# A REVIEW OF SPECIFICATIONS FOR LATERITIC MATERIALS FOR ROADS

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## ABSTRACT

Most lateritic materials such as ferricretes, laterite or lateritic soils do not comply with traditional specifications for road pavement layers. This is a particular problem when materials are required for low volume roads and little else is available. However, experience with many lateritic materials has shown that they can be successfully used with specifications that are outside traditional requirements. A review of various specifications concluded that the specifications used in Brazil for national roads are probably those based on the most pertinent and detailed research, the earliest work on which was carried out in Angola and Mozambique. In this paper the wide range of specifications suggested internationally for lateritic materials is discussed and the properties of several lateritic materials successfully used in roads in various sub-Saharan countries are compared with the Brazilian specifications, suggested for interim use in southern Africa.

**Keywords**: Laterite, Specification, Low volume roads, Brazil.

## 1. INTRODUCTION

A significant increase in the use of laterites and lateritic materials, particularly for structural layers in low volume roads, is required to ensure the provision of an appropriate paved road network in many tropical and sub-tropical countries. In order to achieve this, it is essential that appropriate specifications for the use of laterites be developed and implemented. The traditional specifications employed (e.g. CBR of 80 and Plasticity Index of 6) generally exclude many potentially useful laterites from use as structural layers in roads based on the misleading test results obtained using conventional test methods (Paige-Green and Netterberg, 2024). It is also known (e.g., AFCAP, 2014) that other inherent properties of laterites result in good performance, even when the material properties are outside traditional specifications.

For example, the high volume main road between Lilongwe and the Zambian border at Mchinji was constructed in about 1977 with a laterite base according to the 1974 Brazilian national laterite specifications (DNER, 1974) and recent inspections have shown that the road is still providing excellent service (Figure 1).

In order to implement specifications developed uniquely for laterites and lateritic materials, it is essential that a simple definition of such materials accompany the specification. The unique properties of laterites that allow their use with widened specifications will not be mobilised if the specification is applied to materials that are not laterites and premature failure of the pavements can be expected.

**Figure 1: Lilongwe-Mchinji road, Malawi as at February, 2014 (AfCAP, 2014)**

This paper is the final one in a trilogy based on an AFCAP report (AFCAP, 2014). In this paper research on specifications for lateritic materials is reviewed and some of the properties of laterites that make them conducive to use, despite their poor conformance to traditional specifications are highlighted. Comparisons of the properties of successful roads with the current Brazilian specifications for laterite bases was carried out to see whether the Brazilian specifications could be applied directly in southern Africa.

## 2. SPECIFICATIONS

Laterites have certain unique properties that make them different from other road construction materials (e.g., LNEC et al, 1959: 1969; AFCAP, 2014). This is one of the reasons that often results in their test results not conforming to conventional specification requirements and the materials being rejected for use, despite performing well when used in roads. Gidigasu and Dogbey (1980) noted for instance that the lateritic gravels in Ghana have much poorer gradings than the local residual granitic gravels but nonetheless performed satisfactorily.

Apart from the naturally poor gradings, the particle size distributions of laterites are affected significantly by the material preparation techniques used prior to testing (Paige-Green and Netterberg, 2024). Ackroyd (1967) indicated that the aggregations of silt and clay caused by iron oxides are broken down during normal laboratory testing, but not during construction, giving results that are not directly related to the as-built condition.

Where the materials have weak aggregate particles in the gravel sized range, a good particle size distribution is necessary to ensure that the gravel particles have as many grain to grain contacts as possible with minimal voids. This improves the “support” for the aggregate particles and reduces the internal stresses allowing them to bear larger loads without fracturing. An alternative method of protecting the coarse aggregate is for it to float in the fines, but such a grading is normally inferior to the continuously graded material. It is important that the grading and plasticity allow the materials to be stable under traffic. Most limits for the soil fines were derived in temperate climates and have been partly based on the need to avoid frost damage, rare in countries with extensive deposits of lateritic materials as well as other criteria such as providing stability under temperate conditions.

## 3. REVIEW OF EXISTING SPECIFICATIONS

### 3.1 Typical Specifications

Traditional materials specifications were mostly developed in North America and are generally used internationally, which include specific grading envelopes and a maximum

PI of 6 (e.g. AASHTO M147-65, 2011) have typically been found to be too conservative for pedogenic materials in terms of their strict grading and plasticity requirements.

