Design of Low Volume Roads

AFCAP Workshop on Rural Accessibility and Mobility

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AFCAP Consultant
Outline of Presentation

- General Introduction
- Engineered Earth Roads
- Gravel Roads
- Low Volume Sealed Roads
- Performance Review of Malawi Low Volume Sealed Roads
- DCP Method of Pavement Design
Typical Means of Transport in Rural Areas
Lack of Reliable Access

Adverse impact on mobility
Short sections of road in poor condition can benefit significantly from spot improvement works – attention to drainage.
Rural Economic and Social development in Africa needs commercial, educational, health and infrastructure initiatives that rely on **GOOD PERMANENT ACCESS.**

Unfortunately, **poor access** for millions in rural communities limits the effectiveness of these initiatives, because of:

- unreliable travel or impassability, especially in the rains,
- high unit transport costs for goods, services & people.

**Investment is discouraged by poor access.**

**Critical need to provide more reliable access in a more sustainable and affordable manner.**
Many kinds of low volume roads serving different functions – may be primary, secondary or tertiary/access and may fulfill an access or mobility function.

One characteristic in general – they all carry relatively low volumes of traffic – typically less than 200 vpd or 1.0 MESA
Main components of LVSR provision

Influence level of LVSR components on total cost

Figure 8.1 – Stages in the pathway to implementation
Targeted Intervention Approach

Environmentally optimised, context sensitive design
“The art of the roads engineer consists for a good part in utilising appropriate 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
Most design methods cater for relatively high volumes of traffic, typically > of 0.5 MESA over a 10–15 year design life with attention focused on load-associated distress.

Most LVRs carry < 0.50 million ESAs over their design life so priority attention should be focused on ameliorating effects of the environment, particularly rainfall and temperature, on their performance.
The successful engineering of a low volume road (earth, gravel, sealed) 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 LVR will reduce transport costs and facilitate socio-economic growth and development and reduce poverty in the African region.
Upgrading steps of a typical LVR

- Unformed Natural Soil
- Formed Natural Soil
- Minor Gravel Road
- Major Gravel Road
- Sealed Road

Increasing demand, Traffic and Level of Service

Increasing Cost, Maintenance Demand, Skill Level and Equipment
Fundamental Principle of Road Design

Wheel load transfer through pavement structure
Pavement design process must be fully responsive to the road environment
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Types of Earth Roads

Unformed

Formed

Engineered Natural Surface (ENS)
Manual excavation of side ditch material to form ENS camber (prior to spreading and compaction)
Formation of Earth Roads

Typically consist of excavated, in situ material from alongside alignment which is shaped to form a camber that is raised above ground level and includes side drains.
Performance of Earth Roads

Performance depends on:

- Soil properties
- Rainfall (amount and intensity)
- Traffic (type, volume and tyre pressure)
- Longitudinal gradient
- Quality of drainage
- Level of water table

No formalised design method – too many variables that interact in a complex manner.
Relationship between load, repetition, tyre pressure and CBR for unsurfaced roads


**Construction of Earth Roads**

Wrong

Earth from roadway and ditch

Water from ditch and surrounding country draining on to road

Right

Earth bladed from side drains

Properly maintained earth track
Maintenance of Earth Roads
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Major gravel roads in which the existing road may be eventually upgraded to a bituminous standard. This typically applies to roads which have a design AADT between 25-200.

- The subgrade materials should comply with the requirements of a low volume sealed road.

- Only the wearing course would need replacement at intervals related to the expected annual gravel loss, and Geometry and drainage are upgraded to acceptable minimum levels during construction.
**Approach to Gravel Road Design**

*Thickness Design - Major Gravel Roads - AADT 25 – 300*

The required gravel thickness, \( D \), shall be determined as follows:

1. Determine the minimum subbase gravel thickness necessary to avoid excessive compressive strain in the subgrade \( (D_1) \). *(Design catalogue)*

2. Determine the extra wearing course (WC) thickness \( (D_2) \) needed to compensate for the annual gravel loss (GL) under traffic during the period between regravelling operations \( (N) \). Thus \( D_2 = N \times GL \).

