A Simple Empirical Guide to Low-Volume Road Pavement Design in Indiana

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Purdue University
Acknowledgment

- Indiana Local Technical Assistance Program
- Co-authors
  - Karim A. Abdel Warith
  - Panagiotis Ch. Anastasopoulos
  - Joseph C. Siedel
## Low-Volume Road

<table>
<thead>
<tr>
<th>Organization</th>
<th>Criteria</th>
</tr>
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<tbody>
<tr>
<td>FHWA</td>
<td>ADT&lt;500</td>
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<tr>
<td>AASHTO</td>
<td>50,000&lt;ESAL&lt;1,000,000</td>
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<td>ESAL&lt;10,000</td>
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<td>Washington DOT</td>
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Low-volume roads are important to the nation’s transportation infrastructure
Many local agencies have no pavement design expertise
Local agencies have little or no pavement data acquisition and materials testing capabilities
Objective

- Develop empirical low-volume road design method
  - Minimal input requirements
  - Simple to use
  - Account for weather and subgrade conditions
<table>
<thead>
<tr>
<th>Procedure</th>
<th>ESAL</th>
<th>ADT</th>
<th>Index</th>
<th>Design Period</th>
<th>Growth</th>
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<td>Available</td>
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</table>
USACE Design Procedure

- Three main pavement categories
  - Unsurfaced roads (natural soil)
  - Aggregate surface
  - Bituminous pavements
- Three basic steps
  - Class designation-based on daily traffic
  - Design category-based on traffic composition
  - Design index-based on class and design category
- Determine required thickness over given CBR
NCSA Design Method

- Required inputs
  - CBR-measured or estimated
  - Design index-based on traffic (average ESAL per lane per day over 20 years)
- Design charts
Proposed Design Method

- Based on NSCA and USACE methods
- Assumptions
  - 1,000 vpd or less
  - Life expectancy 15-20 years, regular maintenance
  - All trucks have 3 or more axles (all expected to be tandem axles, except for steering axle)
  - Pickup trucks and light duty vehicles not considered as trucks, considered as general traffic
  - Frost depth per USACE frost zone map
Frost Zone Map

Zone D  (20 in. frost depth)
Zone C  (10 in. frost depth)
Zone B  (5 in. frost depth)
Zone A  (0 in. frost depth)
Proposed Design Method

- Assumptions-continued
  - Subgrade strength given in either CBR or DCP (in./blow) values
  - DCP values can be converted to CBR according to ASTM D6951
Subgrade Strength

- **Weak**
  - CBR<6%, DCP>1.34 in./blow
- **Medium**
  - CBR of 6-10%, DCP of 0.83-1.34 in./blow
- **Strong**
  - CBR of 10-15%, DCP of 0.55-0.83 in./blow
- **High strength**
  - CBR>15%, DCP<0.55 in./blow
Pavement in a frost zone
- Poor/weak-clay gravels, plastic sand clays, silts, silty sand, silty clay
- Medium-sand, sandy clays, silty gravel
- High-gravely soils
Traffic Data

- Traffic
  - Low (less than 70 vpd)
  - Medium (70-200 vpd)
  - High (201-1,000 vpd)
- Truck percentages
  - Less than 1 percent
  - Between 1 and 10 percent
  - Greater than 10 percent
## Pavement Design Index

<table>
<thead>
<tr>
<th>Traffic Volume (vpd)</th>
<th>Percent Trucks</th>
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<tr>
<td></td>
<td>&lt;1</td>
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<td>70-200</td>
<td>1</td>
</tr>
<tr>
<td>201-1,000</td>
<td>2</td>
</tr>
</tbody>
</table>
Pavement Design Index

- Less than 70 vehicles per day
  - Truck percentage: Any
    - Design Index: 1 (Go to Figure 5)
Pavement Design Index

70-200 vehicles per day

- Truck percentage: less than 1%
  - Design Index: 1 (Go to Figure 5)

- Truck percentage: 1-10%
  - Design Index: 2 (Go to Figure 6)

- Truck percentage: greater than 10%
  - Design Index: 3 (Go to Figure 7)
Pavement Design Index

201-10,000 vehicles per day

- Truck percentage: less than 1%
  - Design Index: 2 (Go to Figure 6)

- Truck percentage: 1-10%
  - Design Index: 3 (Go to Figure 7)

