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A Geotechnical Investigation into the Failure of a Typical Road in Southwest Nigeria

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ABSTRACT: *A study of the structural failure of Omuo Ekiti – Ikare Akoko highway in southwestern Nigeria has been undertaken. Geotechnical tests were carried out on soil samples obtained from 10 locations along the road. Laboratory tests on the soil samples collected showed specific gravity (SG) ranging from 2.30 to 2.72, liquid limit (LL) ranging from 26.4% to 55.0%, plastic limit (PL) from 12.95% to 23.89%, plasticity index (PI) from 9.76% to 34.17%, percentage passing sieve no 200 from 23.70% to 59.90%, maximum dry density from 1640kg/m^3 to 2080kg/m^3, optimum moisture content from 8% to 24% and California Bearing Ratio (CBR) for unsoaked and soaked samples from 3.01% to 30.40% and 0.50% to 13.15% respectively. Comparison of these results with the standard specifications stated by the Government of Nigeria Federal Ministry of Works and Housing (1997) showed that the liquid limit and the plasticity index of most of the test samples did not conform to specified values of not greater than 35% and 12% for LL and PI respectively. The CBR values were far below the minimum specified values for unsoaked base, soaked subbase, soaked subgrade, which are 80%, 30% and 5% respectively. The soil samples were predominantly fine-grained based on the percentage passing sieve no 200 > 35% (ASTM D-3282). It was concluded that the base and subgrade soil materials were substandard. Therefore, there is need to remove the substandard materials and replace with suitable materials or rather stabilize appropriately prior to placement of a new layer of bituminous materials on the road.*

KEYWORDS: *geotechnical tests, highway, Nigeria, soil, structural failure.*

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I. INTRODUCTION

Roads have demonstrated worldwide to be the most effective and preferred mode of transportation for goods and persons (Owolabi, 2012). Road transport gain popularity due to its ability to provide better accessibility through door-to-door services and its suitability for short haulage of passengers and freight. In Nigeria, road transport is the most affordable and efficient means of transport to the majority of people as other modes of transport are either too expensive or not fully developed, thus resulting to a rise in the construction of roads. Consequently, there is excessive axle loads on the majority of the roads.

Nigerian roads are predisposed to structural failure after few years of performance and often before reaching design age. Komolafe (2006) stated that, "the state of Nigerian roads stands out like a sore thumb and their national picture is simply scandalous". Reconstruction and rehabilitation of roads in Nigeria without even care to investigate the causes of the perpetual failure is very common. Akintorinwa et al., (2011) reported that several causes such as geotechnical, geological, geomorphological, hydrological, design, material selection, construction practices, maintenance and usage-factor can influence the performance of pavement structures. Gidigasu, (1976) also reported that the prevalent deterioration and failure of Nigerian roads have been attributed to the indiscriminate use of lateritic soils without full knowledge of their limitations. Ogundipe (2008) reported that roads failed due to negligence of road maintenance, inadequacies in design and poor workmanship, poor soil properties like low CBR and high liquid limits etc. among others. Momoh et al. (2008) and Adiat et al. (2009) concluded in their study of failed highway pavements using geophysical methods, that some geological factors such as the near surface geologic sequence, existence of geological structures like fractures and faults, presence of laterites, existence of ancient stream channels, and shear zones influence road failures.

The incessant structural failures on Nigerian roads are becoming alarming and have become a common phenomenon in which the failures can be linked to so many factors such as inadequate information on underlying soil layers in the pavement and the local subsurface geologic data. Adequate information on the actual causes of failure will greatly assist in avoiding this perennial problems hence curbing wastage of the limited economic resources on quick-fix solutions have failed in tackling the problem.

Omuo Ekiti – Ikare Akoko highway is one of the busy southwestern Nigerian roads as it connects two commercial towns. The deplorable status of the road has resulted in accidents that have caused considerable damages to human lives and properties. The route is known for numerous cases of armed robbery attacks, owing to slow movement of the plying vehicles. This has reduced the movement of people and goods, thus reducing the rate of socio-economic growth and development in the corridor. This study has examined the geotechnical properties of the subsurface soil as it adversely affects the road pavement.