3. Determine the total gravel thickness, \( D \), by adding the above two thicknesses \( D = (D_1 + D_2) = D_1 + N \times GL \).
### Catalogue for major gravel roads – strong gravel (G45)

<table>
<thead>
<tr>
<th>Subgrade Strength Class CBR (%)</th>
<th>Traffic Classes (esa x 10⁶)</th>
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<tbody>
<tr>
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<td>S2 (3-4)</td>
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<td>S3 (5-7)</td>
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<td>S4 (8-14)</td>
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<td>S5 (15-29)</td>
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### Catalogue for major gravel roads – medium gravel (G30)

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<tr>
<td>S2 (3-4)</td>
<td>175</td>
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<td>S3 (5-7)</td>
<td>150</td>
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<td>S4 (8-14)</td>
<td>125</td>
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<td>S5 (15-29)</td>
<td>100</td>
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## Catalogue for major gravel roads – weak gravel (G15)

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<th>Subgrade Strength Class</th>
<th>CBR (%)</th>
<th>Traffic Classes (esa x 10^6)</th>
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<th>0.01-0.1</th>
<th>0.1-0.3</th>
<th>0.3-0.5</th>
<th>0.5-1.0</th>
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<td>225</td>
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<td>S3 (5-7)</td>
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<td></td>
<td>200</td>
<td>250</td>
<td>325</td>
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<td>NA</td>
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<tr>
<td>S3 (5-7)</td>
<td></td>
<td></td>
<td>200</td>
<td>250</td>
<td>325</td>
<td>350</td>
<td>NA</td>
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<tr>
<td>S5 (15-29)</td>
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<td>150(1)</td>
<td>150(1)</td>
<td>200(1)</td>
<td>200(1)</td>
<td>NA</td>
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</table>
Approach to Gravel Road Design

Typical gravel road x-section in flat terrain

<table>
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<tr>
<th>Road Class</th>
<th>Climate</th>
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<tr>
<td></td>
<td>Wet (N &lt; 4)</td>
<td>Dry (N &gt; 4)</td>
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<tr>
<td></td>
<td>$h_{\text{min}}$ (mm)</td>
<td>$h_{\text{min}}$ (mm)</td>
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<tr>
<td>DC-1</td>
<td>350</td>
<td>250</td>
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<td>DC-2</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td>DC-3</td>
<td>450</td>
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<tr>
<td>DC-4</td>
<td>500</td>
<td>400</td>
</tr>
</tbody>
</table>

Required min height ($h_{\text{min}}$) between road crown and invert level of drain in relation to climate.
Desirable Material Characteristics

- Skid resistance
- Smooth riding characteristics
- Cohesive properties
- Resistance to ravelling and scouring
- Wet and dry stability
- Low permeability
- Load spreading ability
Material quality zones
Reducing Oversize

Grid roller

Rock buster
Blending of Materials

Ternary diagram for blending gravel materials
**Approach to Gravel Road Design**

**Minor gravel roads** - existing road unlikely in the foreseeable future to be upgraded to a bituminous standard (AADT typically < 25 vpd)

- The subgrade materials should not necessarily comply with the requirements of a low volume sealed road.

- The full thickness of wearing course may not necessarily be provided initially with the remainder being provided at a later date.

- Drainage, but not necessarily geometry, is upgraded to acceptable minimum levels during construction.
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Limitations of Gravel Roads

Traditionally Gravel is used for rural access roads. However:

- They are low (initial) cost and relatively easy to construct
- They are expensive to maintain – typically US$1,600/year
- Each Km of gravel road typically loses more than 70 cubic metres of material EACH YEAR
- A range of constraints means that maintenance is rarely carried out, leading to impassability, or the need to repeatedly regravel.

