Introduction to the DCP Design Method for Low Volume Sealed Roads

Mike Pinard
AFCAP Consultant
Purpose and Scope

- Provide overview of a new approach to the upgrading of unpaved roads to a paved standard using the DCP-DN design method.
Presentation Outline

- Background
- DCP Design Principles
- DCP Design Method
- Summary and Conclusions
Typical Design Methods

- CBR cover curve
- AASHTO structural number
- Mechanistic-empirical
- Catalogue
  - Lab CBR based (e.g. TRL ORN 31, TRH 4)
  - DCP-CBR (TRL/SADC, CSIR)
  - DCP-DN (AFCAP)
    - AFCAP DCP Manual
The CBR Test

- Empirical test developed in 1928/29
- Widely applied in design of flexible pavements
- Standard soaked CBR is strength test most used for materials selection for all pavement layers
- Tried, trusted and understood

BUT

- Very conservative - Risk of failure minimal
- Often excludes materials that are eminently “fit for purpose”
- Test procedure is time consuming, costly and requires large sample for lab testing.
- Poor reproducibility
The CBR test is notoriously inaccurate with low reproducibility.

Standard deviation ($\sigma$) = $10^w$ where $w = (1.4771 - 0.9853^{CBR})$

<table>
<thead>
<tr>
<th>CBR</th>
<th>$\sigma$</th>
<th>95% confidence</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4</td>
<td>± 8</td>
<td>2 – 18</td>
</tr>
<tr>
<td>30</td>
<td>7</td>
<td>± 14</td>
<td>16 – 44</td>
</tr>
<tr>
<td>60</td>
<td>12</td>
<td>± 24</td>
<td>36 – 84</td>
</tr>
<tr>
<td>80?</td>
<td>16</td>
<td>± 32</td>
<td>58 – 122</td>
</tr>
</tbody>
</table>
Accuracy of Common CBR Test

The use of the soaked CBR test also raises the question of variability. Overall the coefficient of variation of the test is of the order of 20% (Ingles*, 1974; Millard and O’Reilly, 1964). That is, with a true mean of 80, the CBR will range from 48 to 112

Relationship between elastic stiffness and CBR for a stress pulse of 40 kPa

CBR – Poor Correlation With Stiffness
Is Soaked Strength Necessary?

- Related to material and not pavement situation
- In situ road conditions are seldom soaked
- Field investigations show that in situ moisture is seldom above OMC
- Equilibrium moisture content of base, subbase and subgrade is usually significantly below OMC
  - Emery (1985) and others
    - Base - between 0.56 and 0.6 OMC
    - Subbase – between 0.7 and 0.82 OMC
    - Subgrade – depends on material – 0.7 to 1.05 OMC
- Material strength varies significantly with moisture content
- Need to capitalise on this during design - *May require sealed shoulders in wet areas*
Typical Moisture Related Relationship

- Equilibrium moisture content
- Optimum moisture content
- Soaked
CBR – Poor Correlation With Performance

South African Low Volume Road Investigation (CSIR)
CBR – Poor Correlation With Performance

Soaked Roadbase CBR

Deterioration Index vs Soaked CBR

Acceptable

Normal minimum

Mozambique Back-Analysis Project
In Summary:

- Very poor reproducibility
- Very poor correlation between soaked CBR and performance for roads constructed with granular bases
- Not appropriate for selecting natural gravels – as often as not, is not a reliable discriminator between suitable and unsuitable materials
Presentation Outline

- Background
- DCP Design Principles
- DCP Design Method
- Summary and Conclusions
DCP Method of Design

- An alternative method of structural design that avoids the use of the CBR test to classify and quantify the strength of materials.
- It uses the DN number obtained directly from DCP measurements without converting to CBR.
- It is becoming popular because of its simplicity.
- It is especially useful for upgrading an existing gravel road to a paved standard.
DCP Design Method