II. STUDY AREA

The highway under consideration is about 28 kilometres and located within latitude 7º 45' 31" N and longitude 5º 43' 20" E to latitude 7º 33' 05" N and longitude 5º 46' 05" E (Figure 1). The road serves as a link between the eastern part of Ekiti State and the northern part of Ondo State. The road connects several towns, villages, farm settlements and market. Omuo Ekiti – Ikare Akoko highway is known to be busy as Ikare Akoko is a commercialised town with a popular market called Osele market. The study area is underlain by Precambrian basement complex which is mainly migmatite-gneiss. The topography of the area under study is rugged and undulating with extrusion rocks. Most of the outcrops chemically weathered into clays which led to poor soil beds.

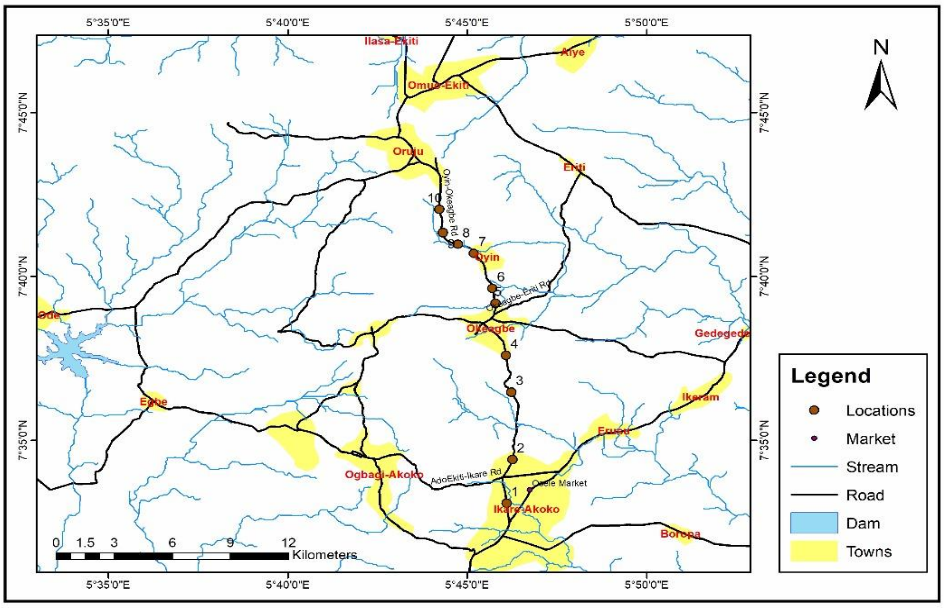

Figure 1: Route map showing sample locations along Omuo Ekiti – Ikare Akoko road

III. MATERIALS AND METHODS

Disturbed soil samples were collected from trial pits along failed sections of the highway at different locations and various depths below the pavement surface to get base samples, subbase samples and subgrade samples at varying depths of 0 - 0.15m, 0.15m – 0.30m and 0.30m – 0.45m respectively. The samples were collected at ten different locations as shown in Figure 1.

The soil samples were air dried and subjected to laboratory tests such as specific gravity, compaction, Atterberg limits, mechanical sieve analysis and California bearing ratio (CBR). The tests were carried out in accordance with BS 1377 (1990).

IV. RESULTS AND ANALYSIS

Specific gravity

The specific gravity of the soils ranged from 2.30 to 2.72 as shown in Figure 1. The specific gravity of lateritic soils falls within a range of 2.60-3.40 (De-Graft Johnson, 1969). Soils from the same parent material with greater degree of laterization will have a better specific gravity. However, the specific gravity of clay ranges from 2.2 - 2.6 (Oyelami & Alimi, 2015). The specific gravity of clay minerals such as montmorillonite, illite and kaolinite range from 2.60 – 2.80 while 2.60 – 2.90 for clayey and silty soils (Das,1990) and the specific gravity of the majority of the soils falls within the clay group which shows that the soils are clayey soils and laterites rich in clay content. The content of clay controls the engineering properties of lateritic soils and the higher the clay content, the more tormenting the soil is.

