THE USE OF SANDS IN ROAD CONSTRUCTION

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Abstract

Kgalagadi sands occur over large areas of southern Africa, including Botswana, where, apart from lesser deposits of pedogenic materials, they provide the only economic source of construction materials for low-volume roads. The use of these sands in their untreated state as pavement layers (roadbase and subbase) has generally been avoided because they do not satisfy the requirements of conventional specifications. However, an investigation of a number of roads constructed with Kgalagadi sands in Botswana has shown that, when correctly selected, tested and constructed, they can be utilized successfully in all layers of a low-volume road. The use of standard geological (sedimentological) techniques for classification purposes was shown to be particularly effective in differentiating sands that perform well or badly as roadbase and subbase materials. The paper describes the investigations and testing that were carried out and the performance-related specifications that were developed to allow the cost-effective use of Kgalagadi sands in low-volume road construction not only in Botswana but, potentially, elsewhere in Africa where similar sands occur.

1 INTRODUCTION

Kgalagadi sands cover vast areas of southern and western Africa, south of the equator (Figure 1). This material forms what is believed to be the largest continuous surface of sand in the world, occupying some 2.5 million sq. kilometres (Wang, et al., 2007). Today, these sands begin north of the Orange River in South Africa, embrace the western two-thirds of Botswana, more than a third of Namibia, and stretch north through eastern Angola, western Zimbabwe and Zambia to the Democratic Republic of the Congo.

Figure 1 – Distribution of Kgalagadi Sands in southern Africa

The investigation of the use of Kgalagadi sands in road construction in Botswana was prompted by the scarcity of traditional road construction materials in most of the western areas of the country covered by the Kgalagadi Desert. In this area, Kgalagadi sands occur in abundance and are of major engineering significance as, apart from the much lesser deposits of pedogenic materials (calcretes, ferricrtes, silcretes, etc), they are generally the only other source of road building material. However, Kgalagadi sands would not normally be specified for use as a structural layer in a pavement as they do not comply with conventional specifications.

In an effort to reduce road construction costs by making more extensive use of untreated sands in the upper layers of road pavements (subbase and roadbase) (see Plate 1), the Roads Department constructed a number of experimental sections on the Serowe-Orapa road in 1989 (Pinard, 1989).

The initial monitoring and analysis of the performance of the Serowe-Orapa experimental sections, coupled with the subsequent investigation and analysis of three other road projects in Botswana where Kgalagadi Sand had been used as a subbase material, has provided a wealth of information on the use of these sands in road construction. In particular, the outcome of these investigations has led to the following:

- A better understanding of the various types, genesis and related properties of the range of sands found in Botswana and, by extension, probably elsewhere in southern Africa.
- Establishment of the engineering performance of the various types of Kgalagadi Sand when used untreated in sealed road pavements.
- Development of specifications for use of Kgalagadi Sands in low-volume sealed roads.

Plate 1–Kgalagadi sand roadbase & subbase on the Serowe-Orapa road

In light of the above, the key objectives of this paper are to:

- Present the general characteristics of Kgalagadi Sands including their classification, distribution and properties;
- Summarise some of the key results emanating from the field and laboratory investigations which provide an important insight into the properties of Kgalagadi sands;
- Present the new specifications developed for the use of Kgalagadi sands and provide guidance on some aspects of construction using these sands.

The aim is to provide practitioners with guidance on the use of a widely-occurring and relatively cheap road building material, Kgalagadi sand, in the construction of all layers of a low-volume road pavement. In so doing, it will dispel the notion that recourse must necessarily be made to the more expensive treatment (lime, bitumen or cement stabilisation) of such materials in road pavement construction, particularly as roadbase in low-volume roads.

2 GENERAL CHARACTERISTICS AND USE

2.1 Definition

There is no commonly agreed definition for sand which tends to depend upon the frame of reference or academic discipline to which the meaning of this naturally occurring, relatively fine-grained, granular material is applied. To a sedimentologist sand is *an unconsolidated (loose)* *rounded to angular rock fragment or mineral grain having a diameter in the range of 0.06 mm to 2 mm* (Folk, 1965). An engineer, on the other hand, may restrict the meaning of sand to include *only rounded fragments having a diameter of 0.074 mm to 4.75 mm* (AASHTO M145).

The above generic descriptions of sand are very broad and do not adequately reflect the differing mineralogy or physical and mechanical properties of this material, all of which influence its engineering properties. Such differentiation is necessary for discriminating between the different types of sand that can be considered for use in the various layers of a road pavement.

2.2 Formation

It is generally accepted that there are three conditions necessary for the formation of large bodies of sands (Bagnold, 1941). These are:

- sufficient sources of materials;
- geological forces (wind, water, etc.) for continual transportation of sand material from one place to another and topography conducive for continued deposition;
- favourable climatic conditions.

Once disaggregated from the original source rock, the resulting material is then eroded and transported by either wind, water or ice, often ending up at the deposits of rivers or lakes, as sand dunes or desserts, or ultimately as sediment in the sea.

Figure 2 – Formation of sand by erosion and weathering of rocks

After deposition, the sands are, over time, reworked by groundwater and environmental forces. These tend to alter their mineralogical composition through weathering, leaching and enrichment. In addition, the physical properties of the sand mass and particles are changed through cementation, consolidation, particle leaching and/or disintegration.

2.3 Composition

The composition of sand varies from place to place and is largely dependent on the nature of the source material as well as the weathering process (physical, chemical or both) acting on rock masses which determine the mineralogical composition of the unconsolidated sands, silts and clays produced. Transportation of these particles by water and wind will further modify the material in terms of its particulate size, shape and mineralogical sorting, physical distribution and the degree and type of secondary consolidation – all of which influence the geotechnical behaviour of sands in road construction.

For example, the sands found in desert areas, such as the Kgalagadi Desert in Botswana, tend to be Aeolian (windblown) deposits which have undergone deposition by wind, while those found on beaches, such as in Cape Town in South Africa, are commonly dominated by silica (silicon dioxide SiO_2), in the form of quartz (one of the minerals least susceptible to weathering) which has been derived from weathering and erosion of the mountain ranges nearby. In contrast, sand from salt pans or lakes, such as Sua Pan and the Makgadikgadi pans in Botswana, are composed of nearly perfect spheres that were precipitated out of the highly salty water. In areas where there is no source of rock fragments, sand is often composed entirely of organic material.