Many specifications for laterites have thus been proposed in the literature emanating from a variety of authorities. Not surprisingly, these have differing requirements, based on local experience. It has therefore been necessary to derive empirical specifications for these materials locally for which some older examples are given in Tables 1 and 2:

**Table 1: Some laterite and lateritic soil base specifications in comparison with the Brazilian general granular base specification (Netterberg and Paige-Green, 1988)**

| **Material** | **Granular** | | **Laterite** | | **Laterite LEA-CE-11-62** | **Fine Sandy Lateritic Soils [2]** |
|---|---|---|---|---|---|---|
| **Authority** | **DNER [1] (1974) Brazil** | **DNER-ER-P10-71** | **DNER (1974) Brazil** | **DNER-ES- P47-74** | **LNEC et al. (1969) (Angola)** | **Utiyama et al. (1977) Brazil** |
| Percent passing (mm) | B | C | A | B | | |
| | | | | | Up to 1.4 times that in ASTM D1241-55T | |
| 50.8 | 100 | | 100 | | | - |
| 25.4 | 75-90 | 100 | 75-100 | 100 | | - |
| 9.5 | 40-75 | 50-85 | 40-85 | 60-95 | | - |
| 4.8 | 30-60 | 35-65 | 20-75 | 30-85 | | - |
| 2.0 | 20-45 | 25-50 | 15-60 | 15-60 | | - |
| 0.42 | 15-30 | 15-30 | 10-45 | 10-45 | | 85-100 |
| 0.074 | 5-15 | 5-15 | 5-30 | 5-30 | | 25-45 |
| | | | | | | |
| LL % | ≤25 | | ≤40 | | ≤40 | 20-30 |
| PI % | ≤6 | | ≤15 | | ≤15 | 6-9 |
| Swell[3]% | - | | ≤10 | | ≤10 | - |
| Aggregate Strength% | LAA (>2mm fraction) ≤55 | | LAA (>2mm fraction) ≤65 | | LAA ≤65 | - - |
| CBR % (soaked) | ≥60(<5mesa) | | ≥60(<5mesa) | | - | >80@OMC |
| | ≥80(>5mesa) | | ≥80 (>5mesa) | | - | |
| S/R [4] | - | | <2 | | <2 [5] | <2? [6] |
| CBR % Swell [7] | ≤0,5 | | ≤0,5 | | ≤0,5 | <0,1 |
| Rainfall (mm) | Mostly 1 000 - 2 500 mm | | | | >700? | 1100-1500 |
| Surfacing | Surface treatment (S.T.) to 50 mm asphalt | | | | S.T. | S.T. to 50 mm |
| Traffic limitations | None? | | None? | | None?[8] | <1 000 or <10mesa [9] |

Notes:

[1] DNER = Department of National Roads standard specification

[2] Mostly B horizons (some A and C) of orthic and acric ferralsols, ferric luvisols and ferralic arenosols in Sao Paulo state of Brazil

[3] De Castro (1969) swell test (LNEC Technical Paper 235) or Brazilian Method DNER-ME 29- 74

[4] S/R = silica/sesquioxide molecular ratio (on <2 mm fraction) by Brazilian Method DNER-ME 30-72

[5] S/R on <5µm fraction by LNEC et al (1959) methods (these specifications were mostly developed in Angola)

[6] Not specified, but probably advisable (preferably on <2 µm fraction) if used outside Brazil

[7] Normal CBR swell requirement 0.2%; however, up to 0.5% allowed if Castro swell < 10%

[8] Outstandingly successful even under quite heavy traffic and over 2000 km built in Angola (dos Santos et al, 1971)

[9] Traffic in this paper is classified as million standard axles (mesa) or vehicles per day (vpd)

**Table 2: Charman's (1988) recommended material selection criteria for lateritic gravel sub-bases and road-bases under thin bituminous surfacing in the tropics**

