract
Engineering behaviour of cement-treated expansive soils refers to changes in the engineering properties of the soil in terms of reduction in values of swelling indicators and increase in values of strength characteristics of the soil when it is treated with various percentages of cement. In this study, engineering properties including liquid limit, plasticity index, linear shrinkage, maximum dry density/optimum moisture content, and California Bearing Ration (CBR) of expansive subgrade soils from Awgu, Southeastern Nigeria, were determined in the laboratory and their behaviour in terms of changes in the engineering properties on treatment with various percentages of cement (2,4,6,8 and 10) investigated. Results of the study show that liquid limit, plasticity index and linear shrinkage values of the treated soil were reduced while the maximum dry density and CBR values were increased. The maximum reduction percentages of 34.61% (56.60 to 37.01%), 72.89% (33.60 to 9.11%) and 46.51% (12.90 to 6.90%) in liquid limit, plasticity index and linear shrinkage, respectively; and maximum percent increase of 7.59% (1.58 to 1.70mg/m^3, on maximum dry density), 236.36% (11 to 37%, on unsoaked CBR) and 800.00% (3 to 27%, on soaked CBR), were obtained on treatment of the soil with 8% cement by weight. The swelling indicators/parameters of the studied soil are liquid limit; plasticity index and linear shrinkage while the strength characteristics/parameters of the studied soil are maximum dry density and California Bearing Ratio (CBR). Treatment of the soil with cement has thus reduced its swelling potential from high to low and increased the strength significantly
Keywords: Subgrade, expansive soils, cement treatment, plasticity characteristics, reduction percentage, strength characteristics, percent increase.

1.0 Introduction

Subgrade in highway construction, is the natural treated ground surface on which highway pavements are constructed (Krynine and Judd,1957). It may also be called foundation soil or subgrade soil of pavements. The thickness of the pavement (sub-base, base course and wearing surface) depends on the strength of the subgrade, traffic and loading conditions. Poor quality subgrade soils may be improved by treatment of the soil in place or treating/stabilizing the materials to be used as sub-bases with cement or lime (Bell, 1995 and 2007).

Highway pavements or roads constructed on active zone of expansive subgrade soils experience failures as a result of volume changes or swelling associated with seasonal changes in the moisture content of the soil. These failures are superficially expressed as cracks on the roads (Chen, 1975; US Army, 1983; Attewell and Taylor, 1984). Expansive soils are formed as weathering products of fine grained extrusive igneous rocks and montneorillomite – rich mudrocks such as shales and mudstones (Gromko, 1974; Harry, 1974).

According to US Army (1983), Day (1999) and Lucian (2011), soils above the depth of active zone of expansion experience wide range of variations in moisture content while those below the depth do not experience changes in moisture content, and thus do not contribute to soil expansion. Factors that determine the depth to active zone in soils susceptible to swelling or shrinkage include water table and climate. Generally, active zone will extend to depth of shallow water table and in terms of climate, the general guide to depth of active zone of expansion is given below (US Army, 1983; Lucian, 2011).

Humid tropics: < 2.5m
Semi – arid tropics: 1.5 – 5m
Arid tropics: > 5m

The primary purpose of treatment or improvement of expansive soil with additives such as cement or lime is to reduce its tendency for volume change when in contact with water. The adverse engineering properties, namely: liquid limit, plasticity index and linear shrinkage that are responsible for swelling behavior of the soil are generally reduced when appropriate percentage of additive is added to the soil. The strength characteristics (California Bearing Ratio (CBR) and Maximum Dry Density (MDD) are also increased. Lime and cement are generally used in treatment of highway pavement subgrades though lime is often preferred because it improves the workability of the clay and achieves higher and faster rate of reduction of the adverse engineering properties within a given limit (Roads and Streets, 1959; Thompson, 1968; Greaves, 1996;).

Treatment of subgarde soils with cement performs better than lime-treated soils particularly in soils with less clay fraction, low plastic characteristics (low swelling potential) and where early strength is desired (Moh, 1962; Peck et al, 1974; US Army, 1984; Mowfy et al, 1985; Bell 1993; Raj, 2008; Jha and Sinha, 2009). Soil-cement mixtures are also widely used as bases (base course) for highway and air field pavements (HRB, 1943) for slope protection and canal/reservoir linings (Scott and Schoustra, 1968). Occurrence of expansive soils and their disastrous effects on engineering structures (including highway pavements) have been reported in Awgu, the study area and other parts Southeastern Nigeria (Uduji et al, 1994; Okeke and Okogbue, 2010a). The expansive soils are believed to have been derived from montmorillonite – rich shale of Awgu Formation (Okeke, 2008).

Fig 1: shows road failure caused by expansive soils in Awgu area.

Awgu lies between latitudes $6^{o}\ 0^{1}$ – $6^{0}\ 8^{1}$ and longitudes $7^{0}\ 35^{1}$ – $7^{0}\ 41^{1}$. It is accessible through Enugu – Okigwe Expressway. The town experiences two seasons, the wet season that lasts from April to October and dry season that lasts from November to March. The average annual rainfall is 1900mm (NMA, 2007)

In this study, changes in engineering properties of expansive subgrade soils (subsurface soils) collected along Awgu-Ndiaboh Road in Awgu town when treated with various percentages of cement in the laboratory were investigated. Results of the study were used to evaluate the effects of treatment of the soil with cement, which would form the basis/guidelines for the field treatment/improvement of the soil and hence mitigation of the swelling problems (expressed as cracks) experienced by highway pavements (roads) built on the soil.

