

Geotechnical basis for failure of sections of the Lagos-Ibadan expressway, south western Nigeria

G.O. Adeyemi · F. Oyejemi

Abstract A number of geotechnical properties of the subgrade soils in some sections of the Ibadan end of the Lagos-Ibadan expressway were investigated with a view to elucidating the geotechnical basis, if any, for the instability of sections of the flexible highway pavement. The results of the investigations show that the subgrade soils below the stable sections have a higher maximum dry density, unsoaked California bearing ratio (CBR) and uncured, unconfined compressive strength than those below unstable sections. In addition, the soils below stable sections have both a lower proportion of fines and clay-sized fraction and a lower optimum moisture content and linear shrinkage than the material below the unstable sections. Surprisingly, the soils below the unstable pavements not only have a lower plasticity index and higher soaked CBRs than those below the stable pavements but also are more mechanically stable. The investigations have shown that significant differences need not exist between the geotechnical properties of soils below stable zones and unstable sections before such parameters can serve as bases for predicting the stability of flexible highway pavements in the tropics.

Résumé L'autoroute Ibadan-Lagos est une liaison importante, entre Lagos et le nord du Nigeria, qui a subi de nombreux dommages. L'article présente les tests géotechniques réalisés sur les matériaux de la plate-forme de terrassement, prélevés au niveau des sections stables et instables de la chaussée d'autoroute, respectivement situées à 142-144 km et 133-141 km de Lagos. Il a été montré que les sols sous la section instable présentaient de plus faibles

indices de plasticité et des valeurs de CBR saturées plus élevées que les sols sous la section stable. Les propriétés mécaniques des sols étant souvent meilleures sous la section instable de l'autoroute, on ne peut prétendre utiliser ces propriétés pour prévoir la stabilité. Les paramètres géotechniques utilisés avaient sérieusement permis de pronostiquer la stabilité de la chaussée, avec seulement de faibles différences pour les sols des deux sections considérées. Il est donc recommandé de développer des travaux de recherche pour établir des spécifications concernant les matériaux de plate-forme de terrassement qui soient plus adaptées aux sols en zone tropicale que les spécifications considérées actuellement.

Key words Laterite · Pavements · Soil stability · Nigeria · Predictions

Mots clés Latérite · Plate-forme de terrassement · Stabilité · Nigeria · Prévisions

