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The Use of a Sedimentological Technique for Assessing the Engineering Performance of Sands in Roads

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Abstract. Although sands cover vast areas of southern Africa, their use as road materials in an untreated state has been generally avoided. An investigation into the properties of various sands has indicated, however, that they can be used as subbase and even base course materials in low volume roads if carefully selected and tested. The investigation has shown that by expressing the particle size distribution of the sands as the mean particle size and standard deviation around this mean using the sedimentological Phi scale, it is possible to differentiate between sands that are likely to perform well and those that will not. The paper discusses this process and its application to selected sands from Botswana, Namibia, South Africa and Mozambique.

Keywords. Sand, road, unbound, Phi-scale

Introduction

The need for an improved road network for better access and increased mobility in many rural areas of southern Africa is growing rapidly as the populations increase. The provision of roads in these areas, however, is often constrained by the cost of obtaining suitable construction materials for use in their bases and subbases. This is particularly evident in those areas of southern Africa including localized parts of South Africa and Mozambique overlain by Tertiary and Quaternary sands and specifically widespread areas in Botswana and Namibia with surficial Kalahari sand deposits (Figure 1). These sands have a variety of origins but are predominantly aeolian with some river and beach deposits.

Use of these sands as structural layers in roads in an untreated state has been generally avoided in the past. Various local investigations into the properties of a range of sands combined with some past experience have indicated, however, that they can have relatively high strengths when compacted in confined conditions and be used as subbase and even base course materials in low volume roads if carefully selected and tested and when properly constructed. This investigation has shown that by expressing the particle size distribution of the sands as the mean particle size and standard deviation around this mean using the sedimentological Phi-scale [1], it is possible to differentiate between sands that are likely to perform well and those that will not.

The paper discusses this technique and its application to selected sands from Botswana, Namibia, South Africa and Mozambique. The objective of the paper is to introduce the concept of the phi technique and not to relate the results of specific sands to performance.

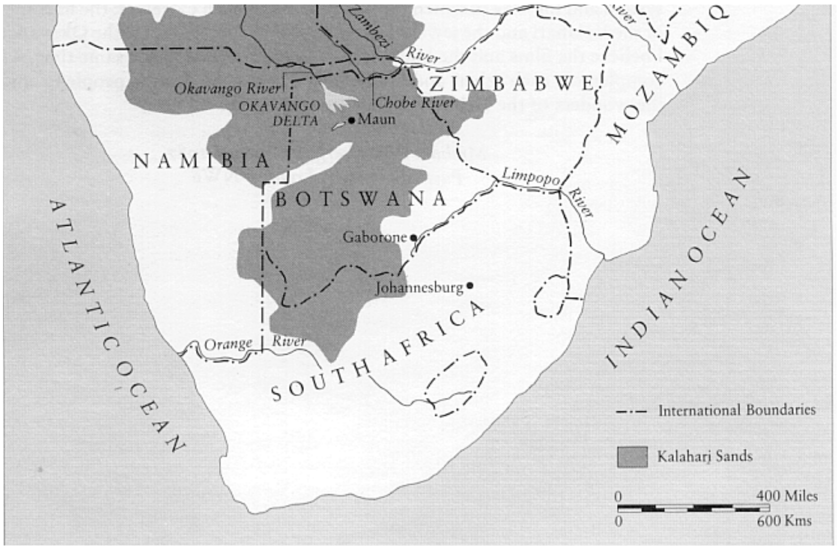

Figure 1. Distribution of Kalahari sands in southern Africa

1. Background

1.1. Types and origin of sand

The sands that predominate in southern Africa were mostly produced by rock weathering after which the constituents have been transported by wind or water. Their composition, shape and properties typically differ from the well-rounded and sorted sands that are normally associated purely with river and beach deposits. It is these unique properties that allow them to perform satisfactorily as road construction materials.