2.4 Classification

A number of systems have been developed by various bodies to classify soils into classes or groups, generally according to their grain size and plasticity characteristics, with each class having similar characteristics and potentially similar behaviour. This enables engineers to understand the general, rather than particular, properties of the soils of other countries or regions.

Two of the classification systems commonly used in southern Africa are the AASHTO and British Standard (BS) Classification Systems which classify and group sands as detailed in (a) and (b) below.

2.4.1 AASHTO Classification System

This system classifies sand into two main categories or group classifications, viz:

- *Fine Sand* which is non-plastic with a maximum of 10% passing the No. 200 sieve (0.074 mm), and

- *Silty or Clayey Gravel and Sand* which varies in plasticity and with a maximum of 35% passing the No. 200 sieve.

2.4.2 British Standard Classification System

This system classifies sand on the basis of three grain sizes as follows:

- Coarse: 0.6 – 2.0 mm
- Medium: 0.2 – 0.6 mm
- Fine: 0.06 – 0.2 mm

The above classification systems which differentiate sand type on the basis of differences between the grain diameters, are not the most useful or convenient scale to use when geological processes which affect the characteristics of sands are to be examined (Bagnold, 1941). It has been found far better to use a log-scale which exhibits the ratios between the grain diameters (McManus, 1982). In this regard, the Wentworth scale for measuring grain size uses a geometric interval of ½ to define the limits of each size fraction in which sand is divided into five sub-categories based on size as follows:

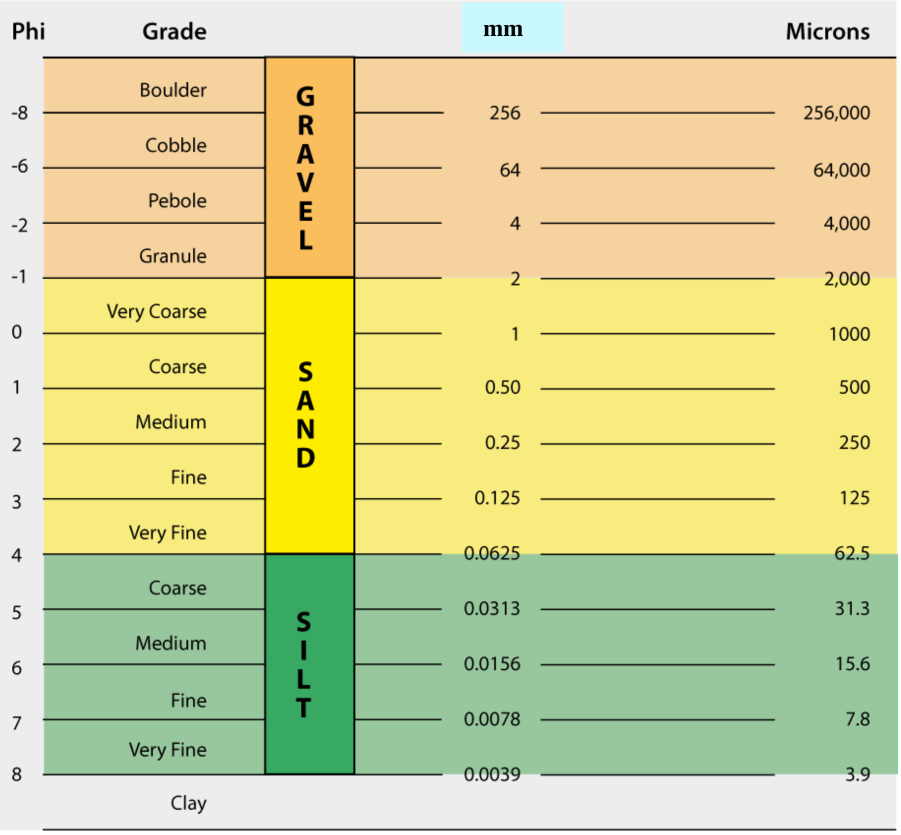
2.4.3 Wentworth Particle Size Classification for Sand (Wentworth, 1920)

This system classifies sand as follows:

- Very coarse sand: 1 – 2 mm
- Coarse sand: 0.5 – 1 mm
- Medium sand: 0.25 – 0.5 mm
- Fine sand: 0.125 – 0.25 mm
- Very fine sand: 0.0625 – 0.125 mm

The above sizes are based on the **"Φ sediment size scale"**, a size scale which is commonly used in sedimentology (Krumblein and Pettijohn,1938; Folk, 1954) and in which Φ is the logarithm to the base 2 of the grain diameter. In this scale the use of Φ, an arbitrary and artificially derived grain size unit, allows the Particle Size Distribution (PSD) to be represented as a single point on a plot of mean particle size against standard deviation in Φ units and thus allows other properties of the sands to be related to that plot – an approach that has been used for improved location and selection procedures of sand in road construction (Metcalf and Wylde, 1984).

For comparative purposes, Figure 3 shows the relationship between grain size data expressed in Φ units, millimetres and microns (Anderson, undated).



Phi	Grade		mm	Microns
	Boulder	GRAVEL		
-8			256	256,000
	Cobble			
-6			64	64,000
	Pebole			
-2			4	4,000
	Granule			
-1			2	2,000
	Very Coarse	SAND		
0			1	1000
	Coarse			
1			0.50	500
	Medium			
2			0.25	250
	Fine			
3			0.125	125
	Very Fine			
4			0.0625	62.5
	Coarse	SILT		
5			0.0313	31.3
	Medium			
6			0.0156	15.6
	Fine			
7			0.0078	7.8
	Very Fine			
8			0.0039	3.9
	Clay			

The Phi scale
In previous research on sediments, grain size data is given in phi (Φ) intervals rather than in microns or mm as statistical and graphic presentations are much simpler when phi diameters are used. Phi is defined as:

$$\Phi = -\log_2 d$$

where d = particle size in mm.

(A particle size of 0.5 mm = φ of 1 and a particle size of 0.125 mm = φ value of 3).

Figure 3 – Alternative measures of grain size (Φ, mm and microns)

2.5 Use in Road Construction

2.5.1 General

As Kgalagadi sands cover the surface of much of Botswana, their use in road construction has, of necessity, had to be made. As a result, the use of these materials has often been based on an instinctive understanding of which materials can be used in which situations as discussed below.