Fig. 1 **Longitudinal and polygonal cracks on a highway pavement at Awgu**

2.0 Geology of the Study Area

The main geologic unit that outcrops in the study area is Awgu Formation, which is one of the sedimentary formations of the Abakaliki Basin, the Pre-Santonian Lower Benue sediments. Other geologic units of the Abakaliki Basin include Asu River Group and Ezeaku Formation. The-Post Santonian Lower Benue sediments are collectively called Anambra Basin and the geologic units include Nkporo Formation, Mamu Formation, Ajali Formation, Nsukka Formation, Imo Formation and Ogwashi – Asaba Formation (Murat, 1972; Hoque, 1977; Agumanu, 1986 and 2009; Umeji, 2006)

The Benue Trough is a rift basin in Central West Africa that extends NNE – SSE for about 800km in length and 150km in width (Obaje et al, 2004). It is a major structural feature in southeastern Nigeria and was developed during the separation of South America and Africa and opening of South Atlantic Ocean at the site of RR triple junction (Burke, 1972; Nwachukwu, 1972; Olade, 1976; Peters, 1978).

Fig. 2: shows the geologic map of Southeastern Nigeria and the location of the study area, while Table 1 shows stratigraphic sequence of sedimentary rocks in Southeastern Nigeria.

Table 1: Generalized regional stratigraphy of Southeastern Nigeria
(Modified from Reyment, 1965 and Offodile, 1975)

	Age	Formation	Lithology
Tertiary	Recent	Recent Sediments	Alluvium/Deltaic Plains
Tertiary	Miocene – Recent	Benin Formation	Unconsolidated sandstone with lenses of clay
Tertiary	Oligocene – Miocene	Ogwashi – Asaba Formation	Unconsolidated sandstones, mudstone, clays and lignite seams.
Tertiary	Eocene	Ameki Formation	Grey to green argillaceous sandstone, shale and limestone units
Upper Cretaceous	Paleocene	Imo Formation	Blue to dark grey shales and subordinate sandstone members (Umuna and Ebenebe).
Upper Cretaceous	Maastrichtian	Nsukka Formation	Alternating sequence of shale, sandstone and coal seams
Upper Cretaceous		Ajali Formation	Friable sandstone with iron stains
Upper Cretaceous		Mamu Formation	Sandstones, shale, siltstone with coal seams
Upper Cretaceous	Campanian	Nkporo Formation/Enugu Shale	Mudstone and shale with thin beds of sandstone.
Upper Cretaceous	Santonian/ Coniacian	Awgu Formation (Awgu Shale)	Shale with intercalations of sandstones and shaly limestones
Upper Cretaceous	Turonian	Ezeaku Formation (Ezeaku Shale)	Siltstone and shale with sandstone lenses
Upper Cretaceous	Cenomanian	Odukpani Formation	Alternating sequence of sandstone, shale and limestone
Lower Cretaceous	Albian	Asu River Group Abakaliki Shale and Awi Formation	Sandy shales, sandstone and sandy limestone lenses
	Precambrian	Basement Complex	Older granites and gneisses.

