Alternative Materials and Pavement Design Technologies for Low-Volume Sealed Roads + Case Studies

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Outline of Presentation

- Introduction
- Materials Issues
- Pavement design issues
- Other issues
Pavement design and materials

Pavement structure terms
Examples

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 – require use of appropriate designs, construction techniques and drainage measures
  - Standard methods of test (e.g. CBR) often do not provide true assessment of performance
  - Conventional specs apply to “ideal” materials and preclude use of many natural gravels (grading, plasticity, strength)
- Local road building materials often “non-standard” compared with temperate climate materials. Disparagingly referred to as “marginal”, “low cost”, etc.
- Regional research work has allowed revised specs to be derived for major groups of natural gravel materials found in region.
Examples

Materials Options

Crushed limestone

As-dug, nodular laterite

Laterite

Calcrete
Pavement design and materials

**The challenge**

- 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 of LVRs are dominated by *the local road environment and details of design (drainage), construction and maintenance practice.*

- 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

Materials and specs

- SADC road building materials mostly derived from weathering and pedogenesis

- 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.
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 (“resource based” specs)
Extensive research has been undertaken in the SADC region over the past 20 – 30 years. This has enabled local, “non-standard” materials to be successfully incorporated in appropriate pavement designs for LVSRs.

- 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.*

- The grading envelopes for natural gravel bases are too narrow. *Alternative (wider) envelopes are recommended for relatively lightly trafficked roads.*

- 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

**CBR versus stiffness**

![Graph showing CBR versus stiffness for different materials: PI = 19 (Keuper Marl), PI = 48 (London Clay), PI = 36 (Gault Clay).](image)
### Pavement design and materials

#### Compaction/density/permeability

<table>
<thead>
<tr>
<th>No. of roller passes</th>
<th>Plastic</th>
<th>Elasto-plastic</th>
<th>Elastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>D₂</td>
<td>B</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D₁</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Compaction to refusal**

Graph showing:
- **Density/Sustainability** as a function of **No. of roller passes**
- **Plastic**, **Elasto-plastic**, and **Elastic** regions

Additional graph showing:
- **Permeability cm/sec** vs **Dry Density Mg/m³**
- Data points indicating compaction characteristics
Pavement design and materials

Stiffness versus density

![Graph showing stiffness versus density](image-url)
Pavement design and materials

Benefits of “Compaction to Refusal”

Reduction in deflection

deflection/life relationship

Increase in life

Max Annual Deflection (mm)

Pavement Life (E80s)
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 5.6 – Pavement material categories and relative characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unprocessed</th>
<th>Processed</th>
<th>Highly processed</th>
<th>Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unbound</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bound</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very highly processed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Types</td>
<td>As-dug gravel</td>
<td>Screened gravel</td>
<td>Crushed rock</td>
<td>Stabilised gravel</td>
</tr>
<tr>
<td>Variability</td>
<td>High</td>
<td>Decreas</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Plastic Modulus</td>
<td>High</td>
<td>Decreases</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Development of shear strength</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>Susceptibility to moisture</td>
<td>High</td>
<td>Decreases</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Design philosophy</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>
</tr>
<tr>
<td>Appropriate use</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>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>Increases</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Maintenance reliability</td>
<td>High</td>
<td>Decreases</td>
<td></td>
<td>Low</td>
</tr>
</tbody>
</table>
Pavement design and materials

Shear strength versus soil suction

- Equilibrium moisture content
- Optimum moisture content
- Soaked

Soil strength (CBR)

Soil suction

pF
Pavement design and materials

Pavement design methods

- Should be based on experience, theory structural and material behaviour
- Should take account of local conditions of climate, traffic, available local materials, other environmental factors
- Sub-grade classes: wide enough to take advantage of range of strong subgrades
- Design traffic class: wide enough to cater incrementally for traffic loadings up to 0.5 m esa
- Material classes: wide enough to cater for full range and differing properties of natural gravels
- Materials specs should be based on proven field performance in relation to traffic, subgrade design class, geo-climatic zone, etc
Pavement design and materials

Pavement design system

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 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

Traffic characteristics

- 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

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 movements

Moisture zones in a LVSR
Pavement design and materials

Pavement configuration

- Pavement configuration influenced by materials properties and influence of water on their properties
- Attention to detail in drainage design and construction is essential for optimum performance
- Essential to avoid permeability inversion
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 ($d \geq 0.75 \text{ m}$)
- Sealed shoulders reduce/eliminate lateral moisture penetration under carriageway
- Avoiding permeability inversion facilitates good internal drainage
## Pavement design and materials