2.5.2 Subgrade and fill

Kgalagadi sands generally rate as excellent to good for use as subgrade or fill materials on most soil classification systems and have generally been used extensively for this purpose in Botswana. When confined they usually provide excellent bearing capacity with CBRs typically well in excess of 15% and often in excess of 30% at 93% Mod. AASHTO compaction.

2.5.3 Subbase and base

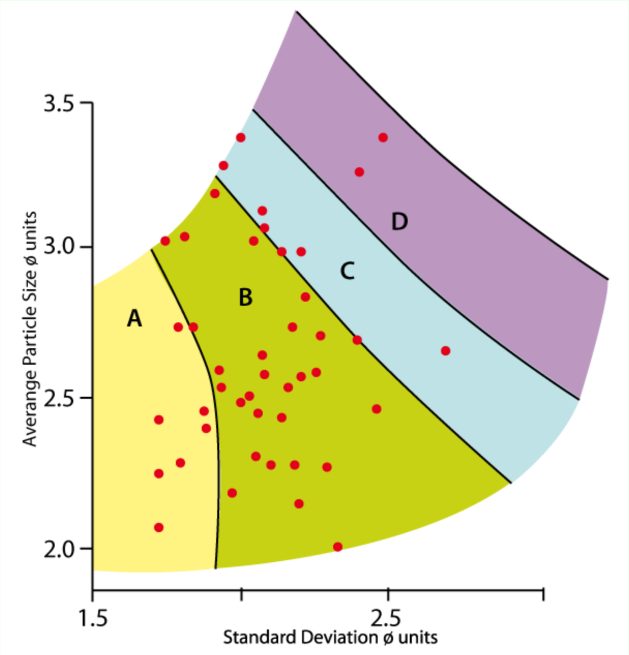
The use of Kgalagadi in pavement layers (subbase or base) has been much less frequent due largely to the fact that they do not comply with conventional selection criteria. Nonetheless, such sands have been used successfully in Botswana as a subbase on lightly trafficked roads and, in one instance, as base (on the Orapa experimental section).

Similar sands have also been used successfully in road pavement layers in Australia and Brazil, two countries that have reported upon their experiences with the use of this material which provide valuable comparative information for Botswana practitioners.

2.5.4 Experience from Australia

Reports from Australia (Metcalf and Wylde, 1984; Emery et al, 2003) indicate the successful use of well-graded silty sands and well graded clayey sands, classifying respectively as SW-SM and SW-SC on the Unified Soil Classification System (UCS), as road base materials. Importantly, the selection of these sands was based on sedimentological parameters – the *Φ sediment size scale* (ref. para. 2.3 (c) **-** rather than on the conventional material selection properties normally specified. On this basis, fine-grained poorly sorted materials that were linked to pavement failures or difficulty during construction were excluded (zones A and D in Figure 4).

Figure 4 (Metcalf and Wylde,1984) shows the selection of materials based on the sedimentological Φ scale whereby the sandy materials were characterised by their mean particle size (in Φ units) representing the fineness of the material, and the standard deviation of the grading (in Φ units), representing the degree of sorting of the sand.



Performance Zones (Metcalf & Wylde, 1984):

A – Sites where sands were described as puggy, loamy, etc

B – Sites where sands were easy to handle and behaved well as sealed base

C - Sites where sands have been used successfully but were difficult to handle during construction

D - Sites where sands were difficult to handle when wet or gave sticky pavements before sealing – unsatisfactory

Note: The term *performance* was interpreted in its broadest sense to include:

- construction behaviour (in excavation, placing and mixing with water, compaction;
- before sealing (as unsealed road before priming, under traffic, rain;
- After sealing (cracking, deformation, edge erosion, etc)

Figure 4 – Particle size distribution of selected Australian sands (in Φ units) related to performance zones

2.5.5 Experience from Brazil

Extensive use has been made of widely occurring “Fine and Sandy soils” in Brazil for use as both subbase and base in lightly trafficked paved roads (Utiyama et al, undated). These relatively plastic, (PI range of 7 – 9 on the material passing the 0.425 mm sieve), poorly graded (C_u 1.8 to 2.5), “laterised” sands classify typically as SP on the Unified Classification System and are reddish in colour due to small quantities of iron oxide in the clay fraction. which impart a reddish colour to the material. SP typically have more than 50% passing the 2.0 mm sieve and retained on the 0.075 mm sieve with a uniformity coefficient ranging from 1.8 to 2.5 and classify as SP.

2.5.6 Lessons learned

Experience with the selection of sands for use in pavements in Australia indicates that the use of the Φ sediment size scale rather than the more conventional engineering classification scales provides a potentially more discriminating and reliable basis for selecting Kgalagadi sands for use in road pavements in their natural state. *This was one of the major aims of the research project – to customise a broad, international classification system for sands in general, to one which reflects the performance characteristics of Kgalagadi sands in particular, based on a good understanding of the mineralogical and engineering characteristics and in service behaviour of local sands.*

3 INVESTIGATIONS, TESTING AND RESULTS

3.1 Distribution of Sands in Botswana

Baillieul (1975) identified four major sand areas in Botswana, each having distinct types of Kgalagadi sand depending on their mode of formation. Of the large number of roads in Botswana where sand has been used as subbase or as neat roadbase (one only – the Serowe-Orapa experimental section in Area IV), four were selected for investigation that are representative of Ballieul's four sand regions. These are shown in Figure 5 below.

Description of Sand Types

Area I: Fine grained (mean diameter 0.17 to 0.23 mm), well to moderately well sorted, quartz sand with the particles coated with a skin of red iron oxide. Where the particles have been affected by water, (fluctuating water table or adjacent to the Okavango Delta) this coating has been removed and the sands are grey in colour with pockets of white sand and tend to be well rounded. The sands have been formed in an aeolian environment.

Area II: The sands are slightly finer (mean diameter 0.14 to 0.2 mm) than those from Area I with similar sorting. They comprise particles of two distinct origins - well-rounded polished quartz grains of aeolian origin and finer (0.125 mm), angular feldspathic particles derived from the underlying Ghanzi sandstones.

Area III: These sands are similar to those of Area II but lack the feldspathic component. Their composition reflects that of the underlying Karoo sandstones. They still, however, show evidence of an aeolian origin.

Area IV: The sands in Area IV are thin and are directly related to the underlying bedrock. They are coarser than the other three types and have been derived predominantly by fluvial action and bioturbation.