Considerable work was carried out in Australia during the early 1980s [2] on the local "sand clays", which are mostly derived from stranded beach ridges and consist of rounded to sub-angular quartz grains, cemented together and containing some clay and iron staining [3]. Brazilian sands tend to be derived from the weathering and transport of sandstones and consist of sandy quartz with kaolinite and ferruginous oxides [4]. The Kalahari sands of southern Africa (known as the Kgalagadi sands in Botswana) were derived from the erosion of underlying rock and subsequent transport and redistribution. This was carried out by rivers into lakes and by wind. The surficial sands observed today were deposited primarily by wind.

Baillieul [5] carried out sedimentological work in Botswana and analyzed samples from the "topmost layer of the sand". He identified four major sand areas, each having distinct types of sand depending on their mode of formation (aeolian, residual, fluvial with bioturbation) using the sedimentological phi-scale classification to characterize the sands.

1.2. Previous work

The lack of materials and widespread nature of the “sand clays” in Australia led to considerable research in this area in the early 1980s [6]. The importance of the particle size distribution was highlighted in this work and was related to the performance of the materials in specifications published in 1984 [7]. These specifications made use of the traditional sedimentological technique of expressing the particle size (mean) and standard deviation about the mean in terms of Phi units and analyzing the materials in this way similar to the method used by Baillieul [5]. The method is discussed in detail below.

Metcalf and Wylde [7] plotted (Figure 2) the mean particle size on the vertical axis and the standard deviation on the abscissa (both in Phi-scale units) and identified a zone into which sand materials suitable for use as base course would fall (B). Materials falling in zone A were described as loamy, boney or puggy, i.e. not enough fines to bind the material and would not perform well as a base course material. Material in zone D is generally too greasy (plastic) for use and although some of the materials in zone C had been used successfully, they had given problems during construction and before sealing.

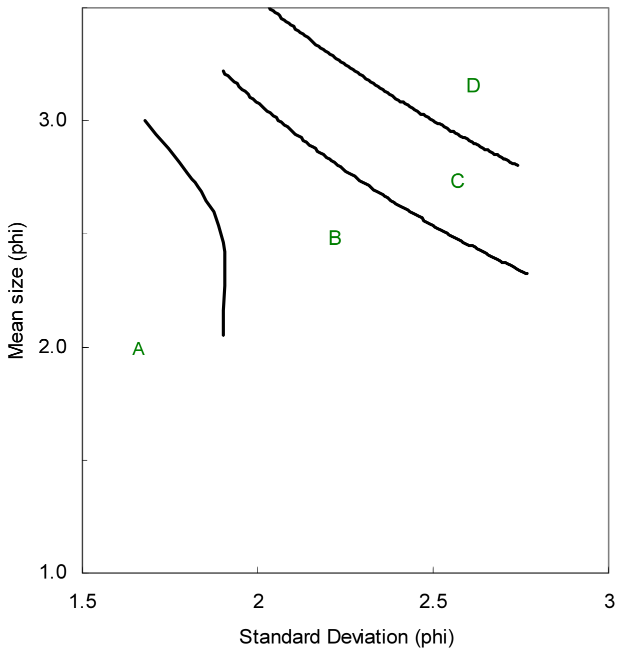

Figure 2. Plat of material performance using mean particle size and standard deviation [7].

This paper applies these sedimentological principles to various sands found in southern Africa, where traditional test methods and classification parameters (e.g., grading modulus) fail to differentiate adequately between the sands.

2. Properties of sands

2.1. Fundamental properties

Engineering materials are generally described in terms of various physical properties, the particle size distribution and plasticity being the common "classification" or indicator tests. These two properties are suitable for typical soils and aggregates but generally lack adequate discrimination for fine sandy materials. Such sands frequently fall within only a few fine sieve sizes with the majority of the material being between 0.075 and 2 mm in size. In addition, the plasticity as determined from the conventional Atterberg test is usually non- or possibly slightly plastic.