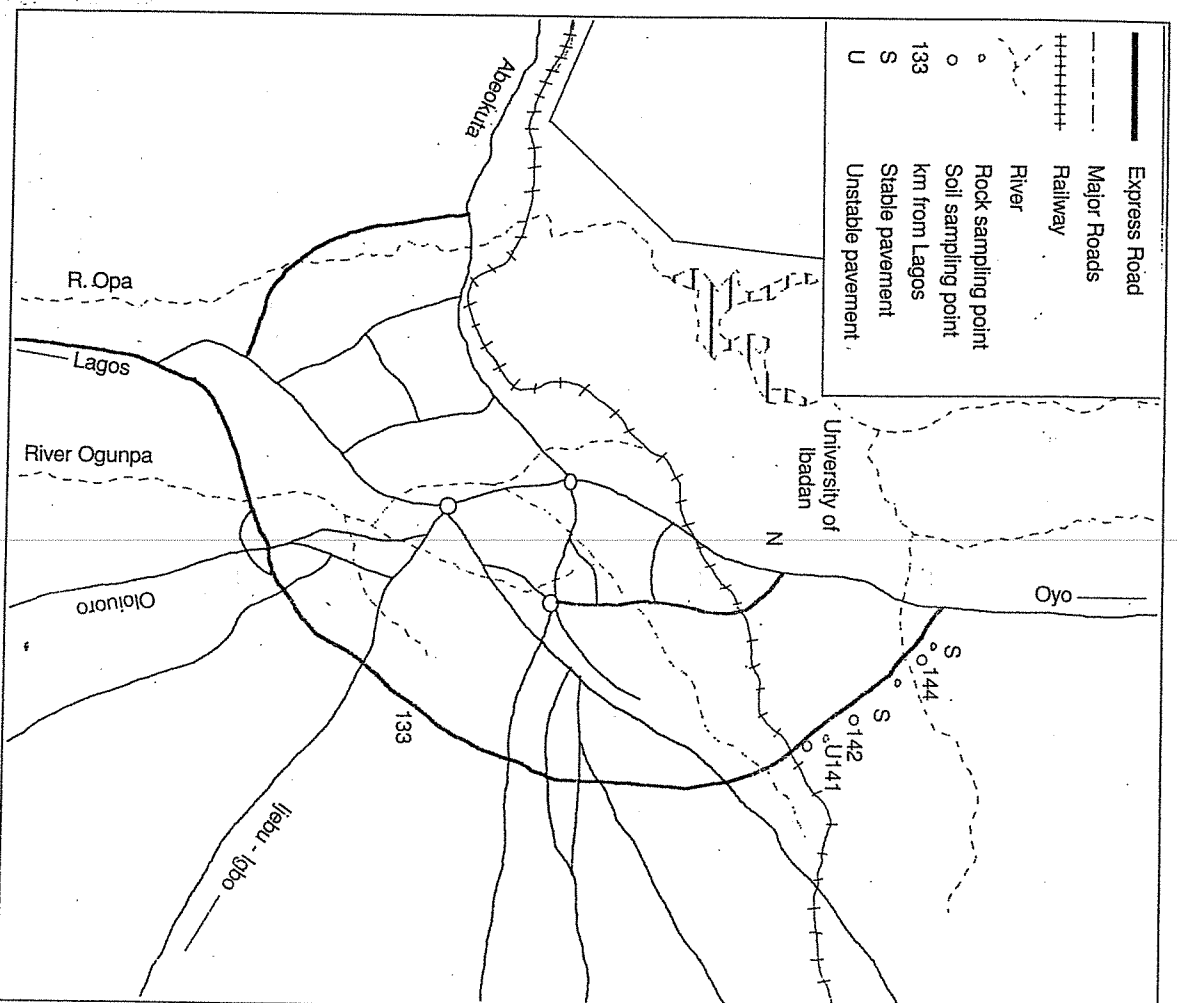
Introduction

Failure of flexible highway pavement is a common phenomenon in most parts of the tropical world. Although failure of road pavements can occur in the form of pitting and rutting, waviness was adjudged to be the most common form (Gidgasu 1976). Whilst a number of contributory causes have been identified, such as misuse, overuse or poor construction (e.g. Ajayi 1982), the majority of road failures in the tropics can be attributed to geotechnical factors, as shown by such workers as Gidgasu (1976), Ajayi (1982), Mesida (1985), Ayangade (1992) and Adeyemi (1992). Ajayi (1987) noted that road failure often occurs where the pavement is founded on saprolite rather than the strong lateritic horizons. Adeyemi (1992) investigated some geotechnical properties of the residual lateritic soils in the Ajebe and Ishara areas adjacent to some sections of

Received: 12 February 1998 · Accepted: 16 August 1999

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Fig. 1
Map of Ibadan (south western
Nigeria) showing locations of
study area



the Lagos-Ibadan expressway, south western Nigeria. He concluded that the degree of stability of the flexible road pavement increased with both the amount of kaolinite present in the subgrade soils and their California bearing ratio (CBR) and unconfined compressive strengths (UCS). Ayangade (1992) could not establish a clear relationship between the index properties of subgrade soils and the stability of the road pavement but noted that there was a positive correlation between the strength characteristics of the foundation soils and the stability of the pavement along the Oshogbo-Gbongan road, south western Nigeria. The Lagos-Ibadan expressway (Fig. 1) has served as a useful link between Lagos and most parts of northern Nigeria. This paper reports on the investigations carried out in an attempt to identify the geotechnical/geological factors that are likely to have the greatest influence on the stability of this highway and to establish the extent to which they can account for the failures of sections of the Ibadan end of the road.

Study methods

The investigations involved the field mapping of rocks and soils in areas of the expressway that had been identified as unstable. Rock samples were collected in order to determine textural and mineralogical characteristics while bulk soil samples were taken at horizons corresponding to their placement levels in the road. Four locations were sampled, two from stable and two from unstable areas.

Detailed petrographic studies of the rocks and soils were undertaken in order to determine whether there was a link between the properties of the rocks and those of the derived soils. Geotechnical tests included grain-size distribution, consistency limits, compaction, CBR and UCS on air-dried soil samples. In general, the procedures followed were those given in BS 1377:1975 (British Standards Institute 1975), although where necessary some modifications were made.

