

Geotechnical Properties and Slaking Characteristics of Shales in the Calabar Flank, Southeastern Nigeria

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Abstract

Samples of Ekenkpon and Nkporo shales from the Calabar Flank in southeastern Nigeria were analysed to determine their swelling and slaking characteristics and effect on pavement construction and stability of slopes. Engineering problems reported in areas underlain by the soils include pavement failure and landslides. Results show that for the Ekenkpon shale, Liquid Limit, Plasticity Index and free swell averaged 45%, 14%, and 23% respectively compared to values for Nkporo shale which were 45%, 14%, and 17% respectively. Montmorillonite, illite and kaolinite are major mineral components of the soils. The undrained cohesion values of 47 to 49kN/m² and angle of internal friction between 3 and 4° suggest low shear strength. The slake durability index of Ekenkpon shale was 41% compared to 8% for Nkporo shale. The index properties, mineralogy and the slake durability index imply that all the shales are soil-like, have moderate expansivity and are of low shear strength. They are susceptible to expansion on moisture influx, which would trigger pavement fatigues and failures, especially in the peak of rains when excessive precipitation promotes slippage along contact points.

Keywords: Calabar Flank, shales, slaking, durability, pavement

1 Introduction

Shales have varied behaviour depending on the geotechnical and mineralogical properties. They contain essentially clay minerals which are sensitive to water, have low friction angles, and are generally poorly cemented, all of which reduce material strength. Although an engineering definition of clay requires an essentially clay fraction material composition, clay-like behavior will be observed in particles with clay-sized earth materials with a much smaller clay component, since clay presence in soils, if even in small amounts affect the engineering properties. Some are hard and behave similarly like hard rocks in civil engineering projects while others are soft and like most other soft rocks perform poorly as engineering materials in construction projects. Soft rocks and

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expansive soils are most often associated with non-durability (Gamble 1971, Ezeribe 1994), foundation problems and structural failures (Holtz and Kovacs, 1982; Coduto, 1999; Punmia et al., 2005) contributed by compositional factors and post depositional processes. Post-depositional processes contributing to weak rock formation include slaking or dissolution in water, weathering, poor cementation and consolidation, development of planes of weakness, and proximity to other layers with substantially different properties (Santi 2006). Since different shales are composed of different clay mineral species, their silicate structure predisposes them to varying degrees of hydroaffinity and volume changes when subjected to cycles of wetting and drying leading to swelling during the rainy season and shrinkage during the dry season. This leads to a number of engineering problems including of failures involving cracking, settlement and shear failure of engineering structures founded on them, or when they are used as construction materials. The slake durability index is laboratory test used to estimate qualitatively the durability of weak rocks in the service environment (ASTM D 2008) and their probable amount of deterioration over a period of time, after simulated exposure to natural wetting and drying cycles. Slaking is defined as the breakdown of large, air-dry soil aggregates (>2-5 mm) into smaller sized microaggregates (<0.25 mm) when they are suddenly immersed in water or as the swelling of a rock containing clay minerals when it comes in contact with water (Franklin and Chandra, 1972). In the Calabar Flank, the alignments of two important national roads in Nigeria, the East-West road from Calabar through Port Harcourt to Benin and the Calabar-Ikom-Ogoja-Katsina-Ala highway that links southeastern and northern parts of Nigeria are underlain by shaly formations - the Ekenkpon and Nkporo shales. Pavement failures are common (Fig 1), including the 2010 landslide that washed away the Calabar-Itu sections of the road which has a length of approximately 41 kilometres. In a study to delineate and evaluate the quality and state of the subgrade at the failed locations using shallow refraction seismic and CBR (Akpan 2005, Ilori et al. 2014) reported high failure rates to be prevalent in sections underlain by shaly or marly subgrade whereas locations characterised by low failure rates are underlain by weathered basement or sandy unit as subgrade. These conclusions obtained from remotely sense data have not been previously complemented with the determination of the engineering properties and the slaking characteristics and of the Nkporo and Ekenkpon shale and implications as engineering materials, hence this study.

