### Annex 1: Classroom Training Programme

#### Classroom training plan – Week 1

<table>
<thead>
<tr>
<th>Date</th>
<th>27 January</th>
<th>28 January</th>
<th>29 January</th>
<th>30 January</th>
<th>31 January</th>
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<tr>
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<td><strong>Senior Management</strong></td>
<td>Field visit, DCP exercise</td>
<td>Module 1 Theoretical background</td>
<td>Module 3 WinDCP software</td>
<td>Data analysis and Pavement design (continued)</td>
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<tr>
<td><strong>Designers/practitioners 1st group</strong></td>
<td>Module 1 Theoretical background</td>
<td>Theoretical background (continued)</td>
<td>Module 4 Data entry</td>
<td>Data analysis and Pavement design (continued)</td>
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<td><strong>Designers/practitioners 1st group</strong></td>
<td>Module 2 Design principles</td>
<td>Module 2 Design principles</td>
<td>Module 5 Data analysis and Pavement Design</td>
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<table>
<thead>
<tr>
<th>1. session</th>
<th>08.30 – 10.00</th>
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<tr>
<td>2. session</td>
<td>10.30-12.00</td>
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<tr>
<td>Lunch</td>
<td>12.00-13.00</td>
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<td>3. session</td>
<td>13.00 – 14.30</td>
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<tr>
<td>Break</td>
<td>10.00-10.30</td>
</tr>
<tr>
<td>4. session</td>
<td>15.00 – 16.30</td>
</tr>
</tbody>
</table>

**Training Sessions:***

1. **Field visit, DCP exercise**

2. **Module 1 Theoretical background**
   - Q & A

3. **Module 3 WinDCP software**
   - Open and Create project
   - Saving, location of files
   - Data entry screen
   - Define design curve
   - DCP data entry
   - Q & A

4. **Module 4 Data entry**
   - Quality assurance of data collection and data entry
   - Report options
   - Data entry
   - Determination of intervention
   - Import of new layer
   - Lab DN test

5. **Module 5 Data analysis and Pavement Design**
   - Cusum analysis
   - Create cusum graph
   - Determine uniform sections
   - Discussion of results
   - Q & A
<table>
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<tr>
<th>Date</th>
<th>3 February</th>
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<th>5 February</th>
<th>6 February</th>
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<td>Module 1 Theoretical background</td>
<td>Module 3 WinDCP software</td>
<td>Module 1 Theoretical background</td>
<td>Module 5 Lab testing</td>
<td>Module 6 Design example</td>
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<td>Data analysis and Pavement Design (continued)</td>
<td>Data entry (continued)</td>
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<td><strong>Designers/practitioners 2nd group</strong></td>
<td>Data analysis and Pavement Design (continued)</td>
<td>Data entry (continued)</td>
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<td>Data entry</td>
<td>Data entry</td>
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<td><strong>Technicians Day 1</strong></td>
<td>Module 2 Design principles</td>
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<td>Module 2 Design principles</td>
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<td><strong>Technicians Day 3</strong></td>
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<td>Lab testing (cont)</td>
<td>Lab testing (cont)</td>
<td>Lab testing (cont)</td>
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</tr>
</tbody>
</table>

**Module 1 Theoretical background**
- Opening
- Create project
- Saving, location of files
- Data entry screen
- Define design curve
- DCP data entry

**Module 2 Design principles**
- Single point analysis
- Average analysis
- Transfer data to excel
- Q & A

**Module 3 WinDCP software**
- Open and Create project
- Saving, location of files
- Data entry screen
- Define design curve
- DCP data entry

**Module 4 Data entry**
- Quality assurance of data collection and data entry
- Report options
- Data entry

**Module 5 Lab testing**
- Sample preparation
- CBR vs DN
- OMC
- FMC
- Lab DN value

**Module 6 Design example**
- Putting lab work into context
- Presentation of design Q & A

**Break 10.00-10.30**

**Lunch 12.00-13.00**

**Break 14.30 – 15.00**
Objectives of Training Programme

“To provide training to personnel at various levels in the relevant government institutions and agencies, academia, and private sector on the use of the DCP Pavement Design Guide to enable wider application of this innovative design methodology for cost-effective provision of low volume sealed roads in Kenya”.

Annex 2: Training Modules

Training Programme

Designers/Practitioners (2 groups @ 3 days/group)
- Field visit: DCP demonstration (full day) (includes technicians)
- Classroom (3 days)
  - Module 1 – Rural Roads – the Kenya challenge
  - Module 2 – The DCP design method + Example of DCP pavement design [detailed]
  - Module 3 – WinDCP software
  - Module 4 – Data entry
  - Module 5 – Data analysis and pavement design, Lab testing

Training Programme-Module 1

Module Number: 1
Course Title: Rural Roads – The Kenya Challenge
Duration: 1hr 10 mins presentation
20 mins discussion

Learning objective
- A heightened appreciation of the challenges faced by road authorities in Kenya in managing the country’s rural, largely gravel, road networks.
- An awareness of the relatively recent, research-led, developments in low volume road technology that have taken place in the eastern and southern African region, and their potential application to Kenya.
- The benefits of new approaches to upgrading gravel roads to a sealed standard compared with the traditional approaches.

Training Programme-Module 2

Module Number: 2
Course Title: The DCP Design Method
Duration: 1hr 10 mins presentation
20 mins discussion

Learning objective
- An outline appreciation of the development of the DCP design method.

Contents:
- Development of the DCP design method
- Principles of DCP design
- DCP design procedure

Objectives of Training Programme

Module Number: 2 (Cont’d)
Course Title: Example of DCP pavement design
Duration: 1hr 10 mins presentation
20 mins discussion

Learning objective
- An outline appreciation of the design of the upgrading of a rural road to a sealed standard.

Contents:
- Collection and analysis of data
- Use of DCP software
- Laboratory measurements
- Determination of pavement structure
- Choice of road surfacing
Objectives of Training Programme

Module Number: 3
Course Title: WinDCP Software
Duration: 1 hr 30 mins interactive session

Learning objective
- Familiarisation with the basic features of WinDCP Software programme

Contents:
- Open and Create project
- Saving, location of files
- Data entry screen
- Define design curve
- Sample DCP data entry

Objectives of Training Programme

Module Number: 4
Course Title: Data Entry
Duration: 3 x 1 hr 30 mins interactive session

Learning objective
- How to enter data into the WinDCP Software programme
- Format and interpret on screen reports
- Do DCP points analysis

Contents:
- Quality assurance of data collection and data entry
- Report options
- Data entry
- Single point analysis
- Average analysis
- Transfer data to excel

Objectives of Training Programme

Module Number: 5
Course Title: Data Analysis and Pavement Design, Lab Testing
Duration: 5 x 1 hr 30 mins interactive session (Designers)
2 x 1 hr 30 mins interactive session (Technicians)

Learning objective
- How to analyse the data to determine uniform sections
- How to determine required design intervention
- How to perform L ע DN test

Contents:
- Cusum analysis
- Create cusum graph
- Determine uniform sections
- Average analysis of uniform sections
- Application of correct percentile
- Enter percentile values for each layer and section in Excel table
- Determination of intervention
- Import of new layer
- L ע testing (EDR vs DN, FMC, OMC)
- Lab DN test

Overview of Presentation

- Background
- Motivation for LVSRs
- Characteristics of LVSRs
- Typical methods for LVR pavement design
- Overview of DCP-DN Design Method
- Surfacing Options for LVRs
- Drainage considerations
- Summary

Kenya Vision 2030
Roads 2000 Strategy, Vision & Mission

The Roads 2000 strategy is a vision to achieve and maintain a strategic, efficient and sustainable road network that meets the needs of Kenya in the twenty-first century and is a major priority of the Government, and a key component of the Vision 2030 blueprint.

Vision Statement:
To achieve and sustain excellence in road development and management that contributes to the national development and well-being of Kenya.

Mission Statement:
To improve access to socio-economic facilities by promoting the development and management of the road network using local resources to the satisfaction of stakeholders.

