Annex 1: Classroom Training Programme

Classroom training plan – Week 1					
Date	27 January	28 January	29 January	30 January	31 January
Training sessions	Trainee categories				
		Senior Management	Designers/practitioners 1st group	Designers/practitioners 1st group	Designers/practitioners 1st group
1. session 08.30 – 10.00		**Field visit, DCP exercise**	**Module 1** **Theoretical background**	**Module 3** **WinDCP software** • Open and Create project • Saving, location of files • Data entry screen • Define design curve • DCP data entry • Q & A	**Data analysis and Pavement design (continued)** • Average analysis of uniform sections • Application of correct percentile
Break 10.00-10.30					
2. session 10.30-12.00		**Module 1** **Theoretical background** • Q & A	**Theoretical background (continued)** • Q & A	**Module 4** **Data entry** • Quality assurance of data collection and data entry • Report options • Data entry	**Data analysis and Pavement design (continued)** • Enter percentile values for each layer and section in Excel table
Lunch 12.00-13.00					
3.session 13.00 – 14.30		**Module 2** **Design principles** • Q & A	**Module 2** **Design principles**	• Single point analysis • Average analysis • Transfer data to excel • Q & A	• Determination of intervention • Import of new layer • Lab DN test
Break 14.30 – 15.00					
4. session 15.00 – 16.30		**Module 3** **Data analysis and Pavement design (demo only)** • Q & A	**Design principles (continued)** • Q & A	**Module 5** **Data analysis and Pavement Design** • Cusum analysis • Create cusum graph • Determine uniform sections	• Discussion of results • Q & A

Classroom training plan – Week 2						
Date	3 February	4 February	5 February	6 February	7 February	8 February
Training sessions	Trainee categories					
	Designers/practitioners 2nd group	Designers/practitioners 2nd group	Designers/practitioners 2nd group	Technicians Day 1	Technicians Day 2	Technicians Day 3
1. session 08.30 – 10.00	**Module 1** **Theoretical background**	**Module 3** **WinDCP software** • Opening • Create project • Saving, location of files • Data entry screen • Define design curve • DCP data entry	**Data analysis and Pavement Design (continued)** • Average analysis of uniform sections • Application of correct percentile	**Module 1** **Theoretical background** • Q & A	**Data entry (continued)** • Data entry • Q & A	**Lab testing (cont)**
Break 10.00-10.30						
2. session 10.30-12.00	**Theoretical background (continued)** • Q & A	**Module 4** **Data entry** • Quality assurance of data collection and data entry • Report options • Data entry	**Data analysis and Pavement design (continued)** • Enter percentile values for each layer and section in Excel table	**Module 2** **Design principles** • Q & A	**Module 5** **Lab testing** • Sample preparation • CBR vs DN • OMC • FMC • Lab DN value	**Lab testing (cont)**
Lunch 12.00-13.00						
3.session 13.00 – 14.30	**Module 2** **Design principles**	• Single point analysis • Average analysis • Transfer data to excel • Q & A	• Determination of intervention • Import of new layer • Lab DN test	**Module 3** **WinDCP software** • Open and Create project • Saving, location of files • Data entry screen • Q & A	**Lab testing (cont)**	**Lab testing (cont)**
Break 14.30 – 15.00						
4. session 15.00 – 16.30	**Design principles (continued)** • Q & A	**Module 5** **Data analysis and Pavement Design** • Cusum analysis • Create cusum graph • Determine uniform sections	• Discussion of results • Q & A	**Module 4** **Data entry** • Quality assurance of data collection and data entry • Report options	**Lab testing (cont)**	**Module 6** **Design example** • Putting lab work into context • Presentation of design Q & A

Annex 2: Training Modules

Republic of Kenya

AFCAP

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

Training Modules 1 and 2

Mike Pinard and Jon Hongve

Objectives of Training Programme

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"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".

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Training Programme

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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

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Training Programme-Module 1

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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 network.
- 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.

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Training Programme-Module 2

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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

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Objectives of Training Programme

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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

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Objectives of Training Programme

Module Number: 3
Course Title: WinDCP Software
Duration: 1hr 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: 2 x 1hr 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 1hr 30 mins interactive session (Designers)
2 x 1hr 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 Lab 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
- Lab testing (CBR 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

Overview of Presentation

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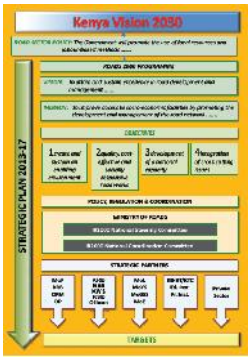
Kenya Vision 2030



Roads 2000 Strategy, Vision & Mission

CROWN AGENTS

The Roads 2000 Strategy is a method of road development and management that ensures optimum utilisation and development of locally available resources where technically; and economically feasible and in a socially responsive manner

Vision Statement

To attain and sustain excellence in road development and management that contributes to the National Development Priorities 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

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Classified Road Network

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Road Network	Administering Agency	Bitumen	Gravel	Earth	Total	%
International Trunk Roads-A	Roads Dept. of Min. of Roads and Public Works	2,886	717	152	3,755	6%
National Trunk Roads-B		1,433	842	524	2,799	4%
Primary Roads-C		2,487	3,209	1,972	7,668	12%
Secondary Roads-D	District Roads Committees	1,167	6,484	3,565	11,216	18%
Minor Roads-E		751	7,206	18,592	26,549	42%
Special Purpose Roads		214	8,724	2,366	11,304	18%
Totals		8,936	27,182	27,171	63,291	100%
%		14%	43%	43%	100%	

Management of large network of unpaved roads imposes a significant technical and financial burden on the organizations concerned

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Summary of Road Condition

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Road Class.	Good	Fair	Poor	Grand Total
Classified	10,651	31,847	19,438	61,936
Unclassified	5,440	22,165	71,345	98,950
Grand Total	16,090	54,012	90,784	160,886
CONDITION CLASSIFIED	17%	51%	31%	100%
CONDITION UNCLASSIFIED	5%	22%	72%	100%
CONDITION ALL	10%	34%	56%	100%

Poor road conditions impact adversely on the national economy

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Paved Roads and Economic Development

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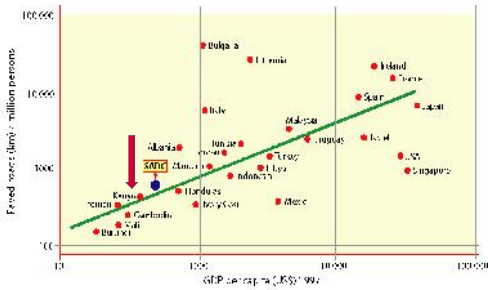

"Much scope for increasing kilometrage of paved roads in Kenya to the benefit of the national economy.

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Importance of Rural Roads in Kenya

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Before

After

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

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Overview of Presentation

CROWN AGENTS

- Background
- **Motivation for LVSRs**
- Characteristics of LVSRs
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- Summary

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Limitations of Gravel Roads

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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 looses 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

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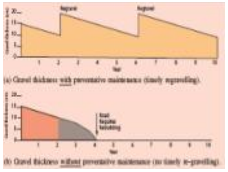

Gravel roads deteriorate rapidly if not maintained by timely grading and regravelling

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Maintaining Gravel Roads - Reality

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

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Technical Viability of Gravel Roads

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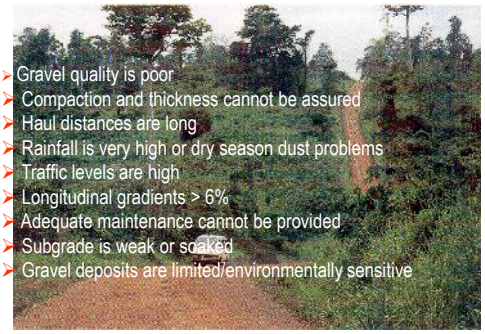
Not viable when:



- 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

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Economic Viability of Gravel Roads

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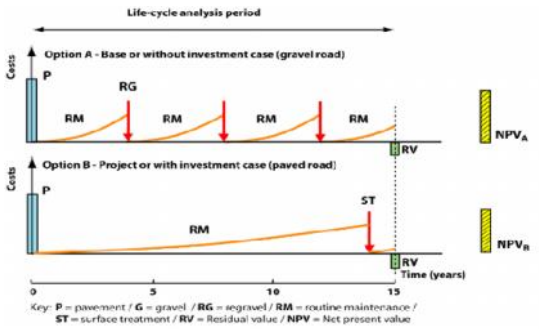

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Factors Favouring Viability of Upgrading

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Parameter	Impact
Use of more appropriate pavement designs	Reduced costs
Use of more appropriate geometric design	Reduced costs
Increased use of natural/unprocessed gravels	Reduced costs
Reduced impacts of depleted gravel resources	Reduced costs
Benefits from non-motorised transport	Increased benefits
Reduced adverse impacts of traffic on gravel roads	Increased benefits
Reduced environmental damage	Increased benefits
Quantified assessments of social benefits	Increased benefits

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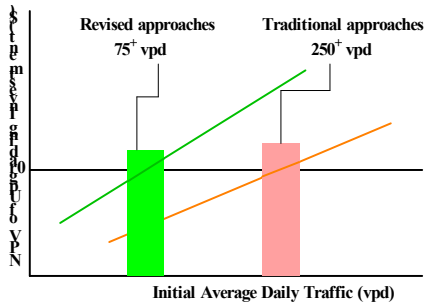
Life Cycle Cost Analysis



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

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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 of road users

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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

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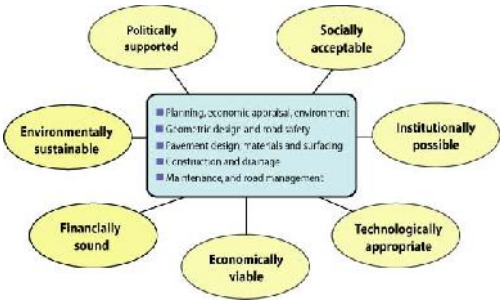
LVSRs – The Reality



Seven dimensions of LVSR sustainability: A prerequisite for success

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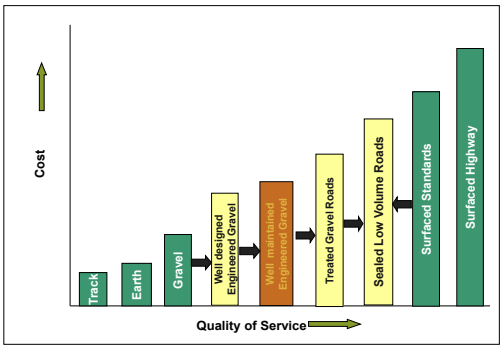
AFCAP



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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 300 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

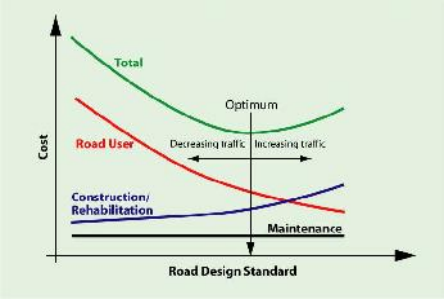
Definition of LVR

- 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.

Definition of LVR

- An alignment which is not necessarily fully "engineered", especially at very low traffic levels, in the sense that some sections may follow the existing alignment and the full length may offer variable travelling speeds that will seldom exceed about 80 km/h, as dictated by the local topography.
- A recognition that pavement deterioration is driven primarily by environmental factors (particularly moisture), with traffic loading being a lesser influential factor in deterioration, and drainage being of paramount importance;
- An appreciation that 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.

Appropriate LVSR Standard?



Level of service to be provided will depend primarily on traffic but with adequate road safety safeguards

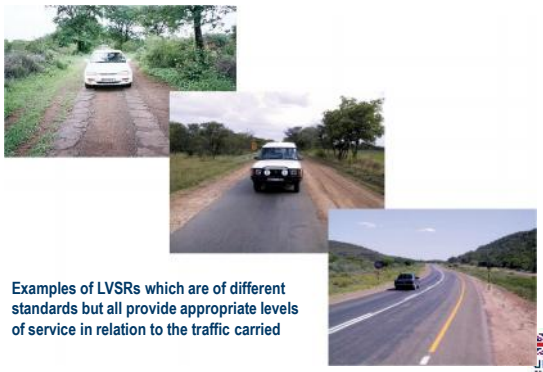
General Characteristics LVSRs?

- 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

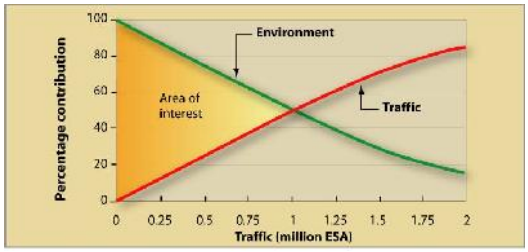
- Locally available, but possible non-standard, materials should play a significant role within LVSR Standards and Specifications. Unfortunately, force of habit and rigid application of conventional specifications & lack of innovation have suppressed the more wide-spread use of local materials
- Need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



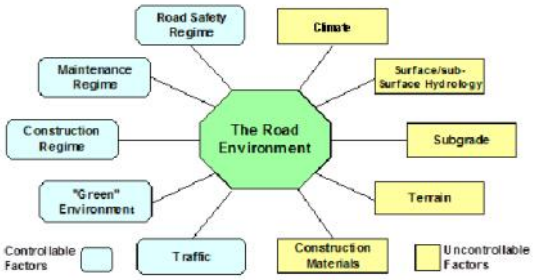
Deterioration of a LVR is driven primarily by environmental factors, with traffic load a lesser factor in deterioration

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

- Specs often insensitive to local road environment and applied in a blanket fashion irrespective of material type.
- High F.O.S often adopted to compensate for lack of intimate knowledge of road environment.
- Wrong design assumptions often made

Specifications should be "tailored" to suit locally available materials as required

Optimization of Local Moisture Conditions

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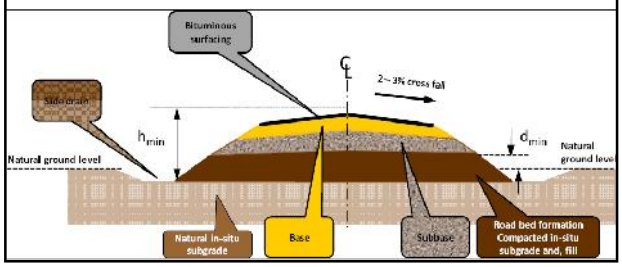
Ensure adequate drainage – fundamental!