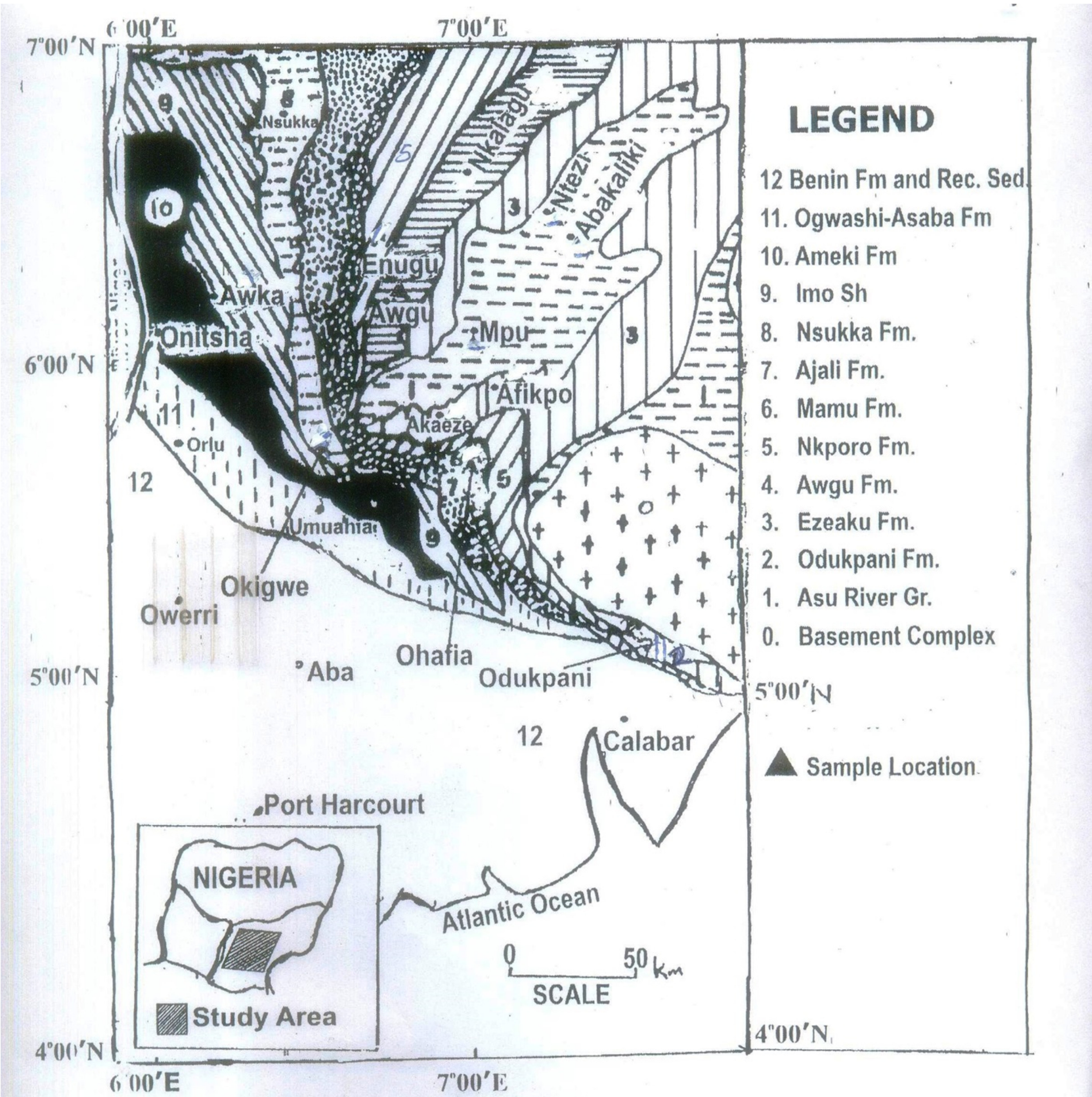

Fig. 2 Geologic map of Southeastern Nigeria (Adapted from Peters, 1978 and Mode, 2004)

3.0 Materials and Methods

3.1 Sample collection

The soil samples that were used in the study were collected with soil augers at depth of 0.5m and 1.0m (then mixed together to represent one sampling point). The process was repeated at another sampling points 50m from first point (that is two sampling point in all) along the failed section of Awgu – Ndiaboh road in the study area (Fig 1). Test pits were also dug in the vicinities of the two sampling points for collection of soils to be used for strength tests (CBR and MDD tests). The techniques of sample collection followed that of US Bureau of Reclamation (USBR, 1963) and Spangler and Handy (1973). The mixed-up samples from the two sampling points were placed in clean polythene bags for preservation of their moisture contents and then transported to the laboratory for analysis.

3.2 Laboratory tests

The soil samples were then subjected to some geotechnical tests including Atterberg limits (liquid limit, plasticity index) linear shrinkage, compaction (dry density and moisture content relations) and California

Bearing Ration (CBR) in the labortary using the guidelines of Akroyd (1957), BS 1377 (1990) and Singh (2004). The soil samples were later treated with various percentages of cement by mixing 2%, 4%, 6%, 8% and 10% of the cement with dry weight of the soil and curing for 7 days (Ingles and Metcalf, 1972; Peck et al, 1974; Nelson and Miller, 1992), before applying the geotechnical tests earlier performed on the soil samples to evaluate the effectiveness of the treatment exercise.

4.0 Results and Discussion

4.1 Results

Table two shows effects of treatment with cement on the geotechnical properties of subgrade soils from Awgu. Note that the results of untreated soils (that is, zero cement percentage) represent average value of two measurements from two sampling points. These effects or behaviours are illustrated graphically in figures 3, 4, 5, 6 and 7.

Table 2:Effects of cement stabilization on engineering properties of expansive subgrade soils from Awgu southeastern Nigeria

% Cement Added	LL (%)	PL (%)	PI(%)	LS(%)	MDD(mg/m³)	OMC(%)	CBR(UN SOAKED)(%)	CBR (SOAKED)(%)
0	56.60	23.00	33.60	12.90	1.58	18.00	11	3
2	49.90	24.60	25.20	11.40	1.62	15.40	19	14
4	45.90	26.11	19.79	9.20	1.65	14.00	27	20
6	41.60	27.30	14.30	8.60	1.66	13.20	35	24
8	37.01	27.90	9.11	6.90	1.70	11.50	37	27
10	43.21	29.91	13.3	4.30	1.72	10.90	31	21

