ReCAP
Research for Community Access Partnership

UKaid
from the British people

Aspects of: DCP-DN Design Methodology for Low Volume Roads (LVR)

Morris De Beer (CSIR, Built Environment)

[Note: Content largely modified from the original (ERA/AfCAP Workshop, 2014) by Pinard and also Page-Green, both AfCAP Consultants]

CSIR
our future through science

33rd RPF - UMHLANGA DURBAN: May 9, 2017

Presentation Outline

- Background
- Dynamic Cone Penetrometer (DCP) Pavement Design Principles
- DCP Pavement Design Method/Process
- AfCAP Low Volume Road (LVR) - DCP Pavement Software
- Summary & Conclusions

Presentation Outline

- Background
- Dynamic Cone Penetrometer (DCP) Pavement Design Principles
- DCP Pavement Design Method
- AfCAP Low Volume Road (LVR) - DCP Pavement Software
- Summary & Conclusions

Environment vs Traffic Loading

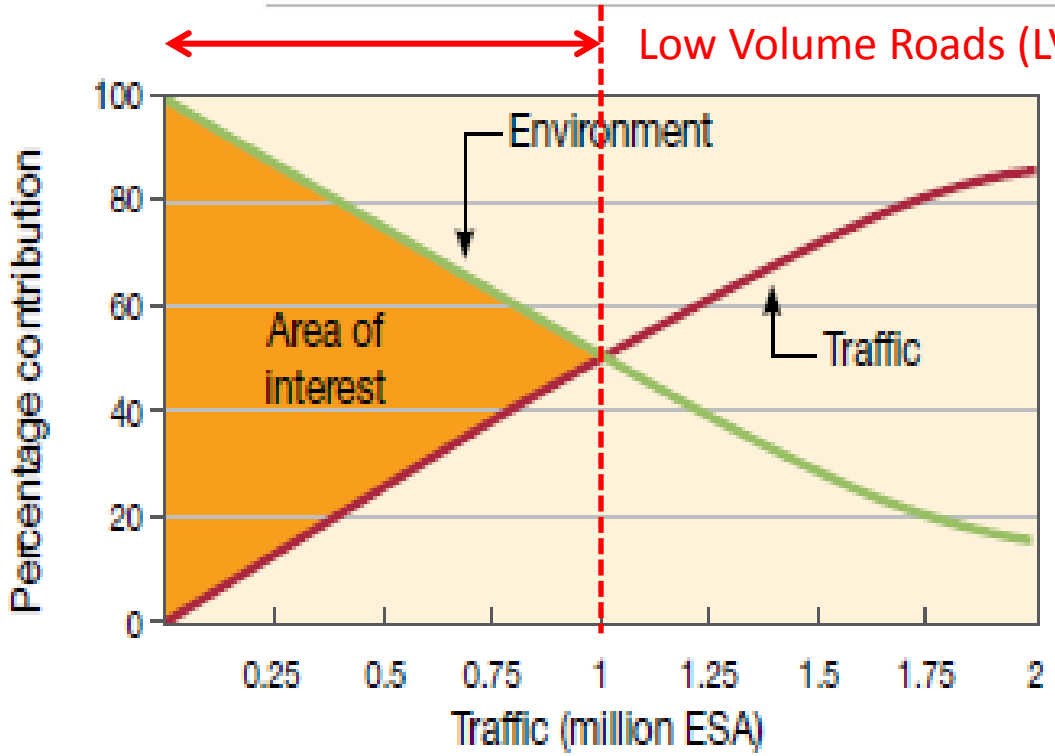
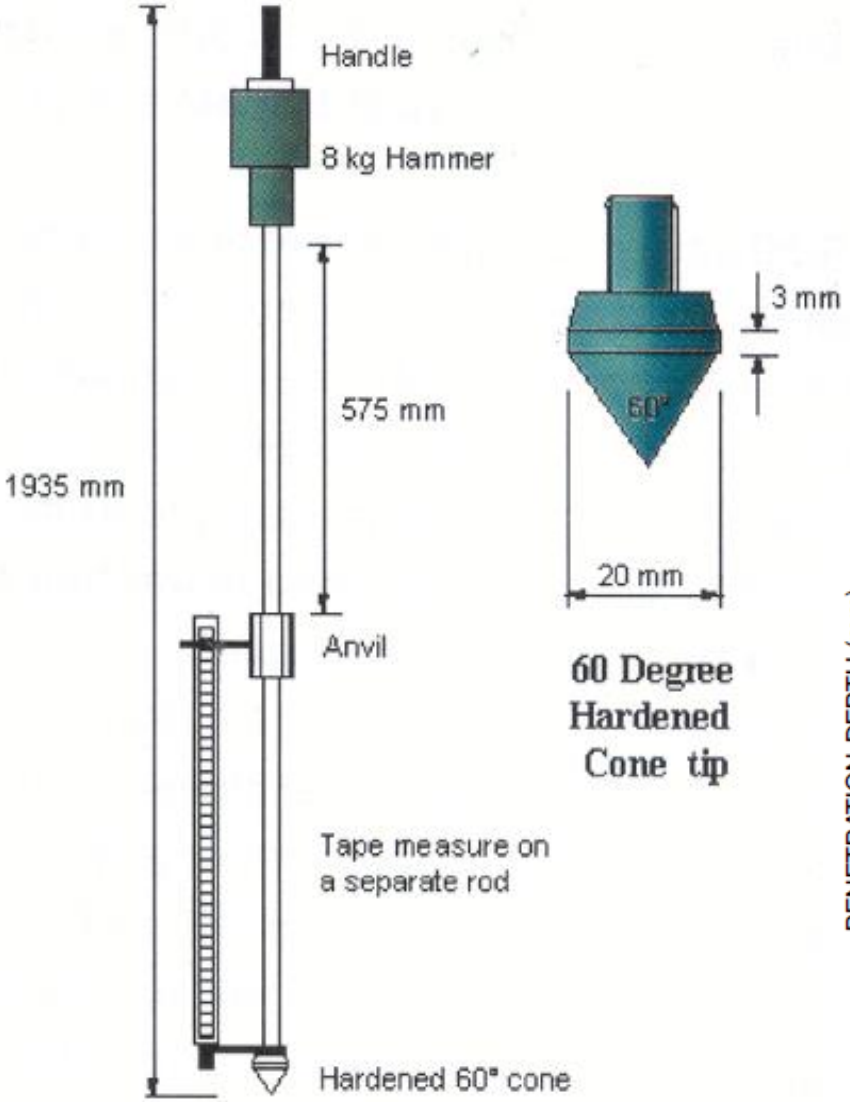
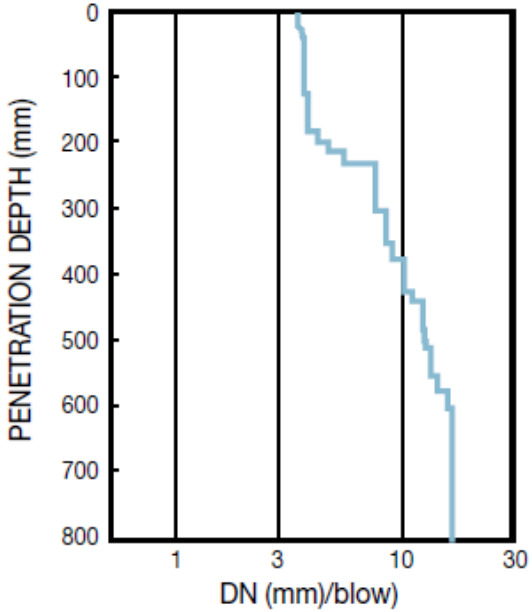


Figure 1-1: Traffic loading versus dominant mechanism of pavement distress (Schematic only)

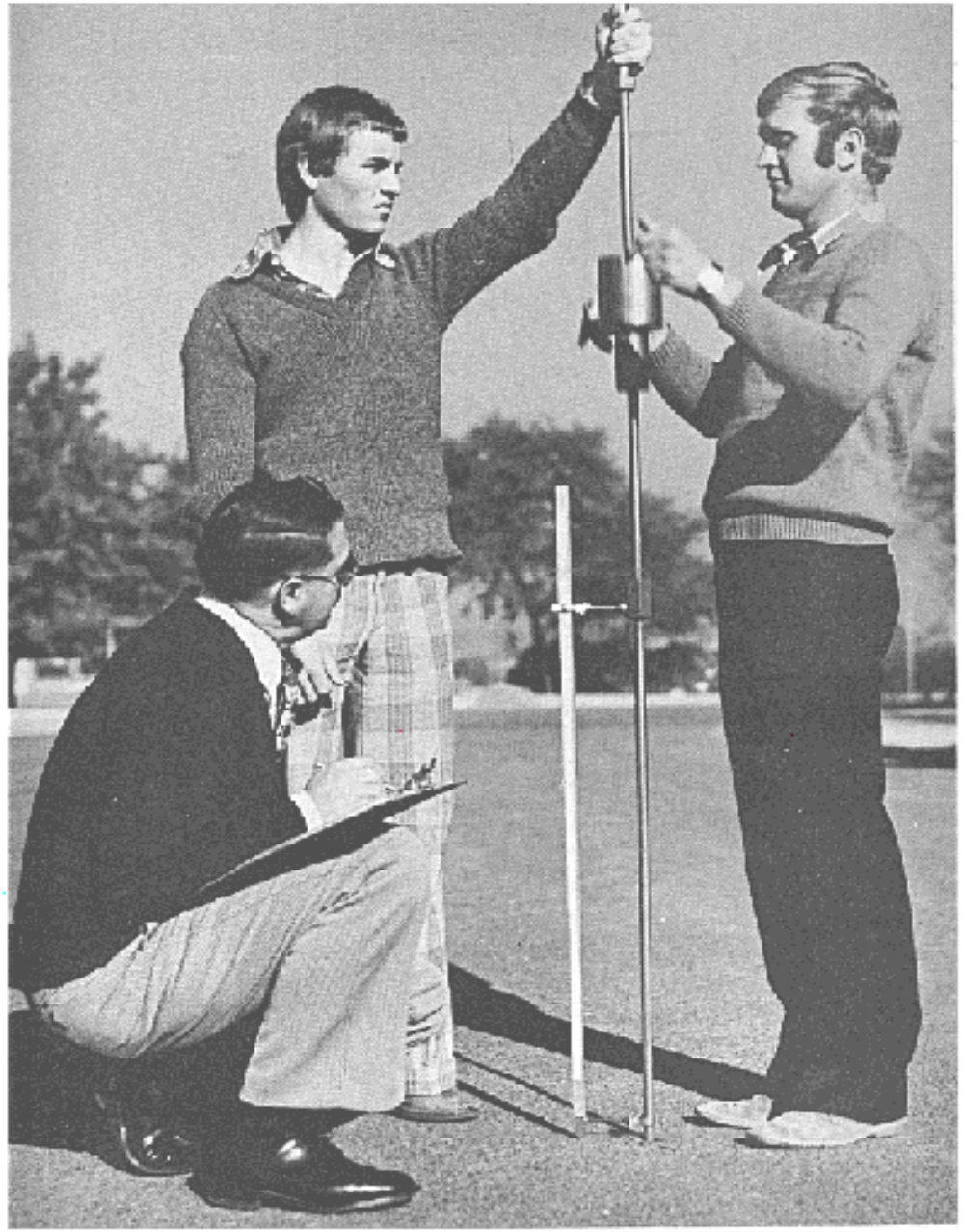
Dynamic Cone Penetrometer (DCP)