Figure 5 – Locations of roads investigated

3.2 Field and Laboratory Testing

A wide-ranging field and laboratory testing programme was undertaken to assess the in service performance of the four road sections investigated and to determine the engineering and mineralogical properties of the sands obtained from the subbase or base layers of the pavement. Table 1 summarises the scope of this programme full details of which are given in the Phase 2 Laboratory Testing Report (InfraAfrica/CPP, 2006).

Table 1 – Field and laboratory testing programme

Fieldwork Programme
• Visual Condition Assessment (in accordance with TMH9 (CSRA, 1992)). • Roughness measurements using MERLIN (Cundhill, 1991). • Crack survey. • Rut depth measurements. • In situ DCP CBR. • Trial pitting for bulk samples and logging of trial pits. • In situ density and moisture content (Troxler surface moisture density gauge.

Laboratory Testing Programme

Standard tests
- Particle size distribution, including particles smaller than 2-micro meter.
- Atterberg Limits including on minus 0.075mm fines.
- Linear Shrinkage including on minus 0.075mm fines.
- Electrical Conductivity and pH.
- Maximum Dry Density.
- California Bearing Ratio at OMC, 4days soaking and 0.5 OMC.
- Vane Shear on the CBR sample.
- Particle Density.

Specialised Tests
- Scanning Electron Microscopy.
- X-ray Diffraction.
- Chemical Analysis.

3.3 Physical/Classification Properties

3.3.1 Colour

The colour of sand is often used as an indicator of mineralogical compounds (Mitchell, 1959) and is often used as an indicator of sand quality. The colour of the Kgalagadi sands investigated, using the Munsell System (ASTM D 1535-80), exhibited a wide range varying from dusky red, to dark reddish brown, to very dark reddish orange, to dark greyish brown, to dark grey, to black, to cream, to white. Plate 2 illustrates the wide range of colours exhibited by the Kgalagadi Sands found in Botswana.

Sand colours as determined from the Munsell Chart with soil in dry condition

Figure 2 – Typical range of colours of Kgalagadi Sands found in Botswana

The red and yellow colouration of the sands is derived from the mobilisation of iron oxides during in situ weathering of feldspatic and ferromagnesian minerals. Such sands types are prevalent in Area IV of the Ballieul map of Botswana (e.g. along the Serowe-Orapa road). In contrast, where the sands have been affected by a fluctuating water table, such as in the vicinity of the Okavango Delta (Area I of the Ballieul map), the iron oxide coating has been removed and the sands are grey/dark grey in colour (e.g. the Maun-Shorobe road). In further contrast, the aeolian component of the sands found in Area II of the Ballieul map are creamish white in colour (e.g. the Nata-Maun road) while those in Area III are similar to Area II but lack the feldspatic component and show signs of aeolian origin (e.g. the Kang-Hukuntsi road).

The various sand types found along the Serowe-Orapa road, which are representative of many of those found elsewhere in the Botswana, show a very striking and clear relationship between iron, (as Fe_2O_3) content and clay fraction (Cf) (Figure 6).

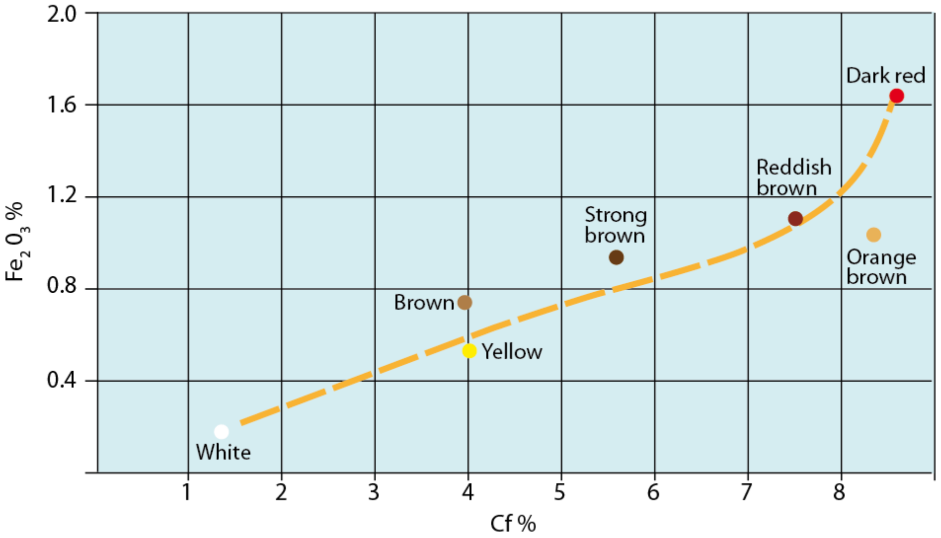


Figure 6 – Clay particle size content versus Iron Oxide content

3.3.2 Particle shape

The shape of sand particles has a significant influence on its compactability, density and stability and, hence, the overall engineering behaviour of the material. For a specific grading, this parameter controls the manner and degree of particle interlock upon which is dependant such components as shearing resistance, crushing resistance and flexural or tensile strengths. Thus, smooth rounded particles would offer less resistance to rearrangement than angular and/or elongated particles with rough surfaces and, therefore, other things being equal, the former would be expected to give higher densities for a given compactive effort.

Kgalagadi sands exhibit a wide range in particle shape, which is influenced by their mode of formation. In this regard, aeolian sands (See Plate 3(a)) tend to exhibit a more rounded shape than sands of mixed origin (see Plate 3(b)), a factor that significantly influences their compactability characteristics and related strength and bearing capacity as discussed above.