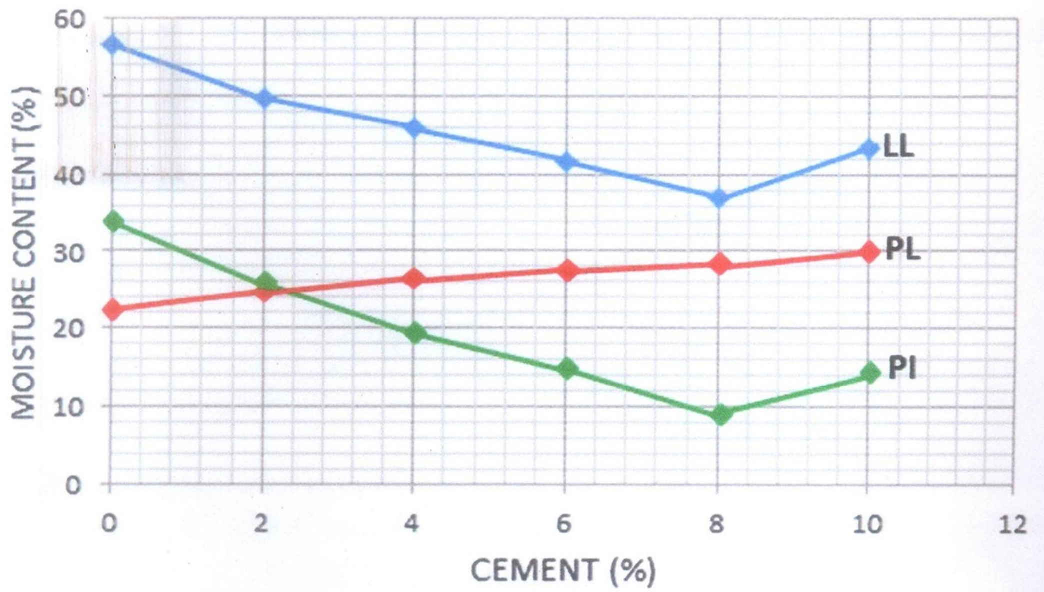

Fig 3: Variation of Liquid Limit(LL), Plastic Limit (PL) and Plasticity Index (PI) of expansive soils from Awgu with different percentages of cement

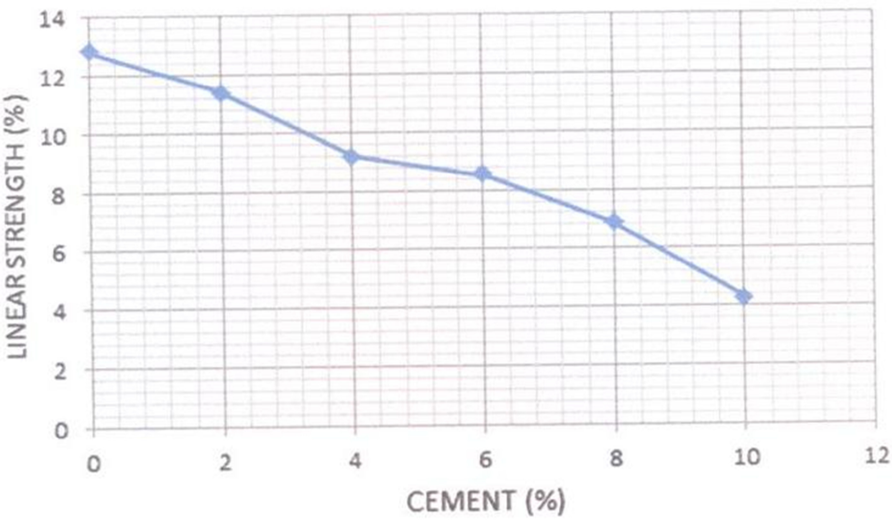

Fig 4: Variation of Linear Shrinkage of expansive soils of Awgu with different percentages of cement

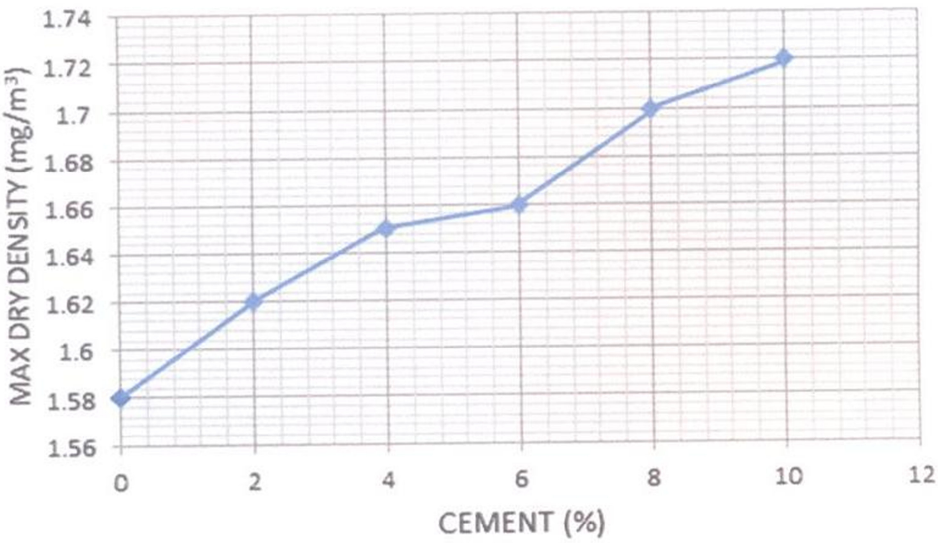

Fig 5: Variation of Maximum Dry Density (MDD) of expansive soils of Awgu with different percentages of cement