ReCAP
Research for Community Access Partnership

DCP – 1970's South Africa



Dynamic Cone Penetrometer (DCP)

Traffic Loading (Traffic Loading Curves (TLCs))

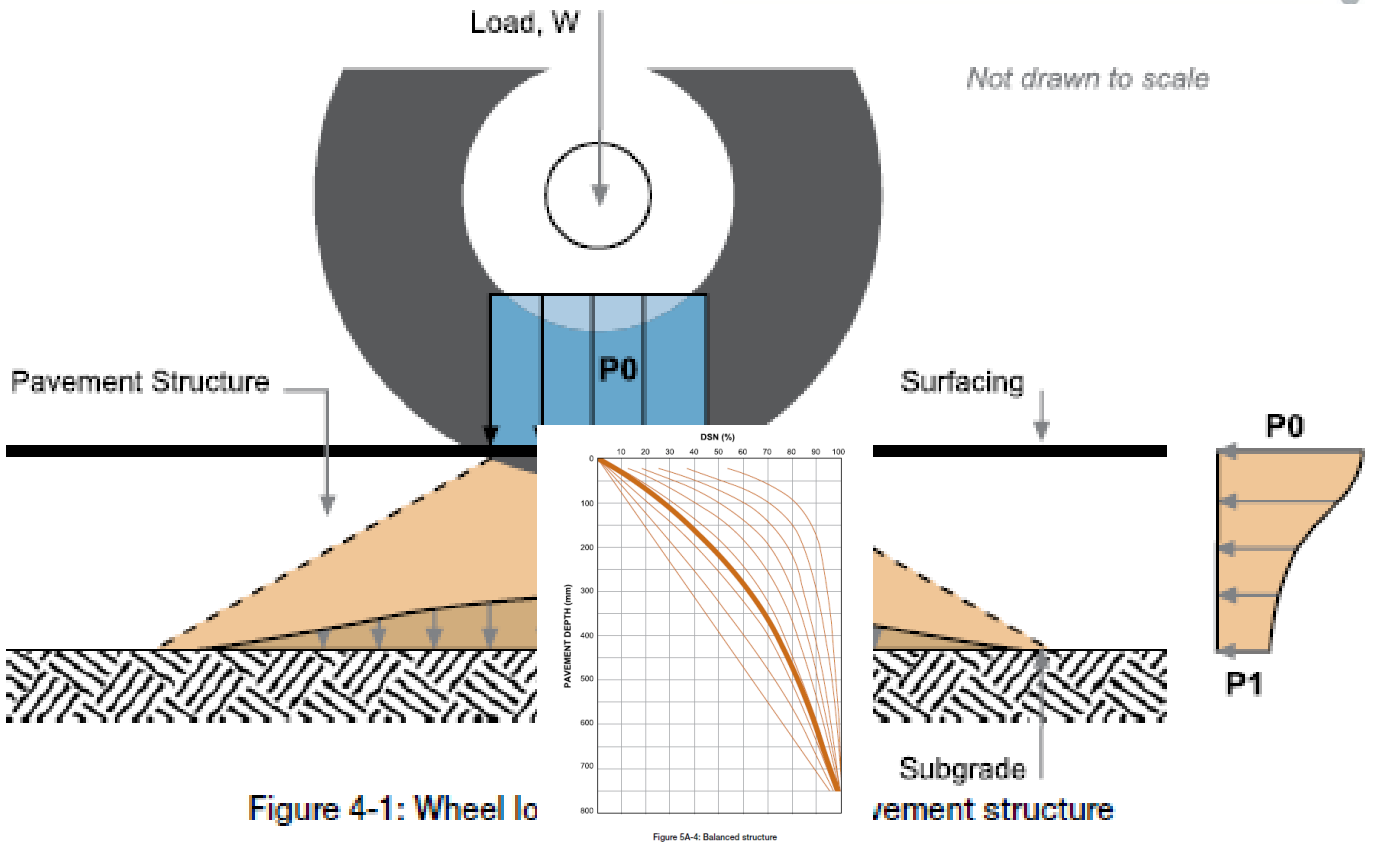


Figure 4-1: Wheel lo ...vement structure

Environment vs Traffic Loading

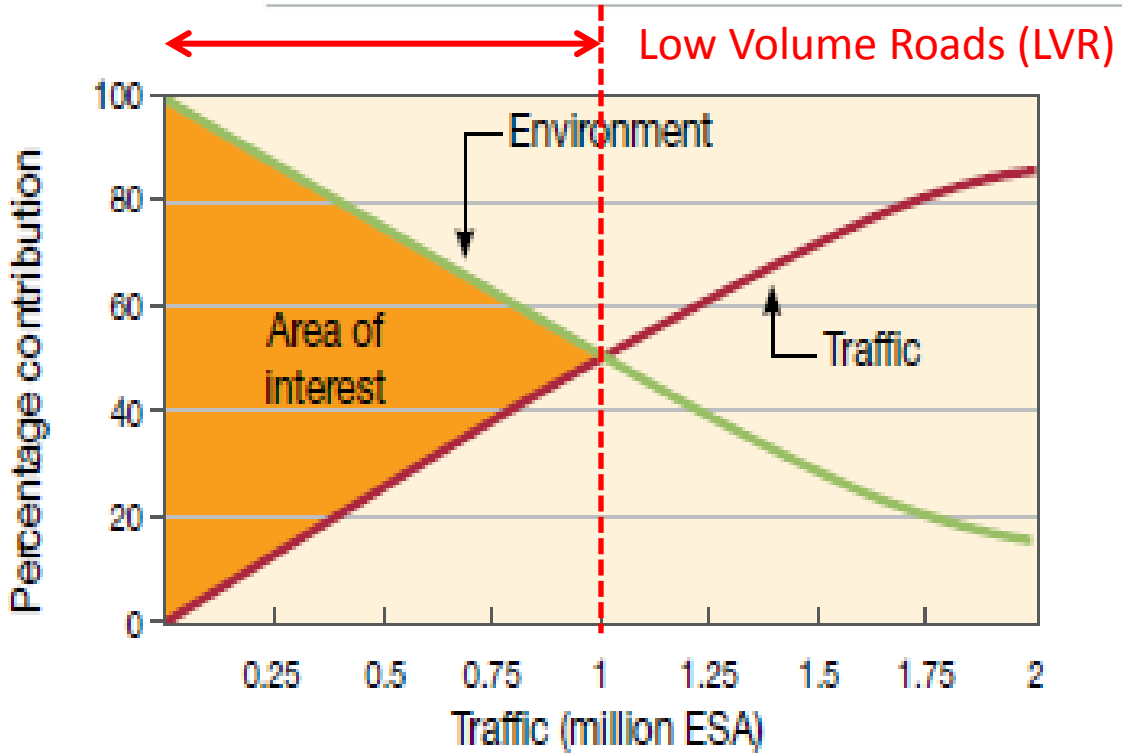
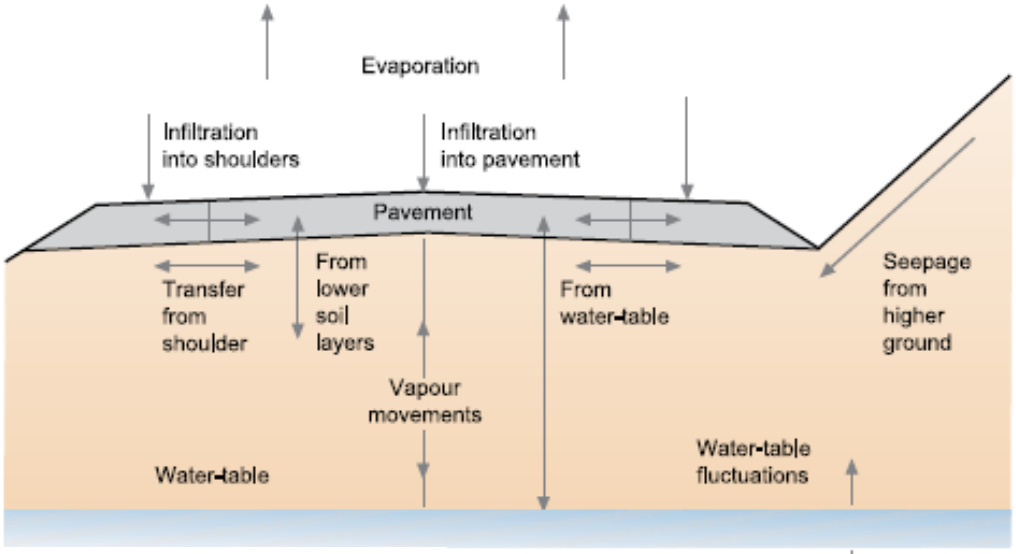


Figure 1-1: Traffic loading versus dominant mechanism of pavement distress (Schematic only)

Environment

Severe erosion of road side slopes in high rainfall areas.



