The Use of Sands in Road Construction

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Outline of Presentation

- Introduction and Background
- General Characteristics and Properties
- Field and Laboratory Investigations
- Design, Specification and Construction
- Summary
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Occurrence of Kalahari Sands in Africa

How extensive is the Kalahari Desert in Africa?

- Occupies much of central and southern Africa encompassing an area of some 2 million sq. km
- Stretches from South Africa’s Northern Cape as far north as the DRC
- Largest continuous stretch of sand in the world
Occurrence of Kgalagadi Sands in Botswana
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 feldspatic particles derived from the underlying Ghanzi sandstones.

Area III: These sands are similar to those of Area II but lack the feldspatic 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.
Typical Range of Colours

- Very pale brown
- Light brown
- Reddish yellow
- Brown
- Brown
- Strong Brown
- Yellowish red
- Dark red
- Gray
- Dark gray
- Dark gray
- Dark grayish brown
Introduction and Background

General Characteristics and Properties

Field and Laboratory Investigations

Design, Specification and Construction

Summary
Grading Envelope for Various Sands

<table>
<thead>
<tr>
<th>BS</th>
<th>CLAY</th>
<th>SILT</th>
<th>SAND</th>
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<tbody>
<tr>
<td></td>
<td>FINE</td>
<td>MEDIUM</td>
<td>COARSE</td>
</tr>
<tr>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
</tr>
<tr>
<td>0.001</td>
<td>0.002</td>
<td>0.006</td>
<td>0.02</td>
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</table>

Summation percentage vs. particle size distribution.
Clay Particle Size vs Iron Oxide Content

- White
- Yellow
- Brown
- Strong brown
- Reddish brown
- Orange brown
- Dark red

Fe₂O₃ % vs Cf % graph showing the relationship between clay particle size and iron oxide content.
Collapse Potential of Kgalagadi Sands

- Loaded soil fabric before soaking
- Loaded soil fabric after soaking
- Flocculated clay particles unconsolidated
- Flocculated clay particles unconsolidated by the concentration of pressure
Collapse Potential Kgalagadi Sands

Dry (Stable)

- colloidal bridge
- quartz grain

Wet (Unstable)

- collapse

A = Normal Settlement (soil partially saturated)
B = Additional Settlement (no change in applied pressure but increase in settlement due to increase in moisture content)
Introduction

Serowe-Orapa Road Location
Serowe-Orapa Sand-Bitumen Trials

**LONGITUDINAL SECTION**

SHOULDER TO BE STABILISED AS PER BASE

SHOULDER TO BE NATURAL SAND

**PLAN**

7 @ 150 m Sections Red Sand B/P 39 + 500

4 @ 150 m Sections White Sand

Overburden @ B/P 42 + 000 RHS

Stabilised depth 150 mm

Stabilised depth 75 mm

Stab. Depth 150 mm

<p>| | | | | | | | | | | |</p>
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<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>0%</td>
<td>1.5%</td>
<td>1.5%</td>
<td>3.0%</td>
<td>4.0%</td>
<td>1.5%</td>
<td>3.0%</td>
<td>3.0%</td>
<td>1.5%</td>
<td>1.5%</td>
<td>1.5%</td>
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</tbody>
</table>
Introduction

Serowe-Orapa Sand Road Base
Sand from Serowe-Orapa Trial Section
Classification of Sand

Number of classification systems

- AASHTO
- Unified Soil Classification
- British Standard
- Wentworth (based on “Φ sediment size scale”)

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
## Classification of Sands by Grain Size

<table>
<thead>
<tr>
<th>Phi</th>
<th>Grade</th>
<th>Mm.</th>
<th>Microns</th>
</tr>
</thead>
<tbody>
<tr>
<td>-8</td>
<td>Boulder</td>
<td>256</td>
<td>256,000</td>
</tr>
<tr>
<td>-6</td>
<td>Cobble</td>
<td>64</td>
<td>64,000</td>
</tr>
<tr>
<td>-2</td>
<td>Pebole</td>
<td>4</td>
<td>4,000</td>
</tr>
<tr>
<td>-1</td>
<td>Granule</td>
<td>2</td>
<td>2,000</td>
</tr>
<tr>
<td>0</td>
<td>Very Coarse</td>
<td>1</td>
<td>1,000</td>
</tr>
<tr>
<td>1</td>
<td>Coarse</td>
<td>0.50</td>
<td>500</td>
</tr>
<tr>
<td>2</td>
<td>Medium</td>
<td>0.25</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>Fine</td>
<td>0.125</td>
<td>125</td>
</tr>
<tr>
<td>4</td>
<td>Very Fine</td>
<td>0.0625</td>
<td>62.5</td>
</tr>
<tr>
<td>5</td>
<td>Coarse</td>
<td>0.0313</td>
<td>31.3</td>
</tr>
<tr>
<td>6</td>
<td>Medium</td>
<td>0.0156</td>
<td>15.6</td>
</tr>
<tr>
<td>7</td>
<td>Fine</td>
<td>0.0078</td>
<td>7.8</td>
</tr>
<tr>
<td>8</td>
<td>Very Fine</td>
<td>0.0039</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>Clay</td>
<td>0.0000</td>
<td>3.9</td>
</tr>
</tbody>
</table>

### 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:

\[ Φ = -\log_2 d \]

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).
The Φ scale 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 typical particle size of the samples analyzed as well as the degree of sorting. This facilitates the interpretation of sand properties using 2 simple parameters and simplifies the direct comparison of properties of different sands.