- h_{min} and d_{min}
- h_{min} > 750 mm
- d_{min} > 150 mm



Control of Moisture

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- Control of moisture is single most important factor controlling performance of LVSRs
- Appropriate pavement configuration is critical for controlling moisture
- Factors to be considered include:
  - shoulders
  - permeability inversion
  - internal, external drainage

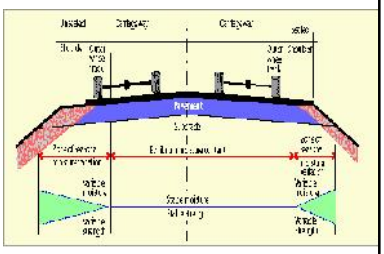

Figure 5.1 Moisture zones in a LVSR

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Ideal Cross Section

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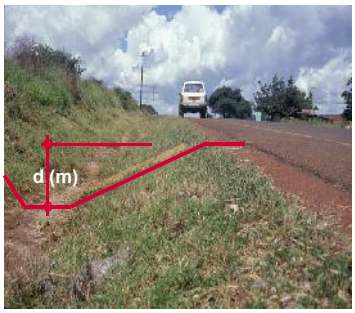

- Crown height is a critical parameter that correlates well with the actual service life of pavements constructed from natural gravels (d ≥ 0.75 m)
- Sealed shoulders reduce/ eliminate lateral moisture penetration under carriageway
- Avoiding permeability inversion facilittes good internal drainage

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Importance of Shoulder Sealing

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Enforcement of QC/QA

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

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Appreciation of Risk Factors

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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

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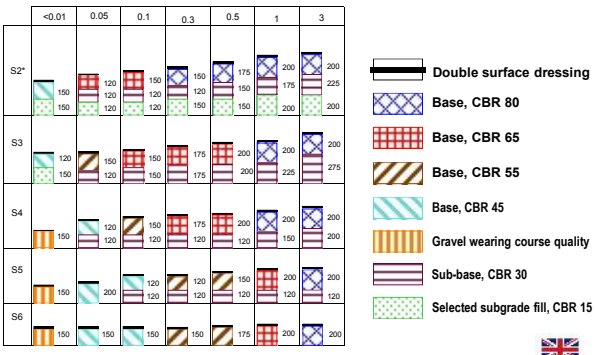
Typical Pavement Design Methods

- **Empirical methods**
  - Derived from empirical studies of pavement performance
  - Satisfactory for use provided materials, environment and traffic loading do not differ significantly from original empirical studies
- **Analytical methods**
  - Derived from theoretical studies of the mechanical behavior of the pavement

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)



Note: * Non-expansive subgrade

CBR Catalogue Approach (Kenya)

Ministry of Transport & Infrastructure	PAVEMENT STRUCTURES FOR LOW VOLUME ROADS		Type LV 2
	BASE (B)	Unbound Material (UB50)	
	SUBBASE SB)	Unbound Material (UB25)	

Subgrade		Traffic Class/Pavement Layer Thickness (mm)										Suitability
		T5-4		T5-3		T5-2		T5-1		T5-0		
Class	CBR (%)					SB	B	SB	B			
S1	2 – 5					325	150	400	150			Technically Unsuitable for T5-0; and, Economically Unjustified for T5-3 & T5-4
S2	5 – 10					150	150	200	150			
S3	7 – 13					100	150	100	150			
S4	10 – 18					100	150	100	150			
S5	15 – 30					–	150	–	150			
S6	>30					–	150	–	150			

Improvement of Subgrade (By Construction of Improved Subgrade/Capping)													
Native Subgrade Class		S1						S2			S3		
Capping / Improved Subgrade	Material	S2	S3		S4			S3	S4		S4	S5	
	Thickness (mm)	400	350	425	275	325	450	300	200	350	300	150	350
New Class		S2	S2	S3	S2	S3	S4	S3	S3	S4	S4	S4	S5

Traffic	
Class	Standard Axles
T5-0	500,000 – 1,000,000
T5-1	250,000 – 500,000
T5-2	100,000 – 250,000
T5-3	25,000 – 100,000
T5-4	< 25,000

- In areas where the mean annual rainfall is > 500mm, subgrade strength shall be determined based on CBR at 100% MDD (AASHTO T99) & 4 days soak.
- In dry areas, where the mean annual rainfall is < 500mm, subgrade strength may be determined based on unsoaked CBR at OMC or equilibrium moisture c
  UB 50 – Unbound natural or blended (mechanically stabilized) material of CBR ≥ 50% measured after 4 day soak

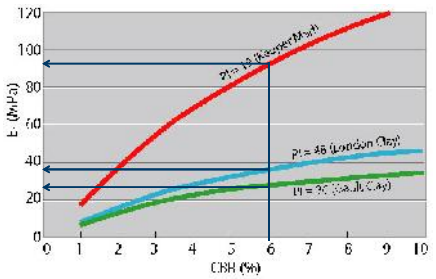
CBR – Very Poor Reproducibility

The CBR test is **notoriously inaccurate with low reproducibility.**

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

CBR	σ	95% confidence	Range
10	4	± 8	2 – 18
30	7	± 14	16 – 44
60	12	± 24	36 – 84
80?	16	± 32	58 – 122

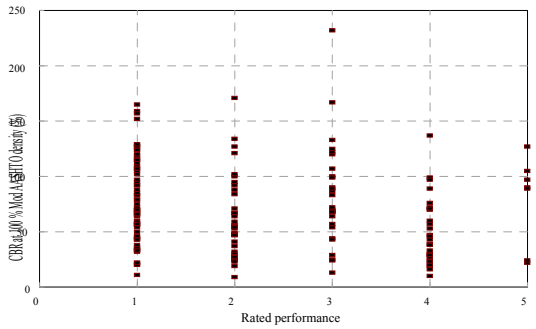
CBR – Poor Correlation With Stiffness



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

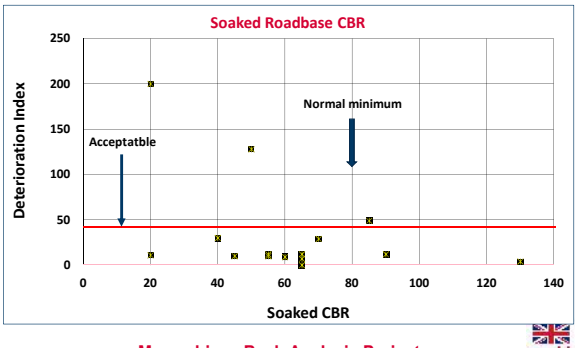
Private and confidential

CBR – Poor Correlation With Performance



South African Low Volume Road Investigation (CSIR)

CBR – Poor Correlation With Performance



Mozambique Back-Analysis Project

Private and confidential

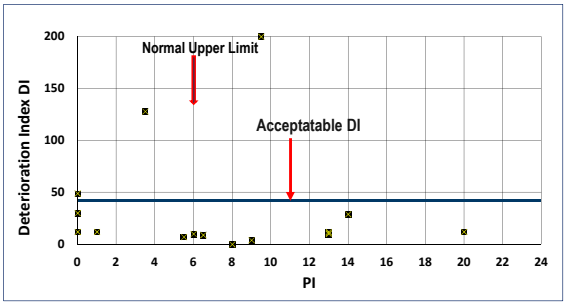
CBR Method - Points to Ponder

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

Private and confidential

PI – Poor Correlation With Performance



Mozambique Back-Analysis Project

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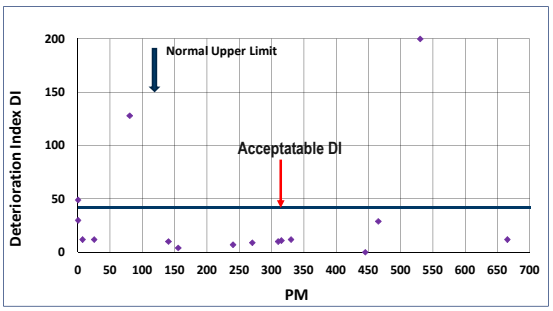
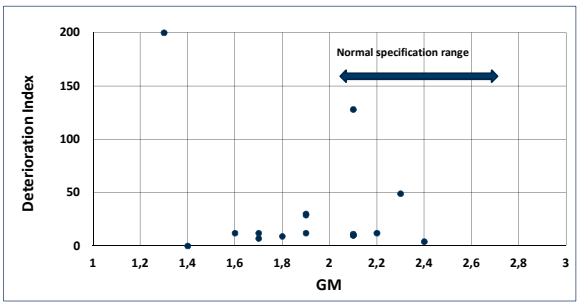
PM – Poor Correlation With Performance



Mozambique Back-Analysis Project

Private and confidential

GM – Poor Correlation With Performance



Mozambique Back-Analysis Project

Accuracy of Common Test Methods

Test	Reported CV (%)	Recommended CV (%)	Comments
CBR	17-58	25	Wide variation
Compaction (OMC)	11 - 43	20, 40	Lower value, clay soils; Higher value, sands & gravels
Compaction (MDD)	1 - 7	5	
Linear shrinkage	57 - 135	100	Refers to gravel & crushed rock; will be lower for soils.
Liquid limit	2 - 48	10	
Moisture content	6 - 63	15	
Plastic limit	9 - 29	10	
Plasticity index	7 - 79	30, 70	Lower value, clay soils; Higher value, sands & gravels

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***

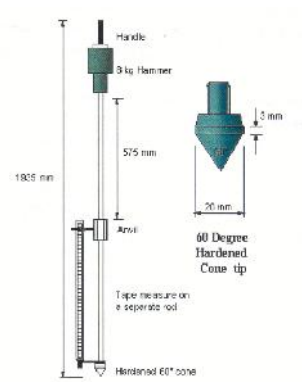
Overview of Presentation

- 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

DCP Design Method

- An alternative to the traditional CBR-based approach
- 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 tarffic categories and moisture conditions.

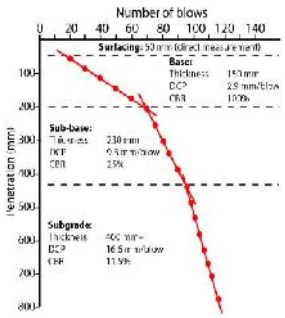
Dynamic Cone Penetrometer (DCP)



DCP test in process

DCP Test and Output

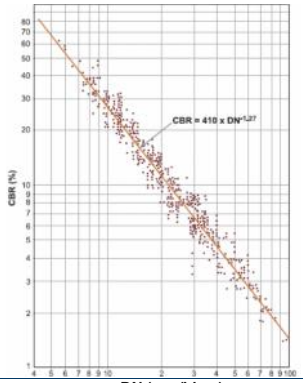
- Measures the weighted penetration per blow into a pavement through each of the different pavement layers
- Rate of penetration is a function of the in situ shear strength of the material at the in situ moisture content and density of the pavement layers at the time of testing.
- Profile in depth of the pavement gives an indication of the in situ properties of the materials in all the pavement layers up to the depth of penetration.



Development of DCP Design Method

- 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

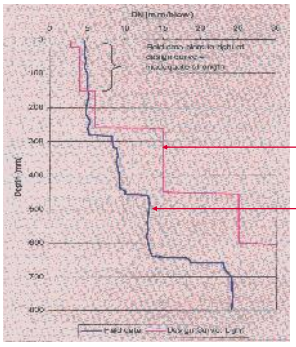


CBR-DCP relationship based on 2000+ measurements in South Africa

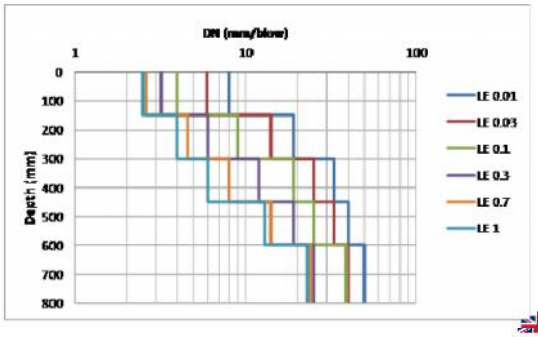
DCP Design Approach

- 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
  - Intergarating required strength profile with in situ sytrength profile

Integration of In Situ and Required Strength Profiles



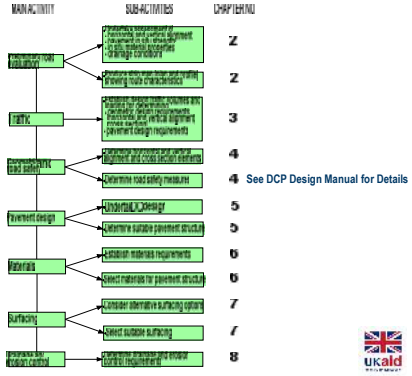
Required Strength Profiles by Traffic Class



DCP Design Catalogue

Traffic Class E80 x 10^6	LE 0.01 0.003 – 0.010	LE 0.03 0.010 – 0.030	LE 0.1 0.030 – 0.100	LE 0.3 0.100 – 0.300	LE 0.7 0.300–0.700	LE 1.0 0.700 – 1.0
0- 150mm Base ≥ 98% MAASHTO	DN ≤ 8	DN ≤ 5.9	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.6	DN ≤ 2.5
150-300 mm Subbase ≥ 95% MAASHTO	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 4.6	DN ≤ 4.0
300-450 mm subgrade ≥ 95% MAASHTO	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 8	DN ≤ 6
450-600 mm In situ material	DN ≤ 40	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 14	DN ≤ 13
600-800 mm In situ material	DN ≤ 50	DN ≤ 40	DN ≤ 39	DN ≤ 25	DN ≤ 24	DN ≤ 23
DSN 800	≥ 39	≥ 52	≥ 73	≥ 100	≥ 128	≥ 143

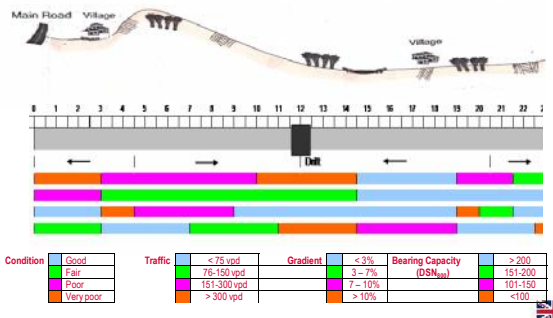
Road Design Process



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

Strip Map – Output of Visual Assessment

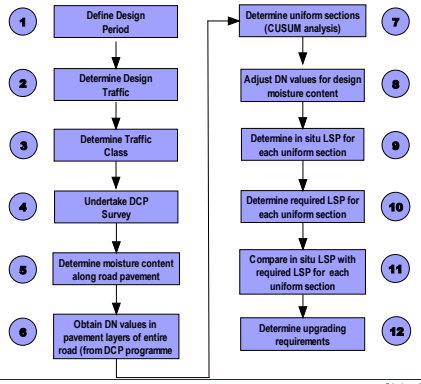


DCP Design – General Design Procedure

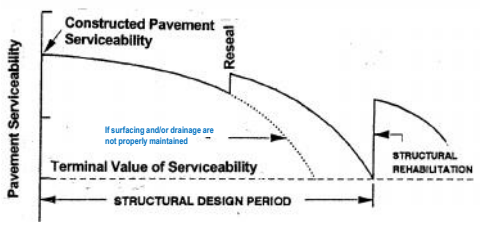
Design follows conventional procedure

- 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

DCP Design Procedure

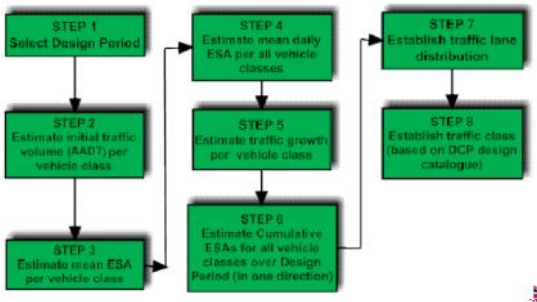


Step 1 - Design Period

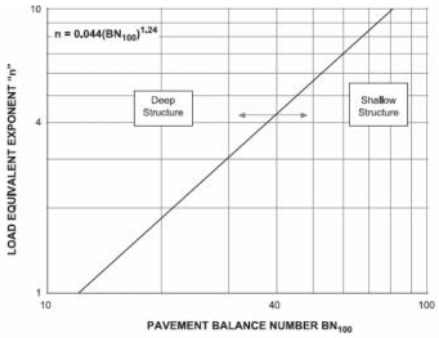


Design data reliability	Importance/level of service	
	Low	High
Low	10 yrs	10 – 15 yrs
High	10 – 15 yrs	15 – 20 yrs

Steps 2 – Determine Design Traffic



Determination of Power Exponent



Lane Width Adjustment Factors

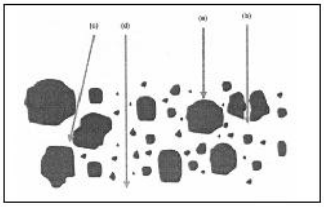
Cross Section	Paved width	Corrected design traffic loading (ESA)	Explanatory notes
Single carriageway	< 3.5 m	Double the sum of ESAs in both directions	The driving pattern on this cross-section is very channelized.
	Min. 3.5 m but less than 4.5.m	The sum of ESAs in both directions	Traffic in both directions uses the same lane
	Min. 4.5 m but less than 6 m	80% of the ESAs in both directions	To allow for overlap in the centre section of the road
	6 m or wider	Total ESAs in the heaviest loaded direction	Minimal traffic overlap in the centre section of the road.
More than one lane in each direction		90% of the total ESAs in the studied direction	The majority of vehicles use one lane in each direction.