- Original development dates back to mid-1950s in Australia based on older Swiss design
- Used initially as non-destructive testing device to evaluate shear strength of material in a pavement
- Use for pavement design enhanced in mid-1960s and 1970s in South Africa where results verified from back-analysis of many pavement sections using Heavy Vehicle Simulator
- DCP design catalogue subsequently developed for various traffic categories and moisture conditions.
DCP Design Methods

- Catalogue-based
  - DCP-CBR (TRL/SADC, CSIR)
  - DCP-DN (AFCAP)
  - AFCAP DCP Manual
### SADC/TRL DCP-CBR Pavement Design Catalogue

<table>
<thead>
<tr>
<th></th>
<th>&lt;0.01</th>
<th>0.05</th>
<th>0.1</th>
<th>0.3</th>
<th>0.5</th>
<th>1</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2*</td>
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<td></td>
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<tr>
<td></td>
<td>150</td>
<td>120</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>175</td>
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<td>150</td>
<td>120</td>
<td>150</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>275</td>
</tr>
<tr>
<td>S5</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>150</td>
<td>120</td>
<td>120</td>
<td>225</td>
<td>200</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>S6</td>
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<td></td>
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<td></td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>175</td>
<td>200</td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**  * Non-expansive subgrade

Double surface dressing
- 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
Dynamic Cone Penetrometer (DCP)

DCP test in process
DCP Test and Output

- Measures the weighted penetration per blow into a pavement through each of the different pavement layers.

- Rate of penetration is a function of the in situ shear strength of the material at the in situ moisture content and density of the pavement layers at the time of testing.

- Profile in depth of the pavement gives an indication of the in situ properties of the materials in all the pavement layers up to the depth of penetration.
Extensive DCP testing was carried out in conjunction with Heavy Vehicle Simulator (HVS) testing of various roads.

Allowed further correlations and developments, e.g. relationships between actual road performance and DCP results.
Relationship between DN and CBR

CBR-DCP relationship based on 2000+ measurements in South Africa (Kleyn)

\[ CBR = 410 \times DN^{-1.27} \]
DCP Design Approach

- Achieve balanced pavement design
- Make use of beneficial traffic moulding and consolidation of gravel road pavement over many wetting and drying cycles
  - Gravel road pavement should not be disturbed during upgrading
- Optimize utilization of in situ material strength as much as possible. Achieved by:
  - determining design strength profile required
  - Integrating required strength profile with in situ strength profile
Integration of In Situ and Required Strength Profiles

- Required strength profile
- In situ strength profile

Field data plots to right of design curve = inadequate strength
## Traffic Class

<table>
<thead>
<tr>
<th>E80 x 10^6</th>
<th>LE 0.01 0.003 – 0.010</th>
<th>LE 0.03 0.010 – 0.030</th>
<th>LE 0.1 0.030 – 0.100</th>
<th>LE 0.3 0.100 – 0.300</th>
<th>LE 0.7 0.300–0.700</th>
<th>LE 1.0 0.700 – 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-150mm</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>
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<tr>
<td>Base</td>
<td>≥ 98% MAASHTO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150-300mm</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>Subbase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 95% MAASHTO</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>300-450mm</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>Subgrade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 95% MAASHTO</td>
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<td></td>
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<tr>
<td>450-600mm</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>In situ material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>600-800mm</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>In situ material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSN 800</td>
<td>≥ 39</td>
<td>≥ 52</td>
<td>≥ 73</td>
<td>≥ 100</td>
<td>≥ 128</td>
<td>≥ 143</td>
</tr>
</tbody>
</table>
DCP Design – General Design Procedure

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
## Undertake DCP Survey

<table>
<thead>
<tr>
<th>Road condition</th>
<th>Frequency of testing/km*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform (low risk)</td>
<td>5</td>
</tr>
<tr>
<td>Non-uniform (medium risk)</td>
<td>10</td>
</tr>
<tr>
<td>Low-lying/distressed (high risk)</td>
<td>20</td>
</tr>
</tbody>
</table>