- Truck percentage: greater than 10%
  - Design Index: 4 (Go to Figure 8)
Design Example

- 400 vpd, 4% trucks
- Frost zone B
- Medium strength soil

Results in a design index of 3
Design Example

Aggregate Road Option

- 4 in. wearing course
- 6 in. subbase
- 8 in. clean soil filter
- 10 in. compacted soil
- using crushed stone

Flexible Road Option

- 3 in. asphalt surface course
- 11 in. base
Method Summary

- Minimal inputs
  - Traffic count and truck percentage
  - Subgrade strength
  - Frost zone (location)
- Simple
- Accounts for weather and subgrade conditions
- Design for aggregate surfaced or bituminous surfaced roads
- Allows for timely design
Thank You!
Evaluation of Various Asphalt Pavement Holding Strategies

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Iowa State University
September 6, 2016
Objective(s)
- Evaluate the cost-effectiveness of various pavement preservation technologies.
- Develop pavement holding strategies for low-volume roads.

Methodology
- Construct test sections and monitor the material physical properties and pavement performance.
- Employ performance evaluation and life-cycle-cost-analysis.
Test Sections

- 10 different combinations of base and surface treatments.
- Total project length = 13.6 miles
- Project started in June 2013 and commenced in September.
Challenging Issues

- Aged highway system
- Increasing financial difficulties
- Low funding priority for low-volume roads
  - No performance target was set by the *Moving Ahead for Progress in the 21st Century Act* (MAP-21) for Non-NHS roads.
## Existing Pavement Structure

<table>
<thead>
<tr>
<th>Seal Coat Placed in 2006</th>
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</thead>
<tbody>
<tr>
<td>Seal Coat Placed in 1990</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>2&quot; Type &quot;B&quot; Asphalt Concrete Surface Course Constructed in 1971</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5&quot; Type &quot;B&quot; Asphalt Concrete Binder Course Constructed in 1971</td>
</tr>
<tr>
<td>0.75&quot; Heavy Surface Constructed in 1951</td>
</tr>
</tbody>
</table>

6" Granular Base Constructed in 1951
Existing Pavement Conditions

- **Pavement Management Information System Data:**
  - AADT: 1040 (8% trucks)
  - PCI: 32
  - IRI: 246 inches per mile
  - Structural rating: 3.63
  - K-value: 46
Conditions (Cont.)

- Pre-construction Pavement Survey:
  - All cracks are top-down cracking.
  - Transverse cracking: 9015 ft./mi.
  - Longitudinal cracking: 489 ft./mi. (wheel path); 1390 ft./mi. (center)
  - Some potholes.
  - Severe raveling at intersections.
  - Severe edge breaks.
Holding Strategy

- Relative low-cost pavement maintenance methods for significantly deteriorated low-volume roads.
- Promote and maintain pavement conditions at acceptable level.
- Delay major rehabilitation or reconstruction.
- Allow more flexible budget allocation.
Technologies for Holding Strategies

- Full-Depth Reclamation
- In-place Recycling
- Thin Interlayer
- Strengthening and Leveling Course
- Thin Surfacing Treatments
Treatments

- **Test Section #1:**
  - mill and fill
  - 1.3 miles

- **Test Section #2:**
  - mill and fill with seal coat
  - 2.0 miles

- **Test Section #3:**
  - scarification and interlayer with ultra-thin asphalt overlay
  - 2.2 miles
Treatments (Cont.)

- **Test Section #4:**
  - Full depth reclamation (FDR) with AC overlay
  - 1.0 mile

- **Test Section #5:**
  - FDR with double seal coat
  - 0.4 miles

- **Test Section #6:**
  - Cold-in-place recycling (CIR) with double seal coat
  - 1.4 miles
Treatments (Cont.)

- **Test Section #7:**
  - CIR with AC overlay
  - 1.6 miles

- **Test Section #8:**
  - HMA overlay
  - 1.4 miles

- **Test Section #9:**
  - Leveling and strengthening course with seal coat
  - 1.9 miles
Treatments (Cont.)

➢ Test Section #10:
  • Scarification with seal coat
  • 0.3 miles
  • “Urban” section in Fayette

Section #10

1” Scarification

Seal Coat
Scarification

Process

• Mill the pavement surface with a profiler.
• Transport RAP using trucks.
• Control dusts with water.
• Sweep scarified surface.
Scarification (Cont.)