Step 3 – Determine Traffic Class

Traffic Class	Cumulative Number of ESAs (CESA – one direction)
LE 0.01	0.003 – 0.01
LE 0.03	0.01 – 0.03
LE 0.10	0.03 – 0.10
LE 0.30	0.10 – 0.30
LE 0.70	0.30 – 0.70
LE 1.0	0.70 – 1.0

Step 4 – Undertake DCP Survey

Road condition	Frequency of testing/km*
Uniform (low risk)	5
Non-uniform (medium risk)	10
Low-lying/distressed (high risk)	20



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;

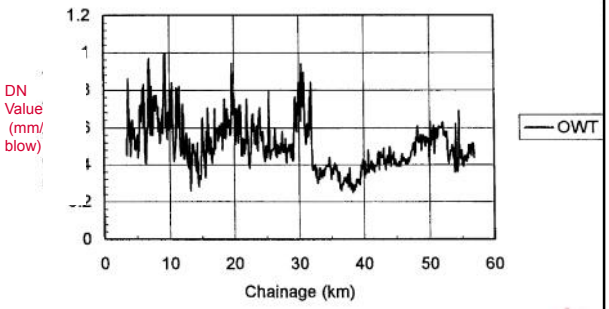
(c) cone tries to push stone aside. Result is high because of side friction generated on cone shaft;

(d) Usually provides a normal result

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.

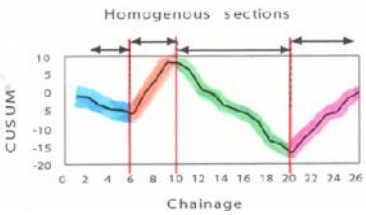
Step 6 – Obtain DN Values Along Road



DCP provides a good "picture" of in situ ground conditions

Step 7 – Determine Uniform Sections

Chainage (Km)	B: Measured DCP (DN Value -mm/blow)	C: Difference from average (C-B)	CUSUM (Accumulated values of C)
1	14	-0.2	-1.2
2	13	-0.2	-1.4
3	15	-2.2	-3.6
4	14	-0.2	-4.0
5	13	-0.2	-5.0
6	14	-0.2	-5.2
7	7	2.0	-3.2
8	9	0.8	3.4
9	8	4.8	8.2
10	13	-0.2	8.0
11	15	-2.2	5.8
12	18	-5.2	0.6
13	14	-0.2	-0.8
14	16	-3.2	-3.8
15	14	-0.2	-5.0
16	14	-0.2	-5.2
17	15	-2.2	-7.4
18	18	-5.2	-13.6
19	14	-0.2	-14.0
20	15	-2.2	-17.0
21	9	3.8	-13.2
22	10	2.8	-10.4
23	9	3.8	-6.6
24	12	0.8	-5.8
25	9	3.8	-2.0
26	11	1.8	-0.2
Average A = 12.6			



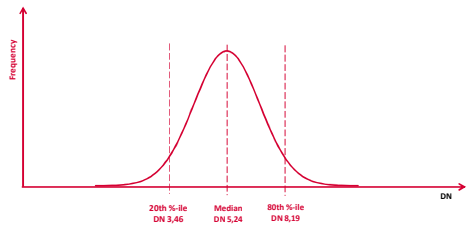
Step 8 – Adjust DN Values for Moisture Environment

Anticipated long-term in-service moisture content in pavement	Percentile of minimum strength profile (maximum penetration rate – DN mm/blow)	
	Design traffic < 0.5 MESA	Design traffic 0.5 – 1.0 MESA
Drier than at time of DCP survey	20	30
Same as at time of DCP survey	50	65
Wetter than at time of DCP survey	80	90

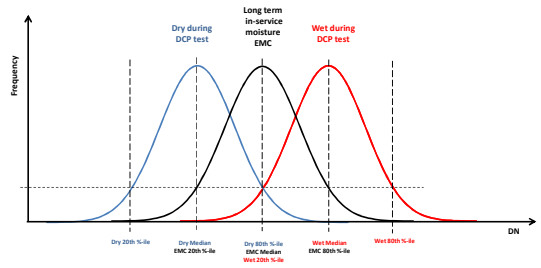
Step 8 – Adjust DN Values for Moisture Environment

Chainage (km)	Point No	DN 0-150 (Base)	Percentile of minimum strength Profile (max. penetration rate – DN)		
			20th	50th (Mean)	80th
0.00	1	2.29	3.46**	5.24	8.19
0.25	2	4.44			
0.50	3	2.00			
0.75	4	8.67			
1.00	5	3.75			
1.25	6	8.07			
1.50	7	5.11			
1.75	8	5.37			
2.00	9	6.60			
2.25	10	10.12			
Anticipated long-term in-service moisture content in pavement*					
Drier than at time of DCP survey			3.46	N/A	N/A
Same as at time of DCP survey			N/A	5.24	N/A
Wetter than at time of DCP survey			N/A	N/A	8.19

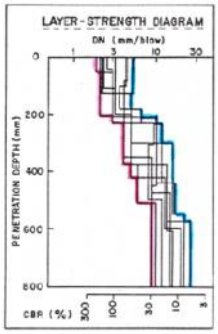
Step 8 – Adjust DN Values for Moisture Environment



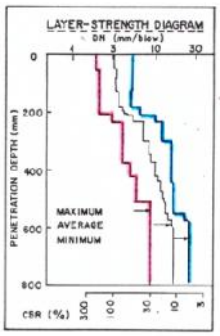
Step 8 – Adjust DN Values for Moisture Environment



Step 9-Determine In Situ LSP For Each Uniform Section



Collective DCP strength profiles

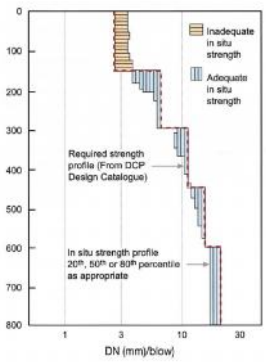


Average and extreme DCP strength profiles

Step 10-Required LSP for Uniform Section

Traffic Class E80 x 10^6	LE 0.01 0.003 – 0.010	LE 0.03 0.010 – 0.030	LE 0.1 0.030 – 0.100	LE 0.3 0.100 – 0.300	LE 0.7 0.300–0.700	LE 1.0 0.700 – 1.0
0- 150mm Base ≥ 98% MAASHTO	DN ≤ 8	DN ≤ 5.9	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.6	DN ≤ 2.5
150-300 mm Subbase ≥ 95% MAASHTO	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 4.6	DN ≤ 4.0
300-450 mm subgrade ≥ 95% MAASHTO	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 8	DN ≤ 6
450-600 mm In situ material	DN ≤ 40	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 14	DN ≤ 13
600-800 mm In situ material	DN ≤ 50	DN ≤ 40	DN ≤ 39	DN ≤ 25	DN ≤ 24	DN ≤ 23
DSN 800	≥ 39	≥ 52	≥ 73	≥ 100	≥ 128	≥ 143

Step 11-Compare In Situ & Required LSP for Uniform Section



Step 12-Determine Upgrading Requirements

	Required DN Value for LV 0.3	DN Values - 80th Percentile						
		Section no.						
		1	2	3	4	5	6	7
0-150	≤ 3.2	8.07	4.81	4.90	4.03	4.45	6.57	3.95
150-300	≤ 6	10.47	7.75	10.07	5.37	5.99	9.71	4.94
300-450	≤ 12	9.69	8.78	10.27	7.79	7.09	9.68	7.37

Inadequate in situ layer
Adequate in situ layer(s)

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

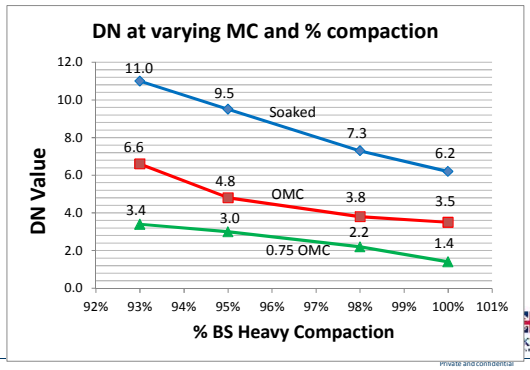
Determine Upgrading Requirements (Cont'd)

- **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.

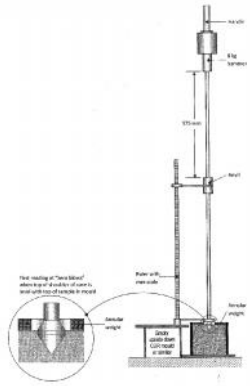
DN/Density/Moisture Relationship



Determination of Laboratory DN Value

DN = h/r where:
h = depth of CBR mould

r= total number of blows to reach depth h



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

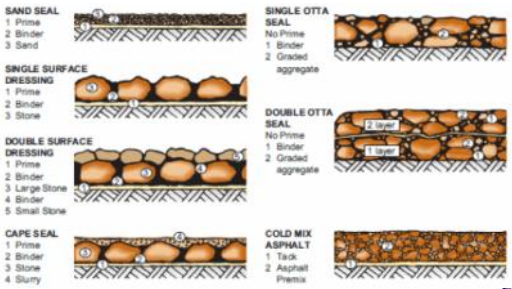
- Use in very coarse granular or lightly stabilized materials.
- Very hard cemented layers in the pavement structure
- The possibility of not recording very weak or thin layers when taking depth measurements every 5 blows
- Poorly executed tests (hammer not falling the full distance, non-vertical DCP, 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
- Typical methods for LVR pavement design
- Overview of DCP-DN Design Method
- **Surfacing Options for LVRs**
- 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

Cobble stone

Burnt clay brick

Reinforced concrete

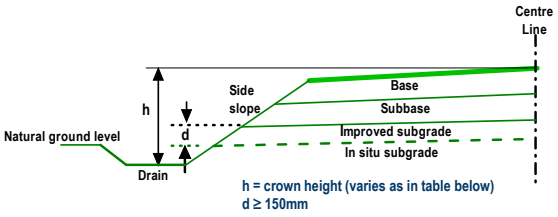
Factors Affecting Choice of Surfacing

- 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.

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

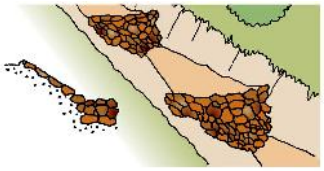
Drainage – Key Considerations



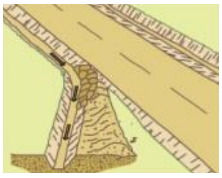
Crown height, h (m)			
Unlined drains		Lined drains	
g < 1%	g > 1%	g < 1%	g > 1%
0.75	0.65	0.65	0.50

Drainage Measures

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

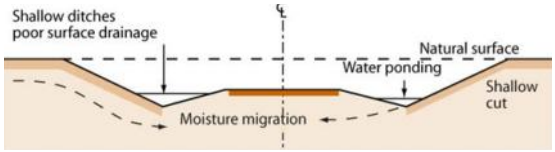


Natural stone scour check



Mitre drain

Drainage – Key Considerations



Avoid this cross section at all costs!

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**

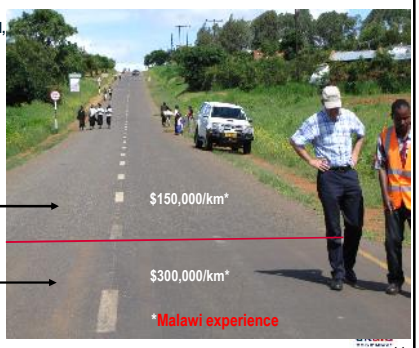
Examples of DCP Designed Roads

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

Road D379 Kiambu, Kenya (after 2 years)

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



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

Republic of Kenya

AFCAP

CROWN AGENTS

UKaid

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

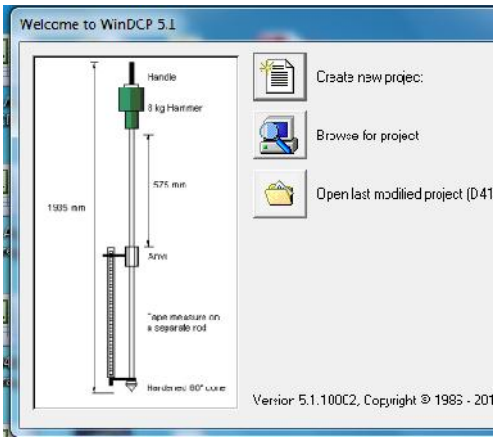
Module 3 – WinDCP Software

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

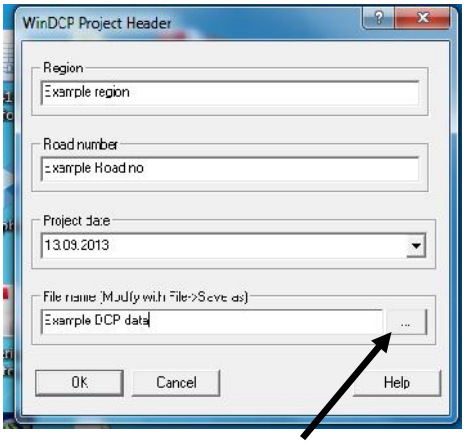
Create new or open project

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



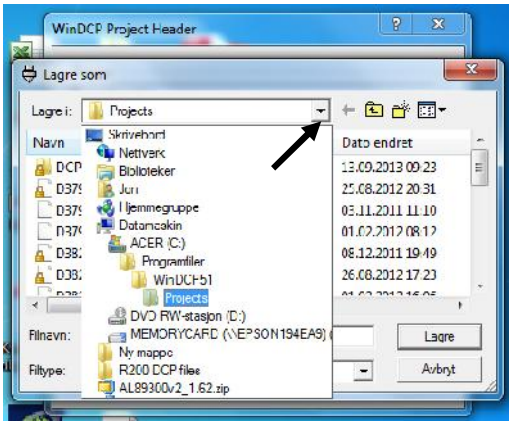
Create new or open project

- 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/.



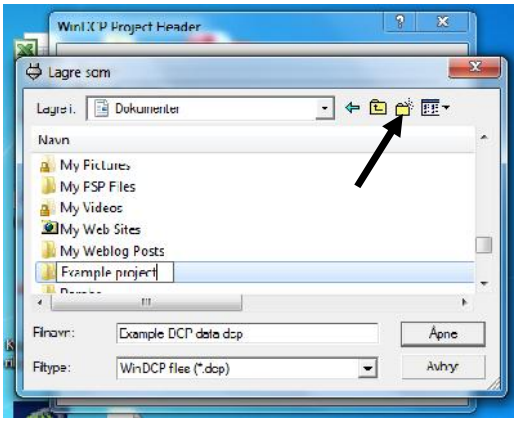
Create new or open project

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



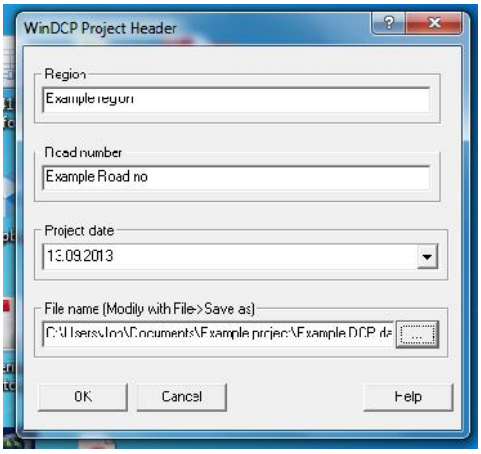
Create new or open project

- 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

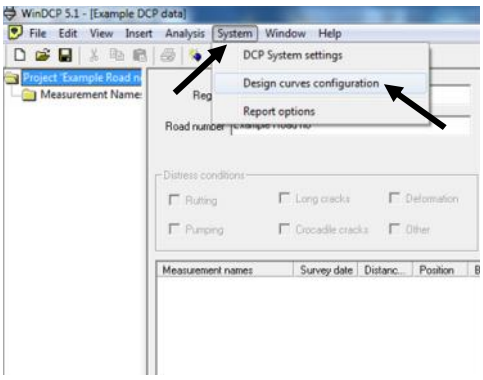
From your traffic count and axle load data, the cumulative number of equivalent standard axles has been calculated, say 150,000 over a 15 year design period. The DCP Design Curve is defined in the DCP Design Catalogue. For this example, use traffic class LE 0.3.