2 Location of the Study Area

The geological map of the Calabar Flank showing the Ekenkpon and Nkporo Formations consisting of the shales are shown Fig. 2 (Akpan 2005). Calabar flank is that part of the southern Nigerian sedimentary basin bounded by the Oban Massif to the North and the Calabar hinge line delineating the Niger Delta basin in the south. The Flank contains up to 4000m of Cretaceous marine sediments in outcrop sections. The geology of the flank has been described in detail by Adeleye and Fayose (1978), Reijers and Petters, (1987) Petters et al., (1995) and Ekwueme et al. (1995). Sedimentation started with deposition of the fluvio-deltaic clastics of the Awi Formation of probably Aptian age, on the Precambrian crystalline basement complex of the Oban Massif. The unconformity between the two is marked by basal conglomerates. The Awi Formation is overlain by carbonates of the Mfamosing Limestone deposited during the marine transgression that

occurred in the Mid-Albian times. The Mfamosing Limestone is succeeded by a thick sequence of black to gray shale unit, the Ekenkpon Formation (Petters et al. 1995) deposited during the Late Cenomanian-Turonian times, and is characterized by minor intercalation of marls and calcareous mudstone. The Ekenkpon Shales are overlain by a thick marl unit, the New Netim Marl. This unit is nodular and shaly at the base and is interbedded with thin layer of shales in up-section. The New Netim Marl is unconformably passes upwards into the carbonaceous dark gray shales of the Nkporo Formation which caps the Cretaceous sequence in the Calabar Flank. This shale unit was deposited during the Late Campanian– Maastrichtian times.

3 Method of Study

A total of twenty (20) fresh rock samples were collected at different locations underlain by Ekenkpon and Nkporo shales along the Calabar - Itu and Calabar-Ikom roads where visible outcrops occur and pavement failures are common. The location of each sampling point was determined with the aid of global positioning system. The samples were labeled and neatly packed in ziplock sample bags before transportation to the laboratory for analysis. All the tests followed procedures specified by relevant sections of BS 1377 (1990) and ASTM (2008) standards. The laboratory tests carried out included water content (BS 1377:1990 Part 2 Section 3.2), liquid limit (BS 1377:1990 Part 2 section 4.5) and plastic limits (BS 1377:1990 Part 2 section 5), 24 hour free swell, organic content and Slake durability test. Organic content was estimated by the dry combustion method, in which a sample of the soil was heated to about 900⁰C and the organic carbon is oxidized by a stream of and purified air. The loss in weight due to ignition was reported as the organic matter content to the nearest 0.1% based on the total oven-dried weight of the soil. The 2 cycle Slake durability test developed by Franklin and Chandra (1972) and standardized by the American Society for Testing and Materials, ASTM D4644-08 (2008) which evaluates the durability of rock in terms of the slake durability index (SDI), was adopted for the study. For the test, representative shale samples each weighing 500g were placed in a screen drum immersed in distilled water, rotated at 20rpm for 10min and then oven-dried to a constant weight. Thereafter, they were subjected to 2 consecutive cycles of wetting and drying. The Slake durability index (SDI) was estimated as a percentage of the ratio of the final to the initial mass of each tested sample. The shear strength parameters of the shales in terms of cohesion (c) and angle of shearing resistance (ϕ) were obtained from the quick undrained unconsolidated triaxial test. (BS 1377:1990 Part 7 section 8). X-Ray power diffraction tests were carried out on both whole rock and clay-sized samples. The selected whole rock samples were run in a General Electric 2100* model diffractometer with the following instrument setting: copper radiation, 45KV 30mA and scanning rate of 2.6^o2 θ per minute.