Summary of Road Condition

<table>
<thead>
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<td>5%</td>
<td>22%</td>
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<tr>
<td>Unconditioned</td>
<td>31%</td>
<td>72%</td>
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Poor road conditions impact adversely on the national economy.

Classified Road Network

<table>
<thead>
<tr>
<th>Road Network</th>
<th>Administering Agency</th>
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<td>878</td>
<td>269</td>
<td>375</td>
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Management of large network of unpaved roads imposes a significant technical and financial burden on the organizations concerned.

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<table>
<thead>
<tr>
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Poor road conditions impact adversely on the national economy.

Importance of Rural Roads in Kenya

Before

Need to provide opportunities for better market accessibility and making products and services much easier to access.

After

Paved Roads and Economic Development

“Much scope for increasing kilometrage of paved roads in Kenya to the benefit of the national economy.”

Overview of Presentation

- Background
- Motivation for LVSRs
- Characteristics of LVSRs
- Typical methods for LVR pavement design
- Overview of DCP-DN Design Method
- Surfacing Options for LVRS
- Drainage considerations
- Summary
**Limitations of Gravel Roads**

Traditionally Gravel is used for rural access roads. However:

- They are low (initial) cost and relatively easy to construct
- However, 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 reconstruct.

...........SENSIBLE?? NO!!!

---

**Maintaining Gravel Roads - Reality**

Gravel roads deteriorate rapidly if not maintained by timely grading and regravelling

---

**Maintaining Gravel Roads - Reality**

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

---

**Technical Viability of Gravel Roads**

Not viable when:

- Gravel quality is poor
- Compaction and thickness cannot be assured
- 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

---

**Economic Viability of Gravel Roads**

Lifecyle analysis period

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**Factors Favouring Viability of Upgrading**

<table>
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<th>Parameter</th>
<th>Impact</th>
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<td>Use of more appropriate pavement designs</td>
<td>Reduced costs</td>
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<tr>
<td>Use of more appropriate geometric design</td>
<td>Reduced costs</td>
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<tr>
<td>Increased use of natural/unprocessed gravels</td>
<td>Reduced costs</td>
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<tr>
<td>Reduced impacts of depleted gravel resources</td>
<td>Reduced costs</td>
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<tr>
<td>Benefits from non-motorised transport</td>
<td>Increased benefits</td>
</tr>
<tr>
<td>Reduced adverse impacts of traffic on gravel roads</td>
<td>Increased benefits</td>
</tr>
<tr>
<td>Reduced environmental damage</td>
<td>Increased benefits</td>
</tr>
<tr>
<td>Quantified assessments of social benefits</td>
<td>Increased benefits</td>
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</table>
**Life Cycle Cost Analysis**

- Revised approaches: 75 vpd
- Traditional approaches: 250 vpd

Break-even traffic for upgrading: Traditional vs revised approaches

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**The Message**

- 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.
- Need for appropriately designed low volume sealed roads.

---

**Why Invest in LVSRs?**

- Provide more sustainable, cost-effective (LCC) solutions in terms of all weather passability.
- Reduce depletion of scarce, natural resources.
- Reduce health problems.
- Reduce institutional capacity requirements.
- Reduce plant requirements.
- Reduce accident problems.
- Satisfy wishes of road users.

---

**LVSRs – The Reality**

- Not possible to upgrade all gravel roads.
- However, many thousands of km of rural access roads carrying light traffic could be justifiably upgraded using a LVSR approach coupled with an appropriate “spot improvement” strategy.
- Guideline provides guidance on achieving this objective.

---

**LVSRs – The Reality**

- Seven dimensions of LVSR sustainability: A prerequisite for success.

---

**AFCAP**

- Cost vs Quality of Service

    - Well designed
    - Engineered Gravel
    - Treated Gravel Roads
    - Sealed Low Volume Roads
    - Well maintained
    - Engineered Gravel

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**Private and confidential**

- The Message
- Why Invest in LVSRs?
- LVSRs – The Reality
- AFCAP

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- Background
- Motivation for LVSRs
- Characteristics of LVSRs
- Typical methods for LVR pavement design
- Overview of DCP-DN Design Method
- Surfacing Options for LVRS
- Drainage considerations
- Summary

Definition of LVR?

- No internationally accepted definition of a LVR.
- In developed countries such as the USA, definition typically applies to roads carrying about 400 vehicles per day (vpd).
- In developing countries, figure that is currently, typically, used is about 350 vpd PLUS a design traffic loading not exceeding about 1 MESA.
- Neither of above definitions provides a complete picture of the characteristics of a LVR.
- Unique characteristics of LVRS challenge conventional engineering practice in terms of pavement and materials engineering, geometric design, road safety and maintenance.
- More holistic definition required

Definition of LVR

- Almost exclusive reliance on use of naturally occurring, often non-standard materials, many of which are quite moisture sensitive.
- Adoption of an “Environmentally Optimized Design” (EOD) approach in which the road is designed to suit a variety of task and environmental factors such as rainfall, available materials, construction capacity, terrain, flood risk, etc., in the most cost-effective and sustainable manner.
- “Relaxation” of geometric design standards within an “Extended Domain Design” context without undue increase in the risk of road users, including a significant amount of non-motorized traffic in urban/per-urban areas, coupled with a focus on traffic safety measures in built up areas.

Appropriate LVSR Standard?

- Pavements may be constructed using non-standard materials
- Geometric design standards may be relaxed without undue increase to the risk of road users
- Deterioration of road is primarily driven by environmental factors, with traffic load a lesser factor in deterioration
- Conventional economic analysis often cannot justify the investment of public funds in the construction and maintenance of these roads in which relatively difficult to quantify benefits of a broad socio-economic nature are likely to occur.

General Characteristics LVSRs?

- Pavements may be constructed using non-standard materials
- Geometric design standards may be relaxed without undue increase to the risk of road users
- Deterioration of road is primarily driven by environmental factors, with traffic load a lesser factor in deterioration
- Conventional economic analysis often cannot justify the investment of public funds in the construction and maintenance of these roads
- Above characteristics challenge conventional engineering in a variety of ways, such as pavement and materials engineering, geometric design and road safety considerations, etc.
Use of Non-Standard Materials

- Locally available, but possible non-standard, materials should play a significant role within LVSR Standards and Specifications. Unfortunately, force of habit and rigid application of conventional specifications & lack of innovation have suppressed the more wide-spread use of local materials.

- Rigid to make specifications fit the materials rather than materials fit the specifications. In other words – “what appropriate road can I build with these materials?” rather than “Where can I find materials to meet these general specs.”

Use of Appropriate Standards

Examples of LVSRs which are of different standards but all provide appropriate levels of service in relation to the traffic carried.

Dominant Mode of Deterioration?

Deterioration of a LVR is driven primarily by environmental factors, with traffic load a lesser factor in deterioration.

Approach to Design

Adoption of “Environmentally Optimized Design” (EOD) approach

- EOD – utilising the available resources of budget, manpower and materials to meet the challenges of the “road environment” to provide appropriate access in the most cost effective and sustainable manner.

- EOD – offers a spectrum of options and solutions for providing low-volume rural road access ranging from a Spot Improvement to a whole link length.

The Road Environment

Factors to consider in the design of LVSRs

Use of Appropriate Specs

Design specs should reflect:

- Road environment
- Level of traffic
- Influence of climate
- Drainage
- Type of material

Specifications should be “tailored” to suit locally available materials as required.
Ensure adequate drainage – fundamental!