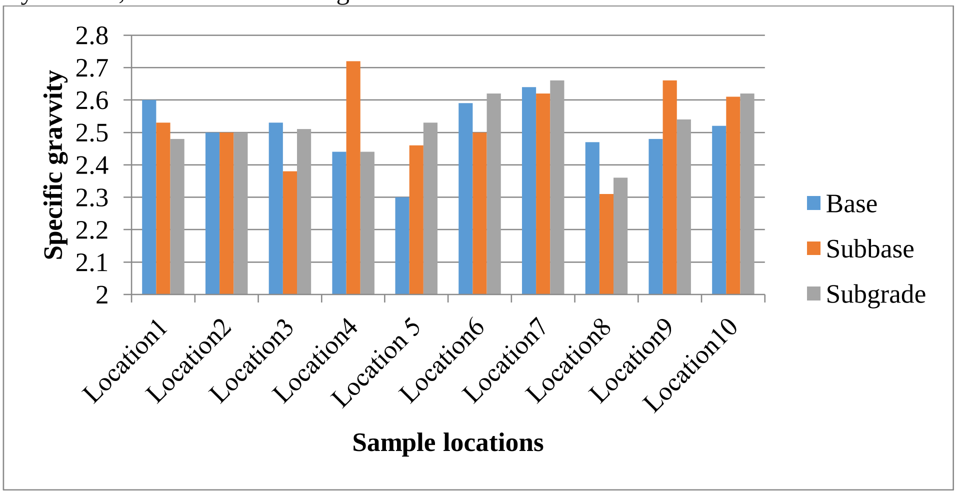

Figure 2. Specific gravity of soil samples along Omuo Ekiti – Ikare Akoko road

Mechanical sieve analysis

Table 1: Percentage passing sieve 200

Locations	1	2	3	4	5	6	7	8	9	10
A	35.76	39.12	33.64	38.48	46.80	31.24	32.48	40.06	32.46	28.52
B	41.52	41.52	43.00	40.02	35.30	23.70	31.16	46.74	49.84	27.62
C	42.24	39.44	33.12	37.20	52.56	38.08	36.44	45.42	26.14	59.90

The percentage passing sieve 200 for soil samples obtained from various locations are shown in Table 1. The values ranged from 23.7% to 59.9%. From the AASHTO soil classification of soil samples for highway, A-1 and A-2 soils are excellent and good soils for highway with percentage passing Sieve No. 200 not more than 35% while A-3 to A-7 soils are fair to poor soils with percentage passing Sieve No. 200 greater than 35%. Most of the soil samples along Omuo Ekiti – Ikare Akoko range from fair to poor soils as observed in Figure 3. The results indicate that most of the soils have clay with low plasticity while few possess high plasticity. Clay is troublesome due to its porosity and low permeability. Clay presence could be responsible for instability of the road pavement under study.