ements in pavements and subgrades

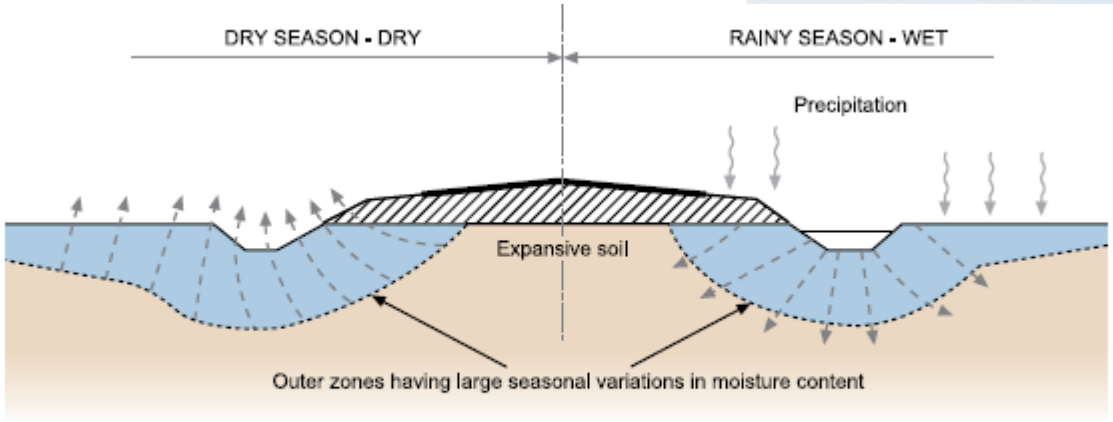


Figure 5-1: Moisture movements in expansive soils under a paved road

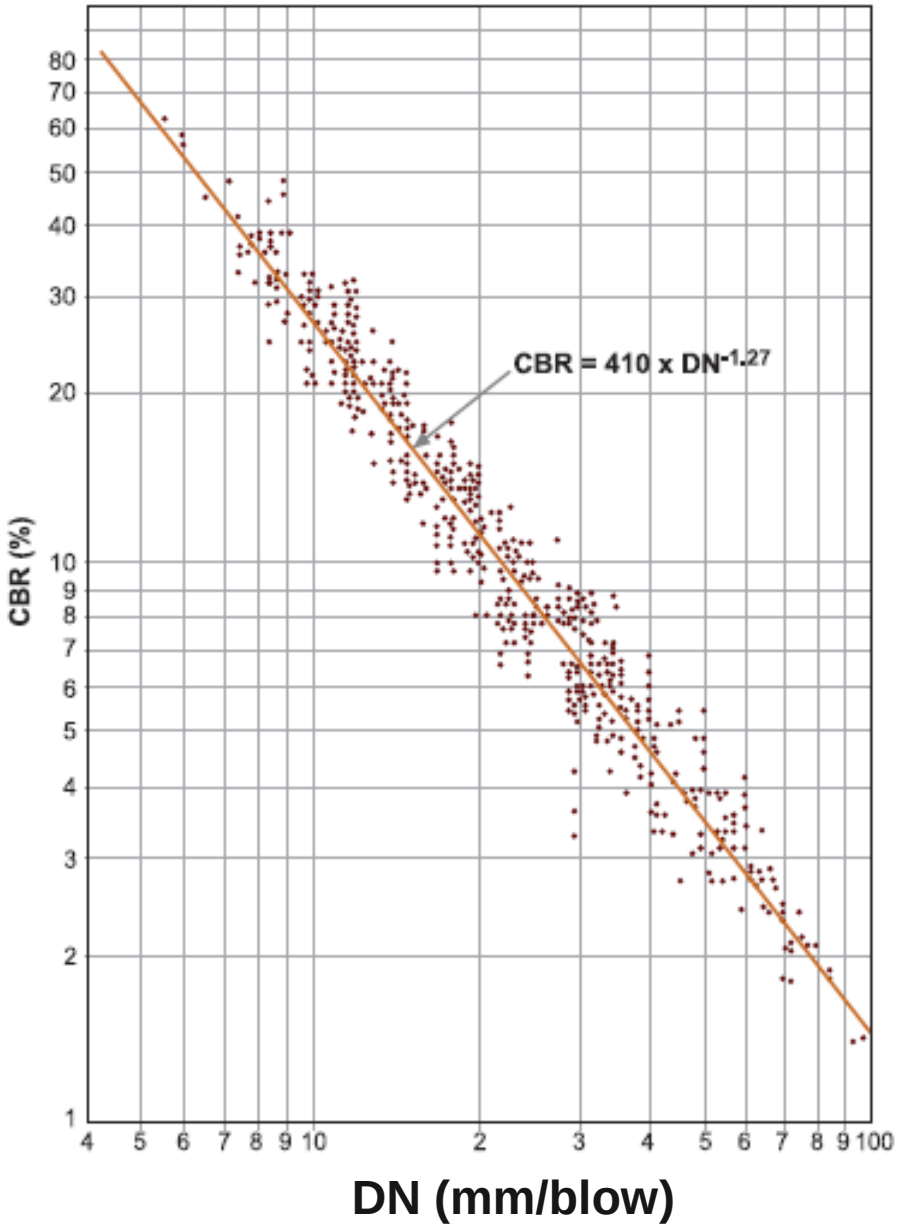
DCP Design Methods

- Current methods both characterise in situ shear strength of existing unpaved road in terms of resistance to penetration (DN value in mm/blow). However:
- DCP-CBR method converts DN values to CBR values to derive subgrade class as part of **CBR design catalogue**.
- DCP-DN method uses DN values to derive subgrade class as part of **DN catalogue**.
- Because of issues related to CBR test, focus under AFCAP 1 has been on the DCP-DN design method.

Background: CBR Test

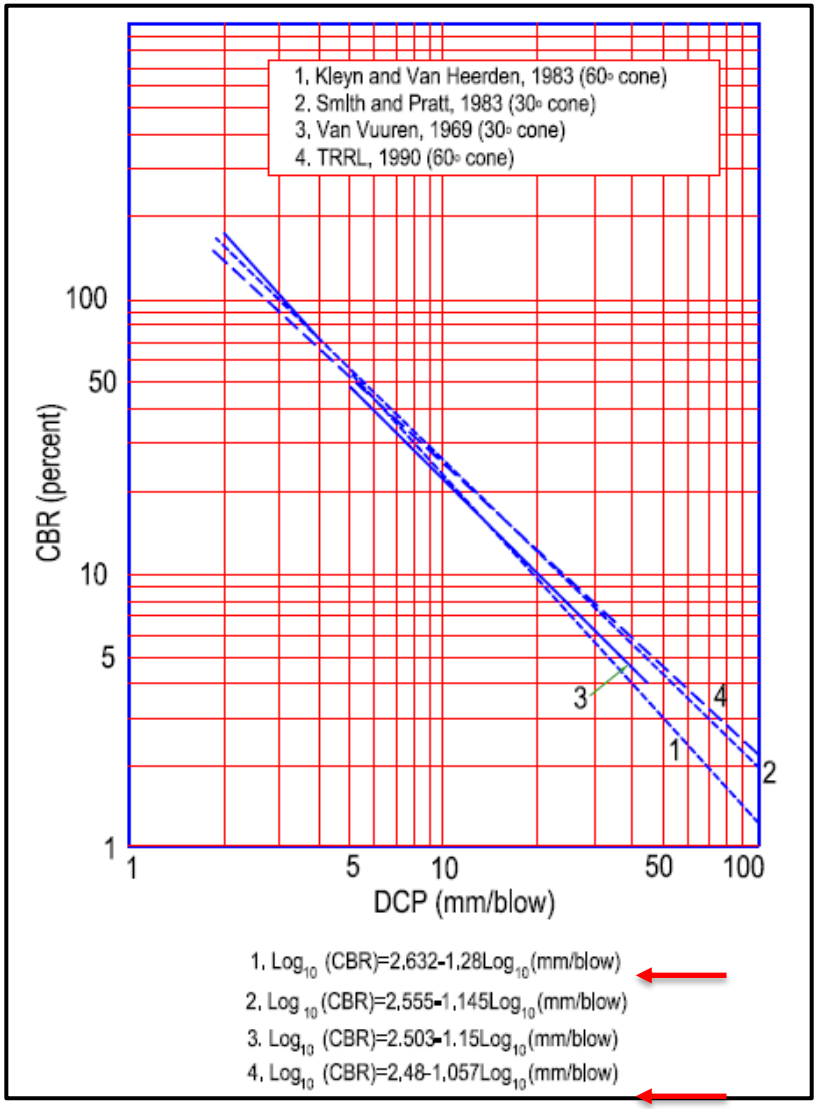
- Developed in 1930's for subgrade soils
- What does it measure?
- Strength or stiffness ?
  - Probably a "mini" plate load test more than shear strength test?
- Repeatability, reproducibility and precision are poor
  - Standard deviation (σ) = 10^{w} where w = (1.4771-0.9853^{CBR})

Relationship between DN and CBR_Kleyn



CBR-DCP relationship based on 2000+ measurements in South Africa (Kleyn, 1978)

Other relationships between DN and CBR



CBR Issues_ VARIABILITY.. !.