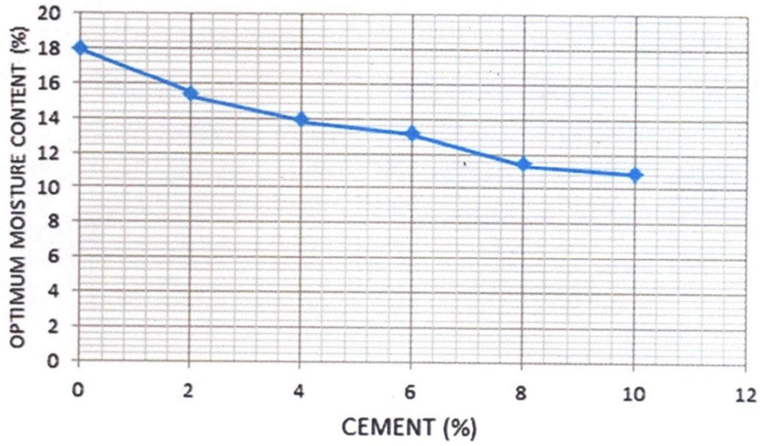

Fig 6: Variation of Optimum Moisture Content (OMC) of expansive soils of Awgu with different percentages of cement

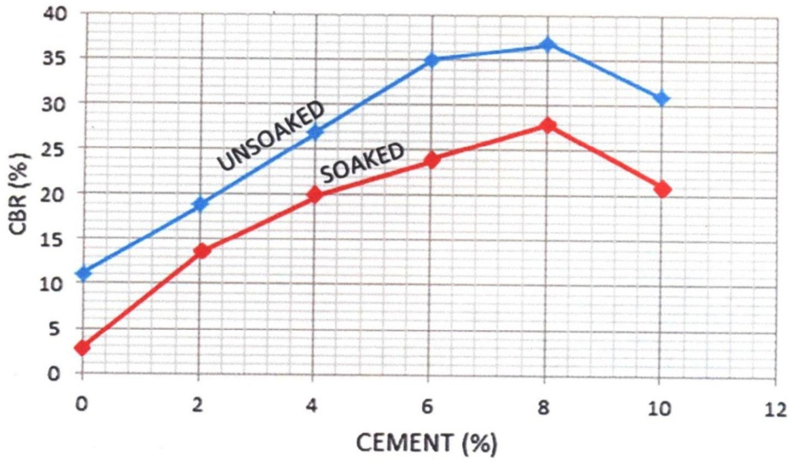

Fig 7: Variation of CBR (Soaked and Unsoaked) of expansive soils of Awgu with different percentages of cement

4.2 Discussion

Improvement or treatment of expansive soils with cement (or any other additive such as lime) has the general effect of decreasing the tendency of the soil to swell (swelling potential) and increasing the strength characteristics. Treatment of expansive subgrade soils from Awgu with different percentages of cement has the effect of reducing the liquid limit, plasticity index and linear shrinkage (swelling indicators) and increasing the maximum dry density and California Bearing Ratio (CBR) (strength characteristics). These reduced/increased values are shown in Table 2.

Table 3 shows the extent of reduction (% reduction) of liquid limit, plasticity index and linear shrinkage of the soil when treated with various percentages of cement. Similarly, Table 4 shows the extent of increase (% increase) of CBR and maximum dry density of the soil when treated with various percentages of cement. On addition of 2% of cement to the soil, rapid rate of reduction percentages of 12.1% (56.60 to 49.90, on liquid limit), 25.10% (33.36 to 25.20%, on plasticity index) and 11.63% (12.90 to 11.40%, on linear shrinkage) were observed. Optimal addition 8% of cement led to maximum reduction percentage of 34.61% (56.60 to 37.01%, on liquid limit) 72.89% (33.60 to 9.11%, on plasticity index) and 46.51% (12.90 to 6.90%, on linear shrinkage). The chemical processes that are responsible for these reactions are mainly hydration and base exchange.

The high values of liquid limit, plasticity index and linear shrinkage: 56.60%, 33.60% and 12.90%

respectively, of the untreated soil (Table 2) are indication of high swelling potential and critical degree of expansion of the soil. Both Ola (1981) and Holtz and Gibbs (1956) Swelling Potential classification of expansive soils based on plasticity index (Pi) values and liquid limit (LL), respectively, are shown in Table 5. Table 6 also shows degree of expansion classification of the soil based on linear shrinkage (Attimeyer, 1956).

Table 3: Evaluation of effectiveness of treatment with cement on engineering index properties of expansive subgrade soils from Awgu.

% cement Added	LL (%)	% Reduction	PI (%)	% Reduction	L S %	% Reduction
0	56.60	-	33.60	-	12.90	-
2	49.80	12.01	25.20	25.10	11.40	11.63
4	45.90	18.90	19.79	41.10	9.20	28.68
6	41.60	26.30	14.30	57.44	8.60	33.33
8	37.01	34.61	9.11	72.89	6.90	46.51
10	43.21	23.66	13.30	60.42	4.30	66.67

Table 4: Evaluation of effectiveness of treatment with cement on CBR and MDD of expansive subgrade soils from Awgu.