| Use | Road Base | | | Sub-Base |
|---|---|---|---|---|
| Type of road | Minor | Major rural | Urban | All |
| | | | | |
| Traffic (mesa) | <0,3 | 0,3-1 | 1-3 | <3 |
| Grading | Grading Modulus ≥1,5[1] | Grading envelopes in Charman, 1988 specifications. | | |
| | | | | |
| Plasticity index (%) | | | | |
| Moist, wet tropical | ≤ 12 | ≤ 10 | ≤ 6 | ≤ 25 |
| Seasonal tropical | ≤15 | ≤12 | ≤10 | ≤25 |
| Semi-arid & arid | ≤ 20 | ≤ 15 | ≤ 12 | ≤ 25 |
| | | | | |
| Plasticity modulus [2] | | | | |
| Moist, wet tropical | ≤ 300 | ≤ 200 | ≤ 150 | ≤ 500 |
| Seasonal tropical | ≤ 400 | ≤ 250 | ≤ 200 | ≤ 750 |
| Semi-arid & arid | ≤ 500 | ≤ 350 | ≤ 250 | ≤ 1 250 |
| | | | | |
| CBR (%) | ≥ 45 [3] | ≥ 65 [4] | ≥ 80 [4] | ≥ 25 [3] |
| | | | | |
| Durability | | | | |
| Los Angeles Abrasion value (%) [5] | ≤ 65 | ≤ 50 | ≤ 50 | n.s |
| 10% fines value (saturated) (kN) | n.s | ≥50 | ≥50 | n.s. |

Notes: n.s. = not specified

[1] Grading modulus = $\frac{300 - (P2{,}0 + P0{,}425 + P0{,}075)}{100}$

Where P2,0 is percentage passing 2 mm sieve
P0,425 is percentage passing 0,425 mm sieve
P0,075 is percentage passing 0,075 mm sieve

[2] Plasticity modulus = plasticity index multiplied by percentage finer than 0.425 mm sieve

[3] CBR on samples compacted to 95% of modified AASHTO or BS (heavy) MDD and soaked for 4 days

[4] CBR on samples compacted to 100% of modified AASHO or BS (heavy) MDD and soaked for 4 days

[5] Los Angeles abrasion value on fraction coarser than 2 or 2.36 mm

Tables 1 and 2 show relaxations in several properties, particularly the grading, plasticity and CBR strength requirements. It is interesting to note that Charman's (1988) requirements link the plasticity to the grading (Plasticity Modulus), a parameter also used in a number of other specifications (e.g., Gourley and Greening, 1997; 1999).

Krinitzsky et al (1976) discuss various "relaxations" of specifications for laterite bases from selected countries. The main relaxations are for plasticity, but in the case of Thailand, PI x percentage passing 0.075mm limits are proposed with values of 15 to 20 depending on traffic. This effectively is much stricter than most conventional specifications. Ghana had at that stage developed specifications for laterite bases for 3 different traffic categories, class I to III. These included slight relaxations of the grading envelopes over the AASHTO requirements, a move away from the LAA specification preferred by many countries towards the ACV (values between 35 and 50%), CBR requirements of 100, 70 and 50 for

Class I, II and III roads respectively and requirements for the products of PI and P075 (200 to 600) and LL and P075 (600-1250).

Krinitzsky et al. (1976) also assessed the specifications for gravel (not specifically laterite) base course materials from 13 African countries where laterites are common and relaxations of certain requirements had been permitted. It is interesting to note that these requirements are for gravels, and although laterites probably predominate in these countries, no distinction appears to be made between the requirements for laterites and other natural gravels.

Grace and Toll (1987) assessed the use of laterites in Kenya and Malawi and referred to the specifications in tropical countries that were summarized by Krinitzsky et al (1976). They reported that the laterites used on two successful roads generally had high PIs (7-21), wide ranging laboratory soaked CBRs (12 to 96 at 95% BS compaction) and percentages finer than 0,063 mm of 15 to 49).

Ruenkrairergsa (1987) discussed the use of laterites on lower volume roads in Thailand, where traditional AASHTO specifications used by the roads authorities resulted in extremely high construction costs. The philosophy in Thailand was to reduce the plasticity of the laterites, rather than to change the specification limits. This resulted in higher processing costs rather than making use of materials that were probably appropriate and thus is probably the incorrect path to follow. Ruenkrairergsa also stated that a Los Angeles Abrasion value of 50% is the upper limit for ensuring durability of laterites for low to medium volume roads.

Akpokodje and Hudec (1992) assessed the possible improvement of determining the aggregate strength using the standard Aggregate Impact Value (AIV). They found that the most important predictors of aggregate strength and abrasion resistance were water absorption and bulk density. Unfortunately, they had no comprehensive performance-related data and compared their data with a typical upper limit of 30% for the AIV identified from previous studies (mostly Bhatia and Hammond, 1970).