4 Results and Discussion

Results of the laboratory tests are summarized in Table 1. The liquid limit of the study soils is approximately 45% which fall within the values of 35-50% implying intermediate plasticity using the Bell (2007) classification. The low to moderate plasticity index (PI

between 6 and 22%) of the shale samples shows the low to medium swelling potentials of the shales according to the relationship established by Ola (1982) between plasticity index and swelling potential of clays. When the liquid limit and plasticity index values were plotted on the plasticity chart, the samples plotted below the A-line (Fig. 3) implying that they are organic clays of intermediate plasticity (OM). The LL and PI values indicate the presence of expansive clay minerals. This is corroborated by the XRD peaks in Figs. 4 and 5 which show the presence of illite and montmorillonite in Ekenkpon shales while kaolinite dominates in the Nkporo shales. The 24 hour free swell test results correlate well with plasticity index results indicating that the degree of expansiveness of the shales range from low in Nkporo Formation (average free swell index of 17%) to moderate in Ekenkpon Formation (average free swell index of 23%). This will trigger a strong decay of these materials, causing them to decay spontaneously when they absorb water. All the shales examined do not meet the Federal Ministry of Works and Housing, FMWH (1997) requirement which specifies that a good sub-base material must have liquid limit and plasticity index of <35 % and <16 % respectively (Table 2). Neither do they satisfy the requirements that the liquid limit and plasticity index of materials must be ≤ 30 % and ≤ 13 % respectively to be suitable as base course materials. The high liquid limit and plasticity index may lead to structural damage. Results obtained from the quick undrained unconsolidated triaxial test show that shear strength of the shales is contributed by both cohesion and frictional resistance. The undrained cohesion values of 47 to 49 kN/m² and angle of internal friction between 3 and 4° suggest poor performance of the shales as engineering materials. The implication of the low value of the cohesion is that the stress needed to destroy the cohesion which binds the individual grains and give the rock its strength is small (Nickmann et al. 2006). The undrained cohesion values fall short of the greater than 103 kN/m² values specified for base course materials (FMWH 1997), thus the shales are not suitable as base course materials for road pavements. Generally, the cohesive strength, angle of internal friction and natural moisture content of the shales do not meet the Underwood (1967) minimum values favourable for durability.

5 Slake Durability

The two cycles slake durability test results indicate that the Nkporo shale samples tend to degrade much quicker than those obtained from Ekenkpon Formation. The lower the strength of the rock fragment, the higher the rate of degradation. This assertion is supported by the relative cohesive strength values of Nkporo (32 to 43 kN/m²) and Ekenkpon shales (48 to 50 kN/m²).

The SDI values of 6.9 to 9.22% and 29.54 to 51.42% for Nkporo and Ekenkpon shales respectively classify in the very low to medium slake durability index group, and they indicate that as engineering materials, that the shales are soil-like and of low durability according to Franklin & Chandra (1972) classification. They belong to the weathering grade IV of Santi (2006) which is described as highly decomposed earth materials made up of 50–100 percent soil from decomposition of the rock mass where large pieces can be broken by hand and the rock readily slakes when a dry sample is immersed in water. This implies that they have low resistance to break down by water and mechanical agitation. At points of high moisture content, there occurred a corresponding drop in the slake durability index value and vice versa. This implies that the natural moisture content is an

important factor that affects the durability of the shale samples. High natural moisture contents also indicate a high degree of weathering, fracturing, or disaggregation (Santi 2006). Slake durability test results showed that exposure to at least one drying-humidifying cycle did increase slaking, similar to results obtained by Adisun et al. (2010). The average organic content for Nkporo and Ekenkpon shales are 9 and 12% respectively. As the organic content increased, the slake durability of the shale sample increased and vice versa. The overall assessment of the results of this work show that the Nkporo shales exhibit relatively lower durability characteristics than the Ekenkpon shales. Thus pavement failures are remarkably more intense at the sections of the road underlain by the former. Generally, results agree with the assertion by Nickmann et al. (2006) that durability is not dependent on a single rock parameter, but on a combination of several parameters as e.g. compressive strength (expression of the bond strength of the matrix), grain size distribution (content of clay minerals susceptible to water) and pore volume (degree of the water conductivity). In fine-grained materials an additional pore water pressure may develop, resulting in the spontaneous decay of the rock.