% cement Added	CBR (%)				MDD (Mg/m^3)	
	Unsoaked		Soaked			
	CBR(%)	% Increase	CBR (%)	% Increase	MDD (Mg/m^3)	% Increase
0	11	-	3	-	1.58	-
2	19	42.11	14	366.67	1.62	2.53
4	27	84.21	20	566.67	1.65	4.43
6	35	218.18	24	700.00	1.66	5.06
8	37	236.36	27	800.00	1.70	7.59
10	31	181.82	21	600.00	1.72	8.86

Table 5: Classification of expansive soils on the basis of plasticity index (PI) and Liquid Limit (LL)

Swelling potential	Ola, 1981; PI (%)	Holtz and Gibbs, 1956; LL (%)
Low	< 15	< 35
Moderate/medium	15-25	35-50
High	25-35	50-70
Very High	> 35	>70

Table 6: Relationship between degree of expansion and linear shrinkage (Attimeyer, 1956)

Degree of expansion	Linear shrinkage (%)
Non-Critical	< 5
Marginal	5-8
Critical	> 8

Treatment of expansive subgrade soils from Awgu (Southeastern Nigeria) also has the effect of increasing the California Bearing Ration (CBR) and the Maximum Dry Density (MDD). These parameters are the strength characteristics of the soil. (Tables 2 and 4; Figures 5 and 7). Maximum percent increase of 236.36% (11- 37%, unsoaked CBR) and 800.00% (3 – 27%, soaked CBR) were obtained on addition of 8% cement to the soil. According to Jha and Sinha (2009) and Gupta and Gupta (2004), the major constituents of cement which have a distinct effect on the strength aspect of soil cement mixture are:

i. Dicalcium silicate ($2Cao.SiO_2$);
ii. Tricalcuim silicate ($3Cao.SiO_2$); and
iii. Free lime

Tricalcium silicate sets fast and is responsible for immediate strength gain. Free lime may bring about base exchange capacity and change of texture of the soil. Dicalcium silicate is responsible for long term strength due to hydration reaction.

The strength of soil-cement mixture increases with increasing amount of cement. If a soil contains too much organic matter, cement would not produce proper strength. Though Lambe et al (1957), suggested that addition of 0.5 to 1% of sodium silicate, calcium chloride or alkali-metal compounds may improve the strength of soil cement mixture.

The factors that affect the performance of soil-cement mixture are soil type, moisture content, method of mixing and compaction (Scott and Schoustra, 1968; Venkatramaiah, 2006). In the case of treatment of expansive soil with lime (Okeke and Okogbue, 2010b), the plasticity/swelling properties were reduced, the maximum dry density was reduced and the strength was increased. On addition of 2% of lime to the soil, the reduction percentages of 16.25% and 50.58% on liquid limit and plasticity index, respectively, were obtained; and on addition of 6% lime to the soil, 20.94% and 70.06% on liquid limit and plasticity index, respectively, were obtained. Treatment of expansive soil with lime is faster than treatment with cement only at low addition percentage (less than 6%), but at higher percentages (greater than 6%) cement treatment gives better performance both in terms of maximum reduction percentage of swelling indicators (34.61% / 72.89% and 20.94% / 70.06%, on liquid limit/plasticity index value for cement and for lime treatment respectively), and percent increase on unsoaked CBR (236.36% and 141.18% for cement and lime treatment, respectively).

The main chemical processes of lime treatment are base-exchange (which leads to flocculation/change in soil gradation) and pozzonanic action due to the reaction between lime, aluumina and silica. This is a long term reaction which strengthens the soil-lime mixture. Strength increase due to soil-lime mixture is therefore due to base-exchange and strength increase due to cement-lime mixture is due to hydration. Hydration process in soil-cement mixture is similar to hydration process in concrete (Shetty, 2005; Gupta and Gupta, 2004); and it contributes more strength and is faster in soil-cement mixture than strength caused by base-exchange process in soil-lime mixture which is generally slow. Strength increase due to lime treatment of expansive soil will increase to a certain limit and start to decrease with increase in quantity of lime. Factors that affect the performance of soil-lime mixture include soil type, quantity of lime and period of curring for soil lime mixture.

In general, lime content of 5 to 10% and cement content of 5 to 12% by weight of dry soils are used in most soil treatment works (Scott and Schoustra, 1968; Venkatramaiah, 2006) with finer soils (containing higher clay fractions) and coarse soils (containing lower clay fractions) requiring less quantity of lime and greater quantity of cement, respectively. However, laboratory tests are needed to establish the appropriate soil-cement and soil lime mixture for field soil treatment works.

5.0 Conclusions

The following conclusions can be made from the study:

1. Treatment of expansive subgrade soils from Awgu (Southeastern Nigeria) has the effect of reducing the values of the geotechnical index properties (liquid limit, Plasticity index and linear shrinkage) of the soil and hence its tendency to swell; and increasing the strength characteristics (California Bearing Ratio and maximum dry density)
2. On addition of 8% cement to the soil, maximum reduction percentages of 34.61% (56.60 t0 37.01%), 72.89% (33.60 to 9.11%) and 46.51% (12.90 to 6.90) on liquid limit plasticity index and linear shrinkage, respectively, were obtained.
3. Using Ola (1981) Swelling Classification of Potential of expansive soils based on Plasticity Index values, the treatment reduced the Swelling Potential of the soil from high to low (33.60 to 9.11%, P_1 values)
4. On addition of 8% cement to the soil, maximum percentage increase of 236.36% (11to 37%, unsoaked CBR), 800.10%) 3 to 27%, soaked CBR) and 7.59% (1.58 to1.70mg/m^3, MDD) were obtained. These increases represent improvements in strength characteristics of the treated subgrade soils.
5. The major chemical reactions that are responsible for reduction of swelling indicators characteristics and increase in strength characteristics of expansive soil treated with cement or lime are hydration and base exchange, though hydration is more pronounced in cement treatment while base exchange is more pronounced in lime treatment.
6. In terms of reduction of swelling potential of expansive soils, treatment of the soil with cement is as good as treatment with lime, though treatment with lime is often preferred when available because it improves the workability (reduces cohesiveness) of the clay.
7. In terms of increase in strength characteristics of soils (particularly CBR and maximum dry density of highway pavement subgrade and materials), treatment with cement should be preferred. Ordinary Portland Cement generally used in soil improvement and other construction works are also easily available compared with lime (slaked lime, $Ca(OH)_2$ or quick lime, CaO) in Nigeria.

Acknowledgements
The Authors are grateful to Mr. Ernest Nwokoro of soils/ materials laboratory, Ministry of Works, Owerri, for his assistance in soil stabilization tests.

REFERENCES

Agumanu, A.E. (1986). Sedimentary geology of parts of Benue Trough Unpubliished Ph.D. Thesis, Obafemi Awolowo University, Ile-Ife.

Agumanu, A.E. (2009). Environment of deposition of Awgu Formation (Late Cretaceous), Southern Benue Trough, Nigeria.

Akroyd, T.N.W. (1957). Laboratory testing in soil engineering. Soil Mechanics Ltd., London.

Attimeyer, W.T. (1956). Discussion of engineering properties of expansive soils by Holtz, W.G. and Gibbs, H.G. (1956). Trans. ASCE, 21, 666-669.

Attewell, P.B. and Taylor, R.K. (1984). Ground movements and their effects on structures. Survey University Press. Blackie and Sons Ltd., London.

Bell, F.G. (1993). Engineering treatment of expansive soils. Chapman and Hall, London.

Bell, F.G. (1995). Cement stabilization of clay soils with examples. Environmental and Engineering Geoscience, 1, 139 – 151.

Bell, F.G. (2007). Engineering geology, 2nd Edition, Elsevier Science Publishers, Oxford, United Kingdom.

British Standards (BS) 1377, (1990). Methods of testing soils for civil engineering purposes. British Standards Institution, London.

Burke, K.C. Dessavagie, T.F.J. and Whiteman, A.J. (1972). Geologic history of the Benue Valley and adjacent areas. In: African geology (T.F.J. Dessavagie and Whiteman, A.J. eds,) Ibadan University Press, Ibadan, 187-205.

Chen, F.H. (1975). Foundations on expansive soils. Developments in Geotechnical Engineering, 12, Elsevier Scientific Publishing, Amsterdam.

Day, R.W. (1999). Geotechnical and foundation engineering design and construction, Mc Graw – Hill Book Company, New York.

Greaves, M.H. (1996). An introduction to lime stabilization. Thomas Telford Services Limited, London.

Gromko, G.J. (1974). Review of expansive soils. ASCE J. Geotech. Eng. Div., 100 (GT6), 667 – 686.

Gupta, B.L and Gupta, A (2004). Concrete technology, 3rd Edition. Standard Publishers Distributors, Delhi, India.

Harry, A.T. (1974) Geologic origin and distribution of swelling soils. Bull. Asso. Of Eng. Geologists, 4, 259 – 275.

Highway Research Board (HRB) (1943). Use of soil – cement mixtures for base courses. War – time problems, No. 7, Washington D.C. U.S.A.

Holtz, W.G. and Gibbs, H.J. (1956). Engineering properties of expansive soils ASCE Trans., 121, 641-677.

Hoque, M. (1977). Petrographic differentiation of tectonically controlled Cretaceous Sedimentary Cycle, Southeastern Nigeria. Sedimentary Geology, 17, 235 – 245.

Ingles, O.G. and Metcalf, J.B. (1972). Soil stabilization: principles and practices. Butterworth Pty Limited, London.

Jha, J. and Sinha, S.K. (2009). Construction and foundation engineering. 7th Edition Khanna Publishers, New Delhi, India.

Krynine, D.P. and Judd, W.R. (1957). Principles of engineering geology and geotechnics. McGraw – Hill Book Company, New York.

Lambe, T.W. Michaels, A.S. and Moh, Z.C. (1957). Improvement of strength of soil cement mixtures with additives, HRB Publication.

Lucian, C. (2011). Geotechnology to determine depth of active zone in expansive soils in Kibaha, Tanzania, Global J. Pure and Applied Sciences, 17 (2), 189 – 195.

Mode, A.W. (2004). Shallow marine transgressive sedimentation in the Nsukka Formation, Southeastern Anambra Basin, Nigeria. NAPE Bull., 17(1), 28-41.

Moh, Z.C. (1962). Soil stsbilization with cement and sodium additives ASCE J. Soil Mech. & Foundations Div., 88 (SM6), 81-105.

Mowafy, Y.M. Baurer, G.R. and Sakeh, F.H. (1985). Treatment of expansive soils: A laboratory study. Transportation Research Record, No. 1032, Transportation Research Board, 34 – 39.