De Graft-Johnson (1969) developed the Suitability Index for the selection of lateritic soils. This parameter is derived from the ratio of the percentage larger than 2 mm and the liquid limit multiplied by the log of the PI. This can be used to predict the CBR (CBR = (SI x 35 – 8)). Typically a value of between 2.1 and 4.0 is required for potential base course materials. De Graft-Johnson et al. (1972) later discussed a laterite rock aggregate classification system for determining the potential for use of the materials in roads proposed by Bhatia and Hammond, (1970). This was based on non-traditional selection criteria in Ghana as presented in Table 3.

**Table 3: Criteria used in Ghana for selecting laterites (De Graft-Johnson et al., 1972)**

| Specific Gravity | Water Absorption After 24h Soaking (%) | Aggregate Impact Value (%) | Los Angeles Abrasion Value (%) | Rating Based on Probable in Situ Behaviour |
|---|---|---|---|---|
| >2,85 | <4 | <30 | <40 | Excellent |
| 2,85–2,75 | 4–6 | 30-40 | 40–50 | Good |
| 2,75–2,58 | 6–8 | 40–50 | 50–60 | Fair |
| <2,58 | >8 | >50 | >60 | Poor |

Gidigasu and Mate-Korley (1984) reviewed the Ghanaian materials and road performance and came up with various specifications for different environments. In the arid zones, a

minimum soaked CBR of 69 (at 100.5% MDD) and maximum PI of 8 was suggested. In the dry sub-humid zones, a PI of 7 ± 4 was suggested and in the moist sub-humid zones a maximum PI of 10 was suggested with maximum products of the percentage passing 0.075 mm and the LL and the PI of 300 and 200 respectively.

Aggarwal and Jafri (1987) studied various laterite roads in Nigeria and based on their performance suggested a relaxation of the PI up to 12 and a minimum CBR of 65, provided that the compaction specification is achieved. No specific detail regarding the compaction specification or whether the CBR is determined at OMC or soaked is given, although in their prior discussion, it is stated that the CBR is carried out at OMC unless the standing water level is within 1.2 m of the road surface.

Gourley and Greening (1997 and 1999) give guidelines for reducing the requirements for laterite bases, after carrying out research on various low volume roads in southern Africa. Relaxations of PI and plasticity modulus (PM) of up to 25 and more than 800 respectively are permitted for very low volume roads (Table 4) with a number of grading options. Whilst a few relaxations are permitted, no full specifications for laterites are provided for in Road Note 1 (TRL, 2023).

**Table 4: Proposed guideline for selection of lateritic gravel base materials for low volume roads with unsealed shoulders (Gourley and Greening, 1999)**

| Subgrade CBR | | Design Traffic Class (mesa) | | | | | |
|---|---|---|---|---|---|---|---|
| | | ⩾ 0,01 | 0,05 | 0,1 | 0,3 | 0,5 | 1.0 |
| S2 | PI | ⩾15 | ⩾15 | ⩾12 | ⩾9 | ⩾9 | ⩾6 |
| | PM | ⩾400 | ⩾250 | ⩾150 | ⩾150 | ⩾120 | ⩾90 |
| | GE | B | B | B | A | A | A |
| S3 | PI | ⩾18 | ⩾15 | ⩾15 | ⩾12 | ⩾9 | ⩾6 |
| | PM | 550 | ⩾320 | ⩾250 | ⩾180 | ⩾120 | ⩾90 |
| | GE | B | B | B | B | A | A |
| S4 | PI | ⩾20[1] | ⩾18 | ⩾15 | ⩾15 | ⩾9 | ⩾9 |
| | PM | ⩾ 800 | ⩾450 | ⩾320 | ⩾300 | ⩾200 | ⩾90 |
| | GE | GM 1.6-2.6 | B | B | B | B | A |
| S5 | PI | ⩾25[1] | ⩾20 | ⩾18 | ⩾15 | ⩾12 | ⩾9 |
| | PM | n/s | ⩾550 | ⩾400 | ⩾350 | ⩾250 | ⩾150 |
| | GE | GM 1.6-2.6 | B | B | B | B | B |
| S6 | PI | ⩾20[1] | ⩾20 | ⩾20 | ⩾18 | ⩾15 | ⩾12 |
| | PM | n/s | ⩾650 | ⩾550 | ⩾400 | ⩾300 | ⩾180 |
| | GE | GM 1.6-2.6 | B | B | B | B | A |