Table 5-1: DCP design catalogue for different traffic classes

Traffic Class E80 x 10^6	LE 0.01 0.003 – 0.010	LE 0.03 0.010 – 0.030	LE 0.1 0.030 – 0.100	LE 0.3 0.100 – 0.300	LE 0.7 0.300 – 0.700	LE 1.0 0.700 – 1.0
0- 150mm Base ≥ 98% MAASHTO	DN ≤ 8	DN ≤ 5.9	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.6	DN ≤ 2.5
150-300 mm Subbase ≥ 95% MAASHTO	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 4.6	DN ≤ 4.0
300-450 mm subgrade ≥ 95% MAASHTO	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 8	DN ≤ 6
450-600 mm In situ material	DN ≤ 40	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 14	DN ≤ 13
600-800 mm In situ material	DN ≤ 50	DN ≤ 40	DN ≤ 39	DN ≤ 25	DN ≤ 24	DN ≤ 23
DN 800	≥ 39	≥ 52	≥ 73	≥ 100	≥ 128	≥ 143

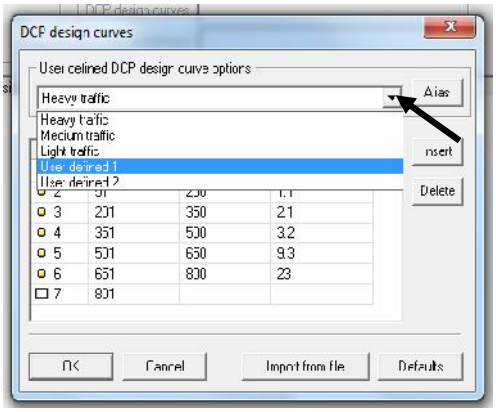
Defining the DCP Design Curve

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



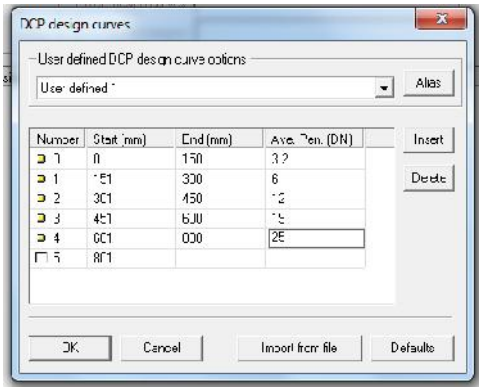
Defining the DCP Design Curve

- Click on the scroll arrow next to “Heavy traffic”
- Select “User defined 1”



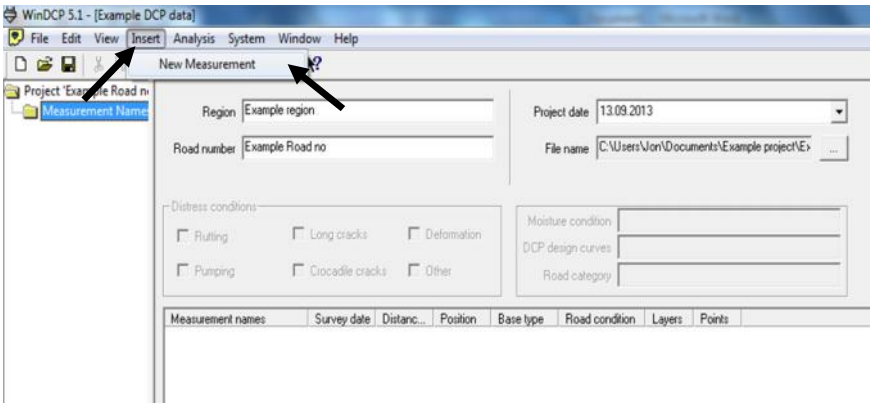
Defining the DCP Design Curve

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



Entering Sample DCP measurement data

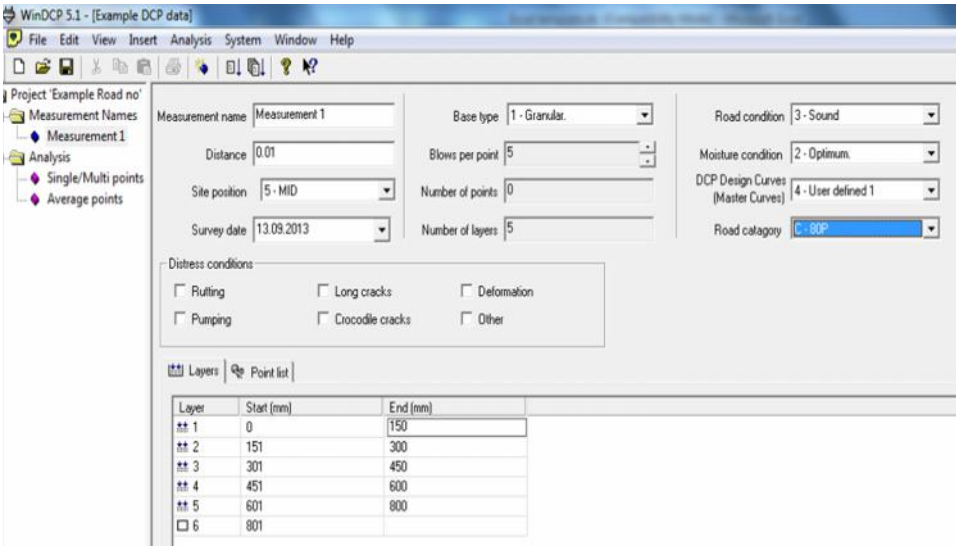
- Click “Insert”, then “New measurement” or the new measurement button in the top menu



Entering Sample DCP measurement data

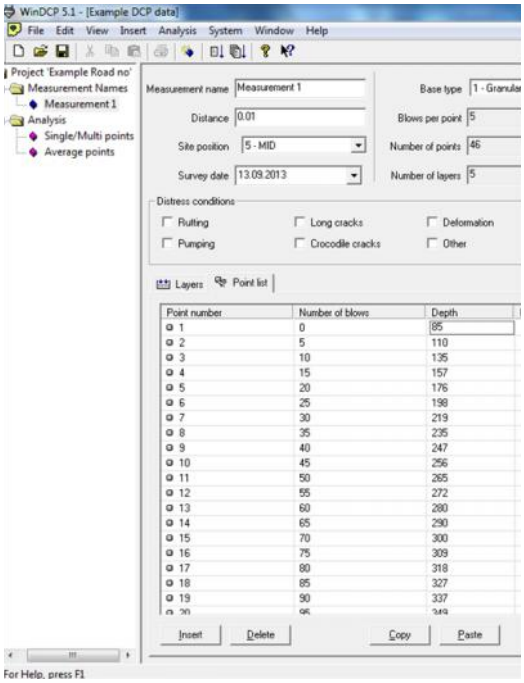
- Change the first Measurement number to 1. For the following measurements, change to the next higher number
- Enter distance from starting point (always record data in increasing chainages)
- Select the position of the measurement (predefined values from 1 to 9)
- Enter the Survey date (this date defaults 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



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:

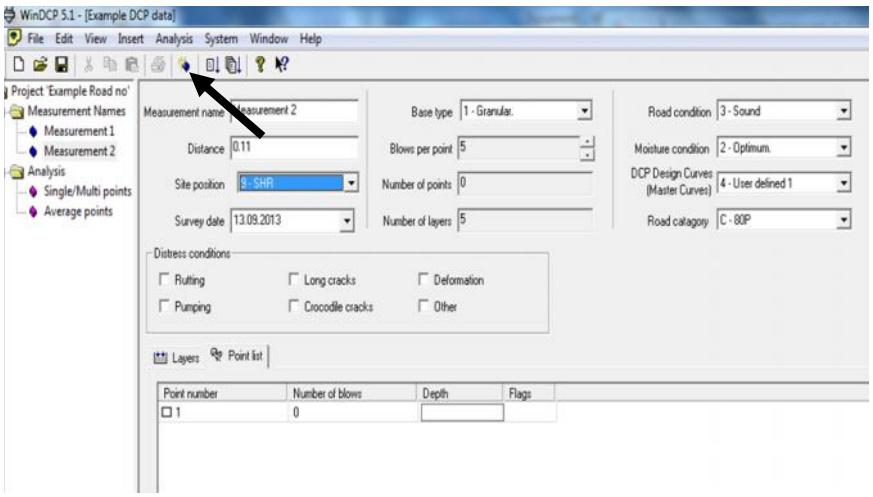
- Quality assurance during data collection and entry
- Being able to enter DCP data systematically and correctly
- Becoming familiar with
  - WinDCP report options
  - Single point and Average analysis
- Learn how to transfer data to Excel for further analysis

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.

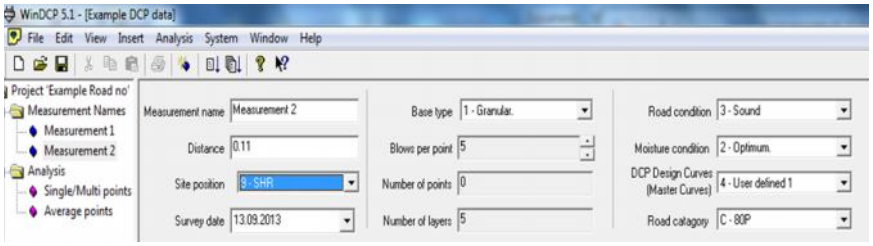
Entering DCP measurements

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



Entering DCP measurements

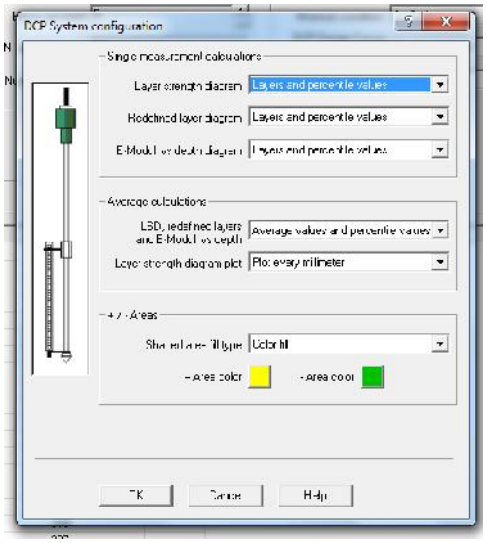
- Change the measurement number to the next higher number (if you forget to do this and do for instance a Single Point Analysis, you will end up having two measurements with the same number and can only change this by deleting and re-entering the measurement)
- Enter the distance from the starting point
- Select measurement position
- Enter the Survey date
- Enter the DCP data in the point list



Report options

System settings

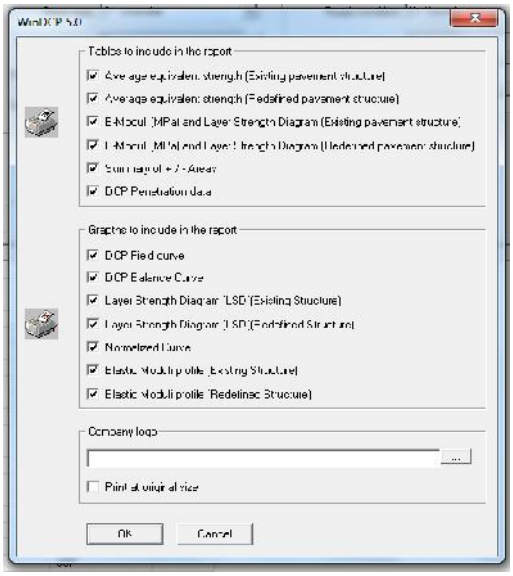
- Click on “System”, then “DCP system configuration” in the top menu
- Select the options shown in the screen shot.
- Click “OK”



Report options

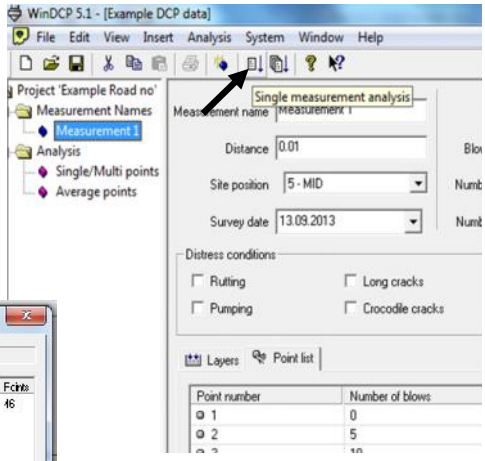
System settings

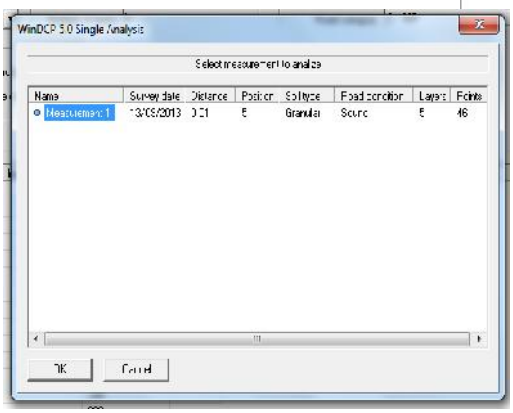
- Click “System”, then “Report options” in the top menu
- Tick all the boxes as shown
- Click “OK”



Single point analysis

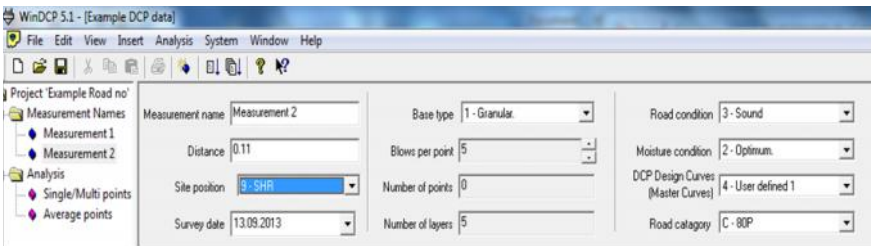
- Click the “Single point analysis” button
- Select the measurement to analyse
- Click “OK”



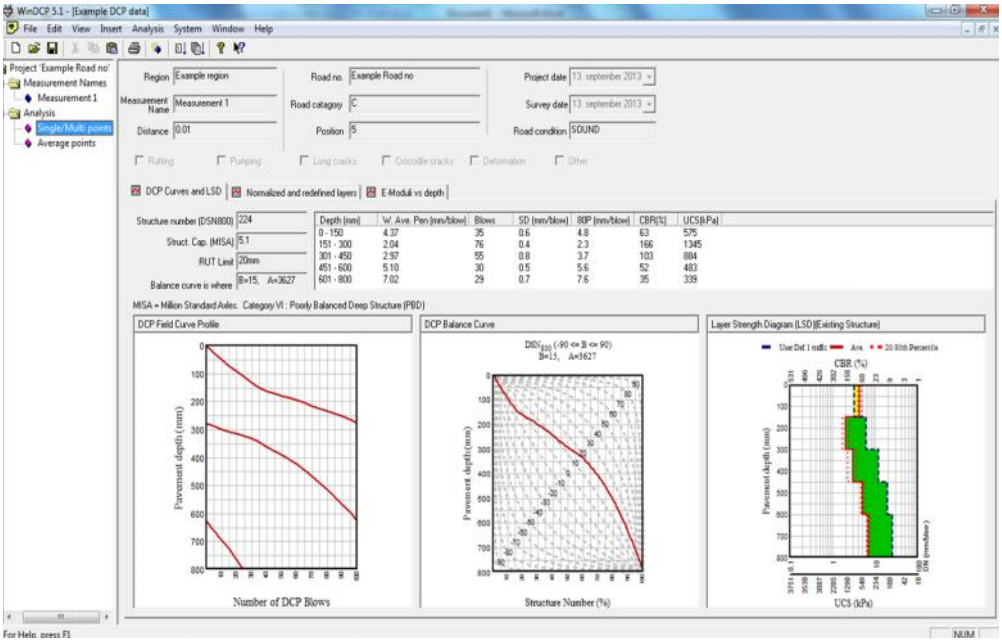


Single point analysis

- 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.