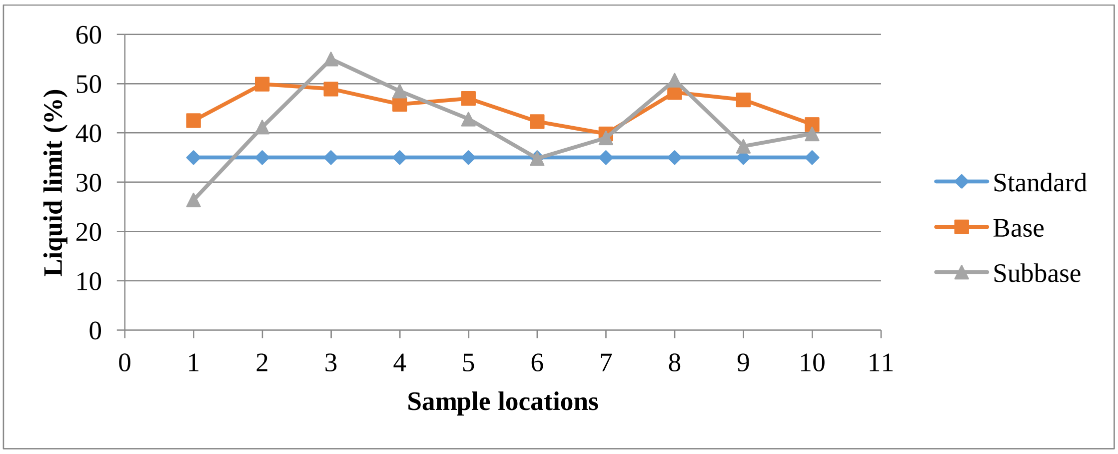

Figure 3 Percentage passing sieve no 200 relationships for base, subbase and subgrade samples along Omuo Ekiti - Ikare Akoko highway

4.3 **Atterberg limits**

The liquid limit and plasticity index for subbase and base course materials should not be greater than 35% and 12%, as determined by American Society for Testing Materials method, serial designation D 432 - 39 and 424 - 39 respectively or as determined by test No 2 or 2A and test Nos. 3 of BS 1377 (1975) (FMWH, 1997). The base and subbase material for the entire soil samples do not meet specified requirement except subbase soil sample from location 1. The subgrade of soil samples from all locations conform to FMWH (1997) requirements indicating that liquid limits not greater than 80% and plasticity index not greater than 55%. Based on soil plasticity values, base and subbase soils are expected to exhibit swelling and shrinkage potential. The consistency behaviour of the soil samples is shown in Figures 4 and 5. All the soil samples except the subbase sample at location1 are not suitable for base and subbase course materials based on their liquid limit and plasticity index values >35% and >12% respectively. Thus, these materials are not suitable owing to their capacity to retain appreciable amount of water hence, susceptible to compressibility.