6 Conclusion

Engineering properties of shales in Calabar Flank indicate that they are soil-like materials with low durability and low to medium swelling potentials. The low value of undrained cohesion and frictional angles imply that the stress needed to destroy the cohesion which binds the individual grains and give the rock its strength is small. The overall assessment of the results of this work show that the Nkporo shales exhibit relatively lower durability characteristics than the Ekenkpon shales, thus there are more pronounced structural failures in the sections underlain by the Nkporo shales compared to the Ekenkpon shale on account of the durability indices. These soils are thus likely to fail under heavy axial load and excessive precipitation will trigger slippage along contact points that will eventually cause landslides. The shales perform poorly as pavement materials in view of their low resistance to weakening and disintegration when they are subjected to cyclic wetting and drying.

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Appendix



Figure 1: Typical pavement failure alongthe Calabar-Itu Road
<http://www.akwaibomnewsonline>

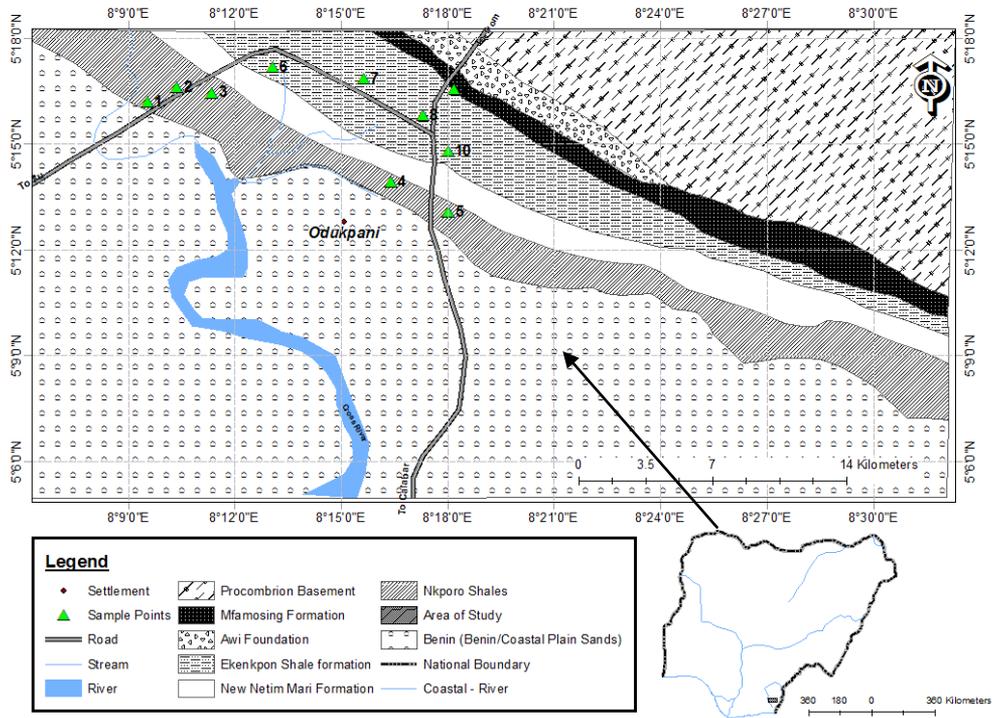


Figure 2: Geological map of Calabar Flank showing distribution of the shales and sampling points (modified from Akpan 2005)