CBR testing was carried out on compacted samples soaked for 48 h in order to simulate the conditions to which the subgrade soils are exposed when there is an ingress of water below the pavement. Some samples of the compacted soil were also cured for a period of 48 h prior to undertaking unconfined compression tests. Curing was effected by wrapping cylindrical samples of compacted soil in cellophane bags to inhibit changes in moisture content. This simulates the conditions to which in situ sub-grade soils are subjected.

Results and discussion

Petrography of the rocks and derived soils

Two major rock types outcrop in the study area. Where the pavement is stable, the granitic gneiss is dark grey in colour, fine-grained and rich in quartz (50%), with smaller proportions of alkali feldspar, biotite, muscovite and hornblende respectively. In unstable areas, however, the coarse porphyritic granite contains some 45% alkali feldspar with subsidiary quartz, biotite and muscovite (Oyeyemi 1995). This rock is likely to weather to fine to medium material while the quartz-rich rock near the stable zones would disintegrate to a coarse-grained soil. This is confirmed by microscopic examination of the regolith. The fine-grained essentially clayey soil in the vicinity of the unstable pavement would be expected to exhibit poorer engineering characteristics than the quartz-rich material near the stable sections.

Consistency limits

Table 1 gives the results of the index tests undertaken on samples from the stable and unstable locations. Surprisingly, it was found that the soils below unstable pavements were less plastic than those from the stable areas, although statistical tests (Table 2) indicated that the difference between the values of the plasticity indices of the two sets of soils was not significant. The statistical test employed was the t-test which is an important statistical method often employed to determine whether the difference between two sets of values for a given parameter is significant. Any degree of freedom has a specific value of " t_p " in the table at a given confidence limit. When the calculated " t_p " is higher than the " t_p " in the table, the difference is adjudged to be significant.

The plasticity values were generally lower than 25, the maximum recommended for subgrade tropical soils (Medina 1963 in Simon et al. 1973). The Casagrande chart indicated medium plasticity and hence the soils would be expected to exhibit low to medium swelling potential (Ola 1982). The average linear shrinkage of the soils below stable locations was lower than that of the samples from the unstable sections, although again the difference is not significant. However, it is of note that the average linear shrinkage of the soils below stable locations was lower than the maximum value of 8% recommended by Madedor (1983) for highway sub-grade soils.

Table 1
Summary of consistency limits of the studied soils

Location	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Linear shrinkage (%)
Stable	Range 41-48	Range 19-38	Range 10-21	Range 5-9
	Average 45	Average 29	Average 16	Average 7
Unstable	Range 39-45	Range 19-37	Range 8-20	Range 8-10
	Average 42	Average 28	Average 14	Average 9

Table 2
Statistical analysis of consistency limits. See text for explanation of " t_p "

	Plasticity index (%)	Linear shrinkage (%)
Computed t	0.211	0.609
t in table	2.92	2.92
Nature of difference	Insignificant	Insignificant

Grain size distribution

Figures 2 and 3 give the grading curves for the studied soils while Table 3 summarises the grain size distribution parameters. It can be seen that again the proportion of fines and the clay fraction was lower in the soils below stable pavements, indicating better geotechnical characteristics. Both sets of samples would be classified as well graded, but the results of the grain-size analyses clearly reflect the mineralogical and textural characteristics of the parent rock.

Moisture content-density relationships

As it is known that the levels recommended by the American Association of State Highways and Transportation Officials (AASHTO) may cause overcompaction and hence excessive degradation of the grains in tropical soils (e.g. Gidigasu 1976), for the present study the soils were compacted at the West African standard. As shown in Table 4, the soils below the stable sections of pavement

Table 3
Average values (%) of grain size distribution parameters of the studied soils

	Stable location	Unstable location
Gravel	12.5	13.0
Sand	48.0	35.0
Silt	32.5	32.0
Clay-sized fraction	7.0	20.0
Amount of fines	39.5	52.0
Fines in compacted samples	54.0	58.0
Increase in fines after compaction	36.7	11.5

