Alternative Materials and Pavement Design Technologies for Low-volume Sealed Roads

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Outline of presentation

- Introduction
- Regional setting
- Planning, appraisal and environment
- Geometric design and road safety
- Pavement design and materials
- Construction and drainage
- Maintenance and road management
- Vision to practice
- Summary/Way forward
Design: Relatively small cost. Influenced by planning phase. Influences construction and maintenance phases.
Pavement design and materials

General

- Materials typically make up 70% of total cost of LVSR
- 90% of problems occurring on LVSRs are materials related
- Overwhelming need to be knowledgeable about use of local materials
- In many respects it is easier to design a pavement for a HVSR than a LVSR – Elton Yoder
Pavement design and materials

Challenge of Using Natural Gravels

- Materials typically make up 70% of total cost of LVSR
- 90% of problems occurring on LVSRs are materials related
- Overwhelming need to be knowledgeable about use of local materials
  - Tend to be variable and moisture sensitive – requires use of appropriate designs, construction techniques and drainage
  - Standard methods of test (e.g. CBR) do not true assessment of performance
  - Conventional specs apply to “ideal” materials and preclude use of many natural gravels
Examples

Materials Options

 Crushed limestone

 As-dug, nodular laterite

 Calcrete
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**Materials and specs**

- Wide range of road building materials in Ghana – laterites, granites, etc.

- Each group has a characteristic range of properties and potential problems which should be taken into account by test methods and specs

- Conventional specs often unnecessarily restrictive and can result in costly failures as well as over-conservative, uneconomic designs

- Specs tied directly to test methods used in carrying out research work – dangerous to mix.

*Traditional specifications for base gravels typically specify a soaked CBR @ 98% MAASHO of 80%, PI of <6 and adherence to a tight grading envelope. However, research in the region has shown that when due consideration is given to factors such as traffic, subgrade strength, drainage, pavement cross-section, etc, substantial relaxations can be made on selection criteria with significant cost savings.*
The grading envelopes for natural gravel bases are too narrow. Alternative (wider) envelopes are recommended for relatively lightly trafficked roads.

The minimum standard of 80 per cent soaked CBR for natural gravel bases is inappropriately high for many LVSRs. New limits are recommended depending on traffic, materials and climate.

Traffic below 300,000 to 500,000 esa was not a significant factor on pavement deterioration. Many road sections performed well even when subjected to a high degree of overloading and with PIs up to 18. New limits for PI are recommended.

Drainage was a significant factor on performance, even in dry areas. A minimum crown height of 0.75 m is recommended.
Pavement design and materials

Output of SADC research work
Many specifications used in Africa (although sometimes modified) have their origins elsewhere. In Europe many specifications have been modified and simplified and concentrate on outputs and outcomes to encourage innovation.
Pavement Design and Materials

Significance of PI?

![Graph showing the relationship between Plasticity Index (%) and Rated Performance]
Plasticity

The plasticity index in many specifications is a critical factor in materials selection. The effect of plasticity on performance differs between materials and depends on both quantity and type of clay minerals present. The potentially adverse impact of clay has been recognised to some extent by the use of plasticity modulus.
Significance of CBR?
Pavement design and materials

**CBR versus stiffness**

![Graph showing the relationship between CBR and Er (MPa)]
The California Bearing Ration (CBR).

- The soaked CBR test is the strength test most used for materials approval for all pavement layers.

- There is very poor correlation between soaked CBR and performance for roads constructed with granular bases. Is it then unsurprising that many roads constructed with (so-called) marginal materials perform far better than expected?
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Alternative to CBR

- Need for alternative to traditional CBR
  - Texas Triaxial? Repeated load triaxial
BS PI and AASHTO PI differ – up to 4 %age points
Max PI = 6 irrespective of test method
CBR is carried out at different compaction efforts using different methods
Wet or dry sieve analysis
Handling of oversize (> 19 mm) – influence on CBR
OMC effort – taken into account
Compaction energy – taken into account?
Soaking – appropriate?
Reproducibility – large!
Using local materials

- Consider materials’ “fitness for purpose”
- Make specification fit materials rather than materials fit specification
### Pavement design and materials

#### Pavement material characteristics

- Material strength derived from combination of:
  - cohesive effects
  - soil suction
  - physio-chemical (stab) forces
  - inter-particle friction

