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Highway failure over talc–tremolite schist terrain: a case study of the Ife to Ilesha highway, South Western Nigeria

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Abstract Several failure stretches along the newly completed Ife–Osu–Ilesha highway in South Western Nigeria have been studied. The sub-grade as well as the borrow materials are schist-derived, residual micaceous soils which contain abundant talc and hydromica. The flaky structure of these soils means it is difficult to achieve adequate field compaction. Extensive deposits of amphibolite-derived residual soils also occur in the area, which would provide a more suitable sub-base/fill material. The case study highlights the importance of an engineering geological appreciation of the ground conditions prior to design and construction.

Keywords Pellitic schist · Hydromica/Sericite · Amphibolite · Talc · Ultramafic

Résumé Plusieurs zones de rupture le long de l'autoroute Ife-Osu-Ilesha, récemment terminée dans le sud-ouest du Nigeria, ont été étudiées. Les couches de forme ainsi que les matériaux d'emprunt sont constitués à partir de sols résiduels micacés dérivés de schistes qui contiennent beaucoup de talc et des hydromicas. La structure feuilletée de ces sols rend les opérations de compactage difficiles. Or, des gisements importants de sols résiduels dérivés d'amphibolites existent aussi dans cette région. Ils donneraient un matériau de meilleure qualité pour les couches de base. L'étude de cas souligne l'importance des études de géologie de l'ingénieur avant les opérations de conception et de construction de tels projets.

Mots clés Schistes pellitiques · Hydromica/Séricite · Amphibolite · Talc · Ultramafique

Introduction

The relationship between all engineering structures and their foundation soils is important and cannot be ignored. Unfortunately, in engineering circles in Nigeria, the value of a realistic engineering geological study is not always fully appreciated. Designs are finalized without relevant regard to the geology and the actual geotechnical behaviour of the sub-grade, sub-base or base course soils in the field.

In Nigeria, the term 'laterite' is often used to imply an excellent soil material which will give rise to few construction problems. As a consequence of this, the recently completed dual highway between Ife and Ilesha (Fig. 1) failed within days of being opened to traffic. Many stretches of the highway have been rendered unstable by massive down-warping of the entire pavement and potholes of 1–2 m across frequently occur (Fig. 2). Also common is the separation of the asphalt finish from the base course

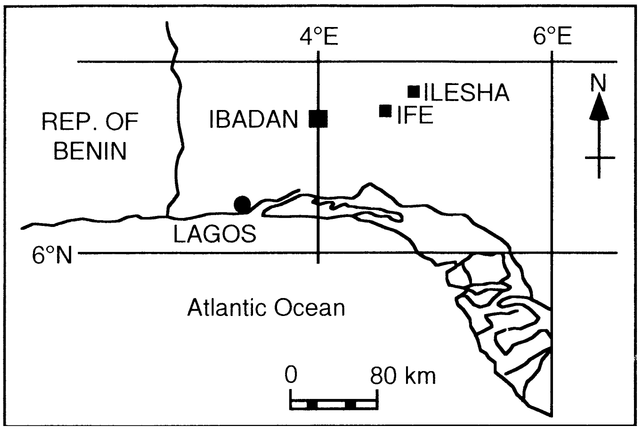

Fig. 1 Location of the study area in South Western Nigeria

(Fig. 3) and verges are constantly being eroded by rainfall (Fig. 4).

This brief case history highlights the urgent need for geotechnical maps to be prepared for areas where development is proposed (Meshida 2002).

Environmental setting

Figure 1 shows the location of the Ife–Ilesha area, which has a relatively rugged terrain, made up of a series of low ridges and escarpments, the southern continuation of the Yoruba Hills. Its general physiography is greatly influenced by the geology of the basement complex rocks.

The vegetation consists of tropical deciduous rainforest and the climate alternates between dry seasons (from the end of November until early April) and wet seasons (April to early November). The annual rainfall is some 1,200–1,500 mm and occurs mostly in thunderstorms. In general the area is well drained.