- Poor reproducibility

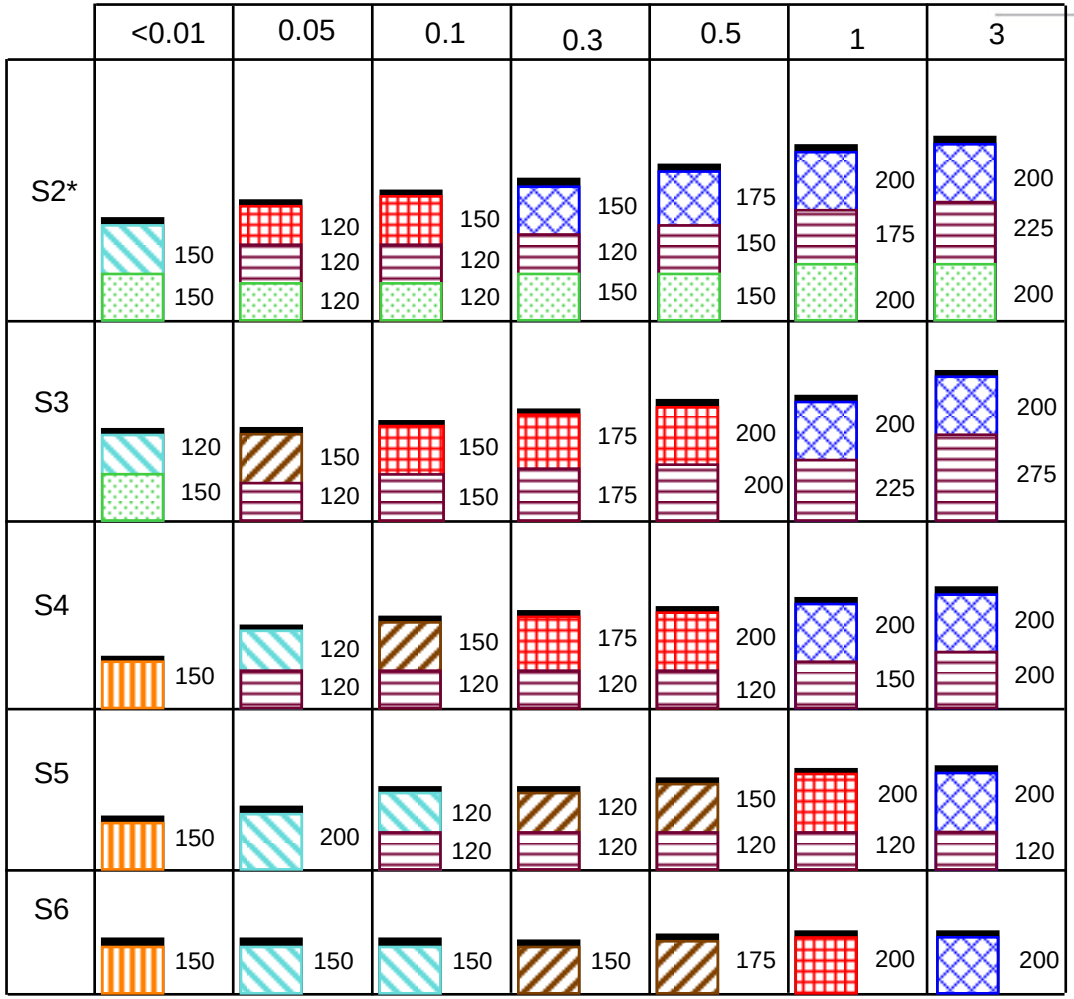
CBR	σ	95% confidence	Range
10	4	± 8	2 – 18
30	7	± 14	16 – 44
60	12	± 24	36 – 84
80?	16	± 32	58 – 122

- Empirical test developed in 1928/29. Tried, trusted and understood, but…..
- Test procedure is time consuming, costly and requires large sample for lab testing
- Often excludes materials that are eminently "fit for purpose"
- When based on soaked condition, irrespective of climate, can be very conservative

DCP-CBR Based Pavement Design Catalogue

ReCAP Research for Community Access Partnership

UKaid from the British people



Double surface dressing

Base, CBR 80

Base, CBR 65

Base, CBR 55

Base, CBR 45

Gravel wearing course quality

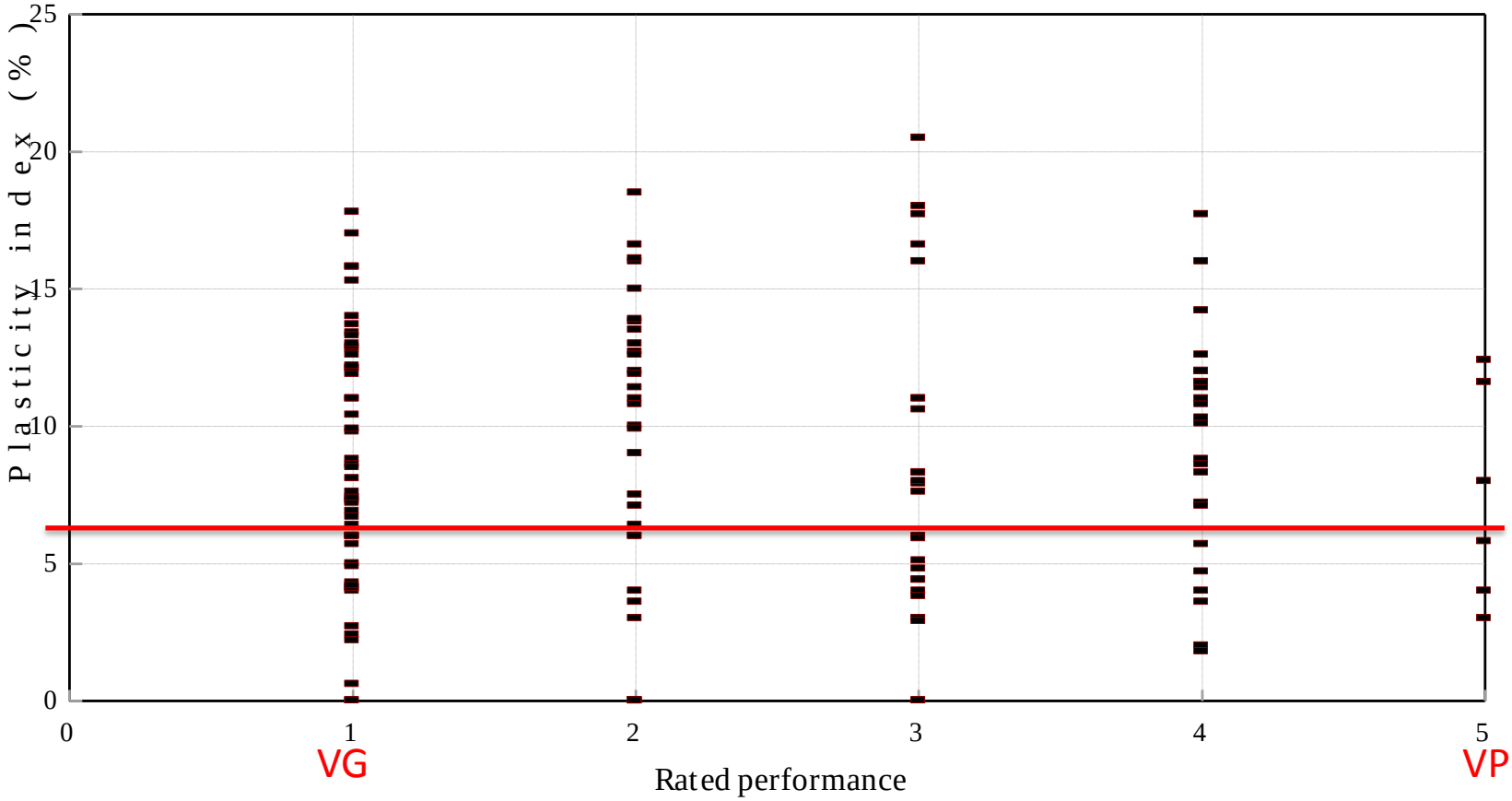
Sub-base, CBR 30

Selected subgrade fill, CBR 15

Note: * Non-expansive subgrade

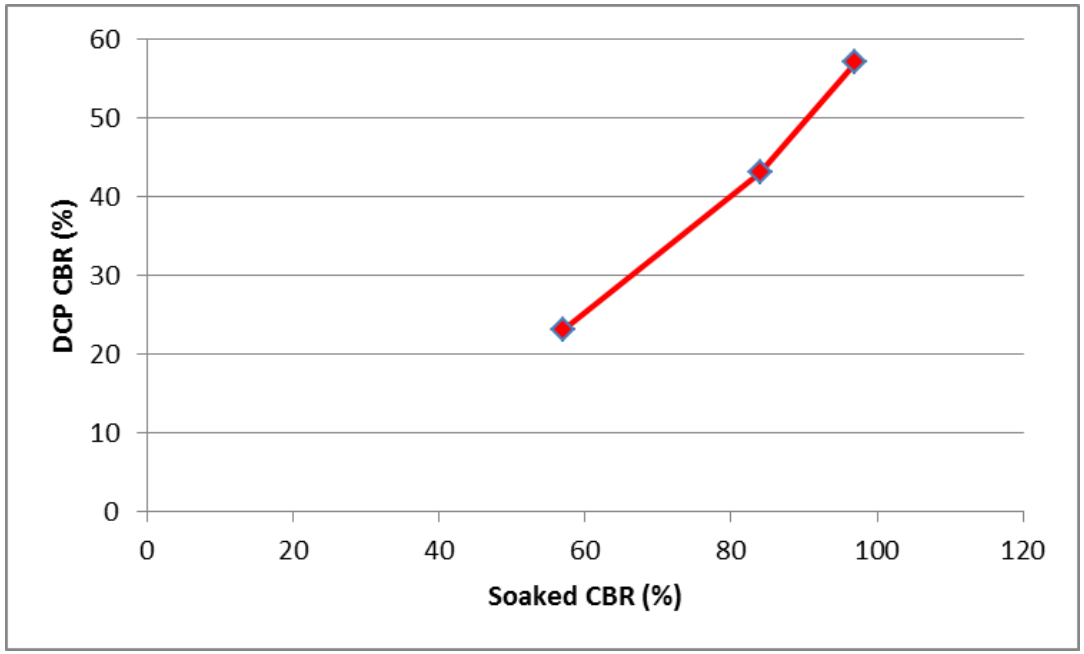
CSIR our future through science

What PI is realistic ?- PI – Poor Correlation With Performance

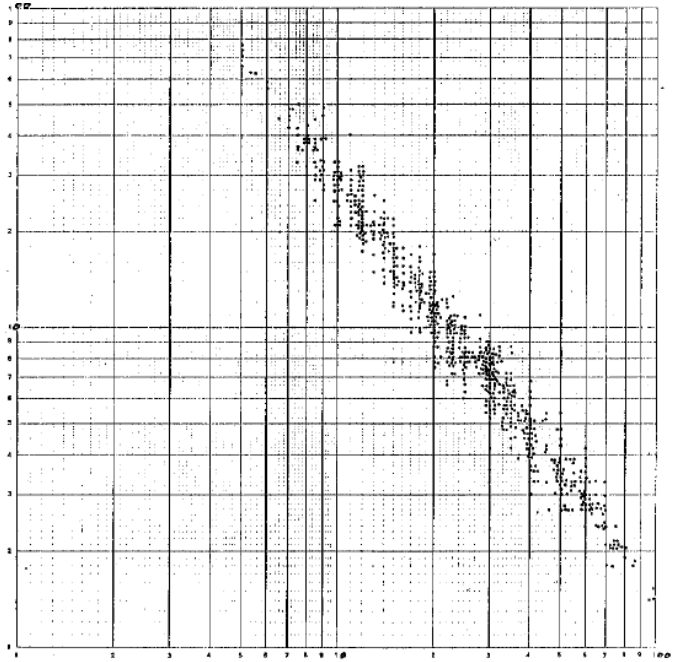


BACKGROUND – CBR VS DCP

- Correlated with DN
- Actual laboratory result
- Consider mostly DN values in this presentation (remove conversion factors)



CBR (%)



DN (mm/bl)

Presentation Outline

- Background
- Dynamic Cone Penetrometer (DCP) Pavement Design Principles
- DCP Pavement Design Method
- AfCAP Low Volume Road (LVR) - DCP Pavement Software
- Summary & Conclusions

Development of DCP Design Method

- Extensive DCP testing was carried out in conjunction with Heavy Vehicle Simulator (HVS) testing of various roads in SA.
  - Allowed further correlations and developments, e.g. relationships between actual flexible road performance and DCP results, including lightly cementitious base/subbase pavements.