- Material selection influenced by:
  - traffic loading
  - environment
  - material properties (plastic mod)
  - pavement configuration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unprocessed</th>
<th>Processed</th>
<th>Highly processed</th>
<th>Very highly processed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material Types</strong></td>
<td>As-dug gravel</td>
<td>Screened gravel</td>
<td>Crushed rock</td>
<td>Stabilised gravel</td>
</tr>
<tr>
<td><strong>Variability</strong></td>
<td>High</td>
<td>Decreases</td>
<td>Low</td>
<td></td>
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<tr>
<td><strong>Plastic Modulus</strong></td>
<td>High</td>
<td>Decreases</td>
<td>Low</td>
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<tr>
<td><strong>Development of shear strength</strong></td>
<td>Cohesion and suction</td>
<td>Cohesion, suction and some particle interlock.</td>
<td>Particle interlock.</td>
<td>Particle interlock and chemical bonding.</td>
</tr>
<tr>
<td><strong>Susceptibility to moisture</strong></td>
<td>High</td>
<td>Decreases</td>
<td>Low</td>
<td></td>
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<tr>
<td><strong>Design philosophy</strong></td>
<td>Material strength maintained only in a dry state.</td>
<td>Selection criteria reduces volume of moisture sensitive, soft and poorly graded gravels</td>
<td>Material strength maintained even in wetter state.</td>
<td></td>
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<tr>
<td><strong>Appropriate use</strong></td>
<td>Low traffic loading in very dry environment.</td>
<td>Traffic loading increases, environment becomes wetter</td>
<td>High traffic loading in wetter environments.</td>
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<tr>
<td><strong>Cost</strong></td>
<td>Low</td>
<td>Increases</td>
<td>High</td>
<td>High</td>
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<tr>
<td><strong>Maintenance reliability</strong></td>
<td>High</td>
<td>Decreases</td>
<td>Low</td>
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</table>
Pavement Design and materials

In-depth Evaluation of Material Properties
Pavement design and materials

Dry density vs Permeability & Stiffness
Benefits of “Compaction to Refusal”

- Reduction in deflection
- Increase in life
- Pavement Life (E80s)
- Max Annual Deflection (mm)

- Pavement design and materials

deflection/life relationship
Soil Improvement by Stabilisation

<table>
<thead>
<tr>
<th>Particle Size Distribution of Material Being Considered for Stabilisation</th>
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</thead>
<tbody>
<tr>
<td>More than 25% passing 75 μm</td>
</tr>
<tr>
<td>Less than 25% passing 75 μm</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Plasticity Index</th>
<th>PI ≤ 10</th>
<th>10 &lt; PI &lt; 20</th>
<th>20 &lt; PI</th>
<th>PI ≤ 6 % passing 75 μm ≤ 60</th>
<th>PI ≤ 10</th>
<th>10 &lt; PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form of Stabilisation:</td>
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<tr>
<td>Granular</td>
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<tr>
<td>Cement</td>
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<tr>
<td>Lime</td>
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<tr>
<td>Bitumen</td>
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</tbody>
</table>

**Key**
- Usually Suitable
- Doubtful
- Usually Not Suitable
Mechanical Stabilisation
Pavement design and materials

Pavement design

5.4.3 - INPUT VARIABLES
- Construction and Maintenance Factors
- Traffic
- Environmental Factors
- Subgrade Soils
- Pavement Materials
- Pavement Configuration

5.4.4 - DESIGN PROCESS
- External Factors (Chapter 3)
- Structural Design
- Cost Comparisons

5.4.5 - DESIGN OUTPUT
- Selected Design
- Implementation

Pavement design system
Pavement design and materials

Requirements of Pavement

Wheel load

Contact area

Functional

Structural

Load Transfer

Surfacing

Pavement structure

Subgrade
Environmentally Optimised Design
Most design methods used in SADC region cater for relatively high volumes of traffic, typically in excess of 0.5 million ESAs over a 10–15 year design life with attention focused on load-associated distress.