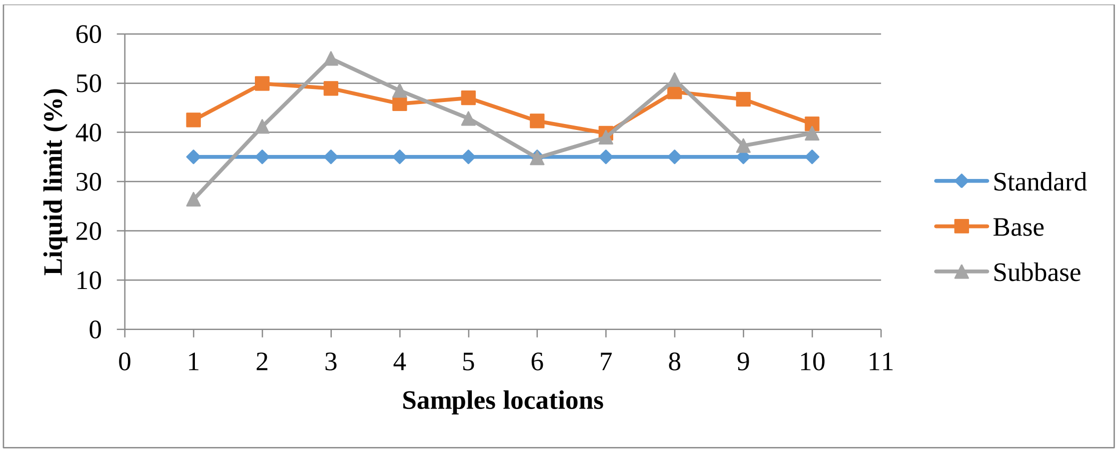

Figure 4 Liquid limit relationships for base and subbase materials

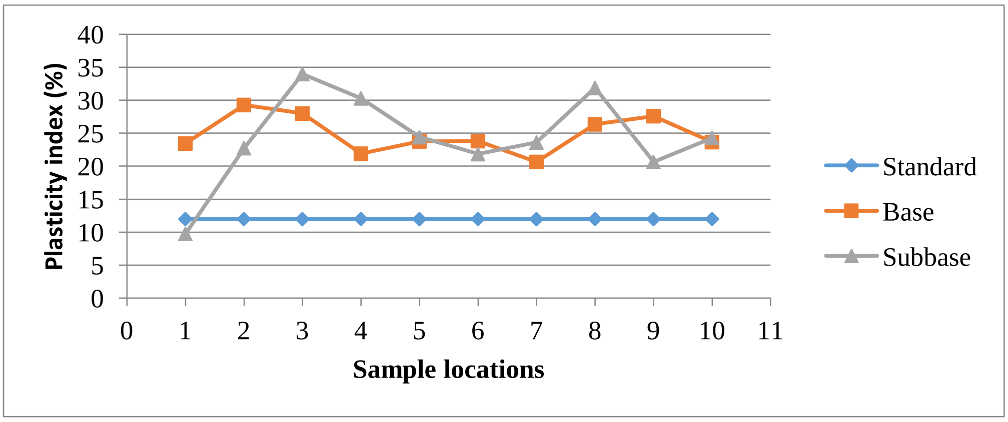

Figure 5 Plasticity index relationships for base and subbase samples

Soil Classification

According to American Association of State Highway and Transportation Official [AASHTO] classification of soil, all soil samples from locations 4, 5, and 8, subbase samples from locations 2 and 3, base of samples from location 1 and 2 together with subgrade of samples from locations 1, 7 and 10 were A-7-6, which indicated clayey soils which are poor soils in highway construction. Soil samples from the subgrade at locations 2 and 6 and subbase sample from location 9 fell within A-6 soils which indicated clayey soils which are poor construction soils. The subbase soil sample from location 1 fell within A-4 soils which are referred to as silty soils. Base soil samples from locations 3, 6, 9, and 10 together with subgrade soil sample from location 3 fell within A-2-7. Subbase soil samples from locations 6, 7 and 10 together with base soil sample from location 7 were within A-2-6. Subgrade soil sample from location 9 fell within A-3/A-2-4. In general, the classification of soil samples along the length of the highway found some of the soils used for subgrade, subbase and base to be inappropriate.

Compaction characteristics

The maximum dry density (MDD) at optimum moisture content (OMC) for various soil samples obtained from test locations are shown in Figure 6. According to Federal Ministry of Works and Housing (1997) specifications MDD for base, subbase and subgrade must not less than 2000 kg/m^3, 2000kg/m^3 and 1760 kg/m^3 respectively. Apart from the subbase sample at location 7 and base soil samples at locations 3, 7 and 10, the MDD of the other subbase and base soil samples were inadequate. The clayey properties of the soil may be responsible for lower maximum dry densities. Density is a factor for soil strength; the strength of the soil will increase as its dry density increases. The potential of soil to absorb water at later times will also decrease with higher densities owing to the reduction in porosity in the soil mass.

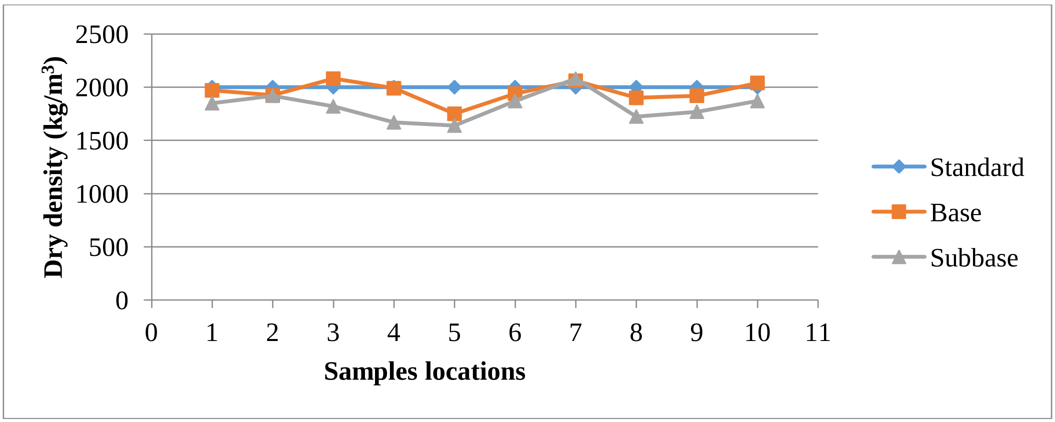

Figure 6: Maximum dry density relationships for base and subbase samples

California Bearing Ratio (CBR)