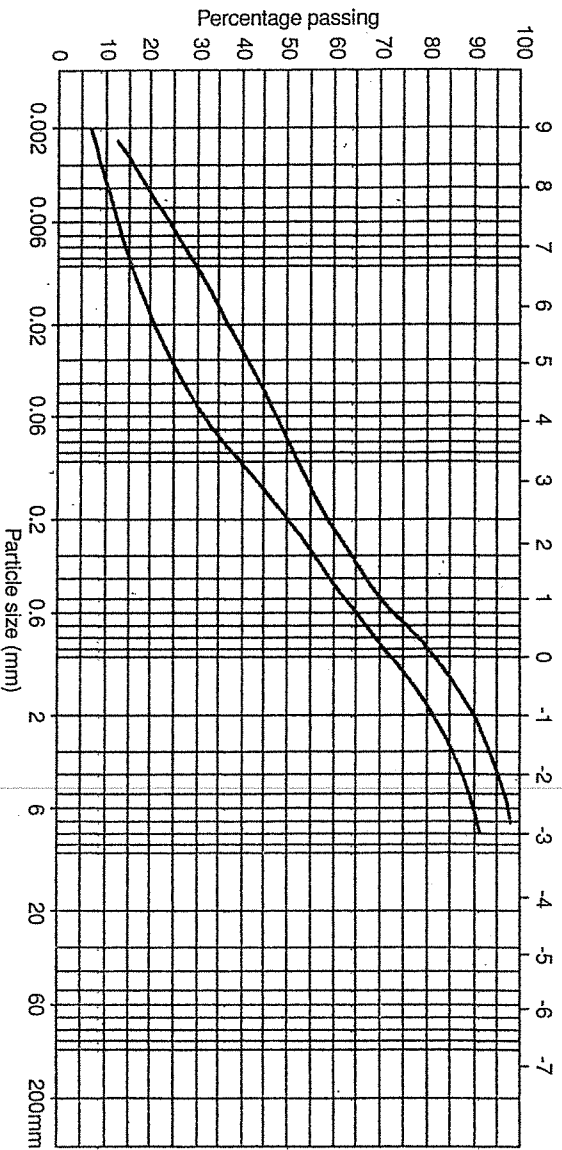


Fig. 2

Particle size distribution curves for soils below the stable locations

had better compaction parameters than those below unstable areas, although again the difference was not significant. Comparing the proportion of fines in the material compacted at the West African optimum moisture content (Figs. 4 and 5) with that in the uncompacted material, it can be seen that there was an increase of 54% in the