- $h_{\text{min}}$ and $d_{\text{min}}$
- $h_{\text{min}} > 750 \text{ mm}$
- $d_{\text{min}} > 150 \text{ mm}$

Control of Moisture

- 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

Optimization of Local Moisture Conditions

- 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

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/effect lateral moisture penetration under carriageway

Avoiding permeability inversion facilitates good internal drainage

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Sealed shoulders reduce/effect lateral moisture penetration under carriageway

Avoiding permeability inversion facilitates good internal drainage

Enforcement of QC/QA

- Improved construction quality control essential
  - Enforce compaction standards; thickness requirements
- Design compliance needs to be enforced
  - e.g. Crown/invert level height, sealed shouldrers
- Poor site procedures to be eliminated
  - e.g. Stockpiling and materials selection needs to be carefully carried out

Importance of Shoulder Sealing

Sealed shoulder

Unsealed shoulder

Effect of unsealed shoulder

Five main risks:

- Drainage
- Material quality
- Construction control
- Maintenance
- Traffic (overloading)

Relax ONE and keep control of others. Risk increases BUT probably acceptable

Relax TWO and risk possible failure
Overview of Presentation

- Background
- Motivation for LVSRs
- Characteristics of LVSRs
- Typical methods for LVR pavement design
- Overview of DCP-DN Design Method
- Surfacing Options for LVRS
- Drainage considerations
- Summary

Typical Pavement Design Methods

- For LVSR – Adopt empirical methods
- Options include:
  - Lab CBR based (e.g. TRL ORN 31, TRL/SADC, TRH 4)
  - DCP-DN (CSIR, TRL)
  - AFCAP DCP Manual

CBR Catalogue Approach (UK-TRL)

CBR – Very Poor Reproducibility

The CBR test is notoriously inaccurate with low reproducibility.

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

<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>807</td>
<td>16</td>
<td>± 32</td>
<td>58 – 122</td>
</tr>
</tbody>
</table>

Note: Non-reproduceable subgrade.
Private and confidential

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

CBR – Poor Correlation With Stiffness

South African Low Volume Road Investigation (CSIR)

CBR – Poor Correlation With Performance

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

CBR Method - Points to Ponder

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

PI – Poor Correlation With Performance

Mozambique Back-Analysis Project

PM – Poor Correlation With Performance

Mozambique Back-Analysis Project
Factors Affecting Variability of Soil Test Results

- The sample measured is not representative of the whole soil (soil variability).
- The sample properties have been altered or disturbed in the process of sampling and transportation to the laboratory (sampling errors).
- The tests themselves were not scrupulously performed according to the prescribed standard (testing errors).
- The test equipment has not been properly calibrated (calibration errors).
- Insufficiently trained and skilled personnel are used for undertaking the tests (operator errors).

Traditional Approaches - Points to Ponder

"Previously, all pavement materials were evaluated by classification tests, such as grading and plasticity.

Research is now beginning to replace these criteria with tests and specifications based on the measurement of the required engineering properties of strength and stiffness and to a lesser extent upon strict compliance with plasticity and grading requirements".

Dr. John Metcalf, Deputy Director, ARRB
27th ARRB Regional Symposium, Queensland, 1989.

Need to consider alternative design approach
- Should be research based, relatively simple to apply, robust and performance-related
Dynamic Cone Penetrometer (DCP)

- 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.

DCP Test and Output

- 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.

Development of DCP Design Method

- 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

Relationship between DN and CBR

- CBR/DCP relationship based on 2000+ measurements in South Africa

DCP Design Approach

- Integration of In Situ and Required Strength Profiles
Required Strength Profiles by Traffic Class

<table>
<thead>
<tr>
<th>Traffic Class</th>
<th>LE 0.01</th>
<th>LE 0.03</th>
<th>LE 0.05</th>
<th>LE 0.1</th>
<th>LE 0.3</th>
<th>LE 0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>E80 x 10 Base</td>
<td>DN ≤ 6</td>
<td>DN ≤ 5</td>
<td>DN ≤ 3</td>
<td>DN ≤ 4</td>
<td>DN ≤ 2</td>
<td>DN ≤ 2</td>
</tr>
<tr>
<td>2x 80 mm BAAMGTO</td>
<td>DN ≤ 9</td>
<td>DN ≤ 7</td>
<td>DN ≤ 4</td>
<td>DN ≤ 6</td>
<td>DN ≤ 4</td>
<td>DN ≤ 4</td>
</tr>
<tr>
<td>150-300 mm Subbase</td>
<td>DN ≤ 27</td>
<td>DN ≤ 21</td>
<td>DN ≤ 14</td>
<td>DN ≤ 18</td>
<td>DN ≤ 14</td>
<td>DN ≤ 14</td>
</tr>
<tr>
<td>2x 80 mm BAAMGTO</td>
<td>DN ≤ 33</td>
<td>DN ≤ 25</td>
<td>DN ≤ 19</td>
<td>DN ≤ 12</td>
<td>DN ≤ 8</td>
<td>DN ≤ 8</td>
</tr>
<tr>
<td>450-750 mm In situ material</td>
<td>DN ≤ 40</td>
<td>DN ≤ 33</td>
<td>DN ≤ 25</td>
<td>DN ≤ 21</td>
<td>DN ≤ 14</td>
<td>DN ≤ 13</td>
</tr>
<tr>
<td>650-800 mm In situ material</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>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 Catalogue

Road Design Process

1. **Preliminary Road Evaluation**
   - **General assessment**
     - Desk study
     - Consultations with local people
     - Geometric and road safety assessment
     - Traffic assessment
     - Climate assessment
     - Materials assessment and laboratory testing
   - **Visual assessment**
     - Road condition
     - Drainage and erosion
   - **Structural assessment**
     - DCP Survey

2. **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**

Strip Map – Output of Visual Assessment

DCP Design – General Design Procedure
DCP Design Procedure

1. Soften Design Pavement
2. Undertake DCP Survey
3. Determine Traffic Class
4. Determine DP Survey
5. Determine moisture content along road pavement
6. Obtain DN values in pavement layers of entire road (from DCP programme)
7. Determine uniform sections (CUSUM analysis)
8. Adjust DN values for design moisture content
9. Determine required LSP for each uniform section
10. Compare in situ LSP with required LSP for each uniform section
11. Determine upgrading requirements

Step 1 - Design Period

- Design data reliability
- Importance/level of service
  - Low: 10 yrs
  - High: 15 yrs

Steps 2 – Determine Design Traffic

Lane Width Adjustment Factors

<table>
<thead>
<tr>
<th>Class Section</th>
<th>Paved width</th>
<th>Corrected design traffic loading (ESA)</th>
<th>Explanatory notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single carriageway</td>
<td>&lt; 3.5 m</td>
<td>Double the sum of ESAs in both directions</td>
<td>The driving pattern on this cross-section is very channelized.</td>
</tr>
<tr>
<td>Min. 3.5 m but less than 4.5 m</td>
<td></td>
<td>The sum of ESAs in both directions</td>
<td>Traffic in both directions uses the same lane.</td>
</tr>
<tr>
<td>Min. 4.5 m but less than 6 m</td>
<td></td>
<td>80% of the ESAs in both directions</td>
<td>To allow for overlap in the centre section of the road.</td>
</tr>
<tr>
<td>&gt; 6 m or wider</td>
<td></td>
<td>ESAs in the heaviest loaded direction</td>
<td>Minimal traffic overlap in the centre section of the road.</td>
</tr>
<tr>
<td>More than one lane in each direction</td>
<td></td>
<td>80% of the total ESAs in the studied direction</td>
<td>The majority of vehicles use one lane in each direction.</td>
</tr>
</tbody>
</table>

Determination of Power Exponent

<table>
<thead>
<tr>
<th>Traffic Class</th>
<th>Cumulative Number of ESAs (CESA – one direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LE 0.01</td>
<td>0.003 – 0.01</td>
</tr>
<tr>
<td>LE 0.03</td>
<td>0.01 – 0.03</td>
</tr>
<tr>
<td>LE 0.10</td>
<td>0.03 – 0.10</td>
</tr>
<tr>
<td>LE 0.30</td>
<td>0.10 – 0.30</td>
</tr>
<tr>
<td>LE 0.70</td>
<td>0.30 – 0.70</td>
</tr>
<tr>
<td>LE 1.0</td>
<td>0.70 – 1.0</td>
</tr>
</tbody>
</table>

Step 3 – Determine Traffic Class
Step 4 – Undertake DCP Survey

<table>
<thead>
<tr>
<th>Road condition</th>
<th>Frequency of testing/km²</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 fast and DSCP 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.

Step 5 – 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.