The California bearing ratio of the soil samples ranged from 3.01% to 30.40% for unsoaked samples and 0.5% to 7.52% for soaked samples respectively, as shown in Figure 7. These values do not meet the requirement that CBR of subbase and base courses should not be less than 30% for soaked and 80% for unsoaked (FMWH, 1997). The CBR for soaked subgrade samples ranged from 0.94% - 13.15%. Apart from samples from locations 7 and 9, all the other subgrade soil samples do not meet the required minimum specification of 5% for CBR for soaked subgrade. The low CBR values may be attributed to the clayey nature of the soil samples. Clayey characteristics in any material used as supporting layer in highway construction will impair the strength characteristics of the pavement.

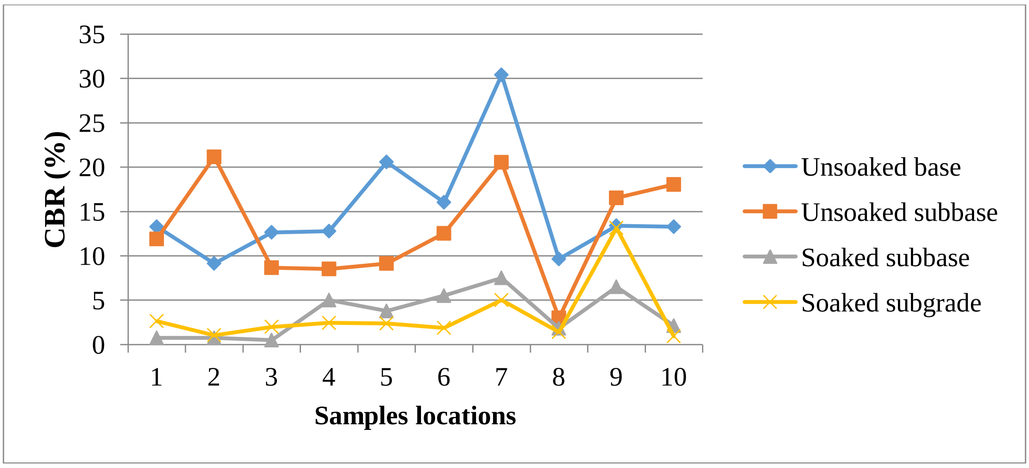

Figure 7 CBR chart for each layer at each location along Omuo Ekiti – Ikare Akoko road

V. CONCLUSION

From the study, it was found out that poor geotechnical properties of underlying soil layers were responsible for the structural failure of Omuo Ekiti – Ikare Akoko highway. The liquid limit and plasticity index of the majority of the soil samples obtained from the subgrade, subbase and base layers did not conform to the Nigerian specification as they were greater than 35% and 12% respectively (FMWH, 1997). The low values of CBR unsoaked base, soaked subbase, soaked subgrade contributed to the failure of the road; such low strength soils will not provide a stable compacted bed. Based upon the findings of this study, the soil samples are poor lateritic soil, which therefore contributed to the failure of the road. Thus, in terms of strength, all soils used are grossly inadequate for use as a subbase and base road construction material while most of the subgrade materials are unsuitable. The geotechnical characterization of the soils from the failed sections along Omuo Ekiti – Ikare Akoko highway vary significantly from the standard set by the Federal Ministry of Works, Nigeria which indicates that the geotechnical status of the soil along the failed sections is challenging. Materials to be used for road pavement construction must conform to specification. In order to mitigate this structural damage; treatments should be carried out carefully during rehabilitation or reconstruction works in order to improve the soil. Moreover, to forestall road failures in Nigeria, construction materials must be adequately tested and treated prior to use to avert problems during or after construction works while adequate routine and emergency maintenance culture should be encouraged. This will prevent Nigerian roads from failing before their designed life span.

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