Fig. 2 Erosional rills created in the poorly compacted verge area along the highway

Fig. 3 Typical failure of asphalt finish by localized subsidence and distortion

Geology

The study area is part of the schist belt of Western Nigeria (Fig. 5) and comprises mainly schist and amphibolite. Some NE–SW ridges occur where quartzites are present trending approximately NE/SW while a more gentle topography is found on the schists and amphibolites. Prominent schistosity is present over the 28 km of the new road at sub-grade level; Fig. 6 shows an example of schists exposed in one of the road cuttings.

Figure 5 is a recent geological map of the study area constructed using the G.I.S. technique. It shows the relationship of the highway alignment to the basement rocks. Detailed geological studies of the alignment show that the lithology of the basement rocks consists of pellitic and semi-pellitic schists and amphibolites (Olade and Elueze 1979; Meshida 1985, 1987, 2004). In particular, the new highway traverses a prominent section of talc–tremolite–sericite schists which are deeply weathered. Talc dominates the engineering characteristics of the soils and is seen in the residual soil mass as a whitish, powdery material. The presence of hydromica and tremolite is indicative of an ultramafic origin of the

Fig. 4 Typical separation/peel-off of asphalt finish

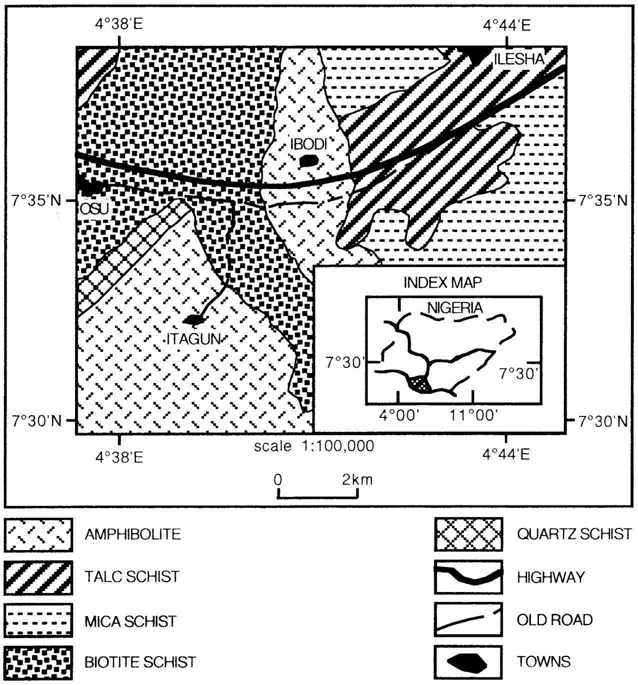

Fig. 5 Geological map of the study area, showing the route alignment

basement complex rocks in the area. Olade and Elueze (1979) suggest a general metamorphic grade for the lower amphibolite facies, with an almandine-amphibolite sub-facies.

Table 1 shows the results of three major element analyses of the talc schists, which generally confirm the basic to ultramafic origin of the basement rocks. The high magnesium content in the analyses is consistent with the suggestion by Weaver and Pollard (1975) that when hydromica occurs in abundance with talc, it creates an environment rich in magnesium, usually signifying an ultramafic origin.

Fig. 6 Schistose structure along cuts typical of the deposits seen in the road cuttings

The soils

The residual soils which developed on the schists retain the schistose structure of their parent rocks. The mottled saprolite horizon has frequently been used as sub-grade. Sesquioxide precipitation is significant as the reddish brown oxidation colour is commonly mistaken for 'laterite'—usually the construction materials specified.

The observed geological history and the present field characteristics of the country rocks have considerable implications for the present structure and engineering characteristics of the sub-grade and fill materials. This relationship between the nature of the geology and the engineering properties/field behaviour of soils, particularly the influences of the mineralogy, geochemistry and degree of weathering, is not usually appreciated.