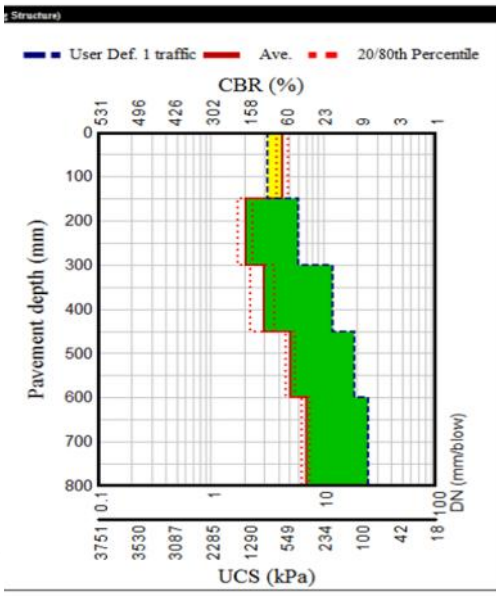


Single point analysis



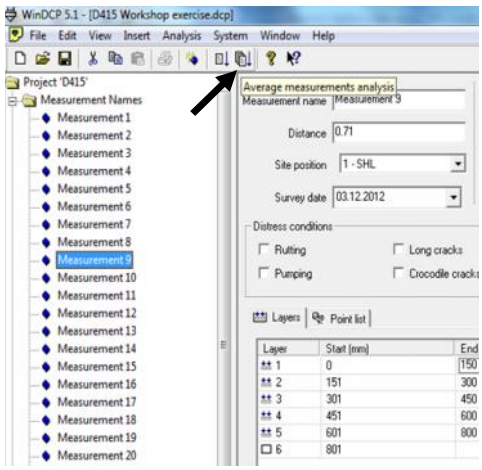
The Layer Strength Diagram

- 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 20th percentile (to the left of the red line) and 80th percentile (to the right of the red line) respectively
- Depending on the moisture condition at the time of the DCP measurements, we want the 20th percentile (if it is wetter than expected in service moisture) or the 80th 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).



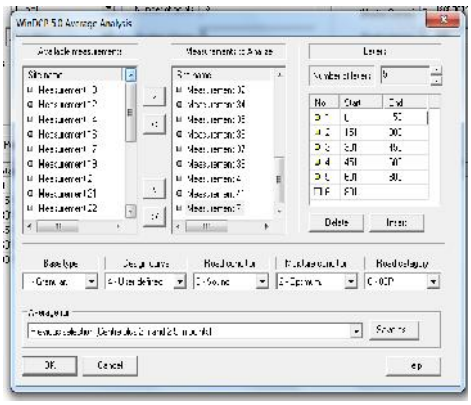
Average analysis

- Click the "Average analysis" button



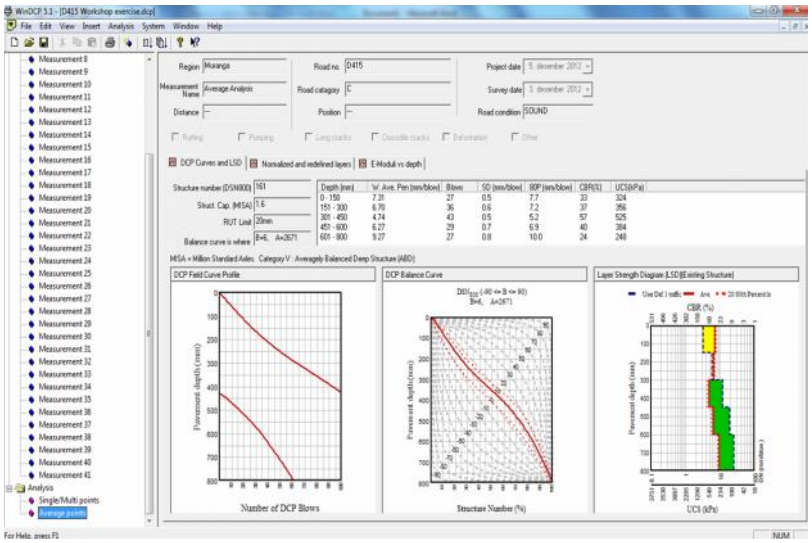
Average analysis

- 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 measurments .
- 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:

DSN800 and Weighted average DN (mm) per layer									
Test no	Chainage	Offset	Date	DSN800	0-150 mm	151-300 mm	301-450 mm	451-600 mm	601-800 mm
1	0,010	CL	03.12.12	224	4,37	2,04	2,97	5,1	7,02
4	0,310	CL	03.12.12	157	7,07	4,37	3,07	6,06	9,96
7	0,410	CL	03.12.12	209	4,16	3,76	2,62	4,28	7,66
11	1,110	CL	03.12.12	165	4,28	3,1	5,1	6,73	9,88
13	1,410	CL	03.12.12	167	7,35	5,84	6,81	3,45	4,69
15	1,810	CL	03.12.12	176	14,34	5,5	2,71	3,53	6,73
18	2,300	CL	04.12.12	181	6,73	6,18	3,09	3,41	6,04
20	2,500	CL	04.12.12	246	3,89	4,59	4,42	3,16	2,55
23	2,800	2,0 RHS	04.12.12	90	6,97	8,43	7,1	11,52	13,61
24	3,000	CL	04.12.12	208	7,61	2,26	2,66	5,22	9,63
25	3,300	2,5 LHS	04.12.12	71	13,69	12,52	7,67	12,21	19,21
26	3,500	CL	04.12.12	186	11,36	6,06	1,98	5,96	8,68
28	3,900	2,0 LHS	04.12.12	166	6,61	4,7	2,82	4,94	9,28
29	4,100	2,0 RHS	04.12.12	156	7,32	5,29	6,15	3,51	5,36
30	4,300	2,0 LHS	04.12.12	101	12,73	13,25	4,56	7,00	11,32
31	4,500	2,5 RHS	04.12.12	117	6,1	6,53	5,47	7,43	10,72
32	4,700	2,5 LHS	04.12.12	76	11,03	12,29	6,83	11,28	18,81
34	5,100	2,5 LHS	05.12.12	71	10,77	30,3	16,55	9,39	10,6
35	5,300	2,0 RHS	05.12.12	195	4,06	2,9	3,08	6,11	9,89
36	5,500	CL	05.12.12	210	3,39	4,28	2,34	5,15	7,99
37	5,700	2,0 LHS	05.12.12	180	4,05	3,19	3,33	6,65	9,17
39	6,100	CL	05.12.12	176	4,07	3,01	4,24	7,13	7,58
41	6,410	2,0 RHS	05.12.12	174	6,09	3,74	3,36	5,00	6,94
Average DN per layer					7,31	6,70	4,74	6,27	9,27
Design catalogue LV 0.3				100	3,20	6,00	12,00	19,00	24,00

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

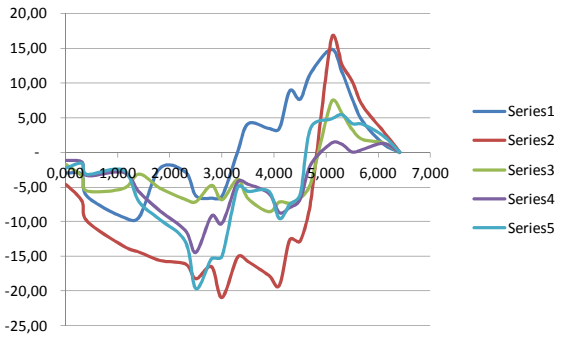
- Do a Cusum analysis for DSN800 and the Weighted Average DN for each layer
  - Calculate the Value for each measurement less the Average of all measurements
  - Calculate the Cumulative Sum of this new value for all measurements

Cusum Analysis

Test no	Chainage	Offset	Date	DSN800	DSN800-Avg	Cusum	0-150 mm	DN-Avg	Cusum	151-300 mm	DN-Avg	Cusum	301-450 mm	DN-Avg	Cusum	451-600 mm	DN-Avg	Cusu
1	0,010	CL	03.12.12	224	63,04	63,04	4,37	-2,94	-2,94	2,04	-4,66	-4,66	2,97	-1,77	-1,77	5,1	-1,17	-
4	0,310	CL	03.12.12	157	-3,96	59,09	7,07	-0,24	-3,17	4,37	-2,33	-6,99	3,07	-1,67	-3,43	6,06	-0,21	-
7	0,410	CL	03.12.12	209	48,04	107,13	4,16	-3,15	-6,32	3,76	-2,94	-9,93	2,62	-2,12	-5,55	4,28	-1,99	-
11	1,110	CL	03.12.12	165	4,04	111,17	4,28	-3,03	-9,34	3,1	-3,60	-13,54	5,1	0,36	-5,18	6,73	0,46	-
13	1,410	CL	03.12.12	167	6,04	117,22	7,35	0,04	-9,30	5,84	-0,86	-14,40	6,81	2,07	-3,11	3,45	-2,82	-
15	1,810	CL	03.12.12	176	15,04	132,26	14,34	7,03	-2,27	5,5	-1,20	-15,60	2,71	-2,03	-5,14	3,53	-2,74	-
18	2,300	CL	04.12.12	181	20,04	152,30	6,73	-0,58	-2,84	6,18	-0,52	-16,12	3,09	-1,65	-6,78	3,41	-2,86	-1
20	2,500	CL	04.12.12	246	85,04	237,35	3,89	-3,42	-6,26	4,59	-2,11	-18,23	4,42	-0,32	-7,10	3,16	-3,11	-1
23	2,800	2,0 RHS	04.12.12	90	-70,96	166,39	6,97	-0,34	-6,59	8,43	1,73	-16,50	7,1	2,36	-4,73	11,52	5,25	-
24	3,000	CL	04.12.12	208	47,04	213,43	7,61	0,30	-6,29	2,26	-4,44	-20,94	2,66	-2,08	-6,81	5,22	-1,05	-1
25	3,300	2,5 LHS	04.12.12	71	-89,96	123,48	13,69	6,38	0,09	12,52	5,82	-15,12	7,67	2,93	-3,88	12,21	5,94	-
26	3,500	CL	04.12.12	186	25,04	148,52	11,36	4,05	4,15	6,06	-0,64	-15,77	1,98	-2,76	-6,63	5,96	-0,31	-
28	3,900	2,0 LHS	04.12.12	166	5,04	153,57	6,61	-0,70	3,45	4,7	-2,00	-17,77	2,82	-1,92	-8,55	4,94	-1,33	-
29	4,100	2,0 RHS	04.12.12	156	-4,96	148,61	7,32	0,01	3,46	5,29	-1,41	-19,18	6,15	1,41	-7,14	3,51	-2,76	-
30	4,300	2,0 LHS	04.12.12	101	-59,96	88,65	12,73	5,42	8,89	13,25	6,55	-12,63	4,56	-0,18	-7,31	7	0,73	-
31	4,500	2,5 RHS	04.12.12	117	-43,96	44,70	6,1	-1,21	7,68	6,53	-0,17	-12,80	5,47	0,73	-6,58	7,43	1,16	-
32	4,700	2,5 LHS	04.12.12	76	-84,96	-40,26	11,03	3,72	11,41	12,29	5,59	-7,21	6,83	2,09	-4,48	11,28	5,01	-
34	5,100	2,5 LHS	05.12.12	71	-89,96	-130,22	10,77	3,46	14,87	30,3	23,60	16,39	16,55	11,81	7,33	9,39	3,12	-
35	5,300	2,0 RHS	05.12.12	195	34,04	-96,17	4,06	-3,25	11,62	2,9	-3,80	12,59	3,08	-1,66	5,67	6,11	-0,16	-
36	5,500	CL	05.12.12	210	49,04	-47,13	3,39	-3,92	7,71	4,28	-2,42	10,16	2,34	-2,40	3,28	5,15	-1,12	-
37	5,700	2,0 LHS	05.12.12	180	19,04	-28,09	4,05	-3,26	4,45	3,19	-3,51	6,65	3,33	-1,41	1,87	6,65	0,38	-
39	6,100	CL	05.12.12	176	15,04	-13,04	4,07	-3,24	1,22	3,01	-3,69	2,96	4,24	-0,50	1,38	7,13	0,86	-
41	6,410	2,0 RHS	05.12.12	174	13,04	-0,00	6,09	-1,22	0,00	3,74	-2,96	-0,00	3,36	-1,38	0,00	5	-1,27	-
Averages per layer				160,96			7,31			6,70			4,74			6,27		
Design catalogue LV 0.3				100			3,20			6,00			12,00			19,00		

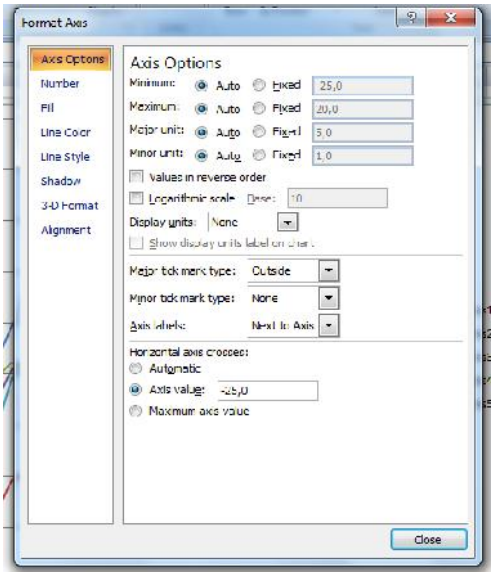
Create the Cusum diagram

- 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)