..........SENSIBLE?? NO!!!
Limitations of Gravel Roads (Cont’d)

- Gravel quality is poor
- Haul distances are long
- Rainfall is very high or dry season dust problems
- Traffic levels are high
- Longitudinal gradients > 6%
- Adequate maintenance cannot be provided
- Subgrade is weak or soaked
- Gravel deposits are limited/environmentally sensitive
Why low volume sealed roads?

Unpaved roads: Require continuous use of a non-renewable resource – gravel. This is inherently unsustainable and environmentally damaging. Is this sustainable? NO!

Unpaved roads: Dusty, health hazard, pedestrian/vehicle safety; crop, natural habitat and vehicle damage. Is this sustainable? NO!

Approx. 175 million cu.m “consumed” annually in SADC region for gravelling purposes.
Gravel roads deteriorate rapidly if not maintained by timely grading and regravelling.
There is an ‘unhealthy’ and unsustainable reliance on gravel roads to solve the all-weather access problems of many countries.

Window of opportunity for using gravel is slowly closing. Need for alternative, more sustainable solutions.

A new approach is required, using a ‘menu’ of more durable, low cost, local-resource-based surfaces, using gravel only where appropriate.

These techniques are ideal for use by SMEs.
Sealed Road Challenge

- Not possible to upgrade all unsealed roads

- However, many thousands of km of rural access roads carrying light traffic that could be justifiably upgraded using “low-cost” seals coupled with appropriate standards and specs.
Life-Cycle Costs: Gravel vs LVSR

In many cases $\text{NPV}_B < \text{NPV}_A$
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Motivation for Project

- Malawi public road network – 15,451km
  - Unpaved - 75%
  - Additional but not classified (unpaved) – 9,500km
  - Characteristics of unpaved roads
    - Seasonal accessibility problems
    - Longer travel times
    - High VOC
    - High maintenance cost
    - Depletion of non-renewable resource (gravel)-unsustainable
    - Environmentally unfriendly
Motivation for Project

Why paved roads?

- Cheaper in terms of both
  - Recurrent maintenance cost
  - Life cycle cost
- More sustainable than unpaved roads
- Stimulate social and economic growth

BUT initial capital investment cost relatively high using traditional standards and specs

Are there not alternative ways of providing paved roads?

YES!! BASED ON A LOW VOLUME/LIGHTLY TRAFFIC SEALED ROADS APPROACH TAKING ACCOUNT OF PERFORMANCE BASED ON RESEARCH CARRIED OUT IN MALAWI AND OTHER COUNTRIES IN SOUTHERN AFRICA
Motivation for Project

- LVSRs in Malawi date back to more than 20 years
  - No proper records in place – need for quantification
  - Discovered through rehabilitation works

- Recent LVSRs – a total of about 20km constructed
  - Have taken advantage
    - Old age of existing earth roads (>20 years) – CONSOLIDATED PAVEMENTS
    - Reasonably engineered alignments
  - Simplistic approach adopted
    - Grade/rehabilitate without affecting the existing pavement and alignment – varying widths for different roads
    - Place gravel (even “marginal” with CBR\(_s\) +/- 50%) compacted to 98% MDD
    - Surface (Cape seal)
    - Use of simplified bidding documentation
After 20 years in use – 6.5m wide and little maintenance
Example of Long-Standing LVSR – Nyika National Park

After 15 years in service: 4m wide and little maintenance
Example of Malawi LVSR – Dowa Road

After 6 years in service – 4m wide and little maintenance
Example of Malawi LVSR – Ntchisi Road

After 9 years in service – 5m wide, little maintenance, excellent condition
Motivation for Project

- NRA needs design standards and specs that are appropriate to LVRs which should reflect historical experience and be acceptable to political decision makers, local consultants and contractors.