Step 6 – Obtain DN Values Along Road

DCP provides a good “picture” of in situ ground conditions.

Step 7 – Determine Uniform Sections

Step 8 – Adjust DN Values for Moisture Environment

Anticipated long-term in-service moisture content in pavement

<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>Drier than at time of DCP survey</td>
<td>Design traffic &lt; 0.5 MESA</td>
</tr>
<tr>
<td>Same as at time of DCP survey</td>
<td>20</td>
</tr>
<tr>
<td>Wetter than at time of DCP survey</td>
<td>80</td>
</tr>
</tbody>
</table>

Anticipated long-term in-service moisture content in pavement

<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>0.00</td>
<td>1</td>
<td>2.29</td>
<td>20# 50# 80#</td>
</tr>
<tr>
<td>0.50</td>
<td>2</td>
<td>4.64</td>
<td></td>
</tr>
<tr>
<td>0.75</td>
<td>3</td>
<td>5.50</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>4</td>
<td>6.07</td>
<td></td>
</tr>
<tr>
<td>1.25</td>
<td>5</td>
<td>5.24</td>
<td></td>
</tr>
<tr>
<td>1.50</td>
<td>6</td>
<td>5.37</td>
<td></td>
</tr>
<tr>
<td>1.75</td>
<td>7</td>
<td>5.87</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>8</td>
<td>6.99</td>
<td></td>
</tr>
<tr>
<td>2.25</td>
<td>9</td>
<td>10.12</td>
<td></td>
</tr>
</tbody>
</table>

Anticipated long-term in-service moisture content in pavement

Drier than at time of DCP survey

Wetter than at time of DCP survey

Step 8 – Adjust DN Values for Moisture Environment
Step 8 – Adjust DN Values for Moisture Environment

1. **Dry during DCP test**
   - 20th % DN: 3.46
   - 80th % DN: 8.19

2. **Long-term moisture in-service**
   - 20th % DN: 5.24
   - 80th % DN: 10.82

3. **Wet during DCP test**
   - 20th % DN: 2.82
   - 80th % DN: 6.76

**Test methods**

**Step 9 – Determine In Situ LSP For Each Uniform Section**

- **Collective DCP strength profiles**
- **Average and extreme DCP strength profiles**

**Step 10 – Required LSP for Uniform Section**

<table>
<thead>
<tr>
<th>Traffic Class</th>
<th>LE 0.1</th>
<th>LE 0.3</th>
<th>LE 0.6</th>
<th>LE 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>E80 ≤ 10%</td>
<td>6.30-6.90</td>
<td>6.63-7.30</td>
<td>10.86-12.00</td>
<td>36.06-38.00</td>
</tr>
<tr>
<td>10% - 15%</td>
<td>6.30-6.90</td>
<td>7.63-8.30</td>
<td>10.86-12.00</td>
<td>36.06-38.00</td>
</tr>
<tr>
<td>15% - 30%</td>
<td>6.30-6.90</td>
<td>7.63-8.30</td>
<td>10.86-12.00</td>
<td>36.06-38.00</td>
</tr>
<tr>
<td>30% - 45%</td>
<td>6.30-6.90</td>
<td>8.63-9.30</td>
<td>11.86-12.00</td>
<td>38.66-38.00</td>
</tr>
<tr>
<td>45% - 60%</td>
<td>6.30-6.90</td>
<td>9.63-10.30</td>
<td>12.86-12.00</td>
<td>40.66-38.00</td>
</tr>
<tr>
<td>60% - 70%</td>
<td>6.30-6.90</td>
<td>10.63-11.30</td>
<td>13.86-12.00</td>
<td>42.66-38.00</td>
</tr>
<tr>
<td>70% - 80%</td>
<td>6.30-6.90</td>
<td>11.63-12.30</td>
<td>14.86-12.00</td>
<td>44.66-38.00</td>
</tr>
<tr>
<td>80% - 90%</td>
<td>6.30-6.90</td>
<td>12.63-13.30</td>
<td>15.86-12.00</td>
<td>46.66-38.00</td>
</tr>
<tr>
<td>90% - 100%</td>
<td>6.30-6.90</td>
<td>13.63-14.30</td>
<td>16.86-12.00</td>
<td>48.66-38.00</td>
</tr>
</tbody>
</table>

**Step 11 – Compare In Situ & Required LSP for Uniform Section**

**Step 12 – Determine Upgrading Requirements**

- **Required DN Value for LV 0.3**

<table>
<thead>
<tr>
<th>Section no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-150</td>
<td>≤ 3.2</td>
<td>4.87</td>
<td>4.90</td>
<td>4.93</td>
<td>4.45</td>
<td>6.57</td>
<td>3.95</td>
</tr>
<tr>
<td>150-300</td>
<td>≤ 6</td>
<td>10.47</td>
<td>7.75</td>
<td>10.07</td>
<td>5.37</td>
<td>5.99</td>
<td>7.11</td>
</tr>
<tr>
<td>300-450</td>
<td>≤ 12</td>
<td>9.69</td>
<td>8.78</td>
<td>10.27</td>
<td>7.79</td>
<td>7.08</td>
<td>9.68</td>
</tr>
</tbody>
</table>

**Comparison of in situ and required layer strength profiles for uniform sections to assess upgrading requirements**
**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.

---

**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 25 – 50 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 or lightly stabilized materials.
- Very hard cemented layers in the pavement structure.
- The possibility of not recording very weak or thin layers when taking depth measurements every 5 blows.
- Poorly executed tests (hammer not falling the full distance, non-vertical DCP, excessive movement of the depth measuring rod, etc.).
- Changes to standard specifications and the associated bidding documents.
- As with all empirical methods, use outside the type of environment (materials, climate, traffic, etc.) in which it was developed.
Overview of Presentation

- Background
- Motivation for LVSRs
- Characteristics of LVSRs
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- Drainage considerations
- Summary

Bituminous Surfacing Options

Menu of surfacing options for consideration

Non-Bituminous Surfacing Options

- Stone paving
  - Cobble Stone
- Fired clay or concrete brick
  - Unmortared/mortared joints
- Concrete
  - Non-reinforced concrete

Examples of Non-Bituminous Surfacings

- Burnt clay brick
- Cobble stone
- Reinforced concrete

Factors Affecting Choice of Surfacing

- Traffic (volume and type).
- Pavement (type – strength and flexural properties).
- Materials (type and quality).
- Environment (climate – temperature, rainfall, etc.).
- Operational characteristics (geometry, gradient, curvature, etc.).
- Safety (skid resistance - surface texture, etc.).
- Construction (techniques and contractor experience).
- Maintenance (capacity and reliability).
- Economic and financial factors (available funding, life cycle costs, etc.).
- Other external factors.

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Drainage – Key Considerations

- Drainage channels
  - Side drains
  - Erosion control devices; scour checks; lined drains.

<table>
<thead>
<tr>
<th>Crown height, h (m)</th>
<th>Unlined drains</th>
<th>Lined drains</th>
</tr>
</thead>
<tbody>
<tr>
<td>g = 1%</td>
<td>0.75</td>
<td>0.65</td>
</tr>
<tr>
<td>g &gt; 1%</td>
<td>0.65</td>
<td>0.65</td>
</tr>
</tbody>
</table>

- Natural stone scour check
- Mitre drain

Avoid this cross section at all costs!