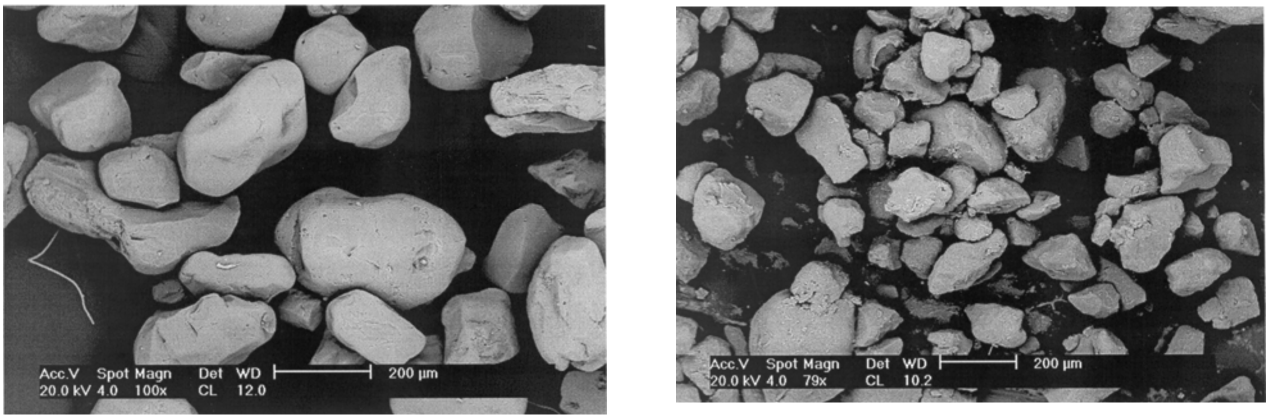


Plate 3 (a) (Left): Sehitwa-Tsau (Area I); (b) (Right) Serowe-Orapa (Area IV)

3.3.3 Grading

Knowledge of the grading of sand is one of the most valuable guides to its classification and performance. As might be expected from sands derived from different origins (i.e. sands of aeolian origin versus sands of mixed origin), their gradings differ somewhat in relation to their mode of formation. Generally, however, as illustrated in Figure 7, they tend to exhibit a S-shaped curve

(Chauvin, undated) with 80 – 100 percent typically passing the 0.425 mm sieve and a 5 – 30 percent silt and clay fraction which influences a number of the soils properties such as plasticity and compactability.

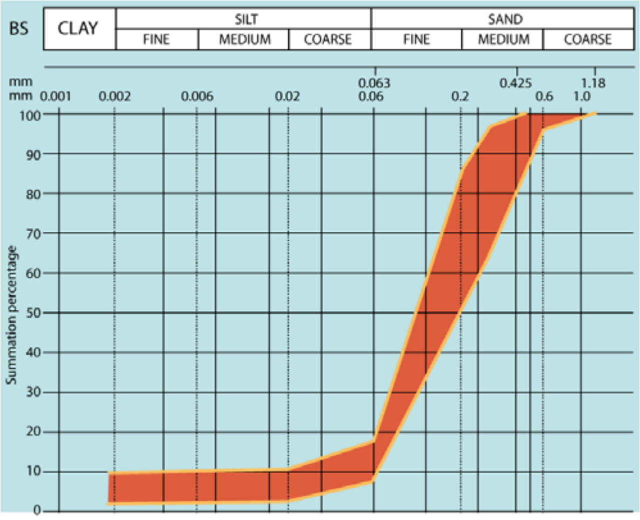


Figure 7 – Grading envelope for typical Kgalagadi sand types found in Botswana

3.3.4 Plasticity

Kgalagadi Sands exhibit variation in plasticity depending primarily on their mode of origin and the consequent presence or not of either clay minerals and calcium carbonate or, possibly in some cases, salts deposited by the evaporation of salt-laden ground water.

Determination of plasticity in the conventional manner, i.e. on material passing the 0.425 mm sieve (P425), tends to mask the plasticity that can be mobilised in the silt and clay fraction of the materials passing the 0.075 mm (P075). Thus, some sands may show non-plasticity on the P425 fraction but significant plasticity on the P075 mm fraction, *which is of much significance when the sands are being considered for use as construction materials.*

3.3.5 Fineness Index

The Fineness Index of sand, FI_{75}, defined as the product of the PI on material passing the 0.075 mm sieve and the percentage material passing the 0.075 mm sieve $(FI_{75} = PI_{075} \ x \ P_{075})$, has been used in Zimbabwe to define the material's "compactability" (Baart, 1961). From experience of the use of aeolian sands in the construction of the Bulawayo-Victoria Falls Road in Zimbabwe, the following compactability criteria were developed:

Table 2 – Compactability criteria for aeolian sands

Fineness Index	Compactability Rating
0 – 200	Good in layers up to 1 m in depth (thickness)
200 – 400	Poor in depth but fair in 150 mm to 200 mm layers with mixing
> 400	Progressively poor, rapidly becoming unworkable

The above criteria have been developed on the basis of a PI determined from a BS Liquid Limit Device which gives, on average, four units higher than that obtained from an ASTM Liquid Limit device (Sampson and Netterberg, 1984).

Typical FI values obtained from the road sections investigated ranged from 135 to 500 with a mean value of 290. This implies the need for excluding those sands with FI > 400 if potential compaction problems are to be avoided.

3.4 Chemical/Mineralogical Properties

3.4.1 Mineral constituents

The mineral composition of the Kgalagadi sands depends primarily on the source of the materials as well as the distance the materials are currently located from their original source. When these particles are not transported very far, the less durable materials such as rock fragments and feldspars occur more frequently in the sands. However, when they have been transported over larger distances, these materials are abraded away and only the harder more resistant quartz grains survive. In this way, a mineralogical sorting occurs.

The results of the mineralogical investigations indicate that the majority of the Kgalagadi sands are relatively quartz rich with only minor components of other materials. The better performing sands, i.e. those giving the highest CBRs, as found in the Serowe-Orapa roadbase, exhibit the highest iron and aluminium oxides with values in excess of 18%. It is noteworthy that the Australian requirement for the use of similar sand clays as neat roadbase is a value greater than 8% (Emery, 2003).

3.5 Mechanical/Engineering

3.5.1 Collapsible properties

Certain types of Kgalagadi sands, typically those partially saturated ones with a dry unit weight below 16 kN/m^3, exhibit a *collapsible fabric.* This results from the production of clays within the soil mass through weathering of the few susceptible particles. As a result, these sands possess an open structure, the void ratio is relatively high and there is very little contact between the sand grains; the structure is held together by colloidal bridges of clay and iron oxide or hydroxide (see Figure 8 and Plate 4). These bridges may also occasionally be formed by calcium carbonate or soluble salts (Brink, 1985).