  - Requested AFCAP to assist with a Performance Review of Design Standards and Technical Specs used on Low Volume Sealed roads in Malawi.

- Project expected to contribute to greater awareness of need for appropriate design standards for LVRs and benefits to local economy.

- Intention is to gain support amongst key decision makers for a subsequent project to develop an official design manual and standard specs for construction of LVRS.
## Location of Road Sections Investigated

<table>
<thead>
<tr>
<th>Description</th>
<th>Typical Mean Annual Rainfall</th>
<th>Weinert N Value</th>
<th>Thornthwaite Moisture index (I_m)</th>
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</thead>
<tbody>
<tr>
<td>Arid</td>
<td>&lt; 250mm</td>
<td>5+</td>
<td>&lt; -40</td>
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<tr>
<td>Semi-arid</td>
<td>250 - 500mm</td>
<td>4 – 5</td>
<td>-20 to -40</td>
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<tr>
<td>Semi-arid to sub-tropical</td>
<td>500 - 1000</td>
<td>2 – 4</td>
<td>0 to +20</td>
</tr>
<tr>
<td>Humid tropical</td>
<td>&gt; 1000mm</td>
<td>&lt; 2</td>
<td>+20 to +100</td>
</tr>
</tbody>
</table>

![Map of Mean Annual Rainfall Malawi](image)

- Arid: < 250mm
- Semi-arid: 250 - 500mm
- Semi-arid to sub-tropical: 500 - 1000mm
- Humid tropical: > 1000mm
Overall Scoping of Project

Stage 1
- Preliminary Activities
  - Stakeholder sensitisation meetings
  - Desk study of historical projects
  - Field visits to select sites
  - Development of field investigation and laboratory testing programme
  - Establishment of investigation procedures
  - Determination of traffic loading

Inception Report

Stage 2
- Field Investigations
  - Visual condition
  - Side drainage
  - Rut measurements
  - DCP measurements
  - IDD and in situ MC measurements
  - Bulk sampling for lab testing

Preliminary Fieldwork Report

Stage 3
- Laboratory Testing
  - Classification
    - grading
    - Atterberg Limits
    - Linear shrinkage
  - Compaction
    - MDD/OMC
  - Strength
    - CBR (soaked, OMC, 0.75 OMC)

Final Fieldwork Report

Stage 4
- Analysis and Reporting
  - Analysis of results
  - Recommendations for LVSRs
  - standards and specifications

Final Project Report
Overview of Field and Lab Testing

Notes:
1. Testing to be undertaken in one lane only (more heavily trafficked lane)
2. 3 No. IDDs and 3 No. moisture contents to be taken in each test pit in each pavement layer
3. Outermost DCP measurements to be 50 cms from edge of surfacing
4. DCP penetration to 800 mm
5. Rut depths with 2 m straight edge in inner wheel path (IWP) and outer wheel path (OWP)
Overview of Field Investigations

IDD testing by sand replacement method

Sampling of base course material
Overview of Field Investigations

Pavement profile showing base (+/- 150mm) and subbase/ subgrade layers
Results: CBR at Varying MC and Density

CBR at varying MC and % Compaction

0.75 OMC

OMC

Soaked

% BS Heavy Compaction

CBR (%) Soaked

OMC

Soaked
## Results: Classification Tests

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<tr>
<th>Road Section</th>
<th>Pavement Layer</th>
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<th>Max. PI</th>
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</table>

Results generally are non-compliant with traditional (ORN 31) specifications
### Results: Field MC/Optimum MC Ratio