For large proportion of LVRs in the region, carrying < 0.30 million ESAs over their design life, priority attention should be focused on ameliorating effects of the environment, particularly rainfall and temperature, on their performance.
Pavement design and materials

**Pavement design methods**

**Mechanistic-Empirical Methods**
- S-N Method (1993)
- TRH4 (1996)

**Empirical Methods**
- DCP Method

**Country-specific**:
- Zimbabwe Pavement Design Guide (1975)
- South African Provincial Design Guides
Pavement design and materials

**General**

- Existing pavement design methods cater to relatively high volumes of traffic with damaging effect quantified in terms of esa. In contrast, main factors controlling deterioration are dominated by the **local road environment and details of design (drainage), construction and maintenance practice.**

- Local road building materials often “non-standard” compared with temperate climate materials. Disparagingly referred to as “marginal”, “low cost”, etc.

- Conventional specs apply to “ideal” materials

- Standard methods of test do not always give a true assessment of performance of local materials
Pavement design and materials

**Why Good Performance**

- Reduced traffic loading (extended “life”) due to inappropriate damage exponent
- Pavement design thickness based on unduly conservative saturated design
- Stiffer pavement layers than anticipated at design stage
- Inappropriate materials specs
There is evidence from HVS and other pavement performance measurements that pavements with gravel roadbases generally perform differently from that predicted by the 4th power law.

Is this a contributory factor to observations that many gravel road bases perform better than expected despite poor maintenance and overloading?
Pavement design and materials

**Moisture effects**

- Control of moisture is single most important factor controlling performance of LVSRs
- Appropriate pavement configuration is critical for controlling moisture
- Factors to be considered include:
  - shoulders
  - permeability inversion
  - internal, external drainage

![Moisture zones in a LVSR](image)

**Figure 5.11**

Moisture zones in a LVSR
Examples
LVSR Pavements (non-ideal cross-section)
Examples

Effects of Moisture Penetration in Shoulder
Examples

LVSR Pavements (ideal cross-section)

- Crown height is a critical parameter that correlates well with the actual service life of pavements constructed from natural gravels ($d \geq 0.75$ m)
- Sealed shoulders reduce/eliminate lateral moisture penetration under carriageway
- Avoiding permeability inversion facilitates good internal drainage
Examples

Overloading

Axles of evil
Examples

Impact of Overloading on Pavements
Examples

Modern Weighbridge Equipment
Case History
Case history

**Lodwar-Lokichokio Road**

The Lodwar-Lokichokio road looking towards Lokichokio and showing the generally good condition of the pavement albeit with some ravelling of the surfacing.
Case history

Lodwar-Kalokol Road

The Lodwar-Kalokol road looking towards Kalokol and showing the excellent condition of the pavement and surfacing after more than 20 years in service with practically no maintenance.

The double Otta seal surfacing constructed from screened quartzitic gravel obtained from adjacent to the road alignment.
## Pavement design and materials

### Typical specifications

<table>
<thead>
<tr>
<th>Traditional</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>19/9.5 mm max. size double surface treatment</td>
<td>19 mm max. size Otta seal surfacing with sand/crusher dust cover seal</td>
</tr>
<tr>
<td>150 mm crushed stone base compacted to 98% Mod AASHTO</td>
<td>150 mm natural gravel G4 base compacted to refusal (100% Mod. AASHTO)</td>
</tr>
<tr>
<td>150 mm natural gravel G5 subbase compacted to 95% Mod AASHTO</td>
<td>150 mm natural gravel G5 subbase compacted to refusal (100% Mod AASHTO?)</td>
</tr>
<tr>
<td>150 mm natural gravel G6 USSG compacted to 93% Mod AASHTO</td>
<td>150 mm natural gravel G6 USSG compacted to refusal (100% Mod AASHTO?)</td>
</tr>
<tr>
<td>150 mm natural gravel G7 LSSG compacted to 93% Mod AASHTO</td>
<td>150 mm natural gravel G7 LSSG compacted to refusal (100% Mod AASHTO)</td>
</tr>
<tr>
<td>Fill, where necessary, at least G10 compacted to 93% Mod AASHTO</td>
<td>Fill, where necessary, at least G10 compacted to refusal (100% Mod AASHTO)</td>
</tr>
</tbody>
</table>

### Life cycle cost ratio

| 1.0 | 1.3 to 1.5 |
Pavement design and materials

Using local materials

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

Unfortunately, force of habit, inadequate specifications and lack of initiative have suppressed the use of local materials and innovative construction technologies”

→ Consider materials’ “fitness for purpose”

→ Make specification fit materials rather than materials fit specification
Thank you