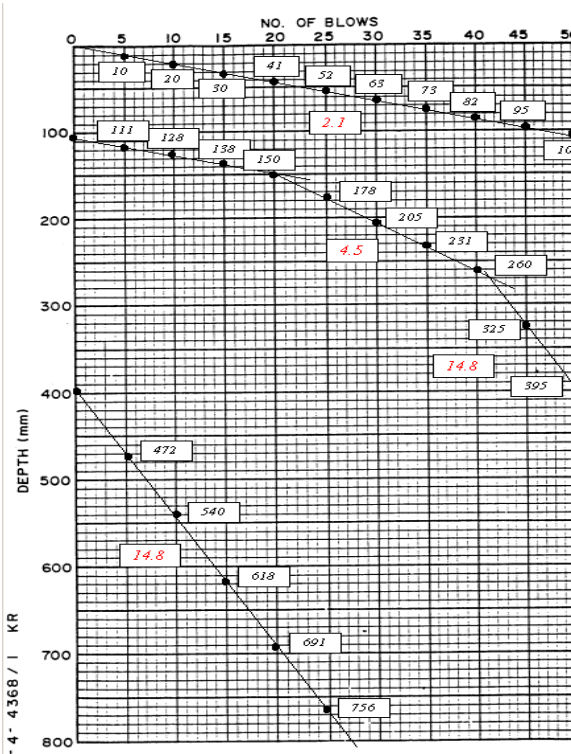
DCP Design Approach

- Make use of beneficial traffic moulding and consolidation of gravel road pavement over many wetting and drying cycles
  - Gravel road pavement should not preferably 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 strength profile

Pavement strength balance concept

- Successful pavements are structurally well-balanced
- Strength decreases evenly with depth (smooth profiles)
- No strength concentrations in pavement

  = well balanced
- Pavement balance number (BN)



Standard Pavement Balance Curves (SPBC):

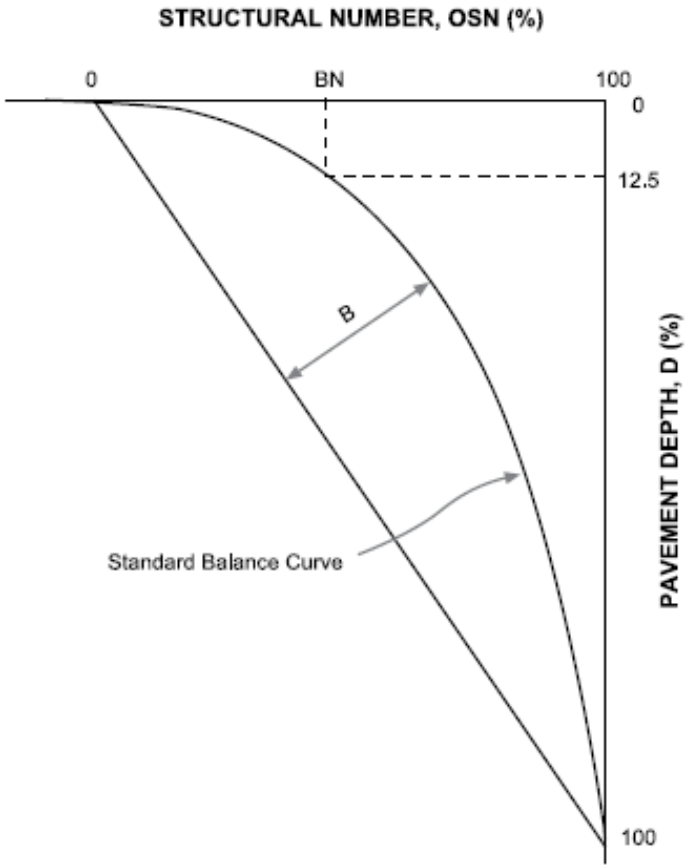


Figure 5A-2: Graphic representation of the formula for the Standard Pavement Balance Curve (SPBC)

Standard Pavement Balance Curves (SPBC):

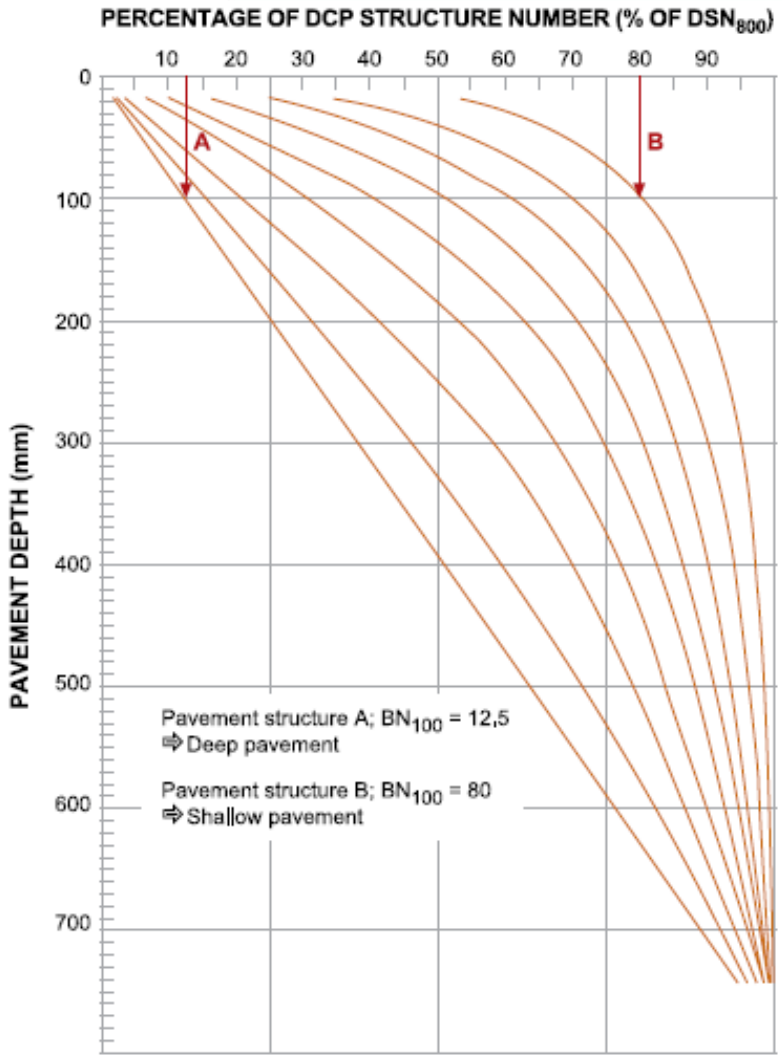


Figure 5A-3: Shows pavement strength-balance curves for typical natural gravel and lightly cemented pavements in the Southern African region.

Standard Pavement Balance Curves (SPBC):

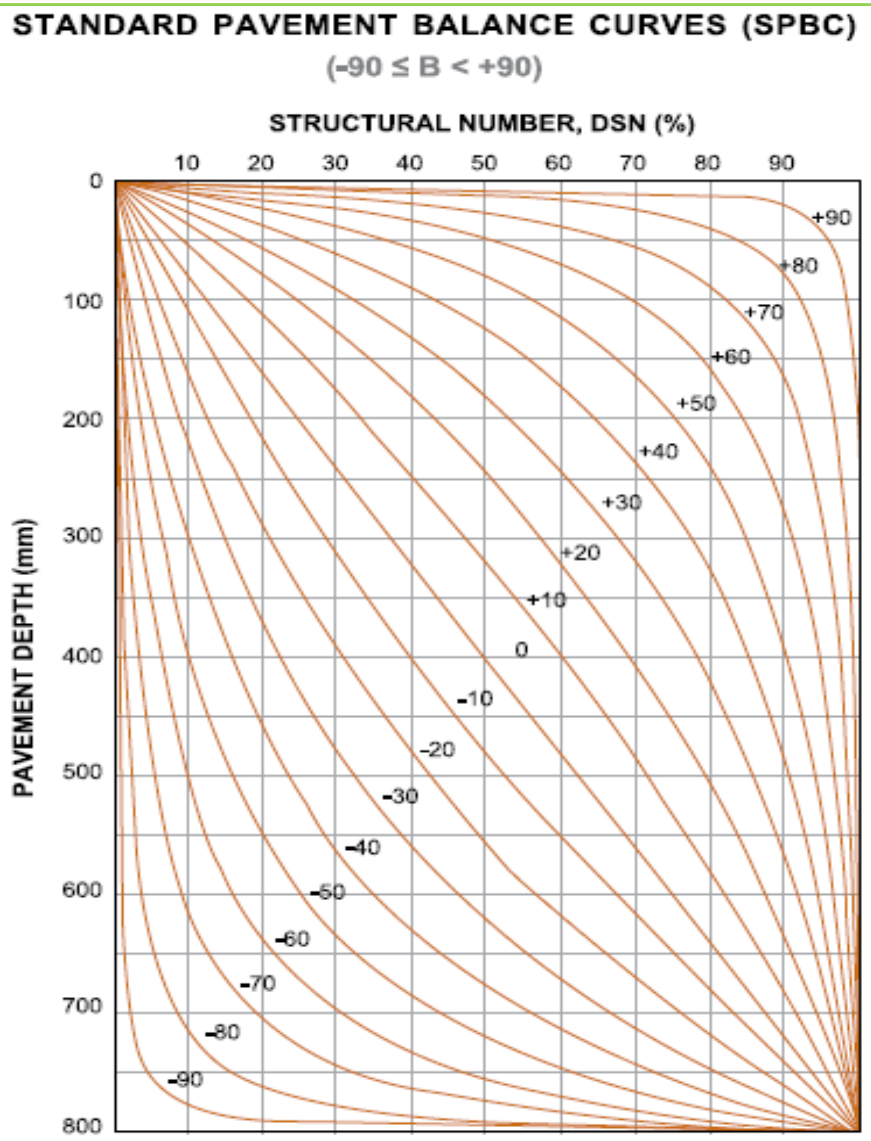


Figure 5A-1: Standard Pavement Balance Curves

Standard Pavement Balance Curves (SPBC):