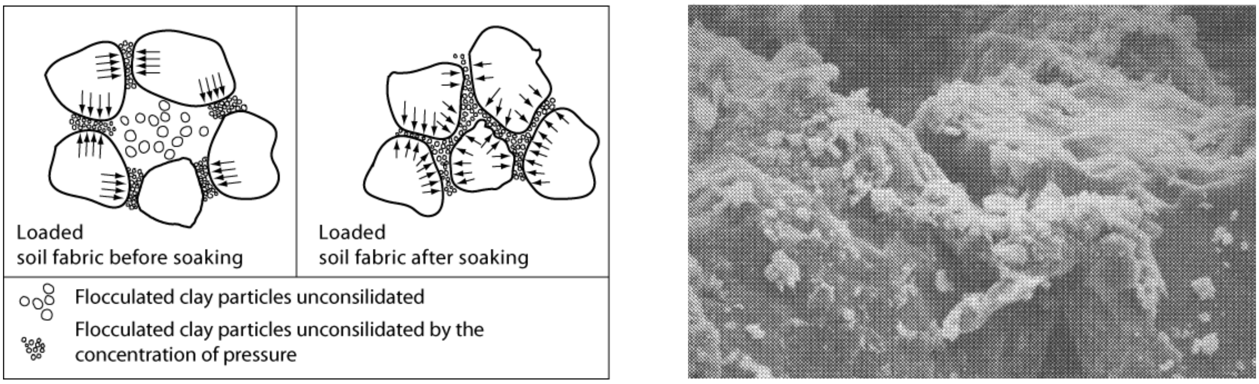


Figure 8 **Plate 4**

Collapsible fabric illustrated graphically (left) and in a photomicrograph (right). (Brink, 1985).

As long as the sand is not loaded, disturbed or wetted, these bridges provide considerable bearing strength. However, if the sand is disturbed or wetted, the bonding bridges between the grains soften and, under pressure above a certain limit (the limit depending on such factors as degree of loading, disturbance or wetting), the bridges break and collapse occurs. To reduce the chances of such collapse occurring in practice, current specifications often require that subgrade soils with a collapsible fabric be densified to a depth of about 1 m (Weston, 1980). However, this can be a very costly requirement to meet in practice, particularly in arid or semi-arid areas where water is often scarce and expensive. Options for dealing with this problem are addressed in Section 5.2.

3.5.2 Compaction characteristics

Laboratory investigations carried out by many practitioners reveal that Kgalagadi sands do not always exhibit the typical parabolic dry density/moisture content curve exhibited by other soils as illustrated in Figure 9 Type B. Instead, as illustrated in Figure 9 Type A, the compaction characteristics of some of these sands are such that they can be compacted over a wide range of moisture contents, without a significant change in density.

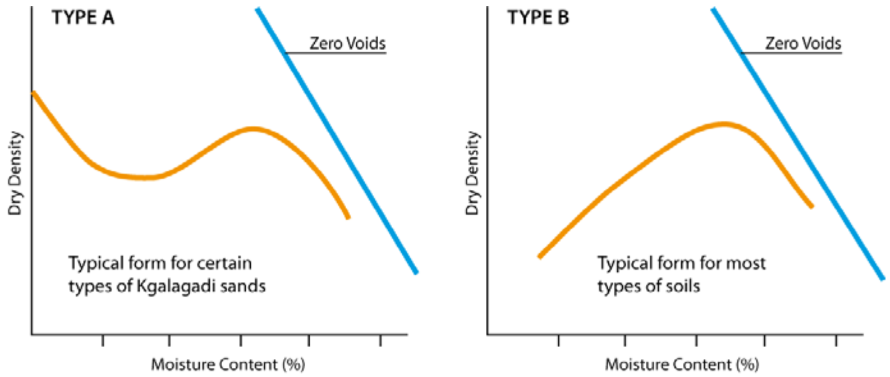


Figure 9 – Forms of compaction curves

Figure 9 Type A indicates that, for some sands, the density obtained in a dry condition can be markedly greater than that obtained at the conventional optimum moisture content. However, much as there may be a temptation to employ “dry compaction” in practice, other pertinent factors are noteworthy. For example, high air voids have a potential for causing post-construction problems (albeit reduced ones in semi-arid environments) such as greater susceptibility to loss of strength, should the degree of saturation increase in service, resulting in a loss in strength and resulting deformation of the pavement structure.

3.5.3 Density/Strength

The method of compaction test used – Mod AASHTO (Static - Rammer) or BS Test 14 (Dynamic - Vibrating Hammer) – significantly affects the results obtained for MDD, air voids at MDD and CBR. Figures 10 and 11 show the benefits to be obtained from using the Vib. Hammer rather than the Mod. Rammer as determined from the Serowe-Orapa experimental section.

Typical results obtained from a number of Mod. AASHTO and Vib. Hammer compaction tests carried out on Kgalagadi sand during the construction of the Serowe-Orapa experimental section were as follows:

- 3.4% increase in density (from 1910 kg/m^3 to 1975 kg/m^3) by Vib. Hammer
- 18% increase in CBR @ 95% MDD (from 38% to 45%) by Vib. Hammer
- 55% reduction in air voids at MDD (from 11% to 5%) by Vib. Hammer

While the gains in density and strength may be moderate, the reduction in air voids is very significant – factors which prompt the use of the Vibrating Hammer test as the preferred compaction test method for assessing the compaction properties of Kgalagadi Sands. A strong correlation (r^2 value = 0.86) was found between CBR and the Al_2O_3 + Fe_2 O_3 contents indicating the usefulness of these oxide content as an indicator of relatively high CBR values.