<table>
<thead>
<tr>
<th>Road Section</th>
<th>Pavement Layer</th>
<th>Relative Compaction (%)</th>
<th>Location</th>
<th>FMC/OMC</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Location</td>
<td>Wet Season</td>
<td>Dry Season</td>
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<tr>
<td>Ntchisi (School)</td>
<td>Base SB/SG</td>
<td>96.7 94.4</td>
<td>OWP</td>
<td>0.76 0.27?</td>
<td>0.62 0.91</td>
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<tr>
<td></td>
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<td>IWP</td>
<td>1.02 0.79</td>
<td>0.91 1.07</td>
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<td>97.3 98.9</td>
<td>OWP</td>
<td>- -</td>
<td>0.94 1.05</td>
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<td>IWP</td>
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<td>0.95 1.10</td>
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<td>Ntchisi (Standard)</td>
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<td>96.6 99.8 90.3</td>
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<td>96.3 93.3</td>
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<td>IWP</td>
<td>0.95 0.84</td>
<td>0.71 0.74</td>
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</table>
## DCP Results

### Pavement Type (DCP Category)

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Deep</th>
<th>Shallow</th>
<th>Inverted</th>
</tr>
</thead>
</table>

### Road Section Details

<table>
<thead>
<tr>
<th>Road Section</th>
<th>DSN&lt;sub&gt;800&lt;/sub&gt;</th>
<th>Pavement Balance</th>
<th>Ave DCP CBR</th>
<th>80%ile minimum DN</th>
<th>Est.Traffic (MESA)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0-150 mm</td>
<td>150-800mm</td>
<td>0-150mm 150-800mm</td>
</tr>
<tr>
<td>Ntchisi</td>
<td>94</td>
<td>ABD</td>
<td>45</td>
<td>20</td>
<td>9.2     22.2</td>
</tr>
<tr>
<td>Dowa</td>
<td>129</td>
<td>WBD</td>
<td>47</td>
<td>30</td>
<td>9.0     14.0</td>
</tr>
<tr>
<td>Rumphi</td>
<td>272</td>
<td>ABI</td>
<td>123</td>
<td>57</td>
<td>6.0     7.8</td>
</tr>
<tr>
<td>C. Maclear</td>
<td>174</td>
<td>WBD</td>
<td>97</td>
<td>28</td>
<td>5.0     11.6</td>
</tr>
</tbody>
</table>
Road Drainage - Variable

Brick-lined drain on longitudinal gradient of peri-urban section of the Ntchisi (school) road. Example of Satisfactory drainage

Poorly drained section of the Ntchisi (school) road. Example of poor drainage.
Functional Performance - Excellent!

Photo: Ntchisi road (school) - constructed in 2002
Condition: Good/sound

Photo: Dowa road – constructed in 2004
Condition: Good/sound
### Pavement Structure Comparisons

<table>
<thead>
<tr>
<th>Bituminous surface treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base: 150mm natural gravel</td>
</tr>
<tr>
<td>CBR &gt;80% soaked @ 98% MDD</td>
</tr>
<tr>
<td>PI &lt; 6</td>
</tr>
<tr>
<td>Grading envelope: Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subbase: 150mm natural gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR &gt; 30% (at emc) @95% MDD</td>
</tr>
<tr>
<td>PI: 6-20 (climate dependent)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subgrade: 150mm natural gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR: &gt; 15% (at emc) @ 93% MDD</td>
</tr>
<tr>
<td>PI: N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In situ material</th>
</tr>
</thead>
</table>

### Typical traditional 3-layer pavement structure (left) and 2-layer LVR structure (right)

- **Base**: 150mm natural gravel
- **CBR >80% soaked @ 98% MDD**
- **PI < 6**
- **Grading envelope: Yes**

- **Subbase**: 150mm natural gravel
  - **CBR > 30% (at emc) @95% MDD**
  - **PI: 6-20 (climate dependent)**

- **Subgrade**: 150mm natural gravel
  - **CBR: > 15% (at emc) @ 93% MDD**
  - **PI: N/A**

- **In situ material**

- **Subbase/subgrade (original surface)**
  - **CBR > 30% at EMC after proof rolling**
  - **PI: N/S**