Particle size distribution curves for soils below the unstable locations

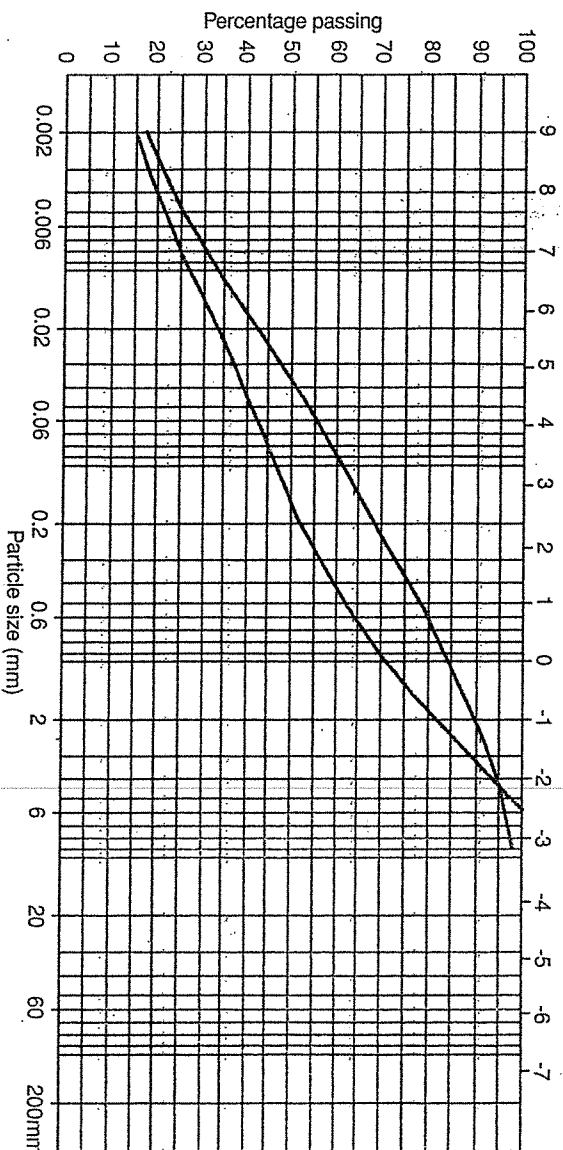


Fig. 3

samples from the stable locations while the compacted samples from the unstable areas showed an increase in fines of only 11.54%. The subgrade soils around the unstable locations can thus be said to be more mechanically stable than those around the stable zone. Maloma (1977) defined mechanical instability characteristics as the susceptibility of grains of a soil to break down when its level of mechanical energy is slightly increased. The mechanical instability characteristics of the studied soils cannot therefore be reliably employed to evaluate their potential as subgrade materials. It is suggested that the mechanical instability characteristics are more applicable to sub-base soils which are closer to the axle loads and hence more likely to be affected by them than would be the subgrade materials.

Table 4
Compaction parameters of the studied soils

Location	Maximum dry density (kg/m ³)		Optimum moisture content (%)		Nature of difference
	Range	Mean	Range	Mean	
Stable	1815–1928	1865	12.9–15.36	14	Insignificant Insignificant
Unstable	1700–1845	1768	14.2–18.4	17	

California bearing ratio

The CBR and UCS tests are often used to evaluate the suitability or otherwise of highway subgrade and sub-base soils (Simon et al. 1973; Gidigasu 1980). As can be seen from Table 5, both sets of subgrade soils meet the 0–7% requirement recommended by the Asphalt Institute (1961), although the CBR of the soils from stable locations was generally somewhat higher than that of the soils from unstable zones. Comparison of the soaked and unsoaked CBR values indicates that for both soils there was a notable reduction in strength as a result of soaking. Adequate drainage would therefore be an important consideration in order to reduce ingress of water below the pavement in which could result in a significant loss of strength of the subgrade soils and hence failure of the overlying highway pavement.

It can be noted from Table 5 that the reduction in strength with soaking was considerably greater for the soils from stable locations (60%) than for the samples from unstable areas (27%), such that after soaking, the CBR was higher for the unstable samples than for the stable ones. The

Table 5
California bearing ratio (CBR)

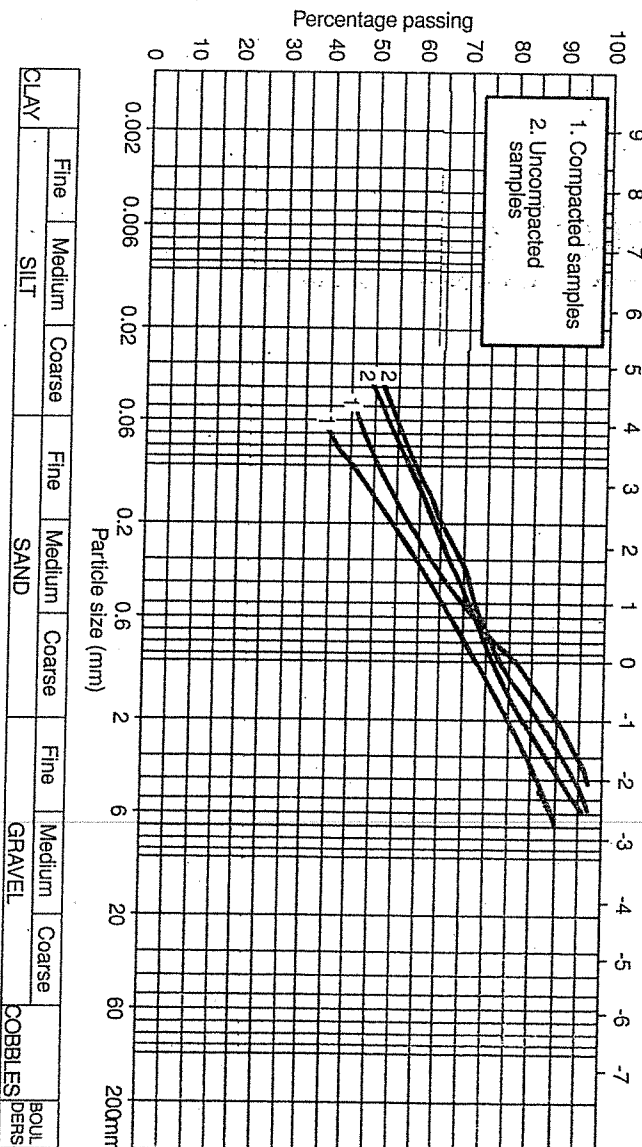
Location	Unsoaked CBR (%)		Soaked CBR (%)		Strength reduction due to soaking (%)
	Range	Mean	Range	Mean	
Stable	28.2–32.7	31.1	11.1–13.7	12.4	60.1
Unstable	26.5–31.1	28.1	19.4–22.0	20.6	26.8