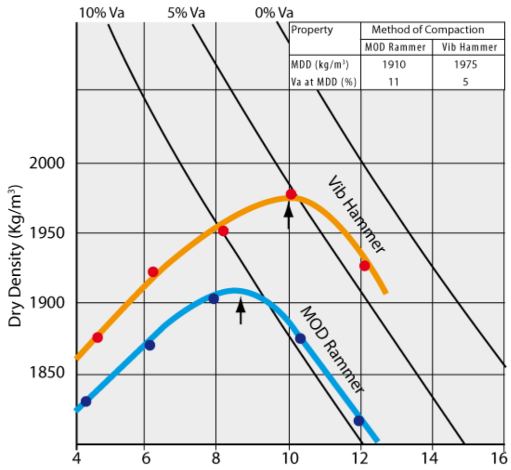


Figure 10 – Density/voids relationship

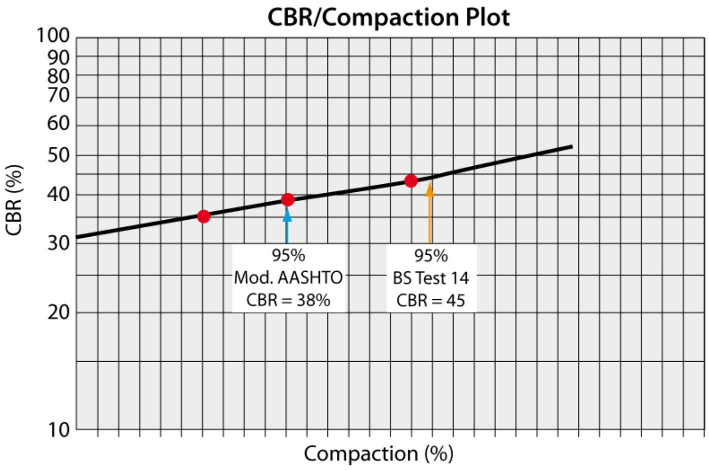


Figure 11 – CBR/Compaction

3.5.4 Soil suction

Soil suction is primarily a function of the soil grading (and inter-particle voids) and clay content. In arid or semi-arid climates, the development of soil suction strength allows some Kgalagadi sands (those with some plasticity and related cohesion) to generate relatively high strengths in service as they dry back from their moisture content at compaction processing to their equilibrium moisture content – typically 0.6 – 0.7 of OMC (Emery, 1992). The soil suction generated over this range of moisture content will be considerably higher than those existing under soaked conditions. However, if the sand is to retain its suction generated strength then the soil suction must be maintained by ensuring that the moisture content in the pavement layers does not increase above the OMC of the material. Measures for ensuring this are discussed in Section 5 6.

From the Orapa experimental section, it was found that those sands with a PI (0.075) of 10–15 (the red/brown sands) usually produced a compacted pavement layer *which could be trafficked by 30 ton tippers with no visible distress*. These sands typically exhibited DCP CBR at field moisture content in excess of 120% (see Figure 12). In contrast, the sands with a PI (P0.075) of less than 5 are generally cohesionless and tend to break up relatively easily when trafficked by construction plant.

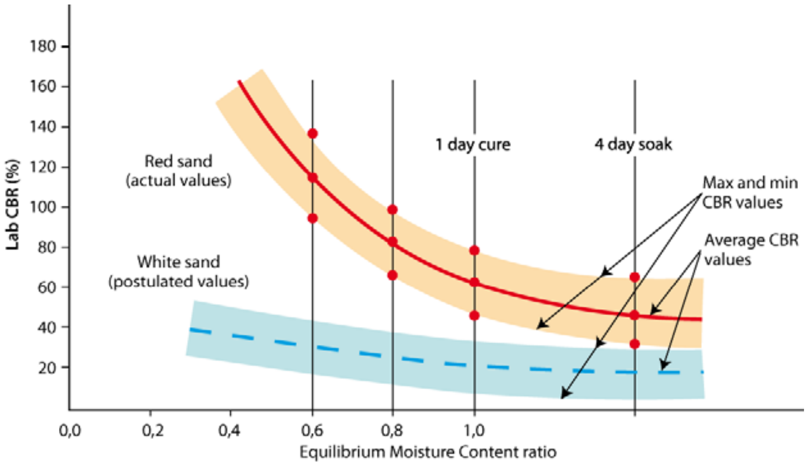


Figure 12 – CBR at various equilibrium moisture content ratios

One of the most important factors arising from the Serowe-Orapa experimental sections was that ***the colour and related cohesion of Kgalagadi sand, within limits, was the most important factor in assessing its suitability as a pavement layer. Sand colour is related to a number of other sand characteristics such as oxide content which is strongly correlated with CBR value (r^2 = 0.86).***

4. SPECIFICATIONS

4.1 Basis of derivation

A framework similar to the one developed in Australia was also developed for Botswana and the sedimentological parameters for the various sands investigated were plotted on the Wylde chart with the outcome as illustrated in Figure 13.

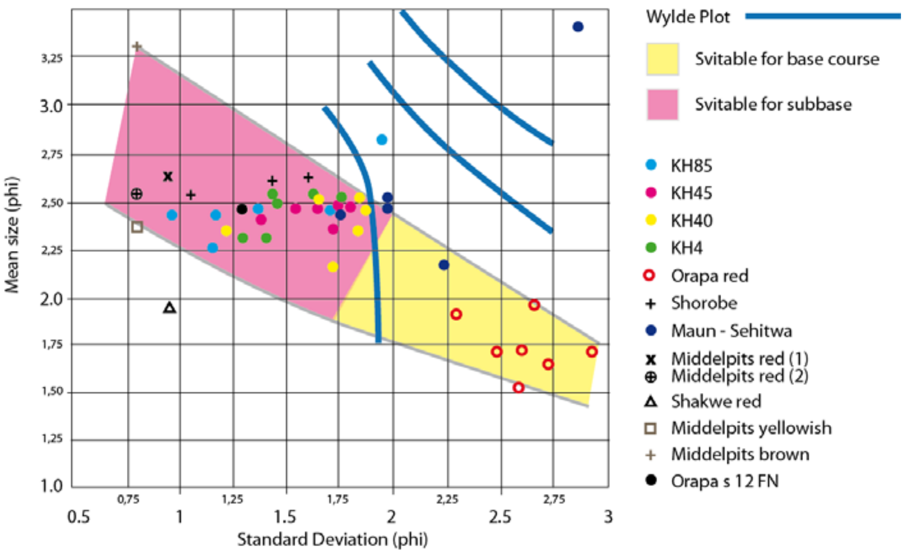


Figure 13 – Placement of Kgalagadi sand samples on Wylde Chart

It is significant from Figure 13 that the Serowe-Orapa sands which have provided proven performance as a base material have all plotted in Area B which confirms their suitability not only in bearing capacity terms but also in terms of constructability. Sands from the subbase of the other road sections generally plotted in Area A indicating, on the basis of Australian experience, probable constructability problems if these sands were to used as base course.

4.2 New specifications

Based on the monitoring and analysis of the 20 years of excellent performance of red sands used as basecourse on the Serowe-Orapa road in central Botswana, a performance-related specification has been developed and is presented in Table 5.1. This specification holds good for at least the traffic carried to date, estimated at 0.3M esa. Given that the road has suffered no serious structural deterioration to date, and that it will be maintained in satisfactory condition in future, it would be reasonable to expect that it could carry up to a total of 0.5M esa before rehabilitation is required.