Murat, R.C. (1972). Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In: African geology (T.F.J. Dessavagie and A.J. Whiteman, eds). University of Ibadan Press, Ibadan, 251 – 266.

Nelson, J.D. and Miller, B.J. (1992). Expansive Soils: problems and practices, in Foundation and pavement engineering. John Wiley & Sons Inc. New York.

Nigerian Metrological Agency (NMA) (2007). Rainfall data of towns in Nigeria. Federal Ministry of Aviation, Abuja, Nigeria.

Nwachukwu, S.O. (1972). The tectonic evolution of the southern portion of the Benue Trough, Nigeria. Geological Magazine, 109, 411 – 419.

Obaje, N.G., Wehnar, H., Schneider, G., Abubakar M.B. and Jauro, A. (2004). Hydrocarbon prospectivity of Nigeria's inland basins: from the viewpoint of organic geochemistry and organic petrology. AAPG Bull, 88(3) 325 – 353.

Offodile, M.E. (1975). A review of the Cretaceous of the Benue valley. In: Geology of Nigeria (C.A. Kogbe, ed.). Elizabethau Publishing Company, Nigeria, 319 – 330.

Okeke, O.C. (2008). Distribution, characterization and improvement of expansive soils in parts of southeastern

Nigeria for engineering construction. Unpublished Ph.D. Thesis, University of Nigeria, Nsukka, Nigeria.
Okeke O.C. and Okogbue, C.O., (2010a). Distribution and geotechnical properties of expansive soils in parts of Southeastern Nigeria. J. Min. and Geol., 46(1), 13-31.
Okeke, O.C. and Okogbue, C.O. (2010b). Effects of lime stabilization on geotechnical properties of an expansive soil from Abakaliki Basin (Lower Benue Trough), Southeastern Nigeria. International J. Environmental Science, 6(1), 139-145.
Ola, S.A. (1981). Mineralogical properties of some Nigerian residual soils in relation with building problems. Eng. Geol., 19, 133 – 148.
Olade, M.A. (1976). On the genesis of lead-zinc deposits in Nigeria's Benue Rift (Aulacogen): A preliminary interpretation. J. Min. and Geol., 13, 20-27.
Peck, R.B. Hansen, W.E. and Thomburn T.H. (1974). Foundation engineering, 2nd Edition John Wiley & Sons Inc. New York.
Peters, S.W. (1978). Stratigraphic evolution of the Benue Trough and its implications for the Upper Cretaceous paleogeography of West Africa. J. Geol., 8, 311-322.
Raj, P.P. (2008). Soil mechanics and foundation engineering. Dorling Kindersley (India) Pvt. Ltd., Delhi, India.
Reyment, R.A. (1965). Aspects of geology of Nigeria. Ibadan University Press, Ibadan, Nigeria.
Roads and Streets, (1959). Lime – stabilized subgrade for Kansas "I" project. 102, 112 – 115.
Scott, R.F. and Schoustra, J.J. (1968). Soil mechanics and engineering. McGraw Hill Book Company, New York.
Singh, A. (2004). Modern geotechnical engineering. CBS Publishers and Distributors, New Delhi, India.
Spangler, M.G. and Handy, R.C. (1973). Soil engineering (3rd Edition). Harper and Row Publishers, New York.
Thompson, M.R. (1968). Lime-treated soils for pavement construction. ASCE J. Highway Div., 94, 59 – 67.
Uduji, E. R. Okogbue, C.O. and Onyeobi, T.U.S. (1994). Geotechnical properties of soils derived from Awgu and Mamu Formations in Awgu and Okigwe areas of southeastern Nigeria, and their relations to engineering problems J. Min. Geol., 30(1), 177 – 223.
Umeji, O.P. (2006). Palynological evidence for the Turonian/Campanian boundary between the Abakaliki and the Anambra Basins, as exposed at Leru along the Enugu-Port Harcourt expressway, Southeastern Nigeria, J. Min. Geol., 42(2), 141 – 155.
U.S. Army, (1983). Foundations in expansive soils. Publication of Headquarters, United States Army Corps of Engineers TM5 – 818 -7 Washington D.C.
U.S. Army, (1984). Soil stabilization for pavement (Em-1110 – 3 – 137). United States Army Corps of Engineers, Washington, D.C.
U.S. Bureau of Reclamation (USBR), (1963). Earth manual. U.S. Government Printing Office, Washington D.C.
Venkatramaiah, C. (2006). Geotechnical engineering. New Age International Publishers, New Delhi, India.

The IISTE is a pioneer in the Open-Access hosting service and academic event management. The aim of the firm is Accelerating Global Knowledge Sharing.

More information about the firm can be found on the homepage:
http://www.iiste.org

CALL FOR JOURNAL PAPERS

There are more than 30 peer-reviewed academic journals hosted under the hosting platform.

Prospective authors of journals can find the submission instruction on the following page: http://www.iiste.org/journals/ All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Paper version of the journals is also available upon request of readers and authors.

MORE RESOURCES

Book publication information: http://www.iiste.org/book/

Academic conference: http://www.iiste.org/conference/upcoming-conferences-call-for-paper/

IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digtial Library , NewJour, Google Scholar