Drainage – Key Considerations

Examples of DCP Designed Roads

- Danger Point road, South Africa (10 years after construction)
- Road D379 Kiambu, Kenya (after 2 years)

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Benefits of Adopting New Approaches

- Application of locally derived, appropriate technology
- Reduced life cycle costs of LVSR provision
- Facilitating socio-economic growth and development and poverty alleviation
- $150,000/km*
- $300,000/km*

* Malawi experience
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
Training on the Use of the DCP Pavement Design Method for Low Volume Sealed Roads in Kenya
Ref: AFCAP/KEN/112/A

Training Modules 3, 4 and 5

Mike Pinard and Jon Hongve

Module 3 – WinDCP Software

Learning objectives:
• Becoming familiar with the relevant features of the design and analysis tool
• Being able to
  – create and open and save project files
  – define DCP design curves
  – enter DCP data
Create new or open project

• Click on the WinDCP icon on your desktop or “Start/All programmes/WinDCP”
• Click on “Create new project”

Create new or open project

• Enter name of Region, Road No, Project date (date of DCP measurements), and File Name
• Click on the button with three dots to the right of the file name to select storage location. Default storage location is C:/Program files/WinDPC51/Projects/. Change the storage location to C:/Documents/My Documents/Project name/.
Create new or open project

- Click on the scroll arrow next to the Projects folder to open up the explorer window
- Click on “Libraries”, then “Documents”

Create new or open project

- Click on the “New Folder” button
Create new or open project

- Enter name of new project
- Click “Open”
- Click “Save”
- Click “OK”

Defining the DCP Design Curve

From your traffic count and axle load data, the cumulative number of equivalent standard axles has been calculated, say 150,000 over a 15 year design period. The DCP Design Curve is defined in the DCP Design Catalogue. For this example, use traffic class LE 0.3.

![Table 5-1: DCP design catalogue for different traffic classes](image)
Defining the DCP Design Curve

• Click on “System”, then “Design curves configuration” in the top menu

Defining the DCP Design Curve

• Click on the scroll arrow next to “Heavy traffic”
• Select “User defined 1”
Defining the DCP Design Curve

- Enter the layer thicknesses and DN values according to the DCP Design Catalogue for LE 0.3
- Click “OK”

Entering Sample DCP measurement data

- Click “Insert”, then “New measurement” or the new measurement button in the top menu
Entering Sample DCP measurement data

- Change the first Measurement number to 1. For the following measurements, change to the next higher number
- Enter distance from starting point (always record data in increasing chainages)
- Select the position of the measurement (predefined values from 1 to 9)
- Enter the Survey date (this date defaults to “today’s date” and must be changed to “Survey date” for each measurement)
- Select the User Defined 1 DCP Design Curve
- Select Road Category C – 80P, which defines the percentiles (20th or 80th) to be used for the design based on in situ moisture condition at the time of the DCP measurements relative to expected in service moisture condition in the pavement
- “Base type”, “Road condition” and “Moisture condition” can be left at default values
Entering Sample DCP measurement data

- Click on “Point list”
- Enter DCP data for the first measurement

Module 4 – Project DCP data entry

In this module, the trainees will enter the DCP project data into the WinDCP software for analysis and design

Learning objectives:
- Quality assurance during data collection and entry
- Being able to enter DCP data systematically and correctly
- Becoming familiar with
  - WinDCP report options
  - Single point and Average analysis
- Learn how to transfer data to Excel for further analysis
Quality assurance during data collection and data entry

- The foot of the ruler should remain in the same position during DCP measurements.
- The operators must concentrate on their task during DCP measurement.
- The person reading the measurements off the ruler should read the number out loud. In that way the other persons may detect any misreading of the results.
- Care must be taken to record data on site such that they are legible to the person entering the data.
- When entering data it is advisable to have one person reading out the measurements and another person repeating the numbers and recording them.
- The programme will not accept DCP data in descending order and will warn about this before saving the data.
- The last DCP measurement should always be higher than 800mm plus the reading at zero blows, otherwise the programme will suggest automatic extrapolation based on the last two measurements or manual extrapolation.

Entering DCP measurements

- Click “Insert”, then “New measurement” or the new measurement button in the top menu.
Entering DCP measurements

- Change the measurement number to the next higher number (if you forget to do this and do for instance a Single Point Analysis, you will end up having two measurements with the same number and can only change this by deleting and re-entering the measurement)

- Enter the distance from the starting point
- Select measurement position
- Enter the Survey date
- Enter the DCP data in the point list

Report options

System settings

- Click on “System”, then “DCP system configuration” in the top menu
- Select the options shown in the screen shot.
- Click “OK”
System settings

- Click “System”, then “Report options” in the top menu
- Tick all the boxes as shown
- Click “Ok”

Single point analysis

- Click the “Single point analysis” button
- Select the measurement to analyse
- Click “OK”
Single point analysis

- The report screen gives an immediate impression of the strength and balance of the pavement
  - Weighted average penetration per layer (compared to the DCP design catalogue)
  - Graphical presentation in the Layer Strength Diagram of the layer strength compared to the DCP design curve. Yellow colour indicates weaker layer than required, green indicates sufficient strength.
The Layer Strength Diagram

- The dotted black line is the User defined design curve as per the DCP design catalogue
- The whole red line is the weighted average penetration per layer
- The two dotted red lines are the 20\textsuperscript{th} percentile (to the left of the red line) and 80\textsuperscript{th} percentile (to the right of the red line) respectively
- Depending on the moisture condition at the time of the DCP measurements, we want the 20\textsuperscript{th} percentile (if it is wetter than expected in service moisture) or the 80\textsuperscript{th} percentile (if it is drier than expected in service moisture) to be to the left of the DCP design curve (with lower or equal DN value / higher strength than specified).

Average analysis

- Click the “Average analysis” button
Average analysis

- Define the layers as shown to correspond to the DCP Design Catalogue
- Select “Granular” base, “User defined 1” design curve, “C-80P” road category. Leave “Road condition” and “Moisture condition” at default values.
- Select points to analyse by clicking the left > or >> to move selected measurements to the right, < or << to deselect measurements.
- Click “Save as” to give the average analysis a descriptive name (so that you understand it later)
- Click “OK”

Average analysis

- The output report is exactly the same as for Single point analysis, only now the result is for the average of the selected points.
- The Average analysis is used once the Uniform sections have been indentified
Transfer data to Excel

• For each measurement, transfer DSN800 and the Weighted Average DN value for each layer into a table as shown below:

<table>
<thead>
<tr>
<th>Test no</th>
<th>Chainage (m)</th>
<th>Offset</th>
<th>Date</th>
<th>DSN800</th>
<th>0-150 mm</th>
<th>151-300 mm</th>
<th>301-450 mm</th>
<th>451-600 mm</th>
<th>601-800 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.010</td>
<td>CL</td>
<td>03.12.12</td>
<td>224</td>
<td>4.37</td>
<td>2.04</td>
<td>2.97</td>
<td>5.1</td>
<td>7.02</td>
</tr>
<tr>
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<td>0.310</td>
<td>CL</td>
<td>03.12.12</td>
<td>157</td>
<td>7.07</td>
<td>4.37</td>
<td>3.07</td>
<td>6.06</td>
<td>9.96</td>
</tr>
<tr>
<td>7</td>
<td>0.410</td>
<td>CL</td>
<td>03.12.12</td>
<td>209</td>
<td>4.16</td>
<td>3.76</td>
<td>2.62</td>
<td>4.28</td>
<td>7.66</td>
</tr>
<tr>
<td>11</td>
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<td>CL</td>
<td>03.12.12</td>
<td>165</td>
<td>4.28</td>
<td>3.1</td>
<td>5.1</td>
<td>6.78</td>
<td>9.88</td>
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<tr>
<td>13</td>
<td>1.410</td>
<td>CL</td>
<td>03.12.12</td>
<td>167</td>
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<td>5.84</td>
<td>6.81</td>
<td>3.45</td>
<td>4.69</td>
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<td>176</td>
<td>14.34</td>
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<td>6.79</td>
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<td>181</td>
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<td>3.09</td>
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<td>6.04</td>
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<tr>
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<td>CL</td>
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<td>157</td>
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<td>4.37</td>
<td>3.07</td>
<td>6.06</td>
<td>9.96</td>
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<tr>
<td>23</td>
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<td>2.0 RHS</td>
<td>04.12.12</td>
<td>90</td>
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<td>7.1</td>
<td>11.52</td>
<td>13.61</td>
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<tr>
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<td>2.66</td>
<td>5.22</td>
<td>9.63</td>
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<tr>
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<td>3.300</td>
<td>2.5 LHS</td>
<td>04.12.12</td>
<td>71</td>
<td>13.69</td>
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<td>7.67</td>
<td>12.21</td>
<td>19.21</td>
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<td>04.12.12</td>
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<td>2.82</td>
<td>4.94</td>
<td>9.28</td>
</tr>
<tr>
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<td>4.100</td>
<td>2.0 RHS</td>
<td>04.12.12</td>
<td>156</td>
<td>7.32</td>
<td>5.29</td>
<td>6.15</td>
<td>3.51</td>
<td>5.36</td>
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<tr>
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<td>2.0 LHS</td>
<td>04.12.12</td>
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<td>4.56</td>
<td>7.00</td>
<td>11.32</td>
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<tr>
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<td>2.5 RHS</td>
<td>04.12.12</td>
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<td>7.44</td>
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<tr>
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<td>4.700</td>
<td>2.5 LHS</td>
<td>04.12.12</td>
<td>76</td>
<td>11.03</td>
<td>12.29</td>
<td>6.83</td>
<td>11.28</td>
<td>18.81</td>
</tr>
<tr>
<td>34</td>
<td>5.100</td>
<td>2.5 LHS</td>
<td>05.12.12</td>
<td>73</td>
<td>10.77</td>
<td>30.5</td>
<td>16.55</td>
<td>9.39</td>
<td>10.6</td>
</tr>
<tr>
<td>35</td>
<td>5.300</td>
<td>2.0 RHS</td>
<td>05.12.12</td>
<td>195</td>
<td>4.04</td>
<td>2.08</td>
<td>3.08</td>
<td>6.11</td>
<td>9.89</td>
</tr>
<tr>
<td>36</td>
<td>5.500</td>
<td>CL</td>
<td>05.12.12</td>
<td>210</td>
<td>3.89</td>
<td>4.28</td>
<td>2.34</td>
<td>5.14</td>
<td>7.99</td>
</tr>
<tr>
<td>37</td>
<td>5.700</td>
<td>2.0 RHS</td>
<td>05.12.12</td>
<td>180</td>
<td>4.05</td>
<td>3.19</td>
<td>3.33</td>
<td>6.65</td>
<td>9.17</td>
</tr>
<tr>
<td>39</td>
<td>6.100</td>
<td>CL</td>
<td>05.12.12</td>
<td>176</td>
<td>4.07</td>
<td>3.01</td>
<td>4.24</td>
<td>7.13</td>
<td>7.58</td>
</tr>
<tr>
<td>41</td>
<td>6.410</td>
<td>2.0 RHS</td>
<td>05.12.12</td>
<td>174</td>
<td>6.09</td>
<td>3.74</td>
<td>3.36</td>
<td>5.00</td>
<td>6.94</td>
</tr>
</tbody>
</table>

Average DN per layer: 7.31 6.70 4.74 6.27 9.27

Design catalogue LV 0.3

| Module 5 – Data analysis and pavement design |

Learning objectives:

• Being able to
  – do a Cusum analysis
  – create the Cusum diagram for determination of uniform sections
  – determine uniform sections
  – do average analysis for uniform sections
  – apply correct percentile values for uniform sections
  – determine the pavement design
Cusum analysis

- Do a Cusum analysis for DSN800 and the Weighted Average DN for each layer
  - Calculate the Value for each measurement less the Average of all measurements
  - Calculate the Cumulative Sum of this new value for all measurements

Create the Cusum diagram

- Select the data ranges (values only, not headings)
  - Chainages
  - Cusum for the layers
  - Do not select the Cusum for the DSN800 as these values are of a different order and would make the graph less informative
- Select “Insert”, Scatter chart (choose the type with curved lines and no data labels)
Create the Cusum diagram

- Drag the diagram down below the data and enlarge it
- Right-click on the vertical axis
- Select “Format axis”
- Select “Horizontal axis crosses” at suitable axis value (in this case -25,0 to get the horizontal axis below the curves)
- Right-click the horizontal axis, add both major and minor gridlines

Create the Cusum diagram
Create the Cusum diagram

- Right-click on the legend, select “Select data”
- Select Series 1, click Edit, enter 0-150 mm
- Select Series 2, click Edit, enter 150-300 mm
- Do the same for the remaining data series

Create the Cusum diagram

- Drag the legend to the bottom, enlarge the chart area
Determine uniform sections

This exercise will be on the actual project data. Example of Cusum diagram and Uniform sections is shown below.

Uniform sections:

Section 1: 0+000 – 1+300
Section 2: 1+300 – 2+500
Section 3: 2+500 – 3+300
Section 4: 3+300 – 4+100
Section 5: 4+100 – 5+100
Section 6: 5+100 – 6+400
Average analysis of uniform sections

- Make a copy of the previous table and format it as shown below.

- Do average analysis for each uniform section and save each analysis with descriptive name (Uniform section 1, 2 and so on)
Average analysis of uniform sections

• Do average analysis for each uniform section and save each analysis with descriptive name (Uniform section 1, 2 and so on)

Average analysis of uniform sections

• Transfer the percentile values (in this case the 20th percentile) for each section into the Excel spreadsheet
Pavement design

- Transfer the percentile values into a new table as shown below
- Compare percentile values with the DN specification
- Shade with green the layers that are within specifications
- Shade with red those that are well outside specification
- Make a judgement for those that are marginally outside specification that may be improved with re-compaction and improved drainage, shade with amber

<table>
<thead>
<tr>
<th>Specification</th>
<th>Section 1</th>
<th>Section 2</th>
<th>Section 3</th>
<th>Section 4</th>
<th>Section 5</th>
<th>Section 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSN800</td>
<td>100</td>
<td>215</td>
<td>207</td>
<td>160,8</td>
<td>178</td>
<td>107,4</td>
</tr>
<tr>
<td>0-150 mm</td>
<td>3,2</td>
<td>3,4</td>
<td>7,16</td>
<td>7,94</td>
<td>8,06</td>
<td>7,32</td>
</tr>
<tr>
<td>151-300 mm</td>
<td>6</td>
<td>3,04</td>
<td>5,06</td>
<td>6,38</td>
<td>3,9</td>
<td>14,18</td>
</tr>
<tr>
<td>301-450 mm</td>
<td>12</td>
<td>3,18</td>
<td>3,42</td>
<td>5,12</td>
<td>3,5</td>
<td>6,1</td>
</tr>
<tr>
<td>451-600 mm</td>
<td>19</td>
<td>4,88</td>
<td>3,08</td>
<td>8,6</td>
<td>4,1</td>
<td>8,06</td>
</tr>
<tr>
<td>601-800 mm</td>
<td>25</td>
<td>8,26</td>
<td>4,2</td>
<td>12,9</td>
<td>7,34</td>
<td>11,62</td>
</tr>
</tbody>
</table>

Pavement design

- Import new layer with DN within specification on top of those that are shaded red.
- The previously weak (red) layers are then moved down in the pavement structure.
- Assess again whether they are within the specification in their new position in the pavement structure (e.g. former base is now sub-base)
- Shade with amber those that are still marginally outside specification but which can be improved in place
- Lastly check that DSN800 is within specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Section 1</th>
<th>Section 2</th>
<th>Section 3</th>
<th>Section 4</th>
<th>Section 5</th>
<th>Section 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSN800</td>
<td>100</td>
<td>215</td>
<td>207</td>
<td>160,8</td>
<td>178</td>
<td>107,4</td>
</tr>
<tr>
<td>0-150 mm</td>
<td>3,2</td>
<td>3,4</td>
<td>7,16</td>
<td>7,94</td>
<td>8,06</td>
<td>7,32</td>
</tr>
<tr>
<td>151-300 mm</td>
<td>6</td>
<td>3,04</td>
<td>5,06</td>
<td>6,38</td>
<td>3,9</td>
<td>14,18</td>
</tr>
<tr>
<td>301-450 mm</td>
<td>12</td>
<td>3,18</td>
<td>3,42</td>
<td>5,12</td>
<td>3,5</td>
<td>6,1</td>
</tr>
<tr>
<td>451-600 mm</td>
<td>19</td>
<td>4,88</td>
<td>3,08</td>
<td>8,6</td>
<td>4,1</td>
<td>8,06</td>
</tr>
<tr>
<td>601-800 mm</td>
<td>25</td>
<td>8,26</td>
<td>3,08</td>
<td>8,6</td>
<td>4,1</td>
<td>8,06</td>
</tr>
</tbody>
</table>
How to carry out DCP laboratory test

1. Secure the CBR mould to the base plate and compact sample in standard CBR mould at 93% / 95% / 98% Mod AASHTO and carry out the test at 4-days soak / OMC / 0.75 OMC and specified curing period as per the procedures in the DCP Design Manual.