- **In situ subgrade material**

**Typical 2-layer LVR pavement structure**: Ntchisi (school) road
Technical and Construction Cost Comparisons

LVR construction

Standard construction
## Cost Comparison
**LVSR versus Standard Construction**

<table>
<thead>
<tr>
<th>Road Design Standard</th>
<th>Construction Cost (US$)</th>
<th>Cost Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVR</td>
<td>150,000</td>
<td>-</td>
</tr>
<tr>
<td>Class I</td>
<td>300,000</td>
<td>100</td>
</tr>
<tr>
<td>Class II</td>
<td>500,000</td>
<td>233</td>
</tr>
</tbody>
</table>
Key Requirements for Good Performance

- Moisture control through effective drainage
  - Sealing shoulders
  - Meeting minimum Drainage Factor

- Retention of existing, traffic-consolidated and moulded pavement structure as much as possible
  - Benefit of deep, well-balanced pavement less prone to overloading

- Compacting base materials to “refusal” with heaviest plant available
  - Reduces permeability and susceptibility to moisture ingress
  - Increases pavement life

- Tightly controlled construction quality

- Effective overload control
Effective Drainage

- Sealed shoulders reduce/eliminate lateral moisture penetration under carriageway.

**Drainage Factor (DF)**

\[ DF = d \times h \]

<table>
<thead>
<tr>
<th>Drainage Factor DF</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2.5</td>
<td>Very poor</td>
</tr>
<tr>
<td>2.6 – 5.0</td>
<td>Poor</td>
</tr>
<tr>
<td>5.1 – 7.5</td>
<td>Moderate</td>
</tr>
<tr>
<td>&gt;7.5 or free draining</td>
<td>Good</td>
</tr>
</tbody>
</table>

Example of a well-drained pavement (DF > 7.5)
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

Figure 5.11: Moisture zones in a LVSR
Benefits of Compaction to “Refusal”

Compaction to “refusal”

Level of compaction in pavement layers influences pavement life – increasing compactive effort is generally economically justified
Outline of Presentation

- General Introduction
- Engineered Earth Roads
- Gravel Roads
- Low Volume Sealed Roads
- Performance Review of Malawi Low Volume Sealed Roads
- DCP Method of Pavement Design
Numerous pavement design methods used in practice

- CBR cover curve
- AASHTO structural number
- Mechanistic-empirical

Catalogue
  - Lab CBR based (e.g. TRL ORN 31, TRL/SADC, TRH 4)
  - DCP based (e.g. Kleyn et al)
    - easiest design method to use
    - theoretical work already undertaken
    - different structures presented in catalogue form for various combinations of traffic loading and subgrade conditions
TRL/SADC Lab CBR-based Design Method

Bituminous surfacing
Base, CBR 80
Base, CBR 65
Base, CBR 55
Base, CBR 45
Gravel wearing course quality
Sub-base, CBR 30
Selected subgrade fill, CBR 15

S2 = 3-4
S3 = 5-7
S4 = 8-14
S5 = 15-29
S6 = 30+

Pavement Catalogue N < 4

Traffic Classes (ESA x 10^6)

<table>
<thead>
<tr>
<th>S2</th>
<th>S2'</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.01</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>0.05</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>0.1</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>0.3</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>0.5</td>
<td>175</td>
<td>175</td>
<td>175</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>1</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>
CBR Test method vs performance

![Graph showing CBR Test method vs performance with different types of clay and their PI values.](image)
Overview of Presentation

- Malawi LVSR Project
  - Motivation for the project
  - Investigations Carried Out
  - Findings and Conclusions

- Pavement Design Methods
  - Lab CBR-based methods
  - DCP based method
    - Application to Upgrading Low Volume Roads
Dynamic Cone Penetrometer (DCP)

The Dynamic Cone Penetrometer
DCP Test and Output

DCP test in process

Typical DCP plot
Advantages of DCP

- Low cost
- Robust
- Quick and easy (many tests)
- Non-destructive (almost)
- Tests in situ condition (density, moisture, stress conditions) to a depth of 800 mm

Disadvantages of DCP

- Affected by stones
- Affected by poor testing technique
- More than one variable (density, moisture, material type)
- Outweighed by advantages
Initially, correlation models developed for both natural and stabilized materials based on comparative field DCP and lab CBR results.