trend of a reduction in strength corresponds with the mechanical instability characteristics determined by compaction of the studied soils. It is further suggested that reduction in strength as a result of soaking should only be used in the evaluation of sub-base soils which are more likely to be affected by ingress of water than the subgrade soils.

Unconfined compressive strength

The results of the UCS tests undertaken on samples at optimum moisture content (obtained according to the West African methods) are given in Table 6. Although the soils beneath the stable areas of the highway had higher unconfined strengths, the increase in strength on curing was

Fig. 4
Particle size distribution curves of the compacted and uncompact soil samples below stable locations



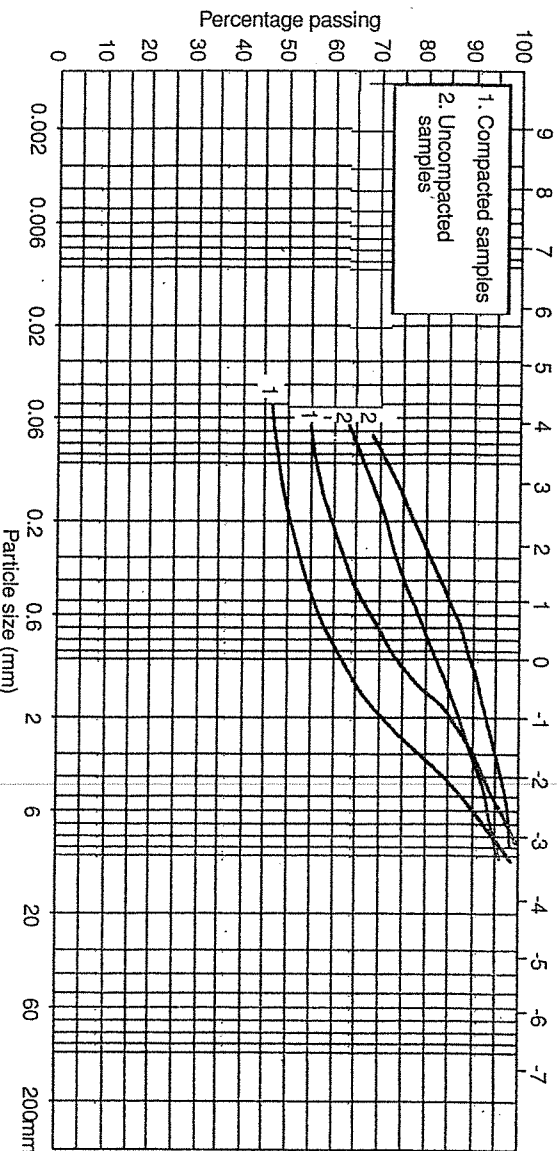


Fig. 5
Particle size distribution curves of the compacted and uncompacted soil samples below unstable locations

of fines in the soils beneath the unstable pavement. Although statistical analysis indicates that the difference was not significant, the strength of the uncured material appears to be a reliable indicator of the degree of stability of the pavement for the section of highway studied.