*Notes:*
[1] PI maximum = 8 x GM
n/s = not specified
Unsealed shoulders are assumed

PI = plasticity index
PM = plasticity modulus
GE = grading envelope
GM = grading modulus

A full specification for the use of laterite gravels is provided by Western Australia Main Roads Department (MRWA, 2002, Cocks et al, 2015). These include a number of specifications for different applications. It is interesting to note that MRWA only specify a requirement for Fe and Al oxides for crushed hardpan laterite (not laterite gravels) and laterites for heavy-duty pavements and then in the form of combined $Al_2O_3$ + $Fe_2O_3$ (≥ 20%) and not silica sesquioxide ratio (S/R). Earlier work within the Department (Cocks and Hamory, 1998) specified a minimum limit for the $Al_2O_3$ + $Fe_2O_3$ content for all lateritic gravels of 10%.

Full specifications including relaxations for laterite bases and pavement designs according to traffic, based upon an comprehensive review and experience in West Africa are also provided by Bagarre (1990).

## 3.2 Summary of Specification Requirements

In a keynote address, Gidigasu (2011) stressed the need for a multi-disciplinary approach integrating such disciplines as geology geochemistry and pedology, etc. with engineering in the development of specifications for lateritic and saprolitic soils and discussed the individual factors such as grading, plasticity, aggregate strength, etc. contributing to performance.

It has become clear in recent years that the most important criterion for the selection of natural gravels and soils and especially pedogenic materials, for pavement materials is a test for compacted strength (e.g. CBR or Texas Triaxial) at the likely in-service moisture content (Pinard et al, 2015), and that grading and Atterberg limit requirements are of lesser importance. However, in addition to a strength requirement it also appears wise to control the CBR swell. Grading also remains important with respect to compactability and finish and plastic gravels cannot be compacted when too wet.

Once compacted, aggregate strength is probably only important for the relatively more heavily trafficked road categories. In Zimbabwe laterites with dry/soaked 10% FACT values of 50/40 kN have been used successfully and a minimum soaked value of about 50 kN seems adequate for traffic up to about 2000 vehicles per day (vpd) (Mitchell et al, 1975).

In applying the specifications shown here – or any foreign specifications for that matter – the test methods employed must be comparable with those of the authority concerned (AFCAP, 2014; Paige-Green and Netterberg, 2024).

In summary, relaxations in Atterberg limits, grading and CBR requirements seem to be the norm when using laterites. The use of combinations of plasticity and grading indices is also prevalent. However, the specification that has probably been the most successfully applied to the greatest length of roads is that used in Brazil, making use of the CBR for lateritic gravels and the Miniature Compaction Test (MCT) procedure for fine-grained lateritic soils.

The variety and ranges of material properties shown and discussed in Tables 1 to 4 indicate the problems in specifying laterites for use in road construction. Another important point is to ensure that one is actually dealing with a lateritic material (Netterberg, 2025). The actual definition of laterites is problematic and as there is no globally accepted definition of the term “laterite”, the usage in this paper is simply that of the sources referred to in the relevant publications. They may or may not classify as laterites according to different definitions. The use of the silica-sesquioxide ratio, i.e. a material with a S/R ratio < 2 appears to be in the right direction. However, this is not always as easy as it appears, and as an interim measure it is *suggested that the molecular S/R ratio on the fraction passing 2 mm as used in Brazil*, in the case of laterites and lateritic soils.

The standard Brazilian specifications for base courses for roads (DNIT 141/2010) are fairly conventional with requirements for particle size distribution (typical Fuller-type requirements), Atterberg limits (PI< 6), dust ratio, CBR (60 for less than 5 million standard axles and 80 for more) and Los Angeles Abrasion loss (max of 55%). However, they also have a separate specification for base courses using lateritic gravels (DNIT 098/2007) which is summarized in Table 5.

## 3.3 Recommended Specification

Based on a review of a number of regional and international specifications for the use of laterite in road pavements, it is apparent that the Brazilian specifications (Associacao Brasileira de Pavimentacao, 1976; Queiroz, 1991) permit considerable relaxations, even for relatively heavy traffic. Thus, in view of the successful use of laterite and extensive local experience and research in the construction of both high and low volume roads in Brazil over the past 40 years, the Brazilian specifications are recommended for use as an interim measure until local performance-related specifications have been developed. It is important, however, that the materials are classified as laterites prior to use, based on the molecular silica:sesquioxide ratio (S/R) in the Brazilian definition (DNIT, 2007):

$$\frac{S}{R} = \frac{\frac{SiO_2}{60}}{\frac{Al_2O_3}{102} + \frac{Fe_2O_3}{160}} \quad (1)$$

The chemical analyses are based on wet chemistry as described in DNER-ME 030/94, and S/R must not be more than 2 to classify the material as a laterite. The current Brazilian laterite and conventional specifications are summarised in Table 5 and 6 for comparison.