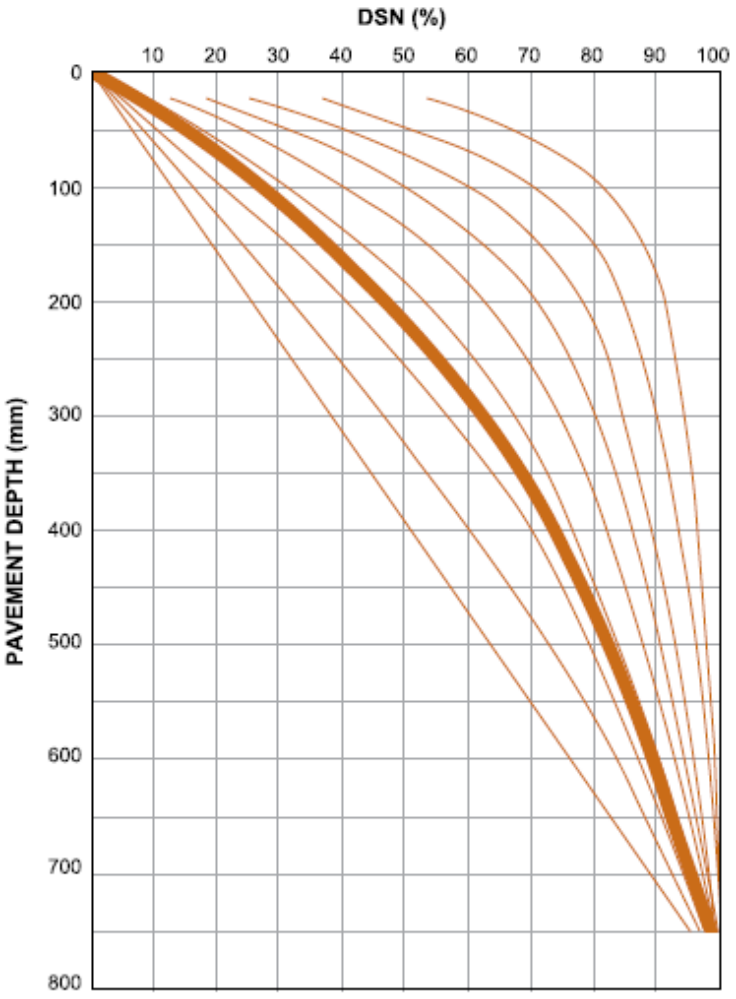


Figure 5A-4: Balanced structure

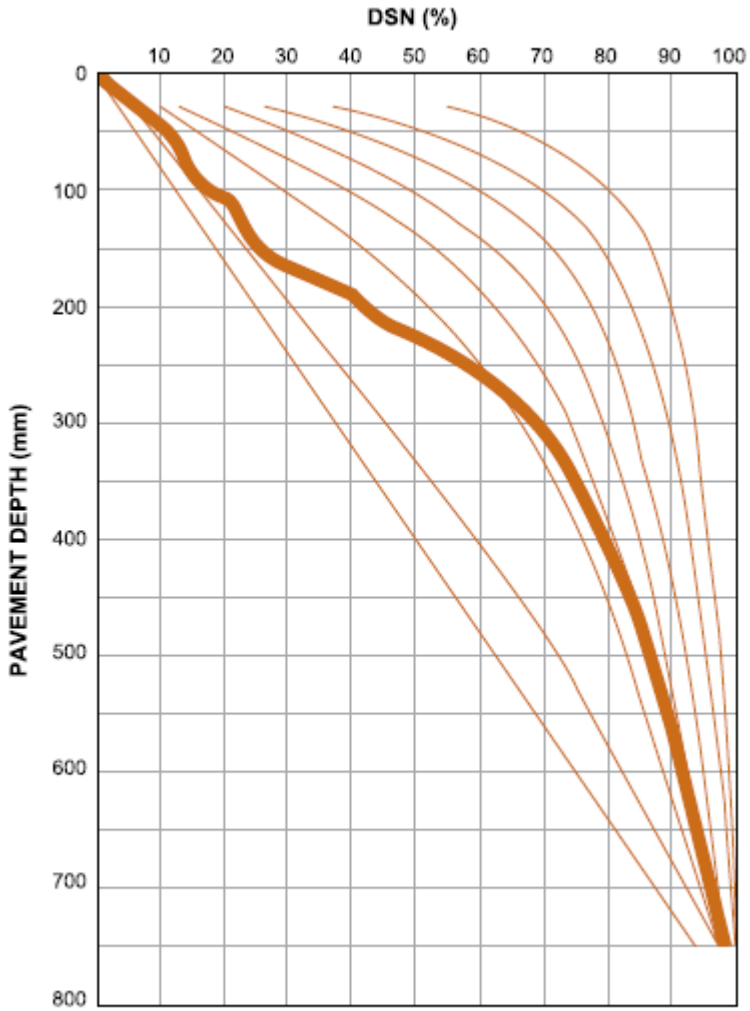
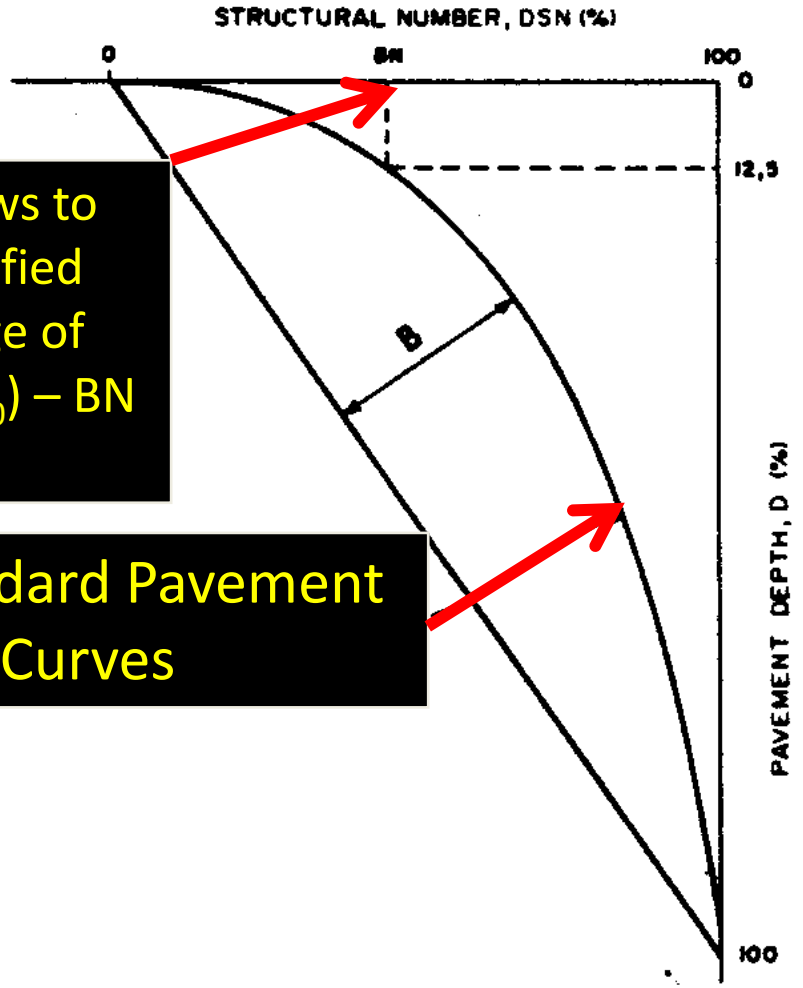
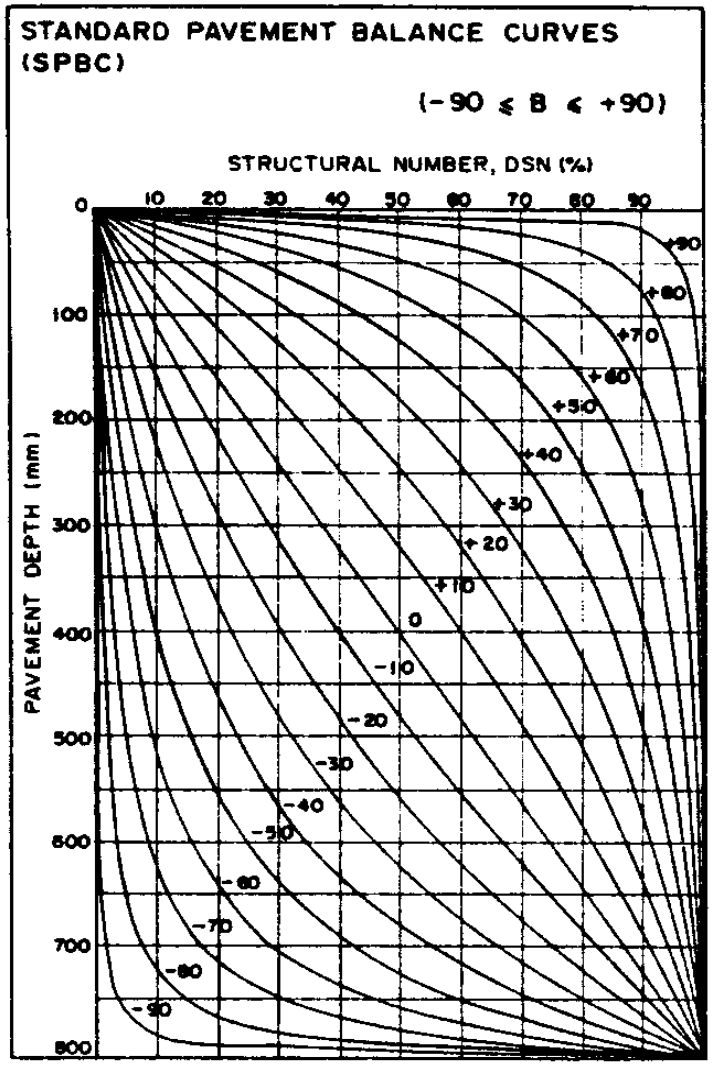