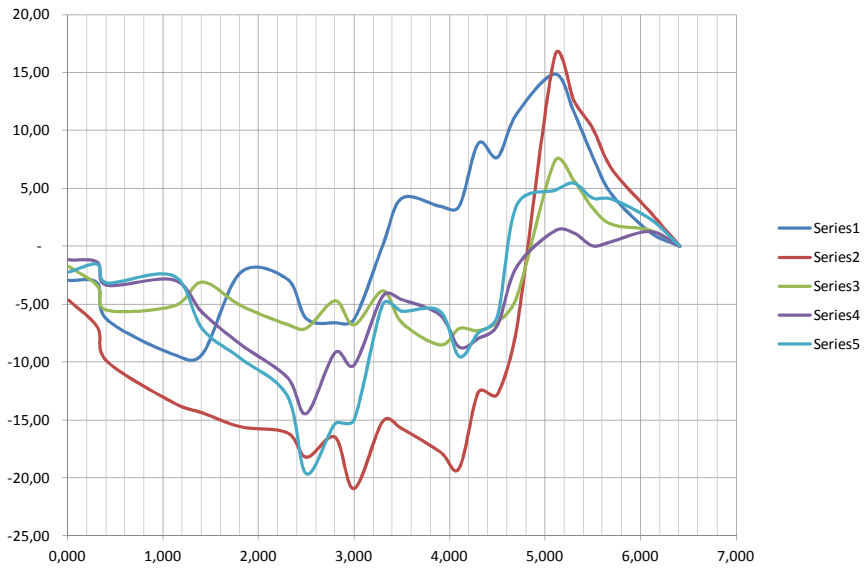


Create the Cusum diagram

- 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

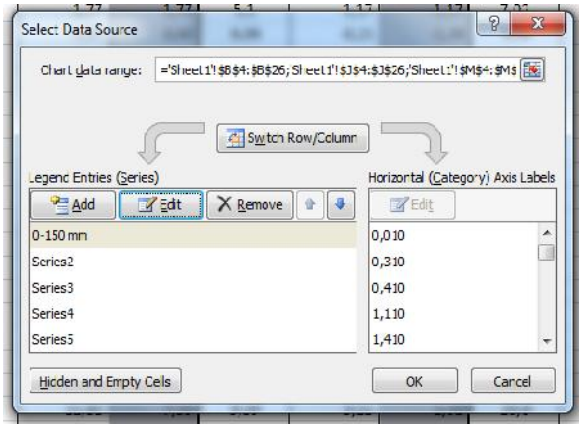


Create the Cusum diagram

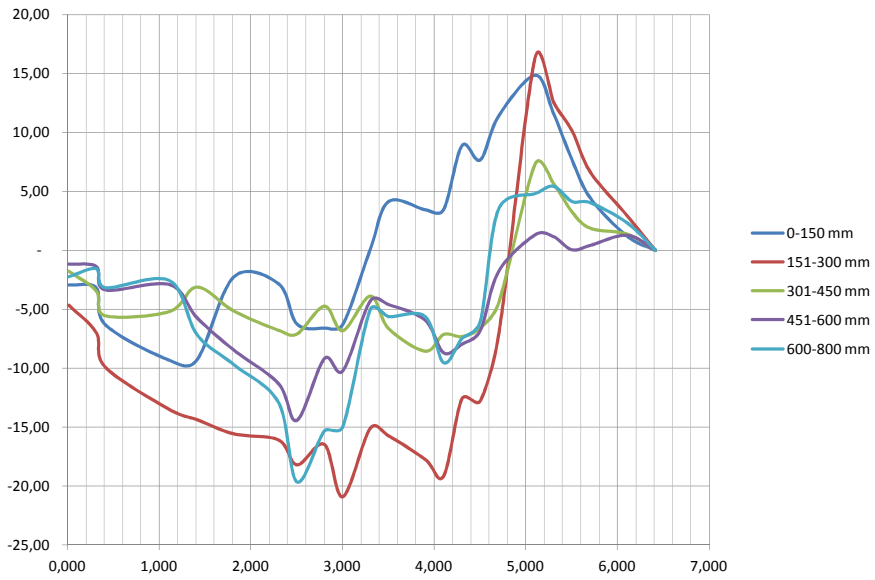


Create the Cusum diagram

- 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



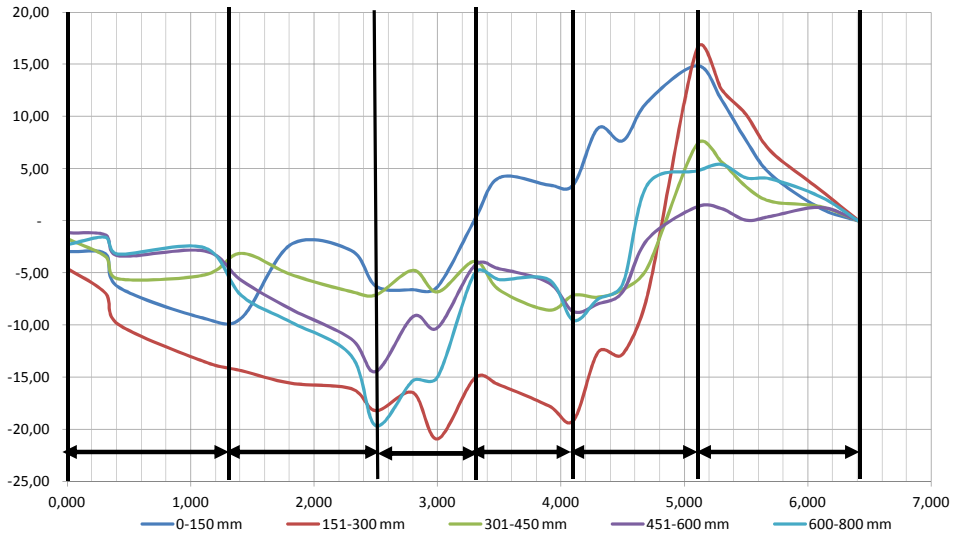
Create the Cusum diagram



- 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.



Determine uniform sections

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.

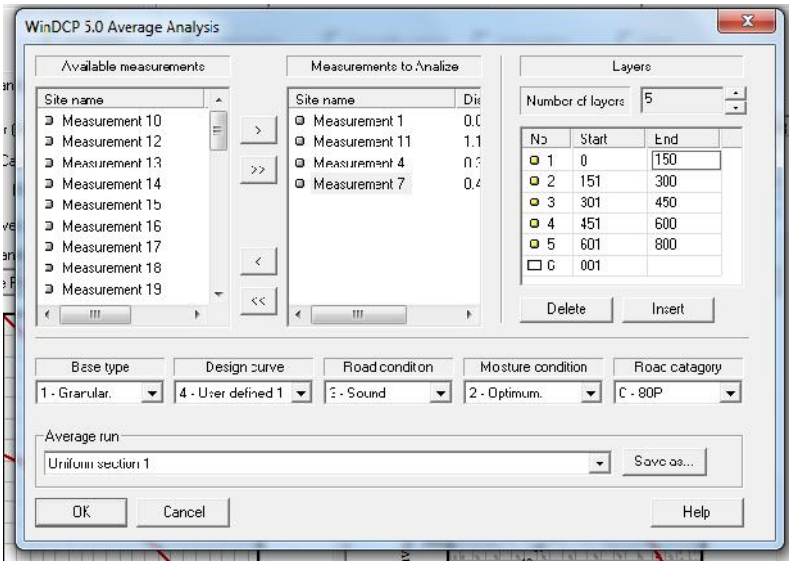
1	20th percentiles for each Uniform Section														
2	Test no	Chainage	Offset	Date	DSN800		0-150 mm		151-300 mm		301-450 mm		451-600 mm		601-800 mm
4	1	0,010	CL	03.12.12	224		4,37		2,04		2,97		5,1		7,02
5	4	0,310	CL	03.12.12	157		7,07		4,37		3,07		6,06		9,96
6	7	0,410	CL	03.12.12	209		4,16		3,76		2,62		4,28		7,66
7	11	1,110	CL	03.12.12	165		4,28		3,1		5,1		6,73		9,88
8	13	1,410	CL	03.12.12	167		7,35		5,84		6,81		3,45		4,69
9	15	1,810	CL	03.12.12	176		14,34		5,5		2,71		3,53		6,73
10	18	2,300	CL	04.12.12	181		6,73		6,18		3,09		3,41		6,04
11	20	2,500	CL	04.12.12	246		3,89		4,59		4,42		3,16		2,55
12	23	2,800	2,0 RHS	04.12.12	90		6,97		8,43		7,1		11,52		13,61
13	24	3,000	CL	04.12.12	208		7,61		2,26		2,66		5,22		9,63
14	25	3,300	2,5 LHS	04.12.12	71		13,69		12,52		7,67		12,21		19,21
15	26	3,500	CL	04.12.12	186		11,36		6,06		1,98		5,96		8,68
16	28	3,900	2,0 LHS	04.12.12	166		6,61		4,7		2,82		4,94		9,28
17	29	4,100	2,0 RHS	04.12.12	156		7,32		5,29		6,15		3,51		5,36
18	30	4,300	2,0 LHS	04.12.12	101		12,73		13,25		4,56		7		11,32
19	31	4,500	2,5 RHS	04.12.12	117		6,1		6,53		5,47		7,43		10,72
20	32	4,700	2,5 LHS	04.12.12	76		11,03		12,29		6,83		11,28		18,81
21	34	5,100	2,5 LHS	05.12.12	71		10,77		30,3		16,55		9,39		10,6
22	35	5,300	2,0 RHS	05.12.12	195		4,06		2,9		3,08		6,11		9,89
23	36	5,500	CL	05.12.12	210		3,39		4,28		2,34		5,15		7,99
24	37	5,700	2,0 LHS	05.12.12	180		4,05		3,19		3,33		6,65		9,17
25	39	6,100	CL	05.12.12	176		4,07		3,01		4,24		7,13		7,58
26	41	6,410	2,0 RHS	05.12.12	174		6,09		3,74		3,36		5		6,94
27				Averages per layer	160,96		7,31		6,70		4,74		6,27		9,27
28				Design catalogue LV 0.3	100		3,20		6,00		12,00		19,00		24,00
29															

Sheet1 | Sheet1 (2) | Sheet2 | Sheet3

Ready

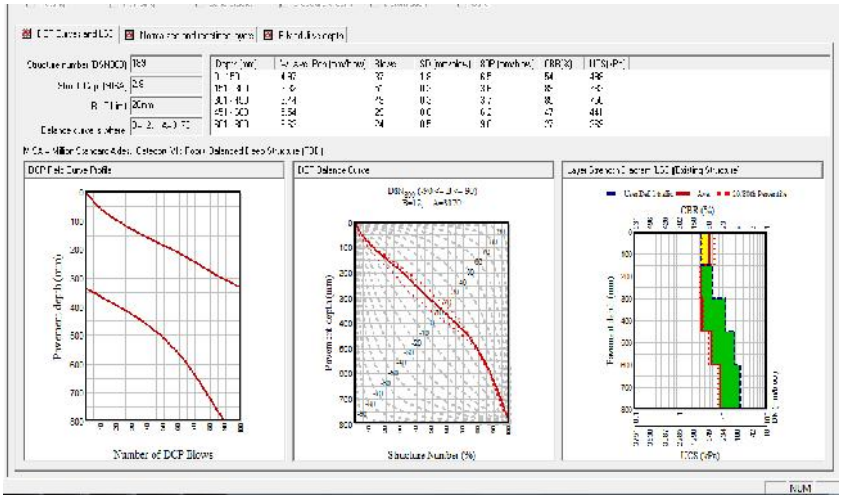
Average analysis of uniform sections

- 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

- 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

1	20th percentiles for each Uniform Section															
2	Test no	Chainage	Offset	Date	DSN800	20th %-ile	0-150 mm	20th %-ile	151-300 mm	20th %-ile	301-450 mm	20th %-ile	451-600 mm	20th %-ile	601-800 mm	20th %-ile
4	1	0,010	CL	03.12.12	224		4,37		2,04		2,97		5,1		7,02	
5	4	0,310	CL	03.12.12	157	215	7,07	3,44	4,37	3,04	3,07	3,18	6,06	4,88	9,96	8,26
6	7	0,410	CL	03.12.12	209		4,16		3,76		2,62		4,28		7,66	
7	11	1,110	CL	03.12.12	165		4,28		3,1		5,1		6,73		9,88	
8	13	1,410	CL	03.12.12	167		7,35		5,84		6,81		3,45		4,69	
9	15	1,810	CL	03.12.12	176	207	14,34	7,16	5,5	5,06	2,71	3,42	3,53	3,08	6,73	4,2
10	18	2,300	CL	04.12.12	181		6,73		6,18		3,09		3,41		6,04	
11	20	2,500	CL	04.12.12	246		3,89		4,59		4,42		3,16		2,55	
12	23	2,800	2,0 RHS	04.12.12	90		6,97		8,43		7,1		11,52		13,61	
13	24	3,000	CL	04.12.12	208	160,8	7,61	7,94	2,26	6,38	2,66	5,12	5,22	8,6	9,63	12,9
14	25	3,300	2,5 LHS	04.12.12	71		13,69		12,52		7,67		12,21		19,21	
15	26	3,500	CL	04.12.12	186		11,36		6,06		1,98		5,96		8,68	
16	28	3,900	2,0 LHS	04.12.12	166	178	6,61	8,06	4,7	3,9	2,82	3,5	4,94	4,1	9,28	7,34
17	29	4,100	2,0 RHS	04.12.12	156		7,32		5,29		6,15		3,51		5,36	
18	30	4,300	2,0 LHS	04.12.12	101		12,73		13,25		4,56		7		11,32	
19	31	4,500	2,5 RHS	04.12.12	117	107,4	6,1	7,32	6,53	14,18	5,47	6,1	7,43	8,06	10,72	11,62
20	32	4,700	2,5 LHS	04.12.12	76		11,03		12,29		6,83		11,28		18,81	
21	34	5,100	2,5 LHS	05.12.12	71		10,77		30,3		16,55		9,39		10,6	
22	35	5,300	2,0 RHS	05.12.12	195		4,06		2,9		3,08		6,11		9,89	
23	36	5,500	CL	05.12.12	210		3,39		4,28		2,34		5,15		7,99	
24	37	5,700	2,0 LHS	05.12.12	180	198	4,05	3,96	3,19	2,84	3,33	2,74	6,65	5,52	9,17	7,92
25	39	6,100	CL	05.12.12	176		4,07		3,01		4,24		7,13		7,58	
26	41	6,410	2,0 RHS	05.12.12	174		6,09		3,74		3,36		5		6,94	
27	Averages per layer				160,96		7,31		6,70		4,74		6,27		9,27	
28	Design catalogue LV 0.3				100		3,20		6,00		12,00		19,00		24,00	

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

	Specification	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
DSN800	100	215	207	160,8	178	107,4	198
0-150 mm	3,2	3,44	7,16	7,94	8,06	7,32	3,96
151-300 mm	6	3,04	5,06	6,38	3,9	14,18	2,84
301-450 mm	12	3,18	3,42	5,12	3,5	6,1	2,74
451-600 mm	19	4,88	3,08	8,6	4,1	8,06	5,52
601-800 mm	25	8,26	4,2	12,9	7,34	11,62	7,92

Pavement design

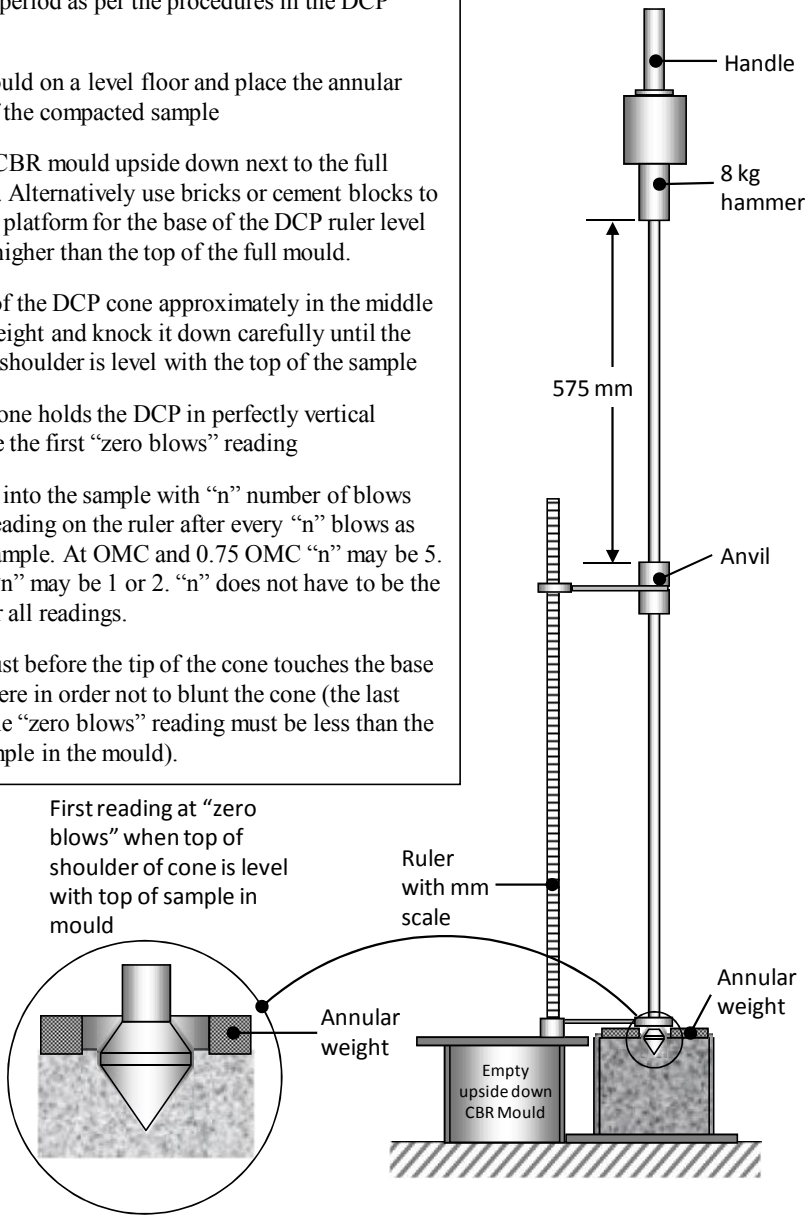
- Import new layer with DN within specification on top of those that are shaded red.
- The previously weak (red) layers are then moved down in the pavement structure.
- Assess again whether they are within the specification in their new position in the pavement structure (e.g. former base is now sub-base)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

	Specification	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6
DSN800	100	215	207	160,8	178	107,4	198
0-150 mm	3,2	3,44	3,2	3,2	3,2	3,2	3,96
151-300 mm	6	3,04	7,16	7,94	8,06	7,32	2,84
301-450 mm	12	3,18	5,06	6,38	3,9	14,18	2,74
451-600 mm	19	4,88	3,42	5,12	3,5	6,1	5,52
601-800 mm	25	8,26	3,08	8,6	4,1	8,06	7,92

Laboratory DN test

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).