Typical DCP effects with large stones in pavement layer:

(a) cone cannot penetrate at all and the test needs to be re-done;

(b) cone breaks stone but penetration is uncharacteristically hard and $DSN_{800}$ is high;

(c) cone tries to push stone aside. Result is high because of side friction generated on cone shaft;

(d) Usually provides a normal result.
Determine MC Along Road Pavement

- Inherent in situ strength of the material is strongly dependent on the prevailing moisture (and density) conditions

- It is essential that an estimate of the in situ moisture condition is made at the time of the DCP survey for comparison with the expected moisture regime in service

- To this end, at least 2 samples per kilometre should be obtained for moisture content determination from the outer wheel track road at depths of 0-150, 150-300 and 300-450 mm.
Obtain DN Values Along Road

DCP provides a good “picture” of in situ ground conditions.
## Determine Uniform Sections

<table>
<thead>
<tr>
<th>Chainage (Km)</th>
<th>Measured DCP (DN Value -mm blow)</th>
<th>Difference from average (A-B)</th>
<th>CUSUM (Accumulated values of C)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
<td>-1.2</td>
<td>-1.2</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>
</tr>
<tr>
<td>5</td>
<td>13</td>
<td>-0.2</td>
<td>-5.0</td>
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<tr>
<td>6</td>
<td>14</td>
<td>-1.2</td>
<td>-6.2</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>5.8</td>
<td>-0.2</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>3.8</td>
<td>3.4</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>4.8</td>
<td>8.2</td>
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<tr>
<td>10</td>
<td>13</td>
<td>-0.2</td>
<td>8.0</td>
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<tr>
<td>11</td>
<td>15</td>
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<td>12</td>
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<td>0.6</td>
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<td>13</td>
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<tr>
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<td>-3.2</td>
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<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>
</tr>
<tr>
<td>18</td>
<td>18</td>
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<td>3.8</td>
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</tr>
<tr>
<td>26</td>
<td>11</td>
<td>1.8</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

Average: A = ±28
Determine Uniform Sections

Base
Subbase
Subgrade
# Adjust DN Values for Moisture Environment

<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>
Compare In Situ & Required LSP for Uniform Section

- Inadequate in situ strength
- Adequate in situ strength

Required strength profile (From DCP Design Catalogue)

In situ strength profile 20th, 50th or 80th percentile as appropriate

Layer Strength Diagram (LSD) (Existing Structure)

- User Def. 1 traffic
- Ave.
- 20/80th Percentile

Computer printout
Determine Upgrading Requirements (Cont’d)

- **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

- 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 is a composite measure of materials resistance to penetration (= shear strength) at given moisture and density and is effected by material grading and plasticity.
Determination of Laboratory DN Value

DN = h/r where:

h = depth of CBR mould

r = total number of blows to reach depth h
DN at varying MC and % compaction

**DN Value**

- **Soaked**
  - DN Value: 11.0
  - OMC: 0.75 OMC

- **OMC**
  - DN Value: 6.6
  - OMC: 0.75 OMC

- **0.75 OMC**
  - DN Value: 3.4
  - OMC: 0.75 OMC

**% BS Heavy Compaction**

- 92%
- 93%
- 94%
- 95%
- 96%
- 97%
- 98%
- 99%
- 100%
- 101%
Examples of DCP Designed Roads

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

Road D379 Kiambu, Kenya (after 2 years)
Conclusions

- Design of light pavement structures using the DCP design method has been successfully carried out on a number of roads in the Southern African region.

- Procedure allows a simple and cost-effective design to be employed, often resulting only in the need to rip and re-compact the exiting upper layer of materials or else to import a single layer of appropriate material that can be placed directly on the reshaped in situ material.

- Using this technique, it will be possible to economically upgrade a significantly greater length of road (often using the in situ materials or at most requiring the importation of a single layer of material) than would be possible using conventional pavement design techniques, without increasing the risk of premature failures.
Thank You