- **Quality Control**
  - Slope check: between 2% to 3%
Scarification (Cont.)
Cold-in-place Recycling

Process

(a) Milling machine
(b) Crushing and screening unit
(c) Pug mill
(d) Oil tank trailer

Material

- Virgin binder content = 2.3%
- Binder: foamed PG52-34 asphalt binder
### Quality Control
- Field dry density: ≥ 94% of lab sample density (corrected with moisture content)

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<tr>
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<th>7/25</th>
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<td>Corrected Laboratory Dry Density, pcf</td>
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<td>Average Corrected Field Dry Density, pcf</td>
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<td>123.7</td>
<td>123.3</td>
<td>121.0</td>
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<tr>
<td>Percent of Laboratory Density, %</td>
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<td>97.3</td>
<td>97.0</td>
<td>95.2</td>
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<td>Percent moisture, %</td>
<td>5.2</td>
<td>4.8</td>
<td>4.7</td>
<td>5.1</td>
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</table>
Cold-in-place Recycling (Cont.)
Full-Depth Reclamation

Process

- Sizing
- Compaction (Sheep’s Foot Compactor)
- Apply Fly Ash
- Rough Grading
- Initial Compaction (Sheep’s Foot Compactor)
- Pulverizing and Mixing (Asphalt Emulsion is added in this step)
- Final Compaction (Smooth Drum Compactor and Pneumatic Tire Roller)
- Final Grading
Full-Depth Reclamation (Cont.)

Process: Sizing
Full-Depth Reclamation (Cont.)

➢ Process (Pulverizing and Mixing)
Full-Depth Reclamation (Cont.)

- Process (Grading and Compaction)
Full-Depth Reclamation (Cont.)

- **Material**
  - Virgin binder content: 2.8%
  - Binder: foamed PG52-34 asphalt binder
  - Fly ash content: 2%

- **Quality Control**
  - Field density at 3/4 of the FDR thickness \( \geq 94\% \) lab sample density (corrected with moisture content)
  - Field density at 1/4 of the FDR thickness \( \geq 97\% \) of the field density at 3/4 of the FDR thickness
Interlayer, Leveling & Strengthening Course

- Thin interlayer and leveling and strengthening course were constructed with conventional HMA paving techniques.

- Interlayer was placed on the scarified surface.

- Leveling and strengthening course was placed on existing pavement directly.

- Tack coat was applied to ensure bonding at the interface of the existing pavement and the newly constructed layer.
# Interlayer, Leveling & Strengthening Course (cont.)

## Material

<table>
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<th>1&quot; Interlayer Course Mix</th>
<th>1&quot; Leveling and Strengthening Course Mix</th>
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<tbody>
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<td><strong>Aggregate</strong></td>
<td><strong>Aggregate</strong></td>
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<td>3/8&quot; ACC Stone</td>
<td>3/8&quot; ACC Stone</td>
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<td>40%</td>
<td>30%</td>
</tr>
<tr>
<td>3/16&quot; Washed Manufactured Sand</td>
<td>3/8&quot; Washed Chips</td>
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<tr>
<td>20%</td>
<td>15%</td>
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<tr>
<td>Washed Concrete Sand</td>
<td>3/8&quot; Washed Manufactured Sand</td>
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<td>25%</td>
<td>30%</td>
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<tr>
<td>Aggregate Lime</td>
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<td><strong>Binder</strong></td>
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<td>7.4%</td>
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HMA Overlay

➢ 2 inches HMA Overlay
  • Serves as the control section
  • Test Section #8

➢ Thin Overlay
  • Layer thickness ≤ 1.5 inches (sometimes a 2” overlay is still called thin overlay)
  • Test Sections #1, #2, #4, #7

➢ Ultra-thin Overlay
  • Layer thickness ≤ 1 inch (most states), ≤ 1.25 inches (California)
  • Test Section #3
## HMA Overlay (Cont.)