The higher the standard deviation, the wider the grading (less sorting) of the sand is and the more material there is available to provide a tighter packing of the sand when compacted and to minimize the voids in the compacted material.
**The Φ scale**

**Mean** particle size (M) determined using the following formula:

\[
M = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}
\]

where \(\phi_{16}\) = the 16\textsuperscript{th} percentile, \(\phi_{50}\) = 50\textsuperscript{th} percentile, etc.

**The standard deviation (σ) calculated from:**

\[
σ = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6}
\]
The Φ scale

\[ \Phi_{\text{mean}} = \frac{P_{84} + P_{50} + P_{16}}{3} = (3.3 + 1.2 + 0.25)/3 = 1.58 \]

\[ \Phi_{\text{SD}} = \frac{\frac{P_{84} - P_{16}}{4} + \frac{(P_{95} - P_{5})}{6.6}}{2} = \frac{(3.3 - 0.25)/4 + (6.9 - (-0.2))/6.6}{2} = 1.83 \]
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Locations of Sands Investigated

- Area I: Maun-Sehitwa
- Area II: Maun-Shorobe
- Area III: Kang-Hukuntsi
- Area IV: Serowe-Orapa
## Fieldwork Programme
- Visual Condition Assessment (in accordance with TMH9 (CSRA, 1992)).
- 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-microns.
  - 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, 4 days soaking and half OMC.
  - Vane Shear on the CBR sample.
  - Particle Density.
- **Specialised Tests**
  - Scanning Electron Microscopy.
  - X-ray Diffraction.
  - Chemical Analysis.
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Performance Characteristics of Australian Sands

Performance Zones (Metcalf and 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
Plotting of Kgalagadi Sands on Wylde Chart

Wylde Plot

- Yellow: Suitable for base course
- Pink: Suitable for subbase

- KH85
- KH45
- KH40
- KH4
- Orapa red
- Shorobe
- Maun - Sehitwa
- Middelpits red (1)
- Middelpits red (2)
- Shakwe red
- Middelpits yellowish
- Middelpits brown
- Orapa s 12 FN

General characteristics and use
### Specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Roadbed</th>
<th>Fill</th>
<th>SSG</th>
<th>Subbase</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Constants</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5&lt; BLS&lt;sub&gt;0.05&lt;/sub&gt;/&lt;sub&gt;Q&lt;sub&gt;mean&lt;/sub&gt;&lt;/sub&gt; &lt; 10</td>
<td>5&lt; BLS&lt;sub&gt;0.05&lt;/sub&gt;/&lt;sub&gt;Q&lt;sub&gt;mean&lt;/sub&gt;&lt;/sub&gt; &lt; 10</td>
</tr>
<tr>
<td>Field Compaction (Vib Hammer)(%)</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Minimum soaked CBR @ 100% Vib Hammer</td>
<td>-</td>
<td>7</td>
<td>15</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>Al₂O₃ + Fe₂O₃ (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>&gt;8</td>
</tr>
</tbody>
</table>
Wide array of compaction plant offers opportunities for dealing with a wide range of soil types and conditions, including thickness of layer.

- Necessary to make appropriate choice of plant as regards energy rating and shape in relation to prevailing soil conditions and layer thickness.
Types of Impact Compactors
Compaction Plant Characteristics

Hammer / nail analogy

Depth of influence

Static roller

Vibratory roller

Impact compactor
Impact Compaction
Materials Issues

Removal of Collapse Potential
Benefits of Compaction to Refusal

**Graph:**
- **Y-axis:** Density/Stiffness
- **X-axis:** No. of roller passes
- **Points and Labels:**
  - D1, D2
  - N1, N2
  - Plastic, Elasto-plastic, Elastic
  - Compaction to refusal

**Graph Details:**
- Reduction in deflection
- Deflection/life relationship
- Increase in life
- Pavement Life (E80s)
Stiffness Produced by Impact vs Conventional Compactors

Impact compacted

E-modulus (MPa)

0-150mm  150-300mm  300-450mm  450-600mm  600-800mm
Construction Aspects
Serowe-Orapa Road After 20 Years

Serowe-Orapa Road: Constructed 1889. Photo 2006. Age 17 years
Uses of Sand in Road Construction

● In Botswana:
  - Subgrade and fill: extensively
  - Subbase: often on Rural Roads projects in 1980s and 1990s
  - Base: Serowe-Orapa experimental section only in 1989

● In Australia:
  - Subgrade, fill, subbase: extensively
  - Base: Well-graded silty sands and well graded clayey sands selected on basis of sedimentological parameters (Φ sediment size scale)

● In Brazil:
  - Subgrade, fill, subbase: extensively
  - Base: Fine and sandy reddish “laterised” soils used extensively
Way Forward

- Greater dissemination and information sharing
- Revision of outdated standards and specification
- Mainstreaming proven research into practice and implementation
Conclusions

Utilisation of Local Materials

- “The art of the engineer consists for a good part in utilising technologies that will make possible the use of materials that he finds in the vicinity of the works”.

- “Force of habit, inadequate specifications and lack of innovation have suppressed the more wide-spread use of innovative technology”

*SADC LVSR Guideline*
The new idea either finds a champion or dies... No ordinary involvement with a new idea provides the energy required to cope with the indifference and resistance that major technological change provokes... Champions of new inventions must display persistence and courage of heroic quality.

Edward Schon, MIT.
“There is nothing more difficult to take in hand, more perilous to conduct or more uncertain in its success, than to take the introduction of a new order of things, because the innovator makes enemies of all those who prospered under the old order, and only lukewarm support from those who would prosper under the new.”

Machiavelli, The Prince (1513)
Thank you