Subsequent DCP testing carried out in conjunction with Heavy Vehicle Simulator (HVS) testing of various roads and allowed further correlations:
- between actual road performance and DCP results
- between cone penetration rate (DN) and CBR (%) and UCS (kPa)
DCP – CBR Relationship

![Graph showing the relationship between DCP and CBR values.]
If DN > 2 mm/blow
\[ CBR = 410 \times DN - 1.27 \]
(or Log CBR = 2.61 – 1.27 log (DN))

If DN < 2 mm/blow
\[ CBR = (66.66 \times DN^2) - (330 \times DN) + 563.33 \]

UCS = 2900 \times DN - 1.09
or UCS = 15 \times CBR^{0.88}
Moisture content at time of testing is extremely important.

Correlations have been developed for making a general correction:

- Ignore density and material type
<table>
<thead>
<tr>
<th>Material Classification</th>
<th>Soaked CBR (%)</th>
<th>Approximate Field DCP-CBR: Unsealed Road</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Subgrade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wet Climate</td>
</tr>
<tr>
<td>G4 (80)</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>G5 (45)</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>G6 (25)</td>
<td>25</td>
<td>59</td>
</tr>
<tr>
<td>G7 (15)</td>
<td>15</td>
<td>45</td>
</tr>
<tr>
<td>G8 (10)</td>
<td>10</td>
<td>38</td>
</tr>
<tr>
<td>G9 (7)</td>
<td>7</td>
<td>33</td>
</tr>
<tr>
<td>G10 (3)</td>
<td>3</td>
<td>20</td>
</tr>
</tbody>
</table>

Note: Moisture contents expressed as ratios of in situ Mod AASHTO OMC as follows: Very dry=0.25; Dry=0.5; Moderate=0.75; Damp=1.0
**Pavement Design Methods**

- **DCP design method**
  - Based on comprehensive method of designing lightly trafficked roads using DCP
  - Provides a light, well-balanced pavement structure for specific design traffic categories summarised in a catalogue
  - Design strength profile integrated with in situ soil strength and strength profile to optimally utilise in situ material strength
DCP Profile: Field data vs Design Curve

Field data plots to right of design curve = inadequate strength.
Pavement structure with adequate strength for lightly trafficked (< 0.2 M esa)

Pavement structure with insufficient structural strength in upper 300mm for medium traffic (0.2 – 0.8M esa)
Design follows conventional procedure

- Determine design traffic
- Undertake DCP survey
  - DCP penetration to 800mm or refusal
  - Adjust DCP spacing in relation to variability
  - Assess moisture conditions
  - Identify uniform sections (use “cumulative sum” technique)
- Analyse data in DCP programme
- Pavement Design
  - Fit pavement structure to in situ conditions on each uniform section
- Carry out design refinement
Define design period
Define design traffic
Identify design class
Define pavement structure (from catalogue)
DCP survey (identify uniform sections)
Compare existing structure with catalogue

Flow diagram of design process

Similar
Shape & surface

Dissimilar
Rework & re-compact
Replace
Augment thickness
### DCP Uniform Sections