### Material

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Percent in Aggregate</th>
<th>Aggregate</th>
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<td>3/8&quot; ACC Stone</td>
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<tr>
<td>1/2&quot; Washed Chips</td>
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<td>3/16&quot; Washed Manufactured Sand</td>
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<tr>
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<td>Washed Concrete Sand</td>
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<tr>
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<td>3/8&quot; Washed Chip</td>
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<td><strong>Percent in Mixture</strong></td>
<td><strong>Binder</strong></td>
<td><strong>Percent in Mixture</strong></td>
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<tr>
<td>PG58-28</td>
<td>5.3%</td>
<td>PG76-34</td>
<td>6.7%</td>
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</table>
HMA Overlay (Cont.)

- Concerns for thin and ultra-thin overlays
  - Temperature drops fast.
  - Compaction needs to be done carefully and quickly.
  - Difficult to recover cores.
  - In-situ density measurements are problematic.
Seal Coat (Chip Seal)

Process

- Clean Pavement Surface
- Spray Asphalt Emulsion
- Place Aggregate Cover
- Sweep Off Loose Aggregate
- Curing (2 hours)
- Compact
- Apply Dust Control Oil
Seal Coat (Cont.)

(Figures were retrieved from California DOT Pavement Maintenance Technical Advisory Guide)
Seal Coat (Cont.)
Pavement Survey

- **Right after construction**
  - No distresses were observed; quality of construction was confirmed.
- **October, 2013**
  - No distresses were observed; FWD test was performed.
- **Other Surveys**

<table>
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<th>Survey</th>
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<td>Pre-construction survey</td>
<td>July 2013</td>
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<tr>
<td>Project construction</td>
<td>August and September 2013</td>
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<tr>
<td>1st post-construction survey</td>
<td>September 2013</td>
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<tr>
<td>2nd post-construction survey</td>
<td>April 2014</td>
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<td>3rd post-construction survey</td>
<td>October 2014</td>
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<tr>
<td>4th post-construction survey</td>
<td>April 2015</td>
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Test Section Performance

- Predominating distress type is transverse cracking.
- Other observed distresses: pothole, stripping of chip seal.
- FDR and CIR were the most effective treatments for cracking mitigation.
- Chip seal surface seems not to decrease the ability of base treatment to correct cracking; however, it has a higher chance to mitigate surface defects than AC overlay.
Test Section Performance

<table>
<thead>
<tr>
<th>Test Section</th>
<th>Description</th>
<th>Test Section</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>1” Scar. + 1.5” AC Overlay</td>
<td>6</td>
<td>2.5” Cold In-place Recycling + 2XSeal Coat</td>
</tr>
<tr>
<td>2</td>
<td>1” Scar. + 1.5” AC Overlay + Seal Coat</td>
<td>7</td>
<td>2.5” Cold In-place Recycling + 1.5” Overlay</td>
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<tr>
<td>3</td>
<td>1” Scar. + 1” Interlayer + 0.75” Ultrathin</td>
<td>8</td>
<td>2.0” Overlay</td>
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<td>4</td>
<td>Full-Depth Reclamation + 1.5” Overlay</td>
<td>9</td>
<td>1.0” Leveling/Strengthening + Seal Coat</td>
</tr>
<tr>
<td>5</td>
<td>Full-Depth Reclamation + 2XSeal Coat</td>
<td>10</td>
<td>1.0” Scar. + Seal Coat</td>
</tr>
</tbody>
</table>
Test Section Performance

• Snow plowing impose significant damage to chip seal surface. Base treatment type seems to have influence on the damage level of chip seal surface.
Cost of Construction

Total construction cost: $1,692,157 ($124,423/mile)
Cost of Construction

<table>
<thead>
<tr>
<th>Test Section</th>
<th>% Unit Cost of 3” Overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1” Scar. + 1.5” AC Overlay</td>
<td>61</td>
</tr>
<tr>
<td>2 1” Scar. + 1.5” AC Overlay + Seal Coat</td>
<td>76</td>
</tr>
<tr>
<td>3 1” Scar. + 1” Interlayer + 0.75” Ultrathin</td>
<td>89</td>
</tr>
<tr>
<td>4 Full-Depth Reclamation + 1.5” Overlay</td>
<td>85</td>
</tr>
<tr>
<td>5 Full-Depth Reclamation + 2XSeal Coat</td>
<td>55</td>
</tr>
<tr>
<td>6 2.5” Cold In-place Recycling + 2XSeal Coat</td>
<td>76</td>
</tr>
<tr>
<td>7 2.5” Cold In-place Recycling + 1.5” Overlay</td>
<td>69</td>
</tr>
<tr>
<td>8 2.0” Overlay</td>
<td>58</td>
</tr>
<tr>
<td>9 1.0” Leveling/Strengthening + Seal Coat</td>
<td>38</td>
</tr>
<tr>
<td>10 1.0” Scar. + Seal Coat</td>
<td>100</td>
</tr>
</tbody>
</table>


Forthcoming Iowa DOT Research Report
Questions?