**Table 5: Summary of Brazilian national specifications for laterite base course and conventional base aggregates**

| **Property** | **(DNIT 098/2007) (laterite)** | | **DNIT 141/2010 (Granular)** | **Comments** | |
|---|---|---|---|---|---|
| Silica-sesquioxide ratio | ≤ 2 | | | | |
| California Bearing Ratio (%) | ≥ 60(<5 mesa)<br>≥ 80 (>5mesa) | | ≥60(<5mesa)<br>≥80(>5mesa)<br>Swell <0,5% | DNER ME 49/74 (56 blows per layer compaction at design moisture content) | |
| Liquid limit (%) | ≤ 40 | | ≤ 25 | | |
| Plasticity Index (%) | ≤ 15 | | ≤ 6 | | |
| Los Angeles Abrasion | ≤ 65 | | ≤ 55 | | |
| Modulus and Permanent Deformation | - | | According to project specification | | |
| Grading (% passing sieve)<br>50.8 mm<br>25.4 mm<br>9.5mm<br>4.8 mm<br>2.09 mm<br>0.42 mm<br>0.075 mm<br>Grading modulus<br>Dust ratio | Grading A:<br>100<br>75 - 100<br>40 - 85<br>20 - 75<br>15 - 60<br>10 - 45<br>5 – 30<br>1,65 – 2,70<br>≤0,67 | Grading B:<br><br>100<br>60 - 95<br>30 - 85<br>15 - 60<br>10 - 45<br>5 – 30<br>1,65 – 2,70<br>0,67 | See Table 6<br><br>Dust ratio ≤ 0,67 | Tolerances specified:<br>Sieve size:<br>9,5 – 25,4<br>0,42 – 4,8<br>0,075 | %age passing:<br><br>± 7<br>± 5<br>± 2 |
| Sand equivalent (%) | ≥ 30 | | ≥ 30 | | |

**Table 6: Grading requirements for conventional materials (DNIT 140.2010)**

| Sieve Size (mm) | Traffic (mesa) | | | | | | Tolerance |
|---|---|---|---|---|---|---|---|
| | N>5 | | | | N<5 | | |
| | A | B | C | D | E | F | |
| 50,8 | 100 | 100 | | | | | ± 7 |
| 25,4 | - | 75-90 | 100 | 100 | 100 | 100 | ±7 |
| 9,5 | 30 – 65 | 40-75 | 50 – 85 | 60 – 100 | - | - | ±7 |
| 4,8 | 25 – 55 | 30-60 | 35 – 65 | 50 – 85 | 55 – 100 | 70 – 100 | ±5 |
| 2,0 | 15 – 40 | 20-45 | 25 – 50 | 40 -70 | 40 – 100 | 55 – 100 | ±5 |
| 0,42 | 8 – 20 | 15-30 | 15 – 30 | 25 – 45 | 20 - 50 | 30 - 70 | ±2 |
| 0,075 | 2 - 8 | 5 -15 | 5 - 15 | 10 - 25 | 6 - 20 | 8 - 25 | ±2 |

## 3.4 General

Numerous specifications have been proposed in the literature emanating from a variety of authorities. Not surprisingly, these have differing requirements, based on local experience. Some of the differences in specification requirements are summarized below:

- Most South African road authorities, other than an old KwaZulu-Natal specification that allowed a PI of up to 10, do not appear to relax their normal requirements in the case of lateritic materials.

- Zimbabwe (Van der Merwe and Bate, 1971; Zimbabwe Ministry of Roads and Road Traffic, 1979), Angola and Mozambique (LNEC et al, 1959; 1969; Dos Santos 1971), have found that relaxations of grading, Atterberg limits and aggregate strength are possible provided certain other criteria are met.

- In the case of Zimbabwe, a 50% relaxation in PI and Plasticity Product (PP) is permitted for “certain” pedocretes (laterites and calcretes: Mitchell et al, 1975; Zimbabwe Min. of Roads and Road Traffic, 1979) provided the strength (usually the Triaxial Class) is met.