Figure 5A-5: Unbalanced structure



BN - # of Blows to get to a specified depth as %age of DSN_{800} (BN_{100}) – BN ~ **40**

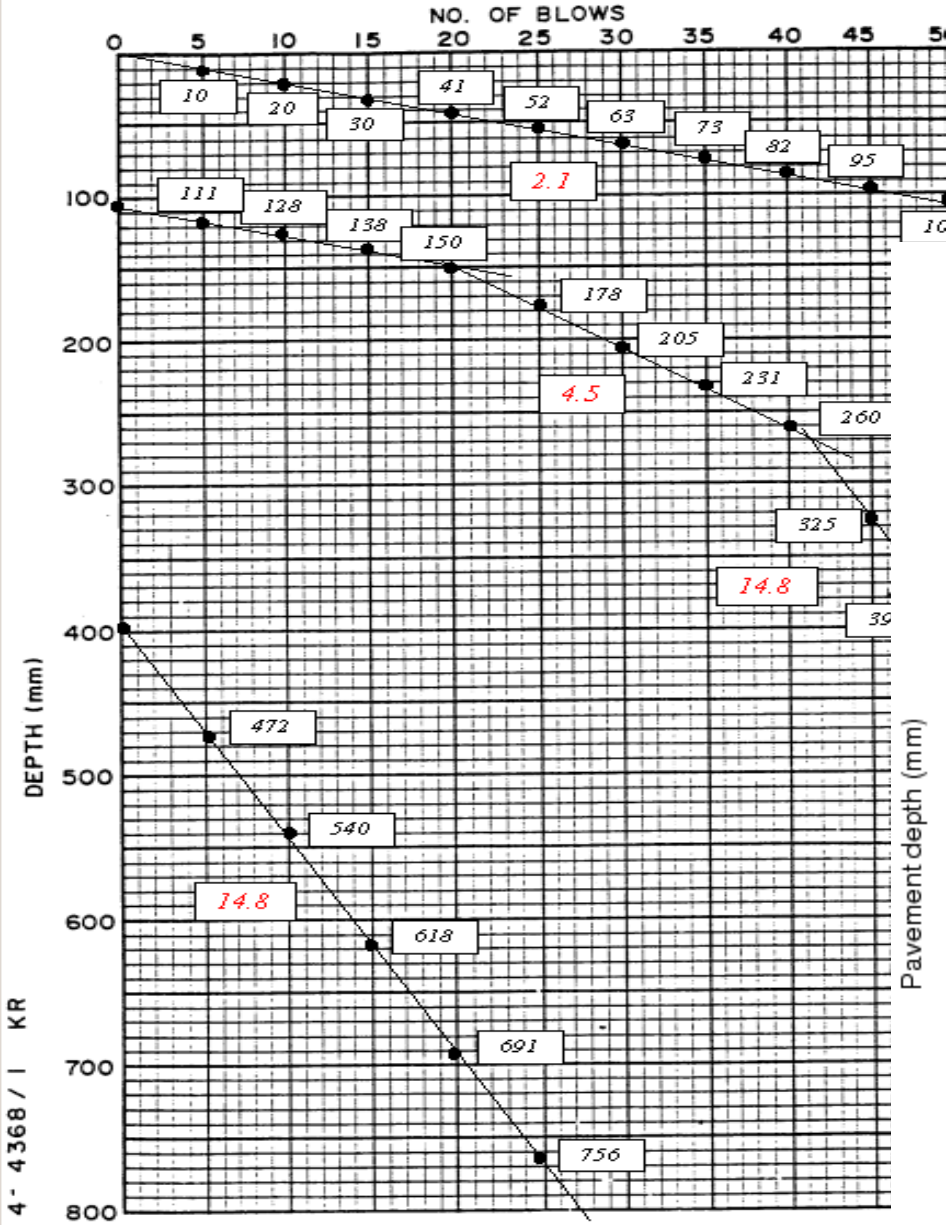
B = Standard Pavement Balance Curves

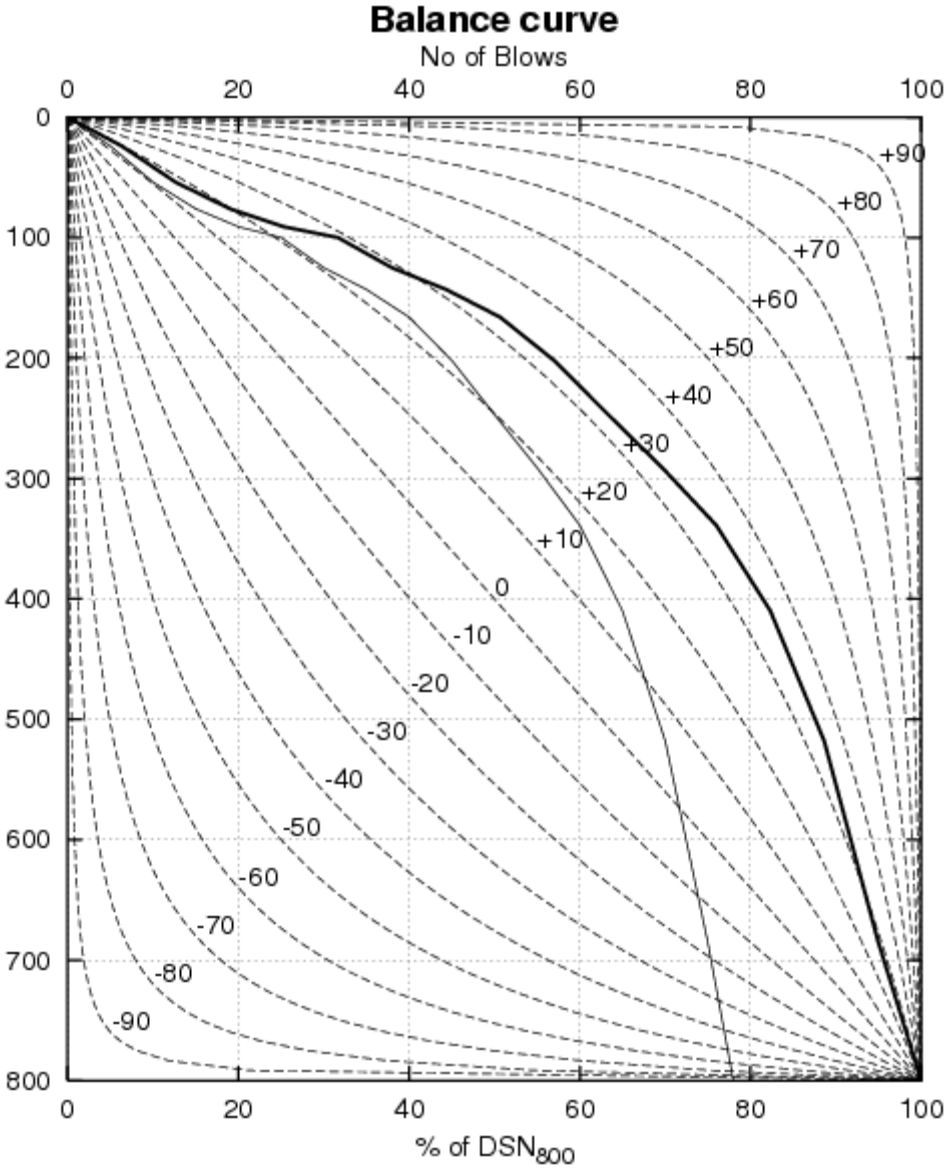


$$DSN\ (\%) = \frac{D\left[400B + (100-B)^2\right]}{40B + (100-B)^2}$$

WHERE $B = 100 - \frac{2}{(BN-D)}\left\{\left[1094\ BN\ (100-BN)\right]^{0,5} - 12,5\ (100-BN)\right\}$ IF $D = 12,5\ \%$

AND $B = 0$ IF $BN = 12,5$


NO. OF BLOWS
0 5 10 15 20 25 30 35 40 45
10 20 30 41 52 63 73 82 95
2.1
111 128 138 150 178 205 231 260
4.5
325
14.8
472 540 618 691 756
14.8
DEPTH (mm)
100 200 300 400 500 600 700 800
Pavement depth (mm)
- 4 - 4368 / 1 KR


Balance curve
No of Blows
0 20 40 60 80 100
+90 +80 +70 +60 +50 +40 +30 +20 +10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
% of DSN800

"Manual" Fitting of layers/sub-layers..