<table>
<thead>
<tr>
<th>Chainage [km]</th>
<th>Rutting measured [mm]</th>
<th>Difference from average (A - B)</th>
<th>CUSUM (Accumulated values of C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
<td>-1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>-0.2</td>
<td>-1.4</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>-2.2</td>
<td>-3.6</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>-1.2</td>
<td>-4.8</td>
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<td>5</td>
<td>13</td>
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<td>7</td>
<td>7</td>
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<td>-0.4</td>
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<td>9</td>
<td>3.8</td>
<td>-3.4</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
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<td>13</td>
<td>-0.2</td>
<td>8.0</td>
</tr>
<tr>
<td>11</td>
<td>15</td>
<td>-2.2</td>
<td>-6.2</td>
</tr>
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<td>18</td>
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<td>-0.8</td>
</tr>
<tr>
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<td>14</td>
<td>-1.2</td>
<td>-0.6</td>
</tr>
<tr>
<td>14</td>
<td>16</td>
<td>-3.2</td>
<td>-3.8</td>
</tr>
<tr>
<td>15</td>
<td>14</td>
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<td>16</td>
<td>14</td>
<td>-1.2</td>
<td>-6.2</td>
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<td>17</td>
<td>15</td>
<td>-2.2</td>
<td>-8.4</td>
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<tr>
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<td>-5.2</td>
<td>-13.6</td>
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<td>19</td>
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<td>-1.2</td>
<td>-14.8</td>
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<tr>
<td>20</td>
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<td>21</td>
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<td>9</td>
<td>3.8</td>
<td>-6.6</td>
</tr>
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<td>24</td>
<td>12</td>
<td>0.8</td>
<td>-6.6</td>
</tr>
<tr>
<td>25</td>
<td>9</td>
<td>3.8</td>
<td>-5.8</td>
</tr>
<tr>
<td>26</td>
<td>11</td>
<td>1.8</td>
<td>-5.8</td>
</tr>
</tbody>
</table>

**Average:** \( A = 12.8 \)

### Plotting of CUSUM against Chainage

**Homogenous sections**

**Interpretation of data:**
A change of slope indicates change of conditions along the data. Four distinct homogenous sections can be seen in the above chart.
Example of Cumulative Sum plot of DCP strengths between 0 and 150 mm depth.
<table>
<thead>
<tr>
<th>Pavement Class</th>
<th>LV 0.01 0.003 – 0.010</th>
<th>LV 0.03 0.010 – 0.030</th>
<th>LV 0.1 0.030 – 0.100</th>
<th>LV 0.3 0.100 – 0.300</th>
<th>LV 1.0 0.300 – 1.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base 150 mm ≥ 98% BSH</td>
<td>DN ≤ 8</td>
<td>DN ≤ 5</td>
<td>DN ≤ 4</td>
<td>DN ≤ 3.2</td>
<td>DN ≤ 2.5</td>
</tr>
<tr>
<td>Subbase 150 mm ≥ 95% BSH</td>
<td>DN ≤ 19</td>
<td>DN ≤ 14</td>
<td>DN ≤ 9</td>
<td>DN ≤ 6</td>
<td>DN ≤ 3.5</td>
</tr>
<tr>
<td>Selected 150 mm ≥ 93% BSH</td>
<td>DN ≤ 33</td>
<td>DN ≤ 25</td>
<td>DN ≤ 19</td>
<td>DN ≤ 12</td>
<td>DN ≤ 6</td>
</tr>
</tbody>
</table>

DCP design curves for various design traffic classes
Required DCP strength profile for different traffic categories
Conclusions

- Analysis of DCP data from unpaved sections indicate that the DCP design relatively closely predicts performance.
- Validity of back-analysis depends strongly on accuracy of traffic counts and moisture conditions assumed at time of DCP survey.
- DCP can provide all the necessary inputs for low volume road pavement design e.g. layer thicknesses, strengths, seasonal moisture changes, but:
  - Need to understand the interactions
  - Apply engineering judgement and experience
Summary

- Make use of the in situ structure as far as possible
- Existing gravel road has been compacted by traffic

DO NOT DISTURB UNNECESSARILY!!
Very difficult to make progress without making change
Research shows that when 20 – 25% of a target population has adopted a new paradigm, the whole process becomes self-sustaining.
The End!
Thanks you for your attention