2. Place the full mould on a level floor and place the annular weight on top of the compacted sample.

3. Place an empty CBR mould upside down next to the full mould as shown. Alternatively use bricks or cement blocks to provide a steady platform for the base of the DCP ruler level with or slightly higher than the top of the full mould.

4. Position the tip of the DCP cone approximately in the middle of the annular weight and knock it down carefully until the top of the 3 mm shoulder is level with the top of the sample.

5. Make sure someone holds the DCP in perfectly vertical position and take the first “zero blows” reading.

6. Knock the cone into the sample with “n” number of blows and record the reading on the ruler after every “n” blows as shown in the example. At OMC and 0.75 OMC “n” may be 5. At 4-days soak “n” may be 1 or 2. “n” does not have to be the same number for all readings.

7. Continue until just before the tip of the cone touches the base plate and stop there in order not to blunt the cone (the last reading minus the “zero blows” reading must be less than the height of the sample in the mould).
How to calculate the Weighted Average DN Value for the DCP laboratory test

1. Record the readings as shown and calculate the DN per “n” blows and Weighted Average DN per blow using the formula (see example):

\[
DN = \frac{\sum (\text{Avg DN per blow} \times \text{DN per n blows})}{\text{Penetration depth}}
\]

Note that the Weighted Average DN is different from the Average DN which is not representative for the sample.

Figure 1 shows the results of the tests. This clearly illustrates the increase in shear strength (reduced DN) with increased compaction and reduced moisture in sample.

2. Carry out at least 2 more tests on the same material and calculate the average DN for the three (or more) tests

3. Assess whether the material satisfies the design criteria from the DCP Design Catalogue

---

**Figure 1: Weighted average DN for different compaction efforts and moisture contents**
## Laboratory DN test

### 4 days soaked

<table>
<thead>
<tr>
<th>No of blows n</th>
<th>DCP Reading</th>
<th>DN per n blows</th>
<th>Avg. DN per blow</th>
<th>Avg. DN per blow</th>
<th>Avg. DN per blow</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>129</td>
<td>0</td>
<td>125</td>
<td>0</td>
<td>135</td>
</tr>
<tr>
<td>2</td>
<td>148</td>
<td>19,50</td>
<td>193</td>
<td>42.50</td>
<td>42.50</td>
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<td>2</td>
<td>193</td>
<td>12,00</td>
<td>253</td>
<td>30.00</td>
<td>30.00</td>
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<tr>
<td>2</td>
<td>220</td>
<td>14.00</td>
<td>253</td>
<td>30.00</td>
<td>30.00</td>
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<tr>
<td>2</td>
<td>255</td>
<td>17.50</td>
<td>253</td>
<td>30.00</td>
<td>30.00</td>
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</tbody>
</table>

Penetration depth: 126, 128, 111

Weighted Average DN: 16.29, 21.12, 36.64

### OMC

<table>
<thead>
<tr>
<th>No of blows n</th>
<th>DCP Reading</th>
<th>DN per n blows</th>
<th>Avg. DN per blow</th>
<th>Avg. DN per blow</th>
<th>Avg. DN per blow</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>152</td>
<td>6,20</td>
<td>150</td>
<td>6,60</td>
<td>160</td>
</tr>
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<td>5</td>
<td>170</td>
<td>3,60</td>
<td>175</td>
<td>5,00</td>
<td>190</td>
</tr>
<tr>
<td>5</td>
<td>186</td>
<td>4,40</td>
<td>215</td>
<td>8,80</td>
<td>221</td>
</tr>
<tr>
<td>5</td>
<td>205</td>
<td>3,80</td>
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<td>5</td>
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<td></td>
</tr>
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</table>

Penetration depth: 130, 139, 141

Weighted Average DN: 4.89, 7.22, 7.11

\[ \text{DN}_{\text{OMC}} / \text{DN}_{\text{98\%}} = \frac{4.89}{7.22} = 0.68 \]

### 0.75 OMC

<table>
<thead>
<tr>
<th>No of blows n</th>
<th>DCP Reading</th>
<th>DN per n blows</th>
<th>Avg. DN per blow</th>
<th>Avg. DN per blow</th>
<th>Avg. DN per blow</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>123</td>
<td>4,00</td>
<td>156</td>
<td>4,20</td>
<td>153</td>
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<tr>
<td>5</td>
<td>148</td>
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Penetration depth: 106, 125, 113

Weighted Average DN: 3.63, 4.28, 5.79
### Annex 3: Training attendance

#### Training attendance

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## Annex 4: Worked design example on Training Road E1641

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### Uniform sections

- **Section 1**
- **Section 2**
- **Section 3**
## Pavement design

<table>
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<tr>
<th>Design class LE 0.1</th>
<th>Spec. DN/layer mm</th>
<th>Section 1 0+000 - 4+800 80%-ile</th>
<th>Section 2 4+800 - 7+200 Mean</th>
<th>Section 3 7+200-8+400 Mean</th>
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<tr>
<td>0-150 mm</td>
<td>4</td>
<td>≤4,00</td>
<td>≤4,00</td>
<td>≤4,00</td>
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<tr>
<td>151-300 mm</td>
<td>9</td>
<td>4,20</td>
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<td>301-450 mm</td>
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<td>10,07</td>
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<td>451-600 mm</td>
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<td>13,80</td>
<td>18,91</td>
<td>17,40</td>
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<tr>
<td>601-800 mm</td>
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<td>23,05</td>
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<td>DSN800</td>
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Import of one layer with required DN value will ensure that all layers satisfy the design criteria.
## Annex 5: Itinerary and Activity Summary

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<tr>
<th>Date</th>
<th>Jon Hongve</th>
<th>Mike Pinard</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.01</td>
<td>Travel from Norway</td>
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<tr>
<td>15.01</td>
<td>- Meeting at KeRRA</td>
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</tr>
<tr>
<td></td>
<td>- Collection of DCP</td>
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</tr>
<tr>
<td></td>
<td>- Travel to Embu</td>
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</tr>
<tr>
<td></td>
<td>- Consolidation of list of Trainees</td>
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</tr>
<tr>
<td></td>
<td>in conjunction with KeRRA Co-</td>
<td></td>
</tr>
<tr>
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<tr>
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<td></td>
<td>for Sagana Quarry Waste</td>
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<tr>
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<td>- DCP tests and moisture sampling</td>
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<td></td>
<td>on training road assisted by</td>
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<tr>
<td></td>
<td>laboratory staff in Kirinyaga</td>
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</tr>
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<td></td>
<td>- Follow-up with KeRRA on</td>
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<td>invitation of trainees</td>
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<tr>
<td></td>
<td>on training road</td>
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<td></td>
<td>- Preparation of samples for</td>
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<td>- Compilation of initial DCP test</td>
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<td>21.01</td>
<td>- DCP tests on training road</td>
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<td>- Estimation of Design Traffic</td>
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<td></td>
<td>- Compilation of initial DCP test</td>
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<td>25.01</td>
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Annex 6: Review of the quality of DCP Equipment

1. Background

With the introduction of the DCP Design method for Low Volume Sealed Roads in Kenya, various makes of DCP equipment have been procured under the AFCAP projects. In addition, DCP equipment has been procured by the Regional Managers in Central Province following the GoK procurement regulations on the basis of quotations obtained from various suppliers.

As a result there are now at least three different makes in use within Central Province, two from South Africa and one produced in UK, that have been put to the test by collection of DCP data for design purposes. Apparently a fourth make produced in Japan was procured by the Regional Manager Kiambu. To what extent this equipment has been used at this point in time is not known, but in all likelihood it has not been extensively used. The quality of this make is therefore as yet unknown and is therefore not included in this review.