When such sands are proposed for use in pavement layers, be it lower support layers or even upper structural layers in low volume roads, more information regarding their properties is necessary. It has become local practice to determine the plasticity index on the fraction passing 0.075 mm (instead of the normal 0.425 mm) and it is not uncommon to measure plasticity indices up to 40 or 50 per cent. These, of course, should not be compared directly with the conventional Atterberg limits but are useful indicators in the context of fine materials. This aspect is not discussed further in this paper.

Comparison of grading analyses is always difficult as these are usually represented graphically or by a combination of various values. Parameters such as the grading modulus (GM) and grading coefficient have been used to reduce particle size distributions to a single value for comparative purposes and are useful in their respective contexts. The grading modulus of sands, however, typically lies in a restricted range (0.9 to 1.2) allowing little discrimination between materials. This is the result of one of the properties (percentage retained on the 2.0 mm sieve) frequently being close to zero and the percentage retained on the 0.075 mm sieve frequently being between 95 and 100. This essentially limits discrimination between sands using the GM to changes in the percentage passing 0.425 mm.

2.2. Interpretation and comparison

The performance of sands thus cannot be determined from typical grading analyses. However, it is known that their performance is a function of the inclusion of some fines, usually too few and too small to be identified without careful hydrometer analyses and not usually considered in the standard interpretation of grading analyses of fine materials. Discussions on some performance aspects of sands in this regard have been published previously [8][9].

3. Proposed sedimentological method

3.1. The phi (Φ) method

Because particle size distribution plots of fine sands using cumulative percentages passing are difficult to compare and quantify in simple terms, sedimentologists [1], [10] have developed and implemented the Phi (Φ)-scale for particle size distribution analysis where

$\Phi = -\log_2 d$

d = particle size in mm.
(A particle size of 0.5 mm = Φ of 1 and a particle size of 0.125 mm = Φ of 3).

The classification of the sands by Baillieul [5] discussed earlier was based on the Phi (Φ)-scale as it allows a simple calculation of the mean particle size (Φmean) and the standard deviation of the particle sizes about the mean (Φsd). These two parameters give a direct indication of the mean particle size of the samples analyzed as well as the degree of sorting, based on the standard deviation. This facilitates the interpretation of sand properties using two simple parameters and simplifies the direct comparison of different sands. The higher the standard deviation, the wider is the grading (less sorting) of the sand and the more material there is available to provide a tighter packing of the sand when compacted to minimize the voids in the material. These fines also contribute to increasing the soil suction as the material dries back from compaction moisture content.

Use of the method requires the determination of the particle size at various percentiles of the particle size distribution plotted in terms of the cumulative percentage retained. If there is a significant portion (more than about 6%) of material finer than 0.075 mm, a hydrometer analysis is required in addition to the standard sieve analysis as the 95th and 84th percentiles (P95 and P84 respectively) retained (measures of the fine fractions) are required for the calculations. The mean (1.61 Φ units or 0.385 mm) and standard deviation (1.84 Φ units) of the following grading analysis (Table 1) are calculated as follows and illustrated with the grading curve in Figure 3 [11].

$$\Phi\text{mean} = (P84 + P50 + P16)/3$$

$$\Phi\text{sd} = ((P84 - P16)/4) + ((P95 - P5)/6.6)$$

Table 1. Grading (sieve and hydrometer) analysis results in phi terms

Sieve size (mm)	Sieve size (Φ)	% passing	% retained
4.75	-2.25	99.0	1.0
2.0	-1.00	98.2	1.8
1.18	-0.24	97.9	2.1
0.425	1.23	50.3	49.7
0.25	2.00	40.4	59.6
0.15	2.74	27.8	72.2
0.075	3.74	9.5	90.5
0.07	3.84	8.7	91.3
0.048	4.38	8.1	91.9
0.029	5.11	7.5	92.5
0.019	5.72	6.8	93.2
0.012	6.38	5.9	94.1
0.008	6.97	4.7	95.3
0.006	7.38	4.5	95.5
0.003	8.38	4.0	96.0
0.002	8.97	3.2	96.8