Laboratory DN test

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):

$$DN = \frac{\Sigma(Avg\ DN\ per\ blow\ x\ DN\ per\ n\ blows)}{Penetration\ depth}$$

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

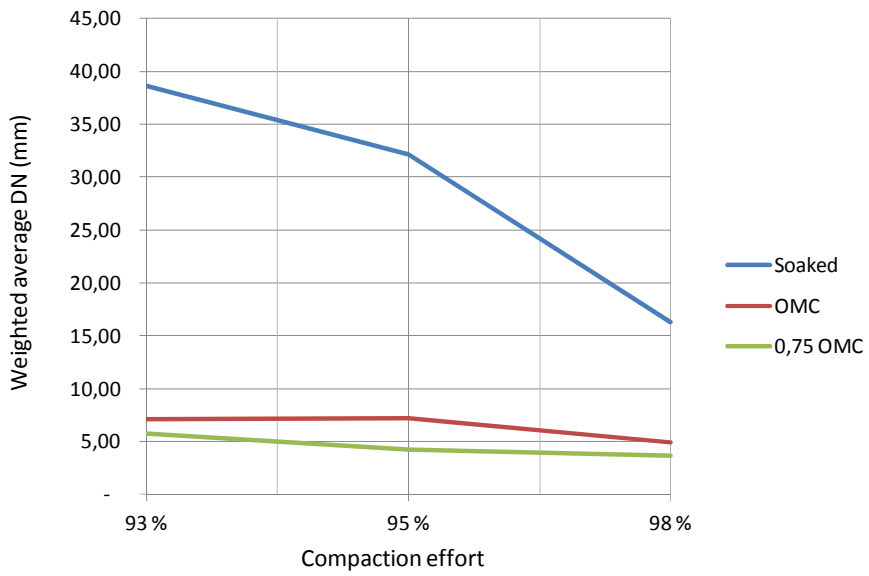


Figure 1: Weighted average DN for different compaction efforts and moisture contents

Laboratory DN test

4 days soaked											
98 %				95 %				93 %			
No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0	129			0	125			0	135		
2	168	39	19,50	2	193	68	34,00	2	220	85	42,50
2	192	24	12,00	2	253	60	30,00	1	246	26	26,00
2	220	28	14,00								
2	255	35	17,50								
Penetration depth		126				128				111	
Weighted Average DN			16,29				32,13				38,64

OMC											
98 %				95 %				93 %			
No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0	121			0	117			0	122		
5	152	31	6,20	5	150	33	6,60	5	160	38	7,60
5	170	18	3,60	5	175	25	5,00	5	190	30	6,00
5	186	16	3,20	5	219	44	8,80	5	225	35	7,00
5	205	19	3,80	5	256	37	7,40	5	263	38	7,60
5	225	20	4,00								
5	257	32	6,40								
Penetration depth		136				139				141	
Weighted Average DN			4,89				7,22				7,11
DN_{OMC}/DN_S =			30 %				22 %				18 %

0.75 OMC											
98 %				95 %				93 %			
No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow	No of blows n	DCP Reading	DN per n blows	Avg. DN per blow
0	123			0	135			0	127		
5	145	22	4,40	5	156	21	4,20	5	153	26	5,20
5	156	11	2,20	5	175	19	3,80	5	176	23	4,60
5	160	4	0,80	5	191	16	3,20	5	205	29	5,80
5	170	10	2,00	5	210	19	3,80	5	240	35	7,00
5	185	15	3,00	5	233	23	4,60				
5	205	20	4,00	5	260	27	5,40				
5	229	24	4,80								
Penetration depth		106				125				113	
Weighted Average DN			3,63				4,28				5,79

Annex 3: Training attendance

Training attendance				Field Training			Classroom training								
							SM	Designers/Practitioners						Techn.	
No	Name	Title	Organisation	22.01	23.01	24.01	28.01	29.01	30.01	31.01	03.02	04.02	05.02	06.02	07.02
1	Julius Mutua Kaliti	Principal Lecturer	KIHBT	V				V	V	V					
2	Caroline Naliaka Maina	Trainer Technician	Norken	V				V	V	V					
3	Benson Mbogo Njuki	Technician	Norken	V				V	V	V					
4	Gregory Thitu Njiru	Technician	KeRRA Kerugoya	V											
5	Geoffrey K. Kingori	Materials Technologist	MTRD Embu	V										V	V
6	Joseph Maina Gikiri	Technician	KeRRA Kerugoya	V											
7	Peter Mnyambi Kinyua	Student Kebete Tech.	Attach. MTRD Embu	V											
8	James Nguyo	Roads Engineer	Max & Partners	V											
9	John S. Ochieno	Roads Engineer	Max & Partners	V							V	V	V		
10	Erick Aberi Masenge	Roads Inspector	Max & Partners	V										V	V
11	Oscar Kimani	Roads Inspector	Max & PArtners	V										V	V
12	W. K. Mburu	Regional Manager	KeRRA Kirinyaga	V				V	V	V					
13	J. N. Kabiru	Regional Manager	KeRRA Nyeri	V				V	V	V					
14	Eliud N. Gitonga	Constituency Roads Officer	KeRRA Kirinyaga	V										V	V
15	Henry Wanyoike	Constituency Roads Officer	KeRRA Kirinyaga	V											
16	Dadson G. Maina	Constituency Roads Officer	KeRRA Nyeri	V										V	V
17	Peter G. Wanyoike	Constituency Roads Officer	KeRRA Kirinyaga	V										V	V
18	Paul Methu	Team Leader	Cas Consultants	V							V	V	V		
19	Bernard G. Ngugi	Chief Lecturer - Design	KIHBT		V						V	V	V		
20	J. Murage	Regional Manager	KeRRA Kiambu		V										
21	Charles Khisa Werunga	Constituency Roads Officer	KeRRA Nyandarua		V									V	V
22	Mary N. Kanyinga	Constituency Roads Officer	KeRRA Kiambu		V										
23	Ngugi Ndichu	Technician	KeRRA Muranga		V									V	V
24	Eric Wambua	Roads Engineer	KenHA		V						V	V	V		
25	Edwin Nyaga	Roads Engineer	Cas Consultants		V						V	V	V		
26	James N. Mbuko	Engineer	KenHA		V						V	V	V		
27	Evans Mainga	Roads Inspector	KenHA		V									V	V
28	Otieno Oguta	Senior Engineer	KenHA		V										
29	P. Githere	Regional Manager	KeRRA Laikipia		V						X	V	V		

Training attendance				Field Training			Classroom training								
							SM	Designers/Practitioners						Techn.	
30	Esther Ngati	Roads Inspector	KenHA		V									V	V
31	Oscar Mwangome	Technician	KenHA		V									V	V
32	Grace J. W. Mwaura	Technician	KeRRA Laikipia		V									V	V
33	Hamidu Mataka	Engineer	PMORALG Tanzania			V	V	V	V	V					
34	George Tarimu	Engineer	RS Morogoro Tanzania			V	V	V	V	V					
35	Gilbert Mwoga	Engineer	PMORALG Tanzania			V	V	V	V	V					
36	Samson Mwanza	Technician	KeRRA Kiambu			V								V	V
37	Wilson Oguba	Technician	KIHBT			V									
38	Joseph H. Saya	Technician	KeRRA HQ			V								V	V
39	Roy Makau	Technician	KeRRA HQ			V								V	V
40	Thomas Kandie	Technician	KeRRA HQ			V								V	V
41	Etale Tunya	Engineer	Max & Partners			V					V	V	V		
42	Kent Kopar	Engineer	Cas Consultants			V					V	V	V		
43	Charles Oduk	Roads Inspector	Cas Consultants			V								V	V
44	John Agutu	Roads Inspector	Cas Consultants			V								V	V
45	Julius Wambugu	Technician	MTRD Muranga			V								V	V
46	David Mutuohoro	Engineer	KURA				V	V	V	V					
47	Musuku Gaitano	Trainer Technician	Norken					V	V	V					
48	V. N. Njerenga	Engineer	KURA					V	V	V					
49	Palistus Barasa	Engineer	KURA					V	V	V					
50	Peter Githiomi	Engineer	Norken					V	V	V					
51	J. M. Onyinkwa	Engineer	KURA					V	X	X					
52	Joseph Rugenyi	Chief Supt. Roads	KeRRA Kiambu					V	V	V					
53	M. Gumbi	Manager	KURA					V	V	V					
54	Wycliffe Omollo	Supt. Roads	KeRRA Embu					V	X	X					
55	J. Olawo	Manager	KeRRA				V			V					
56	A. Korir	Manager	KeRRA				V								
57	S. Kinoti	General Manager	KURA				V								
58	J. K. Gakubia	Manager	KeRRA				V								
59	Eric Goss	Team Leader	Egis International				V								
60	Peter Mundinia	General Manager	KURA				V								

Training attendance					Field Training			Classroom training								
								SM	Designers/Practitioners						Techn.	
61	M. A. Ngala	Senior Engineer	KenHA									X	X	V		
62	Paul Mose	Senior Supt. Roads	KURA												V	V
63	Marclus Kiranga	Senior Supt. Roads	KURA												V	V
64	Paul Siele	Senior Supt. Roads	KURA												V	V
65	Joseph K. Wambugu	Senior Supt. Roads	KURA												V	V
66	N. G. Kithenge	Constituency Roads Officer	KeRRA												V	V
67	Samuel Njuguna	Constituency Roads Officer	KeRRA												V	V
68	Jemimah N. Nyamweya	Senior Lecturer	KIBHT												V	V
69	Nkululeko Leta	Technical Manager	AFCAP					V	V	V	V					
			Total / Present per day	**69**	**18**	**14**	**13**	**11**	**18**	**16**	**17**	**8**	**9**	**10**	**26**	**26**

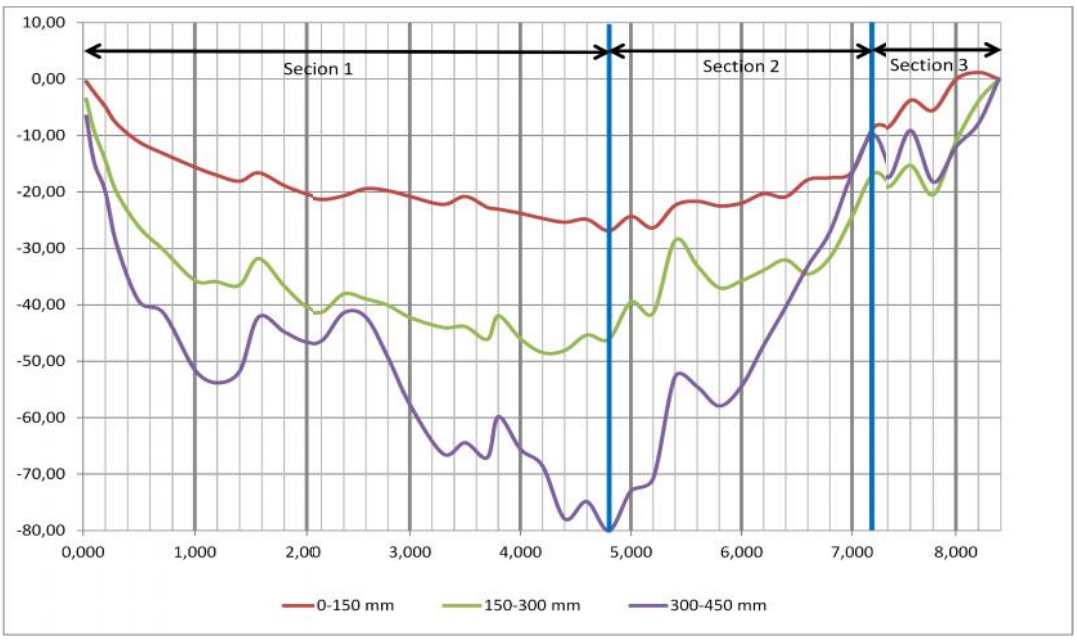
Training attendance by organisation		Field Training			Classroom training								
					SM	Designers/Practitioners						Techn.	
		22.01	23.01	24.01	28.01	29.01	30.01	31.01	03.02	04.02	05.02	06.02	07.02
KeRRA	25	8	6	4	3	4	3	4	0	1	1	12	12
KURA	11				3	5	4	4				4	4
KenHA	7		6						2	2	3	3	3
KIHBT	4	1	1	1		1	1	1	1	1	1	1	1
MTRD	3	2		1								2	2
Consultants	15	7	1	4	1	4	4	4	5	5	5	4	4
PMORALG, Tanzania	3			3	3	3	3	3					
AFCAP	1				1	1	1	1					
Total / Present per day	**69**	**18**	**14**	**13**	**11**	**18**	**16**	**17**	**8**	**9**	**10**	**26**	**26**