This brief case history is presented to highlight the importance of an understanding of the influence of the soils and demonstrate how talc, the softest mineral on the Mohr Scale, combined with hydromica, is a formidable enemy of highway stability (Fig. 5). Unfortunately all the borrow pits for the Ife–Ilesha highway were established on the talc schists such that both the sub-grade and the borrow materials consist of badly weathered schists.

Grain size distribution

Careful visual examination of several samples of the schist-derived soils at many chainages along the entire alignment of the Ife–Ilesha highway in Southwest Nigeria confirmed the remarkable absence of macro size sand grains in their mineralogical assemblage. Pseudo sand sizes in the grains were sesquioxide precipitations rather than quartz. Such materials characteristically crumble and disintegrate with the intensity of agitation and manual squeezing imposed prior to wet sieving. As a

Table 1 Major elements analysis of the talc schist from Ilesha (adapted from Olade and Elueze 1979)

Elements	Sample no. 16 (%)	Sample no. 56 (%)	Sample no. 57 (%)
SiO_2	46.08	49.21	48.06
TiO_2	1.36	0.47	1.90
Al_2O_3	9.57	5.57	6.15
Fe_2O_3	16.01	10.90	14.38
MgO	16.14	22.52	18.60
CaO	5.93	5.70	7.43
Na_2O	1.18	0.51	1.01
K_2O	0.06	0.21	0.04
P_2O	0.33	0.26	0.40
MnO	0.37	0.19	0.30
L.O.I.	2.66	3.66	1.31
Total	99.69	99.31	99.58

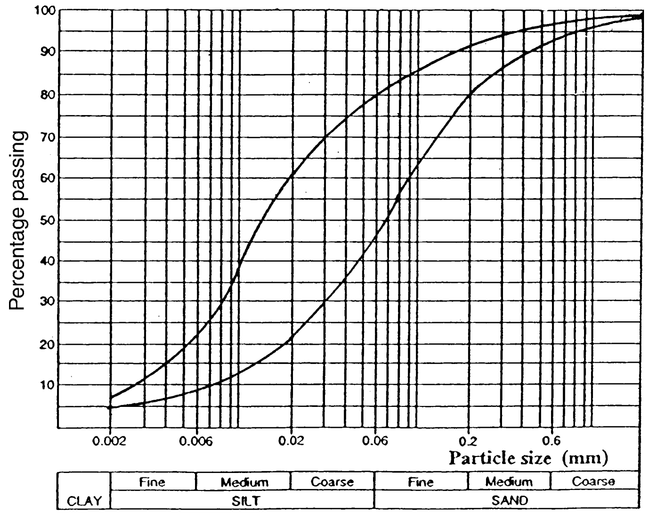

Fig. 7 Location of major borrow pits established on the schists

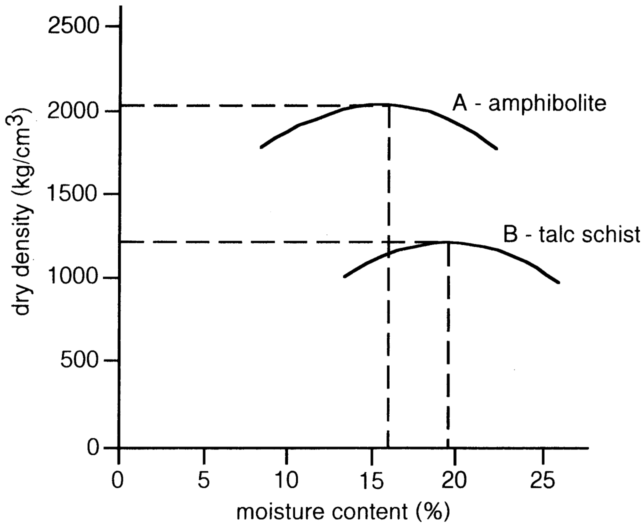

Fig. 8 Location of failures where the compacted base course was schist

consequence, at the end of the wet sieving process, a relatively uniform aggregate of silt-size grains was invariably obtained. Occasionally, the sesquioxide cementation was sufficient to form coarse grain particles 2–4 mm in diameter. The absence of clay-sized particles is significant, with a maximum of 3% being recorded in the envelopes for the 102 particle size analyses (see Fig. 7).