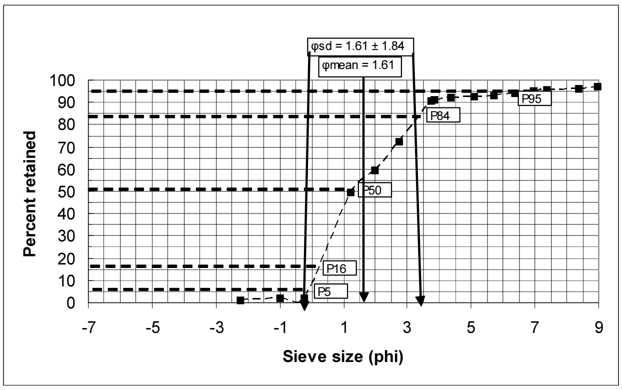

Figure 3. Cumulative percentage retained plot and percentile values.

4. Application to southern African sands

4.1. Botswana

During an investigation into the use of various Kgalagadi sands in structural layers in low volume roads, the technique was applied to a wide range of sand materials from Botswana. Those sands that performed well as base course materials were clearly identified using this approach [9]. The results of all of the analyses are shown in Figure 4.

It can be seen that there is a wide spread of results allowing separation between different materials that was not possible using the grading modulus. Those materials that plot with low Φmeans and high Φsds indicate slightly coarser sands with a wider particle size distribution, providing higher strengths and better filling of voids.

4.2. Namibia

A similar investigation to that described above was carried out in Namibia, in which materials that performed well as unsealed wearing course gravels were compared with those that performed poorly. The results of the analyses are also plotted on Figure 4, where the materials with the higher standard deviations performed markedly better than those with lower standard deviations.

4.3. Mozambique

Testing of various aeolian/river sands for use in road construction has been carried out in Mozambique as well. It is interesting to note that these sands contained a high proportion of heavy mineral particles (e.g. ilmenite and zircon), which obviously affects a particle size distribution analysis based on gravimetrically determined size fractions. These materials, however, were generally quite coarse grained (average mean particle diameter = 0.6 mm) and had wide gradings (Figure 4). High densities and good CBR strengths were obtained from those materials that had the higher standard deviations.

4.4. South Africa

The South African data is restricted to a number of test results from an investigation carried out on a road rehabilitation project in northern KwaZulu-Natal - KZN (Figure 3). The materials were relatively fine (mean particle size 0. 25 mm) but those with the higher standard deviations gave higher densities and were markedly stronger (CBRs > 30%)

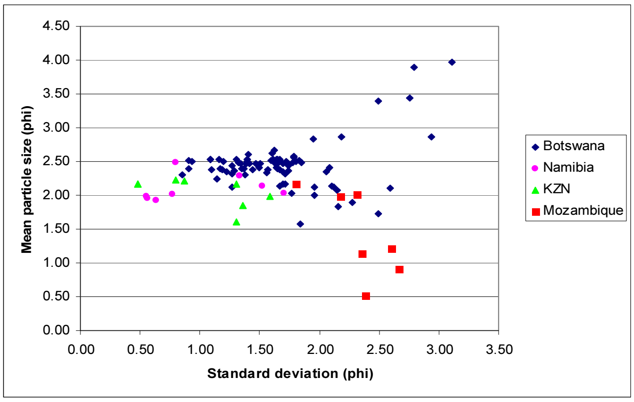

Figure 4. Plots of Φmean versus Φsd for various southern African sands

It is clear that the distribution and spread of the data plotted show marked differences between the sands from the various regions as well as significant differences within sands from any one region. This illustrates the potential usefulness of the Phi-scale technique.

5. Conclusion

The comparison of fine sands using conventional engineering test methods is very difficult. Recent research making use of the sedimentological Phi (Φ)-scale has allowed direct comparison of different sands based on a simple sieve analysis together with a hydrometer analysis when necessary. The results allow much better discrimination between the different materials and have been correlated with higher strengths and improved field performance.

It is recommended that more use should be made of this simple technique when sandy materials are being investigated in engineering projects, particularly for investigations related to the performance (good or bad) of sandy materials.

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