2. Purpose of the review

Key to the success of the DCP Design Method is availability of good quality, robust DCP equipment that can withstand the rigours of DCP data collection without breaking down and needing frequent repairs. Moreover, having good quality DCPs produced locally would simplify supply and repairs when needed.

From use in the field it has become evident that all three makes, the two South African made and the one made in UK, all have strong and weak points. The purpose if this review is therefore to identify and combine the best design features from all three models to make the DCP as robust and user friendly as possible.

The three makes or models are:

- TRL model (UK, manufacturer unknown)
- Dick King model (South Africa)
- RT Agencies model (South Africa)

3. The TRL Model

3.1 Carrying case

The TRL model comes in a solid carrying case made of plywood which has been reinforced in the corners. The case has internal dividers and slots for the rods and the steel ruler and compartments for spare cones and spanners etc. This should be the standard for all models.

Picture 1: Carrying case for TRL Model
3.2 Build quality
The general build quality is good with rods and cones seemingly of high quality steel (exact specifications unknown).

3.3 Assembling the DCP
3.3.1 Handle, rods and cone
The rods and cone parts are mounted together by means of threaded connections while the handle is permanently fixed to the top rod.

![Picture 2: Attachment of handle and top rod](image)

Handle is fixed on the top rod
Top rod screwed into the anvil

![Picture 3: Attachment of bottom rod to anvil](image)

Bottom rod screwed into the anvil

The threads on the bottom rod take all the strain when the hammer hits the anvil with the risk of eventually getting worn and making the connection loose. The bottom rod should rather be permanently fixed to the anvil as on the Dick King Model.

The purpose of the handle is to stop the hammer at the correct dropping height (575 mm) and to make it comfortable to hold the DCP during operation. Fixing the handle permanently to the top rod is not necessary for this purpose.

During DCP data collection the DCP is typically transported at the back of a pick-up or carried from one point to the next. It would then be convenient to remove the hammer from the top rod. A simple removable pin through a hole in the handle and top rod would hold the handle securely in place during operation and facilitate easy removal of the handle and hammer for transport between DCP points.
The TRL model has the best cone design. The cylindrical part between the treads and the cone fits tightly into the bottom rod and takes the bending strain off the thinner threaded part when the cone hits a stone.

3.3.2 Holder for ruler
The ruler is held in place to the anvil by means of a stiff plastic holder which is attached to the anvil by small bolts and steel disks.

As can be seen this connection if not very robust. The bolts broke in use and the holder got loose. While it may be relatively easy to have this repaired, a more robust arrangement similar to the Dick King Model is preferred.

3.3.3 Ruler and foot for ruler
The TRL model comes with a stainless steel ruler with mm scale. The ruler goes through a narrow slot in the holder on the anvil and is held in place on the ground by an aluminium foot.

The stainless steel ruler is robust and makes it easy to read off the mm scale.

The attachment to the foot is however not very robust and comes loose in use. The attachment with pin as shown in picture 6 is good, but the foot itself should be one piece welded together and made from mild steel.
4. The Dick King Model

4.1 Carrying bag
Unlike The TRL model, the Dick King model comes in a canvas bag with an outer pocket for spanners and spare cones etc. The bag looks solid at first sight, but experience has shown that after some time in use, the seam of the bag at the bottom end comes apart.

Packing the parts in the bag is unnecessarily difficult and the ruler supplied with the DCP is vulnerable to damage in the bag during transport.

4.2 Build quality
The general build quality is good with rods and cones seemingly of high quality steel (exact specifications unknown). The cones in particular seem to be very durable even when going through stony pavement layers.
4.3 Assembling the DCP

4.3.1 Handle, rods and cone

The handle is screwed onto the top rod. The threads on the top rod are quite deep and is weakening rod at this point. As a result the rod will tend to break at this point after some time in use due to tapping with the hammer on the handle when extracting the DCP from the ground and bending strain during transport with the hammer in place on the rod.

![Top rod has broken at the attachment of the handle](image)

The purpose of the handle is to stop the hammer at the correct dropping height (575 mm) and to make it comfortable to hold the DCP during operation. Fixing the handle with a threaded connection to the top rod is not necessary for this purpose. A simple pin attachment shown in Figure 1 through the top end of the handle would prevent breaking of the rod at this point and make it easy to remove the handle and hammer for transport in between DCP tests.

The top and bottom rods are joined at the anvil, which is split in two parts, with a threaded connection on the top rod screwing into the bottom part of the anvil.

![Joint for top and bottom rod](image)

This design is very robust. With the handle easy to remove as in Figure 1, there is no need for a threaded connection of the top rod to the anvil, thereby removing a possible weak spot.

The Dick King cones are very durable, but the design of the attachment to the bottom rod should be improved. The TRL design is recommended.
The cone is attached by means of a separate threaded pin which screws into the bottom rod. If the cone is not securely fixed to the bottom rod and it hits a stone, the threaded pin will easily bend. This has been experienced on several occasions making it difficult to remove the damaged pin either from the bottom rod or the cone itself.

4.3.2 Holder for ruler

Picture 9 shows the holder for the ruler being attached between the top and bottom part of the anvil. The anvil has notches fitting the supplied purpose made spanners. If drawn very tight before operations the connection tends to stay tight. However, the operator should check that this connection does not get loose during operation.

This is a very robust design. The round hole for the ruler should however be changed to a narrow slot for the recommended stainless steel ruler.

4.3.3 Ruler and foot for ruler

The ruler and the foot for the ruler come in one piece. This makes the packing of the ruler in the canvas bag awkward and the rather weak ruler is susceptible to damage during transport.

The scale is simply in the form of a cut-off steel measuring tape attached to an aluminium rail by rivets. The scale gets easily damaged and gets loose from the rail.

The ruler should be replaced by a stainless steel ruler similar to the one supplied with the TRL model, but with a separate foot in mild steel as recommended.
5. The RT Agencies Model
The overall build quality and design in all aspects of this model is so poor that it is not worthy of further discussion.

![RT Agencies DCP](image)

6. Extruder
Both Dick King and RT Agencies can supply DCP extruders. No experience has been gained with the Dick King extruder, but the one supplied by RT Agencies soon proved to be too weak for hard ground conditions.

A locally made extruder has proven very durable and to work perfectly. There is hence no need to import this kind of equipment to Kenya.

![Extruder](image)

7. Summary and recommendations
In summary, Dick King model with the following improvements is recommended.

<table>
<thead>
<tr>
<th>Item</th>
<th>Recommendation</th>
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<tbody>
<tr>
<td>Handle</td>
<td>Pin connection to top rod as in Figure 1</td>
</tr>
<tr>
<td>Holder for ruler</td>
<td>Round hole changed to narrow slot fitting a stainless steel ruler</td>
</tr>
<tr>
<td>Ruler</td>
<td>Should be changed to 1 m stainless steel ruler</td>
</tr>
<tr>
<td>Foot for ruler</td>
<td>Similar to the TRL model, but in one piece made from mild steel</td>
</tr>
<tr>
<td>Cones</td>
<td>Design should be similar to the TRL model</td>
</tr>
<tr>
<td>Extruder</td>
<td>To be locally made</td>
</tr>
</tbody>
</table>

Table 1: Recommended improvements to the Dick King DCP model
Certificate of Competency

Intermediate Level

in the DCP Method of Design of Low Volume Sealed Roads

has been awarded to

full name

for completing the 3-day DCP Design Course 29-31 January 2014 at Izaak Walton Inn, Embu

M I Pinard
Lead Trainer- IT Transport
31 January 2014

Mwangi Maingi
Director General - KeRRA
31 January 2014
Certificate of Competency

Intermediate Level

in DCP data collection, Operation of WinDCP Software and Laboratory DN testing

has been awarded to

(full name)

for completing the 2-day course 6 - 7 February 2014 at Izaak Walton Inn, Embu

M I Pinard
Lead Trainer- IT Transport
7 February 2014

Mwangi Maingi
Director General - KeRRA
7 February 2014