Thank You!
New Approaches for Upgrading Gravel Roads to a Low Volume Sealed Standard Based on the Use of the Dynamic Cone Penetrometer

Presenter: M. I. Pinard
(P. Paige-Green, J. Hongve, E. Mukandila)
Africa Community Access Programme
Outline of Presentation

- Background
- DCP Design Method
- Material Selection and Specification
- Compaction Quality Control Using the DCP
- Strengths and limitations of DCP design method
- Summary
Background

- Approximately 1 million km of unsealed roads on African continent

- Increasingly difficult to maintain:
  - **Constraints:** financial, logistical, and technical burden coupled with depletion of non-renewable resource (gravel)
  - **Consequence:** lack reliable access to many rural communities

- **Solution:** Upgrade unpaved roads to a paved standard

- **Problem:** Cost of upgrading following traditional approaches is prohibitively expensive

- **Way forward:** Research has led to development of new approach for upgrading gravel roads to a paved standard based on the use of the Dynamic Cone Penetrometer (DCP)
DCP Outline Details

- DCP measures in situ shear strength which is a function of material moisture, density, grading and plasticity at time of testing.

- Test entails dropping an 8 kg mass from 575 mm height, recording the penetration of the cone in the material per number of blows and evaluating the weighted average of the rate of penetration in mm/blow (DN value).

- DCP structure number: number of DCP blows required to penetrate a pavement structure or layer, e.g. DSN\textsubscript{800} = number of blows to penetrate 800mm of pavement.
DCP Test

DCP test in progress

DCP resistance to penetration versus depth
Development of DCP Design Method

- Original development dates back to mid-1950s in Australia
- Used initially as non-destructive device to evaluate shear strength of material in pavement
- Further developed in S. Africa in mid 1970s as an empirical method of LVR design on basis of extensive back-analysis of existing pavements in conjunction with Heavy Vehicle Simulator (HVS) testing
- Allowed relationships to be developed between DCP penetration curves and life of pavements.
- Further enhanced under AfCAP to include material selection and specification and laboratory DN testing.
## DCP Design Catalogue

<table>
<thead>
<tr>
<th>Traffic Class E80 x 10^6</th>
<th>TLC 0.01 &lt; 0.010</th>
<th>TLC 0.03 0.010 – 0.030</th>
<th>TLC 0.1 0.030 – 0.100</th>
<th>TLC 0.3 0.100 – 0.300</th>
<th>TLC 0.7 0.300–0.700</th>
<th>TLC 1.0 0.700 – 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0- 150mm Base</strong></td>
<td>DN ≤ 8</td>
<td>DN ≤ 5.9</td>
<td>DN ≤ 4</td>
<td>DN ≤ 3.2</td>
<td>DN ≤ 2.6</td>
<td>DN ≤ 2.5</td>
</tr>
<tr>
<td><strong>≥ 98% MAASHTO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>150-300 mm Subbase</strong></td>
<td>DN ≤ 19</td>
<td>DN ≤ 14</td>
<td>DN ≤ 9</td>
<td>DN ≤ 6</td>
<td>DN ≤ 4.6</td>
<td>DN ≤ 4.0</td>
</tr>
<tr>
<td><strong>≥ 95% MAASHTO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>300-450 mm subgrade</strong></td>
<td>DN ≤ 33</td>
<td>DN ≤ 25</td>
<td>DN ≤ 19</td>
<td>DN ≤ 12</td>
<td>DN ≤ 8</td>
<td>DN ≤ 6</td>
</tr>
<tr>
<td><strong>≥ 95% MAASHTO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>450-600 mm In situ material</strong></td>
<td>DN ≤ 40</td>
<td>DN ≤ 33</td>
<td>DN ≤ 25</td>
<td>DN ≤ 19</td>
<td>DN ≤ 14</td>
<td>DN ≤ 13</td>
</tr>
<tr>
<td><strong>600-800 mm In situ material</strong></td>
<td>DN ≤ 50</td>
<td>DN ≤ 40</td>
<td>DN ≤ 39</td>
<td>DN ≤ 25</td>
<td>DN ≤ 24</td>
<td>DN ≤ 23</td>
</tr>
<tr>
<td><strong>DSN 800</strong></td>
<td>≥ 39</td>
<td>≥ 52</td>
<td>≥ 73</td>
<td>≥ 100</td>
<td>≥ 128</td>
<td>≥ 143</td>
</tr>
</tbody>
</table>
To achieve a balanced pavement structure whilst optimizing the utilization of the in situ material strength.