Annex 4: Worked design example on Training Road E1641

Cusum Analysis E1641

Test			DSN800			0-150 mm			151-300 mm			301-450 mm			451-600	601-800
no	Chainage	Position	DSN	DSN-Avg	Cusum	DN	DN-Avg	Cusum	DN	DN-Avg	Cusum	DN	DN-Avg	Cusum	DN	DN
1	0,030	CL	115	6,86	6,86	4,03	-0,46	-0,46	5,19	-3,56	-3,56	8,40	-6,60	-6,60	12,08	14,82
2	0,100	2,0 LHS	161	52,86	59,73	2,58	-1,91	-2,36	3,17	-5,58	-9,15	6,93	-8,07	-14,68	11,56	15,77
3	0,200	2,0 RHS	181	72,86	132,59	1,94	-2,55	-4,91	3,53	-5,22	-14,37	9,77	-5,23	-19,91	17,33	25,01
4	0,300	2,0 LHS	226	117,86	250,45	1,53	-2,96	-7,86	3,11	-5,64	-20,02	5,71	-9,29	-29,20	11,01	16,72
5	0,500	CL	303	194,86	445,32	1,23	-3,26	-11,12	2,59	-6,16	-26,18	4,88	-10,12	-39,32	9,19	13,58
6	0,720	2,0 LHS	130	21,86	467,18	2,40	-2,09	-13,20	4,66	-4,09	-30,28	12,88	-2,12	-41,45	25,51	32,43
7	1,000	1,0 LHS	246	137,86	605,05	2,10	-2,39	-15,59	3,37	-5,38	-35,66	4,96	-10,04	-51,49	9,04	15,79
8	1,190	CL	96	-12,14	592,91	3,10	-1,39	-16,97	8,51	-0,24	-35,91	12,69	-2,31	-53,80	19,74	27,84
9	1,400	1,5 RHS	88	-20,14	572,77	3,37	-1,12	-18,09	8,13	-0,62	-36,53	17,02	2,02	-51,78	24,06	28,37
10	1,570	2,0 LHS	57	-51,14	521,64	5,97	1,48	-16,60	13,47	4,72	-31,82	24,63	9,63	-42,16	29,74	27,68
11	1,800	CL	143	34,86	556,50	2,22	-2,27	-18,87	3,90	-4,85	-36,67	12,39	-2,61	-44,77	22,36	29,40
12	2,000	CL	119	10,86	567,36	2,99	-1,50	-20,36	5,07	-3,68	-40,35	13,17	-1,83	-46,60	24,42	33,91
13	2,200	2,0 RHS	84	-24,14	543,23	3,53	-0,96	-21,32	7,78	-0,97	-41,33	15,23	0,23	-46,37	29,64	44,13
14	2,400	2,0 LHS	65	-43,14	500,09	5,13	0,64	-20,67	12,01	3,26	-38,07	19,94	4,94	-41,44	27,45	30,71
15	2,600	CL	77	-31,14	468,95	5,75	1,26	-19,41	7,87	-0,88	-38,96	14,27	-0,73	-42,17	18,40	23,71
16	2,800	2,0 LHS	118	9,86	478,82	4,12	-0,37	-19,77	7,63	-1,12	-40,08	7,89	-7,11	-49,28	8,63	12,44
17	3,000	CL	121	12,86	491,68	3,48	-1,01	-20,78	6,60	-2,15	-42,24	6,59	-8,41	-57,69	13,17	20,11
18	3,300	2,0 RHS	174	65,86	557,55	3,07	-1,42	-22,19	6,97	-1,78	-44,02	6,32	-8,68	-66,38	8,63	4,65
19	3,500	2,0 LHS	65	-43,14	514,41	5,89	1,40	-20,79	8,90	0,15	-43,88	16,94	1,94	-64,44	24,30	36,18
20	3,700	1,0 RHS	115	6,86	521,27	2,56	-1,93	-22,71	6,51	-2,24	-46,12	12,39	-2,61	-67,05	20,33	23,24
21	3,800	2,0 LHS	68	-40,14	481,14	4,16	-0,33	-23,04	12,91	4,16	-41,97	22,25	7,25	-59,80	33,89	39,95
22	4,000	2,5 LHS	118	9,86	491,00	3,76	-0,73	-23,77	4,71	-4,04	-46,01	9,23	-5,77	-65,58	14,80	18,52
23	4,200	CL	119	10,86	501,86	3,57	-0,92	-24,68	6,28	-2,47	-48,48	12,02	-2,98	-68,56	10,25	13,87
24	4,400	1,5 RHS	126	17,86	519,73	3,82	-0,67	-25,35	9,15	0,40	-48,09	5,66	-9,34	-77,90	8,97	16,64
25	4,600	2,0 LHS	82	-26,14	493,59	4,99	0,50	-24,84	11,47	2,72	-45,37	18,04	3,04	-74,86	22,70	24,40
26	4,800	2,0 LHS	149	40,86	534,45	2,46	-2,03	-26,87	8,04	-0,71	-46,09	9,89	-5,11	-79,98	10,64	7,86
27	5,000	2,0 RHS	64	-44,14	490,32	7,03	2,54	-24,32	15,32	6,57	-39,52	22,03	7,03	-72,95	17,11	17,52
28	5,200	CL	119	10,86	501,18	2,46	-2,03	-26,35	6,81	-1,94	-41,47	17,16	2,16	-70,79	26,93	34,66
29	5,400	2,0 LHS	41	-67,14	434,05	8,47	3,98	-22,36	21,65	12,90	-28,57	33,10	18,10	-52,69	38,25	40,39
30	5,600	2,0 RHS	98	-10,14	423,91	5,20	0,71	-21,65	4,22	-4,53	-33,11	13,17	-1,83	-54,53	25,90	38,67
31	5,800	CL	106	-2,14	421,77	3,67	-0,82	-22,46	4,87	-3,88	-36,99	11,62	-3,38	-57,91	29,86	28,54
32	6,000	1,5 LHS	66	-42,14	379,64	4,97	0,48	-21,98	9,99	1,24	-35,76	18,50	3,50	-54,41	28,95	32,60
33	6,200	1,5 RHS	58	-50,14	329,50	6,15	1,66	-20,31	10,63	1,88	-33,88	22,24	7,24	-47,17	30,33	33,18
34	6,400	CL	82	-26,14	303,36	3,95	-0,54	-20,85	10,59	1,84	-32,04	21,81	6,81	-40,37	30,75	38,00
35	6,600	1,5 LHS	78	-30,14	273,23	7,50	3,01	-17,83	6,25	-2,50	-34,55	22,23	7,23	-33,14	27,44	31,11
36	6,800	1,5 RHS	72	-36,14	237,09	4,84	0,35	-17,48	11,69	2,94	-31,61	21,08	6,08	-27,06	26,87	31,00
37	7,000	CL	63	-45,14	191,95	5,50	1,01	-16,46	16,00	7,25	-24,37	25,32	10,32	-16,74	30,38	29,64
38	7,200	1,5 LHS	45	-63,14	128,82	12,45	7,96	-8,50	16,42	7,67	-16,70	21,82	6,82	-9,93	21,44	21,00
39	7,400	1,5 RHS	106	-2,14	126,68	4,41	-0,08	-8,57	6,33	-2,42	-19,13	7,46	-7,54	-17,47	16,19	23,58
40	7,600	2,0 RHS	47	-61,14	65,55	9,28	4,79	-3,78	12,57	3,82	-15,31	23,34	8,34	-9,13	29,21	33,17
41	7,800	1,0 RHS	183	74,86	140,41	2,72	-1,77	-5,54	3,56	-5,19	-20,51	5,89	-9,11	-18,24	9,64	12,01
42	8,000	2,0 LHS	42	-66,14	74,27	9,94	5,45	-0,09	18,12	9,37	-11,14	21,20	6,20	-12,05	27,09	42,02
43	8,200	2,0 RHS	64	-44,14	30,14	5,73	1,24	1,16	16,00	7,25	-3,90	19,20	4,20	-7,85	21,62	29,33
44	8,380	2,5 LHS	78	-30,14	0,00	3,33	-1,16	0,00	12,65	3,90	0,00	22,85	7,85	0,00	36,15	41,07
			108,14			4,49			8,75			15,00			21,41	26,26

Uniform sections



Pavement design

Design class LE 0.1	Spec. DN/layer mm	Section 1 0+000 - 4+800 80%-ile	Section 2 4+800 - 7+200 Mean	Section 3 7+200-8+400 Mean
0-150 mm	4	4,20	5,52	6,84
151-300 mm	9	8,70	10,07	12,24
301-450 mm	19	13,80	18,91	17,40
451-600 mm	25	20,40	25,55	23,05
601-800 mm	39	24,60	28,65	28,88
DSN800	>73			

Marginal/can be improved	Outside spec.	Within spec.

Import of one layer with required DN value will ensure that all layers satisfy the design criteria

Design class LE 0.1	Spec. DN/layer mm	Section 1 0+000 - 4+800 80%-ile	Section 2 4+800 - 7+200 Mean	Section 3 7+200-8+400 Mean
0-150 mm	4	≤4,00	≤4,00	≤4,00
151-300 mm	9	4,20	5,52	6,84
301-450 mm	19	8,70	10,07	12,24
451-600 mm	25	13,80	18,91	17,40
601-800 mm	39	20,40	25,55	23,05
DSN800	>73			

Annex 5: Itinerary and Activity Summary

Date	Jon Hongve	Mike Pinard
14.01	Travel from Norway	
15.01	- Meeting at KeRRA - Collection of DCP - Travel to Embu - Consolidation of list of Trainees in conjunction with KeRRA Co-ordinator	
16.01	- Meeting with Regional Manager, Kirinyaga - Compilation of Lab DN test results for Sagana Quarry Waste - DCP tests and moisture sampling on training road assisted by laboratory staff in Kirinyaga - Follow-up with KeRRA on invitation of trainees	
17.01	- DCP tests and moisture samples on training road - Preparation of samples for demonstration of Lab DN tests during the Classroom training - Compilation of initial DCP test results	
18.01		
19.01	- Travel to Nairobi	
20.01	- Meeting with Chief Engineer, MTRD to follow up on the invitation to the training courses among other pending issues - Return to Embu	
21.01	- DCP tests on training road - Estimation of Design Traffic loading on training road - Compilation of initial DCP test results	
22.01	- Field training	
23.01	- Field training	
24.01	- Field training	
25.01	- Compilation of DCP results, preparation of training material	
26.01		Travel from Botswana
27.01	Field visit to training road, preparation of training material	
28.01	Classroom training Senior Management	
29.01	Classroom training Designer/Practitioners Group 1	
30.01	Classroom training Designer/Practitioners Group 1	
31.01	Classroom training Designer/Practitioners Group 1	
01.02		
02.02		
03.02	Classroom training Designer/Practitioners Group 2	
04.02	Classroom training Designer/Practitioners Group 2	
05.02	Classroom training Designer/Practitioners Group 2	
06.02	Classroom training Technicians	
07.02	Classroom training Technicians	
08.02	Compilation of material for report	
09.02		- Travel to Nairobi
10.02	- Travel to Nairobi - Drafting report	- Travel to Botswana
11.02	- Debriefing meeting with DG KeRRA - Drafting report	
12.02		- Finalise Draft Report
13.02		- Finalise Draft Report
14.02	- Travel to Norway	- Submit Draft Report
15.02	- Travel to Norway	

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

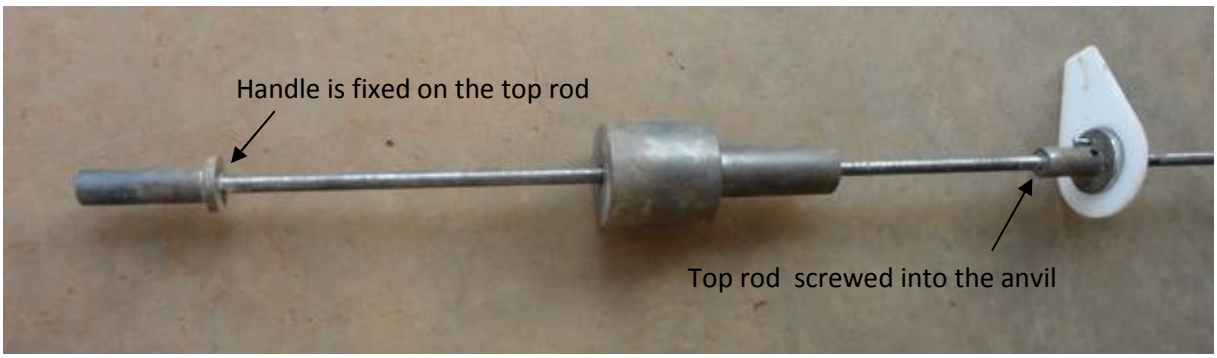
3.2 Build quality

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.



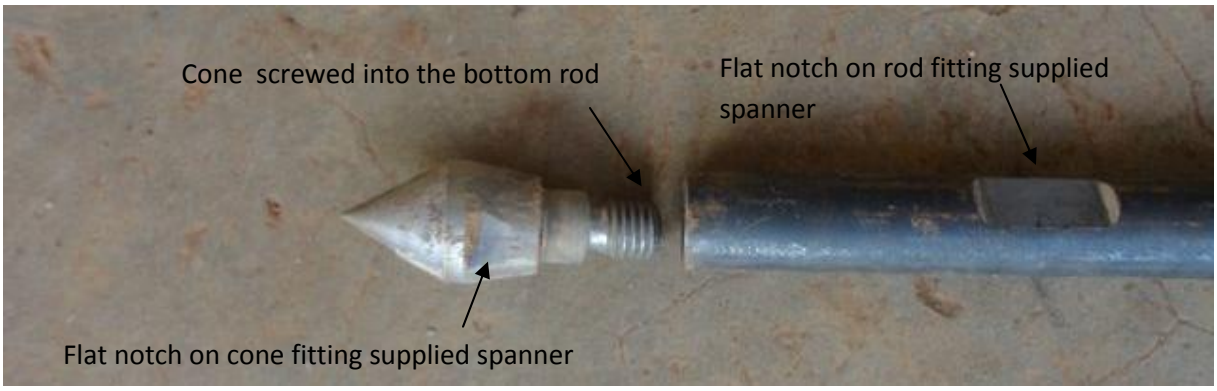
Picture 2: Attachment of handle and top rod

Picture 3: Attachment of bottom rod to 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.



Picture 4: Attachment of cone to bottom rod

The TRL model has the best cone design. The cylindrical part between the treads and the cone fits tigthly 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.

Picture 5: Attachment of stiff plastic holder for the ruler to the anvil

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.

Picture 6: Attachment of stainless steel ruler to aluminium foot


Picture 7: Attachment of ruler to foot

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 unneccesarily 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 weaking 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.

Picture 8: Top rod has broken at the attachment of the handle

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.

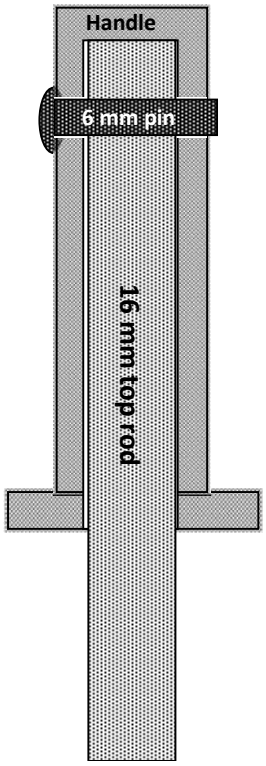
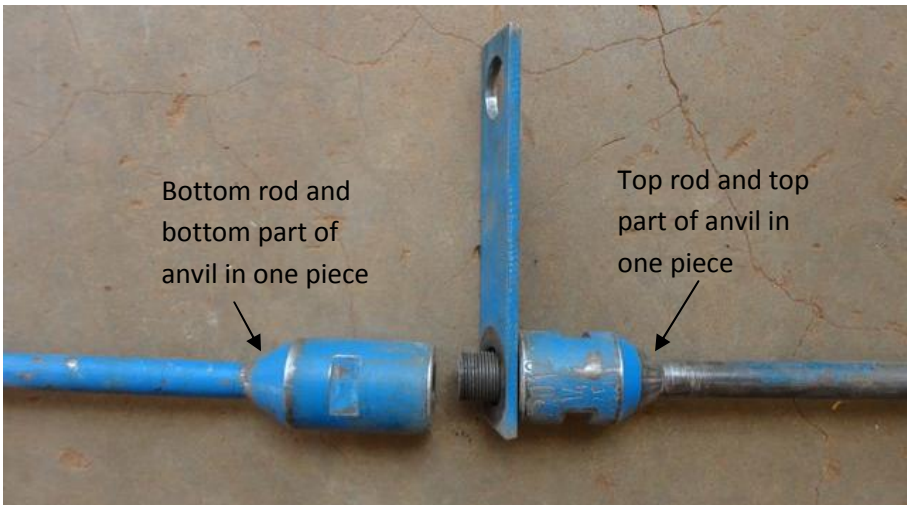


Figure 1: Pin attachment of handle to top rod

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.



Picture 9: Joint for top and bottom rod

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.

Picture 10: Cone attachment on the Dick King model

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

Picture 11: Ruler for the Dick King model

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.

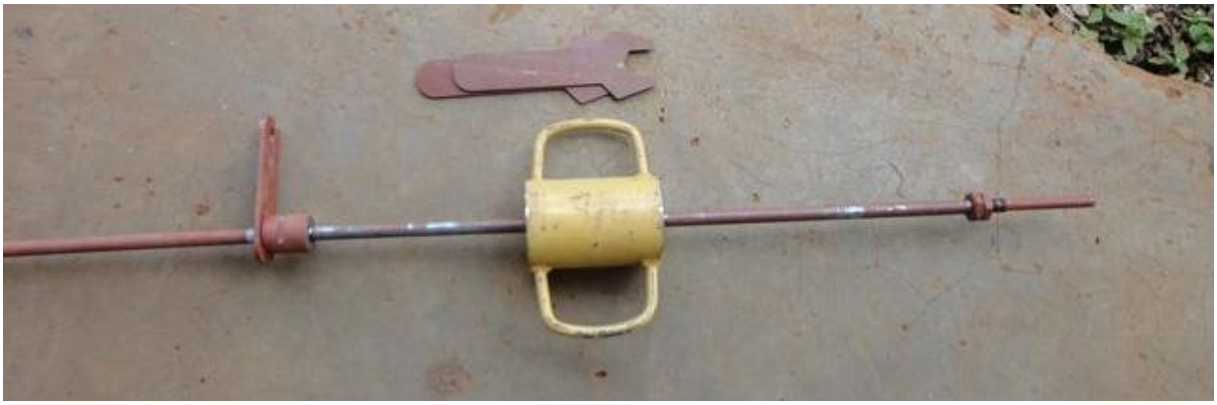
The scale is simply in the form of a cut-off steel measuring tape attached to an aluminium rail by rivets. The scale gets easily damaged and gets loose from the rail.

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.

Picture 12: Close-up of ruler for Dick King model

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.



Picture 13: RT Agencies DCP

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.

7. Summary and recommendations

In summary, Dick King model with the following improvements is recommended.

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

Table 1: Recommended improvements to the Dick King DCP model

Annex 7: Draft Certificates

CROWN AGENTS

AFCAP

UKaid from the British people

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

KENYA RURAL ROADS AUTHORITY
KeRRA
Opening up Rural Kenya

.....

Mwangi Maingi
Director General - KeRRA

31 January 2014

CROWN AGENTS

AFCAP

UKaid from the British people

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

KENYA RURAL ROADS AUTHORITY
KeRRA
Opening up Rural Kenya

.....

Mwangi Maingi
Director General - KeRRA

7 February 2014