- In the case of the LNEC et al (1969) the other criteria are the swell in the De Castro (1969) test as well as the silica/sesquioxide ratio. Plasticity indices of up to 15 are permitted (LNEC et al, 1969), but values of up to 21 can be used for less than 300 vpd (50% heavy vehicles) provided an impermeable seal is used and construction to specification is strictly controlled (Meireles, 1967). Although California Bearing Ratio (CBR) requirements are shown, it appears from Dos Santos et al. (1971) that these two PI requirements would ensure minimum CBRs of 60 and 50 respectively. However, these authors emphasize that the quality of the seal is more important than that of the base course and over 2000 km road using laterite had been built in Angola by 1971.

- The Brazilian specifications (e.g., Associacao Brasileira de Pavimentacao, 1976; DNER, 1974 and DNIT, 2007, 2010), by comparison with their specifications for other materials, shows that considerable relaxations are allowed, even for relatively heavy traffic and by 1971 over 2000 km of road had generally performed well (De Souza et al, 1971).

- In the Angolan specification the De Castro (1969) swell test is omitted in preference to a maximum CBR swell of 0.5% (LNEC et al, 1969). Brazilian (DNER) practice is to require a maximum CBR swell of 0.2% (at Modified AASHO or intermediate compaction) unless the De Castro (1969) swell is less than 10%, in which case 0,5%

is permitted (De Souza et al., 1984). The molecular silica/sesquioxide ratio of ≤2 is still required.

- Specifications for natural lateritic materials in subbase and other applications are also given by most of the authorities discussed above, while Zimbabwe has specifications for modified and stabilized laterites.

- Specifications for laterites have also been formulated by others such as Morin and Todor (1976) and Gidigasu (1976; 1988; 2011), while sections of roads with laterite bases comparable to those in Table 2, have performed successfully in Botswana (Overby, 1982), Kenya and Malawi (Grace, 1991).

- Obviously, issues such as construction techniques and equipment, material variability, overloading and pavement drainage are all important and always need to be considered.

## 4. REGIONAL PERFORMANCE-RELATED STUDIES

A number of roads have been constructed in the sub-Saharan African region (South Africa, Mozambique, Botswana, Kenya, Ghana and Ethiopia) in which laterite has been used in the pavement layers, both as base course and subbase. The engineering properties of the laterites used in these projects which were considered to have performed successfully were compared with the Brazilian specifications presented in Table 5. Only the Atterberg Limits, gradings and CBRs were available for most of the roads that were reviewed. It should also be noted that the CBRs determined for all of the African examples are the soaked laboratory values. However, indications are given in some documents regarding in situ CBR values, determined using a Dynamic Cone Penetrometer.

The full performance-based evaluations are discussed in detail in AfCAP (2014) and cannot be covered in this paper. However, in general, none of the laterites used in the construction of the LVRs complied fully with the traditional standards and specifications normally applied in the respective countries, nor even the Brazilian specifications, despite the roads performing well.

## 5. CONCLUSIONS

There is compelling evidence to indicate that lateritic materials that do not comply with standard specifications can perform particularly well when used in road construction, even as base course. In order to construct cost-effective roads, particularly those classified as low volume roads, it is essential that maximum use is made of these local materials. This will require the development of appropriate specifications for their selection.

Extensive research on lateritic materials has been carried out in a number of countries and the science of their use is fairly well advanced. However, it is necessary to review the specification limits that are currently being applied internationally and optimize these for use in sub-Saharan Africa.

Based on the literature, it is recommended that the Brazilian specifications would probably be the best initial approach for selecting materials in sub-Saharan Africa. These would need to be calibrated for wider use.

It is, however, clear that many of the materials that have performed well in a number of African countries do not comply even with the Brazilian national specifications for lateritic gravel bases for roads designed to carry up to 5 million equivalent standard axles (mesa).

The use in Africa is generally for roads carrying considerably less than 5 mesa and thus the use of laterites for such roads can be easily justified based on their good performance in much higher trafficked roads. In general, the main factor governing performance of base courses is the in situ strength (in relation to overall pavement balance) and being able to maintain this through varying moisture conditions. The potential benefits associated with laterites with respect to self-cementation appear to be clearly exhibited in the field, but cannot be relied on, particularly during the early life of the roads where the traffic effects may influence the road prior to any self-cementation occurring.

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