- Determining design strength profile needed
- Integrating strength profile with in situ strength profile

**DCP Design Principle**

![Diagram showing required strength profile and in situ strength profile.](image)
DCP Design Procedure

1. Undertake DCP Survey
2. Determine moisture content along road pavement
3. Determine DN values in pavement layers of entire road (from DCP programme)
4. Determine uniform sections (CUSUM analysis)
5. Adjust DN values for design moisture content
6. Determine in situ LSP for each uniform section
7. Determine required LSP for each uniform section
8. Compare in situ LSP with required LSP for each uniform section
9. Determine upgrading requirements
Step 1: Undertake DCP Survey Along Road

DCP provides a good “picture” of in situ ground conditions
Step 4: Determine Uniform Sections
### Step 5 – Adjust DN Values for Design Moisture Content

<table>
<thead>
<tr>
<th>Anticipated long-term in-service moisture content in pavement</th>
<th>Percentile of minimum strength profile (maximum penetration rate – DN mm/blow)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design traffic &lt; 0.5 MESA</td>
</tr>
<tr>
<td>Drier than at time of DCP survey</td>
<td>20</td>
</tr>
<tr>
<td>Same as at time of DCP survey</td>
<td>50</td>
</tr>
<tr>
<td>Wetter than at time of DCP survey</td>
<td>80</td>
</tr>
</tbody>
</table>
# Adjustment of DN Values for Moisture

<table>
<thead>
<tr>
<th>Chainage (km)</th>
<th>Point No</th>
<th>DN 0-150 (Base)</th>
<th>Percentile of minimum strength Profile (max. penetration rate – DN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>20&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.00</td>
<td>1</td>
<td>2.29</td>
<td>3.46</td>
</tr>
<tr>
<td>0.25</td>
<td>2</td>
<td>4.44</td>
<td>N/A</td>
</tr>
<tr>
<td>0.50</td>
<td>3</td>
<td>2.00</td>
<td>N/A</td>
</tr>
<tr>
<td>0.75</td>
<td>4</td>
<td>8.67</td>
<td>N/A</td>
</tr>
<tr>
<td>1.00</td>
<td>5</td>
<td>3.75</td>
<td>N/A</td>
</tr>
<tr>
<td>1.25</td>
<td>6</td>
<td>8.07</td>
<td>N/A</td>
</tr>
<tr>
<td>1.50</td>
<td>7</td>
<td>5.11</td>
<td>N/A</td>
</tr>
<tr>
<td>1.75</td>
<td>8</td>
<td>5.37</td>
<td>N/A</td>
</tr>
<tr>
<td>2.00</td>
<td>9</td>
<td>6.60</td>
<td>N/A</td>
</tr>
<tr>
<td>2.25</td>
<td>10</td>
<td>10.12</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Anticipated long-term in-service moisture content in pavement**

- Drier than at time of DCP survey: 3.46
- Same as at time of DCP survey: N/A
- Wetter than at time of DCP survey: 8.19

Step 6 - Determine In Situ LSP For Each Uniform Section

Collective DCP strength profiles

Average and extreme DCP strength profiles
Step 8: Compare In Situ & Required LSP for Uniform Section

[Graph showing comparison of in situ and required LSP for uniform section]
Step 9: Determine Upgrading Requirements

● Reworking the existing layer
  ➢ if only the density is inadequate and the required DN value can be obtained at the specified construction density and anticipated in-service moisture content.

● Replacing the existing layer
  ➢ if material quality (DN value at specified construction density and anticipated in-service moisture content) is inadequate, then appropriate quality material will need to be imported to serve as the new upper pavement layer(s).