Table 6
Unconfined compressive strengths (UCS) of the studied soils

Location	Uncured UCS (MPa)		Cured UCS (MPa)		Increase after curing (%)
	Range	Mean	Range	Mean	
Stable	28-172	101	87-208	139	38
Unstable	22-134	73	105-337	200	173

Conclusions and recommendations

considerably less than occurred with the soils from the unstable zones, such that after curing the material from the unstable zones was stronger than that from the stable areas. It is likely that this is due to the greater percentage

Table 7 summarises the geotechnical properties of the soils beneath the stable and unstable areas of the studied section of the Ibadan-Lagos expressway, between 133 and 144 km from Lagos. It can be seen that increased stability of the flexible road pavement is associated with higher values of maximum dry density, unsoaked CBR and uncured UCS. The table also indicates that the soils beneath the stable parts of the highway had smaller percentages of fines and of linear shrinkage as well as lower optimum moisture

Table 7
Summary of geotechnical properties of subgrade soils beneath stable and unstable sections of pavement, 142-144 and 133-141 km from Lagos respectively

Properties	Stable location	Unstable location	Nature of difference
Plasticity index (%)	16	14	Insignificant
Linear shrinkage (%)	7	9	Insignificant
Fines content (%)	40	52	Insignificant
Clay-sized fraction (%)	7	20	Significant
Optimum moisture content (%)	14	17	Insignificant
Maximum dry density (kg/m ³)	1865	1768	Insignificant
Fines in compacted soil (%)	54	58	Insignificant
Increase in fines after compaction (%)	37	15	Insignificant
Unsoaked CBR (%)	31	28	Insignificant
Soaked CBR (%)	12	21	Insignificant
Uncured UCS (kPa)	101	73	Insignificant
Cured UCS (kPa)	139	200	Insignificant

contents. Although these differences are not statistically significant, they nevertheless appear to be a reliable indicator of the degree of stability of the road pavement.

In contrast, the work has shown that the soils beneath the unstable zones are more mechanically stable, hence mechanical properties cannot be used to predict stability of pavements. As a consequence, it is likely that rigid adherence to existing standard specifications may not always be the most appropriate method of assessing the suitability of highway subgrade soils. Particular attention is drawn to the fact that there are relatively small differences in geotechnical properties between the soils beneath the stable and unstable zones of the highway studied. It is therefore recommended that further investigation of the geotechnical properties of as many subgrade soils as possible is undertaken in order to elucidate the influence of the geotechnical and geological factors. This would assist in the evolution of a set of standard specifications for subgrade soils which would be more relevant to the conditions in the tropical world.

Acknowledgements The authors are indebted to Yinka Olasupo who assisted in the geotechnical tests, Dele Ajala and E.B. Ogunseye who drafted the drawings, Dayo Folorunso and S.B. Adekoya who assisted with the preparation of the manuscript and Olufem Ogunyipe who translated the abstract into French.

References

- Adeyemi GO (1992) Highway geotechnical properties of laterised residual soils in the Ajebo-Ishara geological transition zone of south western Nigeria. PhD Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria
- Ajayi LA (1982) Proposal for engineering classification of Nigerian soils. Proc 1st Natl Conf Nigerian Geotech Assoc, Lagos
- Asphalt Institute (1961) Soil manual. Asphalt Institute, Maryland, 176 pp
- Ayangade JA (1992) Some geotechnical properties of two highway sub-grade soils along Gbongan-Osofbo road, southern Nigeria. Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria
- British Standards Institution (1975) Methods of testing of soils for civil engineering purposes, BS 1377. British Standards Institution, London
- Gidgasu MD (1976) Laterite soil engineering. Elsevier, Amsterdam, 554 pp
- Gidgasu MD (1980) Geotechnical evaluation of residual gravels in pavement construction. Eng Geol 15:173-194
- Madedor AC (1983) Pavement design guidelines and practice for different geological areas in Nigeria. In: Ola SA (ed) tropical soils of Nigeria in engineering practice. AA Balkema, Rotterdam, pp 291-297
- Malomo S (1977) The nature and engineering properties of some red soils from north east Brazil. PhD Thesis, University of Leeds, Leeds
- Mesida EA (1985) The influence of geological factors on the engineering properties of some western Nigeria residual lateritic soils as highway construction materials. PhD Thesis, University of Ife, Nigeria
- Ola A (1982) Geotechnical properties of an attapulgite clay shale in north western Nigeria. Eng Geol 19:1-13
- Oyeyemi F (1995) Geotechnical properties of some highway laterite sub-grade soils along the Ibadan section of the Lagos-Ibadan expressway, south western Nigeria. MSc Thesis, University of Ibadan, Nigeria
- Simon AB, Giesecke J, Bidlo G (1973) Use of laterite soils for road construction in north Dahomey. Eng Geol 7:197-21