Atterberg limits

Even though up to 3% clay size particles or grains were present, all the soils were non-plastic. This is believed to be due to the presence of the hydromica, which could be inferred from Grim (1948) as producing platy minerals, such that the test specimens did not stick together in the plastic limit test while in the liquid limit test they would tend to slide rather than 'flow'. Dry samples of the soil lacked any significant strength when squeezed with the fingers, crumbling into a fine powder.

Compaction

Compaction tests were carried out on ten samples using the modified AASHTO technique. At the end of each compaction exercise, the soils became fine grained with very brittle consistency. Compacted densities were very low; Fig. 8 shows a typical curve of the amphibolite-derived soil (a) and the schist-derived soil (b). The contrast in the compaction characteristics of the two soils is evident from the curves. The schist soil would not satisfy requirements for a construction material.

California bearing ratio

Not surprisingly, the soils yielded extremely poor California bearing ratio (CBR) values, both in the unsoaked and soaked tests. When soaked for 48 h, the CBR ranged from 2 to 4%. Such low values indicate that the soils are not likely to provide stable compacted material.

Field behaviour

Detailed field notes were maintained during the construction works to record the actual behaviour of the soils, many of which were obtained from cuts along the road.

The compacted fills crumbled and subsided en-masse such that in many cases filling and compaction had to be repeated along the failed stretches. Where the asphalt layers had already been placed, it was necessary to re-excavate these and undertake remedial compaction before re-surfacing.

It was observed that the more the soils were compacted, the more powdery they became—a characteristic feature of schist-derived soils which contain abundant

Table 2 Classification of the soils following AASHTO

Horizon	Amphibolite	Talc schist
Upper	A-4	A-6
Laterite	A-4	A-6, A-7
Intermediate	A-4	?
Saprolite	A-4	A-5

chlorites, sericite, or talc. In many cases, sub-base layers of crushed granite chips of up to 400 mm thick were placed over areas where sub-grade instability was present, but this in itself offered little improvement.

Recommendations

It was observed that the old alignment at the Ibodi township appeared stable. The sub-grade and the base course consisted of amphibolite-derived residual soils. This material occurs abundantly in this location as well as around Itagunmodi, also very close to the new alignment. Earlier studies on the amphibolite-derived residual soils (Meshida 1985) gave the results tabulated in Table 2 and were found to be A-4 grade under the Unified Soil Classification System. From this, the writer considers these amphibolite soils could be utilized for the remedial works.

Conclusions

Highway engineers operating in Nigeria are strongly advised to utilize well-established geotechnical techniques for the comprehensive studies and assessment of their alignment terrains prior to finalizing the details of their designs. The search for the appropriate construction borrow materials is a serious scientific process that must not be treated with levity. The task should not be left entirely to the contractor. The Ile–Ilesha failed highway experience should drive this geotechnical lapse home for the avoidance of similar cases.

The evidence from the Ife–Ilesha highway has also shown that the necessary background studies were not undertaken by personnel with an appropriate understanding of the ground conditions. Whereas the amphibolite provided quite good sub-grade and base course material, the use of talc schists created many problems.

Unfortunately, in some parts of Nigeria, the expertise of the engineering geologist is not sufficiently appreciated. As a consequence, in the author's opinion, avoidable mistakes have been made in the construction of the nation's highways, which not only involve additional expense, but also lead to delays as well as posing safety risks to those using the roads.

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