### Typical specifications

<table>
<thead>
<tr>
<th><strong>Traditional</strong></th>
<th><strong>New</strong></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** |
## Benefits of Adopting Recommendations

<table>
<thead>
<tr>
<th>Option</th>
<th>Potential Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Replacing a conventional geometric design process by a “design by eye” approach, where appropriate</td>
<td>● Reduced earth works and environmental damage.</td>
</tr>
<tr>
<td>● Use of more appropriate pavement designs and natural gravel rather than crushed stone.</td>
<td>● Reduced pavement costs due to lesser haulage distances and reduced materials processing costs.</td>
</tr>
<tr>
<td>● Utilising an existing gravel wearing course e.g. as base or sub-base.</td>
<td>● Reduced haulage distances and materials costs.</td>
</tr>
<tr>
<td>● Compacting pavement layers to refusal, where feasible, rather than to arbitrary prescribed levels.</td>
<td>● Increased density, reduced road deterioration and increased maintenance intervals.</td>
</tr>
<tr>
<td>● Adopting appropriate surfacing technologies such as sand seals and Otta seals.</td>
<td>● Reduced haulage distances, reduced processing costs.</td>
</tr>
<tr>
<td>● Increasing the use of labour and local resources where appropriate.</td>
<td>● Lower economic/financial costs for specific tasks.</td>
</tr>
<tr>
<td>● Using seals as a spot improvement measure.</td>
<td>● Reduced surfacing costs whilst maintaining year round access.</td>
</tr>
</tbody>
</table>
Pavement design and materials

Life cycle cost analysis

Key:
- PC = Initial Pavement Construction
- RM = Routine Maintenance
- ST = Surface Treatment
- RV = Residual Value
- OV = Overlay

Components of a Life Cycle Costing

Break-even traffic
Traditional vs revised approaches
Pavement Design Philosophy

Maintenance Actions

Moisture Ingress

No Maintenance

(Typically Designed for Traffic Expected over 15 - 20 Years)
Cost of Maintenance Delay

- **3-5 Years**
  - Repair Cost = R 0.1 mill / km

- **5-8 Years**
  - Repair Cost = R 0.6 mill / km
  - Ratio 1:6

- **Road Condition**
  - Good
  - Fair
  - Poor
  - Very Poor

- **Repair Cost = R 1.8 mill / km**
  - Ratio 1:18
Cost of Maintenance Delay

- Repair Cost = R 0.1 mill / km
- Repair Cost = R 0.6 mill / km (Ratio 1:6)
- Repair Cost = R 1.8 mill / km (Ratio 1:18)

Road Condition:
- Good
- Fair
- Poor
- Very Poor
Examples

Impact of Overloading on Pavements
Examples

Impact on Pavements

Pavement performance under legal load limits

Pavement performance under overloading
Examples

Cost of Overloading

- Botswana – 2004: US $2.6 million
- South Africa – 2002: US $100 million
- Sub-Saharan Africa – 2004: US $500 million
Examples

Developments in Overload Control

- Mandatory off-loading of over-loaded vehicles

- **Decriminalisation** of offenses for overloading by handling them administratively and imposing a requirement on the overloader to pay an overloading fee

- Linking level of imposed fees for overloading with actual cost of road damage, i.e. by imposing **economic fees**

- **Outsourcing** weighbridge operations to the private sector on a concession basis, i.e. embarking on a commercialised public/private sector approach to overload control
Examples
Modern Weighbridge Equipment
Examples

Environmental issues – borrow pits

- Children exposed to risk of drowning and poor quality water
- Ponding increases level of mosquito-borne disease

Introduction of Technical Audits at Feasibility Stage

Typical, un-renovated borrow-pit in the SADC region
Examples

Environmental issues – borrow pit restoration

Before

After
The Final Result – A Meeting of Minds
The successful engineering of a low volume sealed road requires ingenuity, imagination and innovation. It entails “working with nature” and using locally available, non-standard materials and other resources in an optimal and environmentally sustainable manner.

It will rely on planning, design, construction and maintenance techniques that maximize the involvement of local communities and contractors.

When properly engineered to an appropriate standard, a LVSR will reduce transport costs and facilitate socio-economic growth and development and reduce poverty in the SADC region.
Finally – Our Vision

“It is not wealth which makes good roads possible – but, rather, good roads which make wealth possible
– Adam Smith
Thank you