Table 3 – New specification for the use of Kgalagadi Sands in roads

Parameter	Road layer				
	Roadbed	Fill	SSG	Subbase	Base
Soil Constants	-	-	-	$5 < BLS_{0.075}/\varphi_{mean} < 10$	$5 < BLS_{0.075}/\varphi_{mean} < 10$
Field Compaction (Vib Hammer)(%)	100%	100%	100%	100%	100%
Min soaked CBR @ 100% Vib Hammer	-	7	15	30	60
$Al_2O_3 + Fe_2O_3$ (%)	-	-	-	-	>8

Notes: BLS = Bar Linear Shrinkage; SSG = Selected subgrade

5 CONSTRUCTION

5.1 Compaction

One of the critical aspects of using Kgalagadi sands in road construction is to maximise their strength and increase their stiffness and bearing capacity by producing the highest possible density in the subgrade and pavement layers. This can be achieved, not necessarily by compacting to a pre-determined relative compaction level as is traditionally done but, rather, by compacting to the highest uniform level of density (“compaction to refusal” where possible (i.e. where there is no significant

Reduction in deflection

breakdown of the soil particles which is unlikely with sands as they are composed mostly of silica (quartz) – one of the minerals least likely to breakdown under compaction). In so doing, as illustrated in Figures 14 and 15, there is a significant gain in density, strength and stiffness, the benefits of which usually outweigh the costs of a few additional passes of the roller.

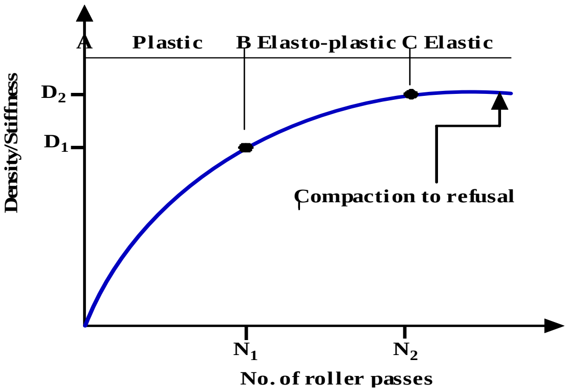


Figure 14 – Illustration of concept of "compaction to refusal"

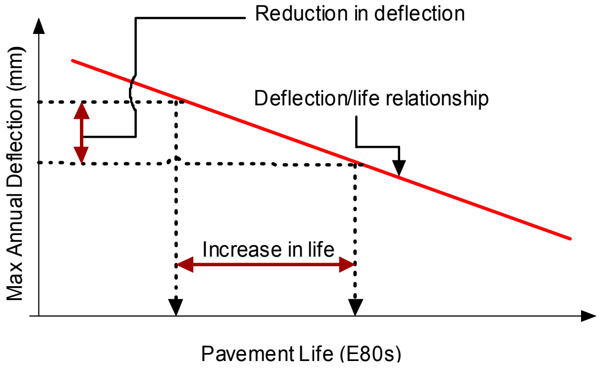


Figure 15 – Deflection/life relationship

The use of *dry compaction* (i.e., at natural moisture content, which could be between 3 and 4 percent) can produce the same density as conventional compaction at OMC. The air voids are, however, significantly higher in this material and the benefit of suction forces developed during drying back of moist compacted materials is lost. Moreover, should wetting up of the relatively high voided material occur in service, this is likely to lead to loss of strength and consequent deformation of the pavement. Thus, the implications of this should always be considered when dry compaction is a possible option.

5.2 Density and strength

In order to maintain its density and strength, sand needs to be confined. This can be achieved by keeping the pavement levels as low as possible, but this is not always desirable, as the pavement drainage characteristics are reduced. Widening the layer to be compacted and using flat side slopes can achieve a similar effect whilst improving the pavement drainage and overall structural capacity.

5.3 Collapsible sands

The mitigation of collapse of sand requires a high degree of compaction. Using conventional plant (i.e., heavy vibrating rollers), the application of large quantities of water is necessary. Where compaction water is scarce or expensive, high-energy impact compaction to pre-collapse the Kgalagadi sands can be a cost-effective solution compared with more conventional vibratory rollers. This type of compaction produces a much deeper effect than conventional plant and relies on high energy to collapse the materials instead of moisture. The use of high-energy impact compaction to pre-collapse Kgalagadi sands has produced good results (Pinard, 1988) and significant economies in terms of water usage can be achieved.

5.4 Surface shear

A frequent problem observed during the compaction of essentially uniform sized sandy materials is the tendency for shearing of the material during compaction, particularly when excessive vibration is used. The use of heavy static rollers at slow speeds can overcome this but generally, it is necessary to carry out compaction trials using combinations of padfoot or grid rollers, pneumatic tyred rollers and vibratory compactors of different sizes to determine the optimum combination. Generally high amplitude, low frequency vibrating roller operations are more likely to cause shearing than low amplitude (< 1.1 mm), high frequency (> 35 Hz) operations (Murphy, 1981).

5.5 Compaction moisture

The compaction moisture content is critical to the successful compaction of Kgalagadi sands. It is therefore imperative that strict control of moisture is exercised during compaction. This may be complicated by the fact the OMC differs for different compaction efforts and that the OMC determined in the laboratory may or may not necessarily be applicable for the plant actually used on site. Compaction trials are the best way of determining the OMC for any combination of plant. The recommended technique for this is to prepare strips of material at various moisture contents, partly compact these with the same number of roller passes and find the one with the highest density (i.e. OMC for the plant used). Another test strip is then compacted at the identified OMC to determine the optimum number of passes to achieve maximum density (Wylde, 1979).

It is also necessary to ensure that premature sealing does not lock in construction moisture. Allowing the material to dry back from its OMC before priming, can minimise the incidence of long term shrinkage cracks developing through the seal (Sandman, Wall and Wilson, 1974) as well as allow the sand to develop a large part of its suction strength (Pederson, 1988). It should be noted, however, that some sands tend to lose density on drying out but are quite firm while still wet. It would be advisable therefore to cover such sands as soon as possible after compaction.

5.6 Surfacing

Bituminous surfacing of a sand base is carried out generally in a similar manner as for other types of surfacing. Minor amendments include the use of a relatively higher viscosity prime (e.g. MC 250 rather than MC 70 or MC 30) to allow good penetration of the uppermost 20 mm of the base. The relatively hard surface so obtained will reduce surfacing aggregate embedment. The use of an “inverted” seal can also be employed beneficially in that the smaller size first application aggregate is less susceptible to punching into the surface of the sand base.

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