● Augmenting the existing layer
  ➢ if material quality (DN value) is adequate but the layer thickness is inadequate, then imported material of appropriate quality will need to be imported to make up required thickness prior to compaction.
Material Selection and Specification

- DN value serves as criterion for selecting materials to be used in upper/base layer of LVSR pavement.

- Provided design DN value is achieved, then in service performance indirectly takes account of actual grading and plasticity at given moisture and density which do not need to be separately specified.
  - DN value provides a composite measure of materials resistance to penetration (= shear strength) at given moisture and density and is affected by material grading and plasticity.
  - Limits also placed on GM 1.0 – 2.2

- Criterion widens scope for more extensively utilising local materials that would otherwise be excluded, even though they are “fit for purpose”.
PI – Poor Correlation With Performance

Plasticity Index (%)

Rated performance

Very Good

Very Poor
Laboratory Determination of DN value

DCP used to penetrate the CBR mould

<table>
<thead>
<tr>
<th>4 days soaked sample, sealed for 4 days in plastic bag</th>
<th>Soaked DN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample at OMC, sealed for 4 to 7 days in plastic bag</td>
<td>OMC DN</td>
</tr>
<tr>
<td>Oven sample (0.75OMC), sealed for 4 days in plastic bag</td>
<td>0.75 OMC DN</td>
</tr>
</tbody>
</table>
DN/Density/Moisture Relationship

DN at varying MC and % compaction

% BS Heavy Compaction

DN Value

Soaked: 11.0, 9.5, 7.3, 6.2, 4.8, 3.8, 3.5, 3.4
OMC: 6.6, 4.8, 3.0, 2.2, 1.4
0.75 OMC: 3.4, 3.0, 2.2, 1.4
Compaction Quality Control Using DCP

- Traditional methods (Sand Replacement, core cutter, rubber balloon and nuclear density gauge): slow, hazardous, uncertain accuracy, and impractical for variation of material along tested section.

- Alternative method of compaction quality control with DCP:
  - level and uniformity of compaction
  - relatively simple and low cost compared
  - procedure is based on the DN value criterion, used in the pavement design
  - assessing compaction compliance, field DN versus required DN value using strength/density/moisture relationship and adjustment factor for confinement effect of mould.
Summary of DCP Method-Strengths

- Relatively low cost, robust apparatus that is quick and simple to use allowing comprehensive characterization of the in situ road conditions.
- Provides improved precision limits compared to the CBR test.
- Very little damage is done to the pavement being tested (effectively non-destructive) and very useful information is obtained.
- The pavement is tested in the condition at which it performs and the test can be carried out in an identical manner both in the field and in the laboratory.
- The simplicity of test allows repeated testing to minimize errors and also to account for temporal effects.
- The laboratory DN value is determined over a depth of 150 mm and not just the top 2.5 – 5.0 mm as with the CBR test.
- The method is as good or better than any other method in taking into account variations in moisture content and provides data quickly for analysis.
Summary of DCP Method-Limitations

- Use in very coarse granular (> 37.5mm or lightly stabilized materials)
- Very hard cemented layers in pavement structure
- Poorly executed tests (hammer not falling the full distance, non-vertical DCP, excessive movement of the depth measuring rod, etc.)
Conclusions

- The DCP-DN design method:
  - Makes use of a relatively inexpensive, multi-purpose device for characterising existing gravel road, testing pavement materials and undertaking compaction quality control.
  - Is based on a relatively simple design procedure that produces cost-effective, environmentally optimised designs.
  - Has been used successfully in the past two decades to design many kilometres of light pavement structures in the Southern African region.
  - Allows more extensive use to be made of local materials
  - Offers potential for economically upgrading a significantly greater length of gravel roads to a paved standard with similar risk as conventional pavement design techniques.
  - Need for full appreciation of the strengths and weaknesses of the DCP device
Examples of DCP Designed Roads

Danger Point road, South Africa (10 years after construction)

Road D379 Kiambu, Kenya (4 years after construction)
Benefits of Adopting New Approaches

- Application of locally derived, appropriate technology
- Reduced life cycle costs of LVR provision
- Facilitating socio-economic growth and development and poverty alleviation

$150,000/km*

$300,000/km*

Malawi experience
Thank you!