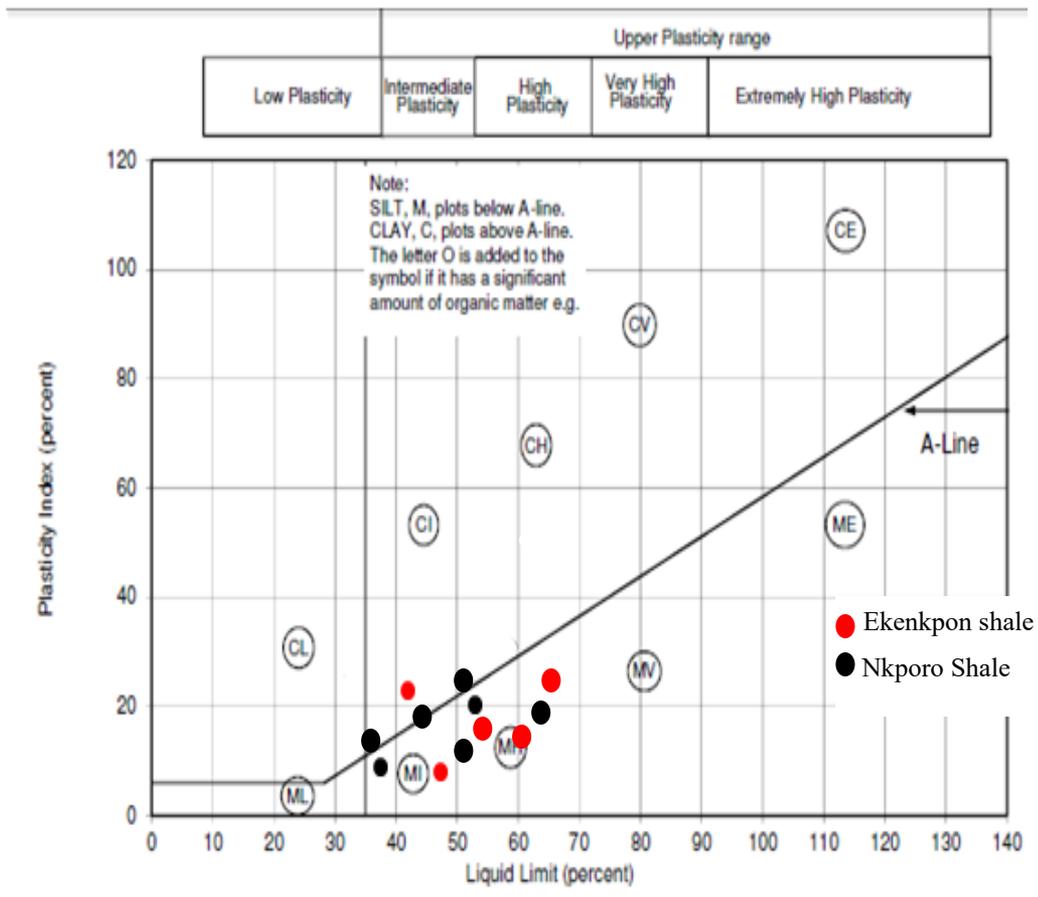


Figure 3: Plasticity classification of the shales

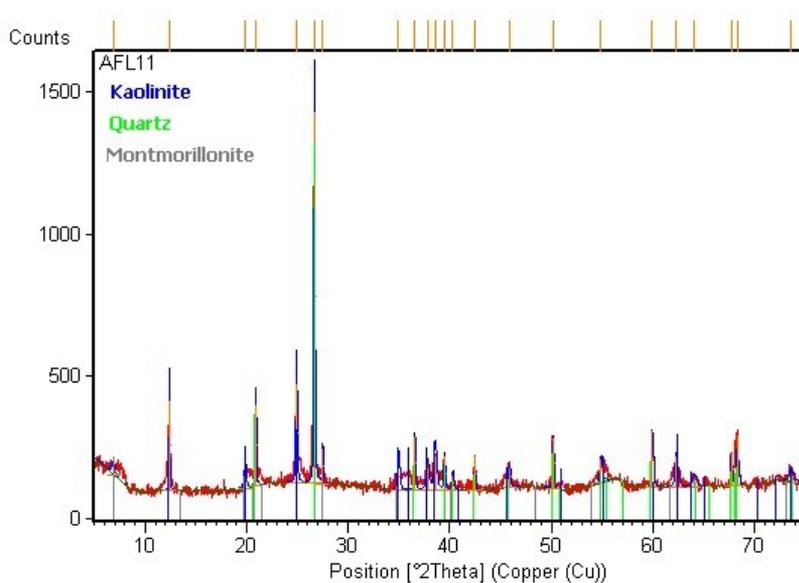


Figure 4: Typical diffractogram pattern of the Ekenkpon shales

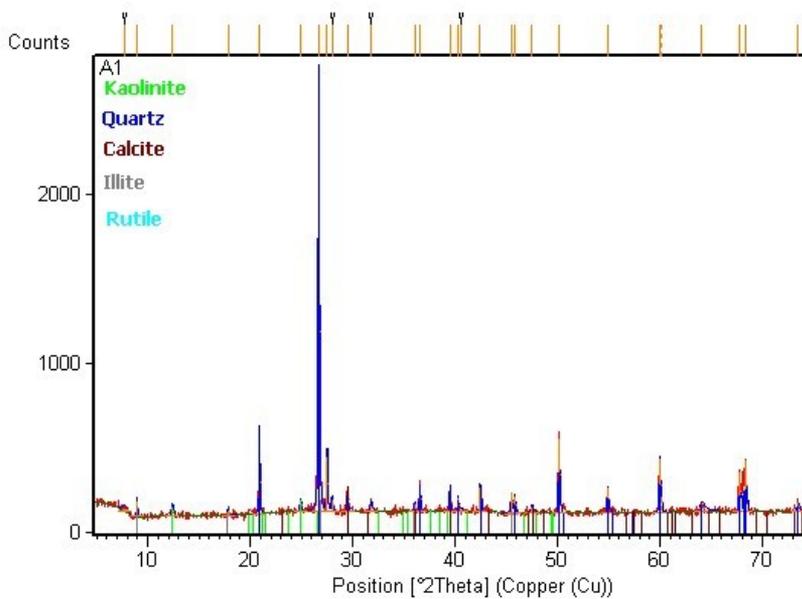


Figure 5: Typical diffractogram pattern of the Nkporo shales

Table 1: Properties of the shales

Property	Nkporo shale			Ekenkpon shale		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Natural moisture content %	55	19	37	4	8	6
Liquid Limit%	37	53	45	42	47	45
Plastic Limit%	28.2	32.6	30.3	19.6	41.2	30.4
Plasticity index%	8.8	20.4	14.6	5.8	22.4	14.1
SDI%	6.9	9.22	8.06	29.54	51.42	40.48
SDL %	90.78	93.1	91.94	48.58	70.46	59.52
Organic content%	4	13	8.5	5	19	12
Free swell%	7	27	17	13	33	23
Cohesion (kN/m ²)	32	43	37.5	48	50	49
Angle of friction Φ	4	3	3.5	3	5	4

Table 2: Comparison of results with FMWH (1997) specifications for bridges and roads

Properties of Material	FMWH	Nkporo shale	Ekenkpon shale	Remark
<u>General filling & Embankment</u>				
Liquid Limit	<40	37-53	53	Unsuitable
Plasticity Index	<20	9 -20	6 - 22	
<u>Sub base Course</u>				
Liquid Limit	<35	3 -53	42 - 47	Unsuitable
Plasticity Index	<16	9-20	6 - 22	
<u>Base course</u>				
Liquid Limit	< or = 30	37-53	42 - 47	Unsuitable
Plasticity Index	< or =13	9 -20	6 - 22	