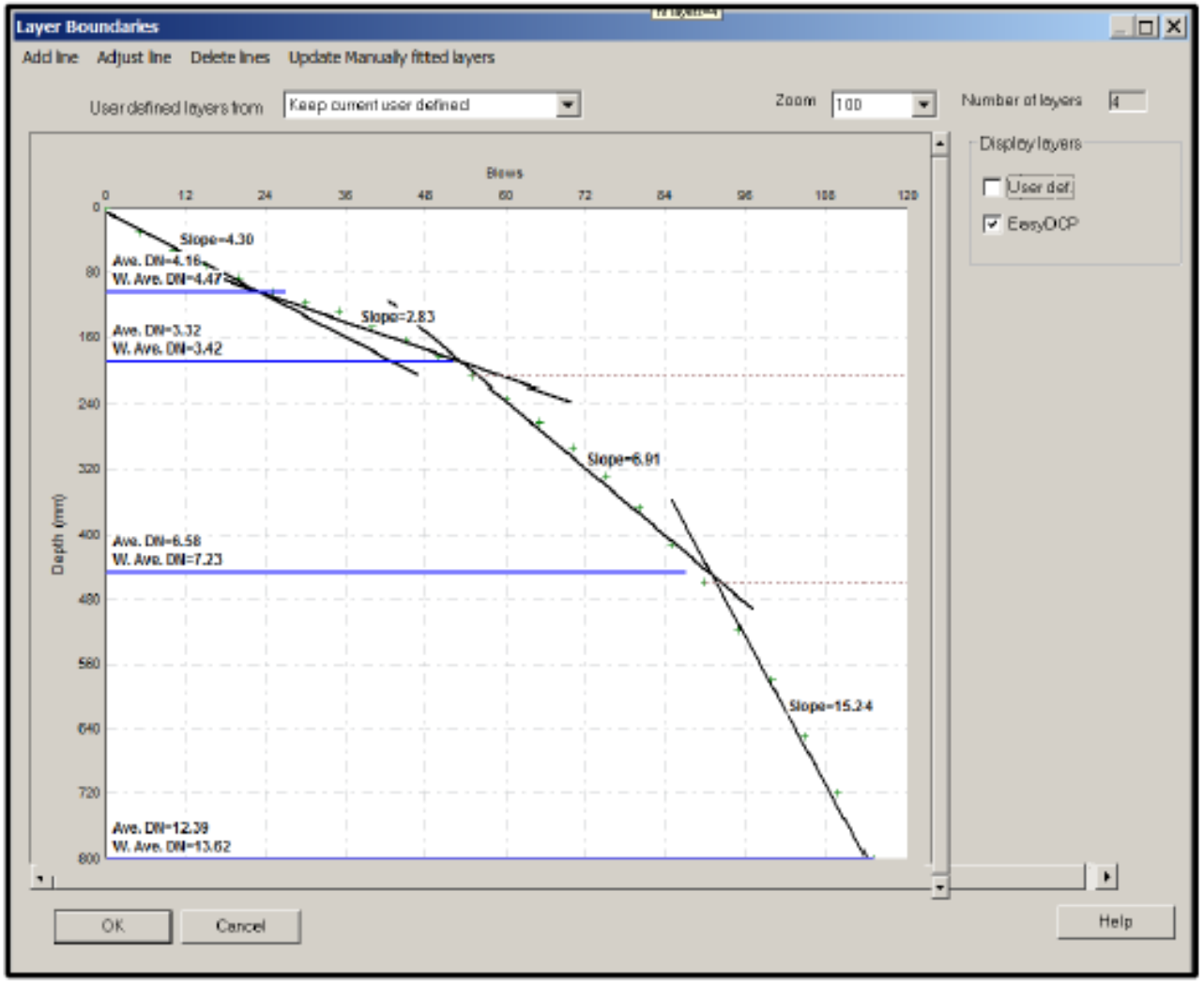
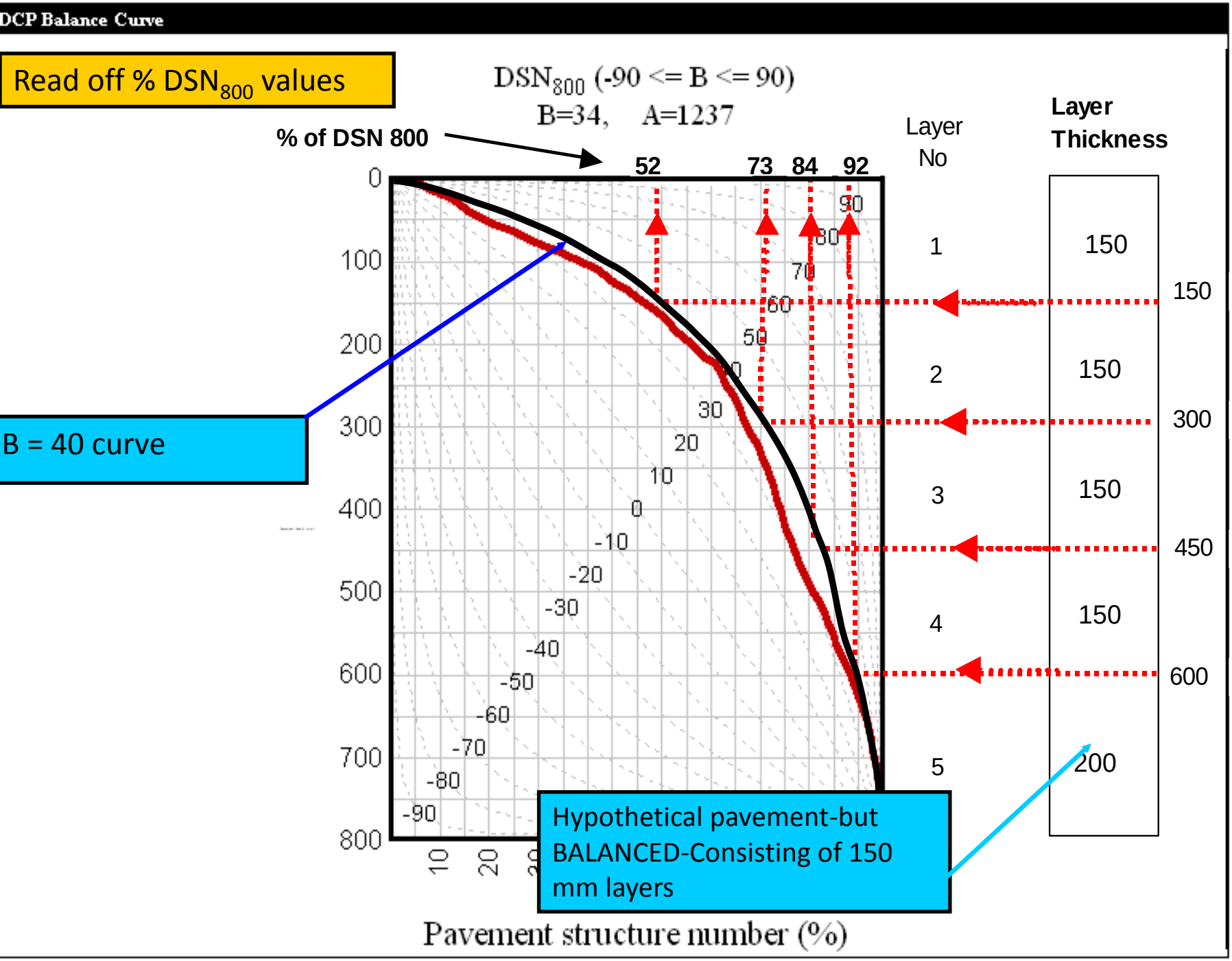
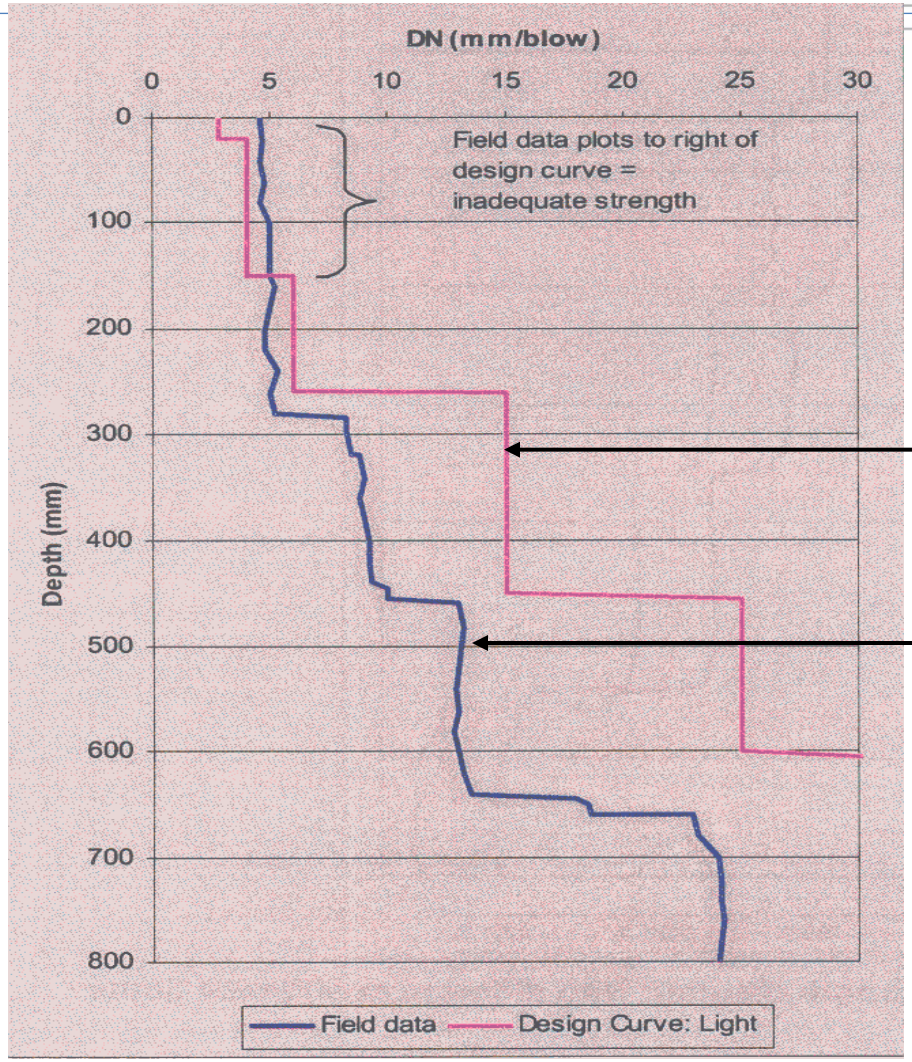


Figure 28. Manual layer fitting menu for layer boundaries to be defined. Note: EasyDCP auto re-defined layers also shown here by the broken lines.


DCP Balance Curve
Read off % DSN800 values
DSN800 (-90 <= B <= 90)
B=34, A=1237
% of DSN 800
52
73
84
92
Layer No
Layer Thickness
1
2
3
4
5
150
150
150
150
150
150
300
450
600
B = 40 curve
Hypothetical pavement-but BALANCED-Consisting of 150 mm layers
200
Pavement structure number (%)

Integration of In Situ and Required Strength Profiles



Required strength profile

In situ strength profile

6 x Traffic Loading Curves (TLC)

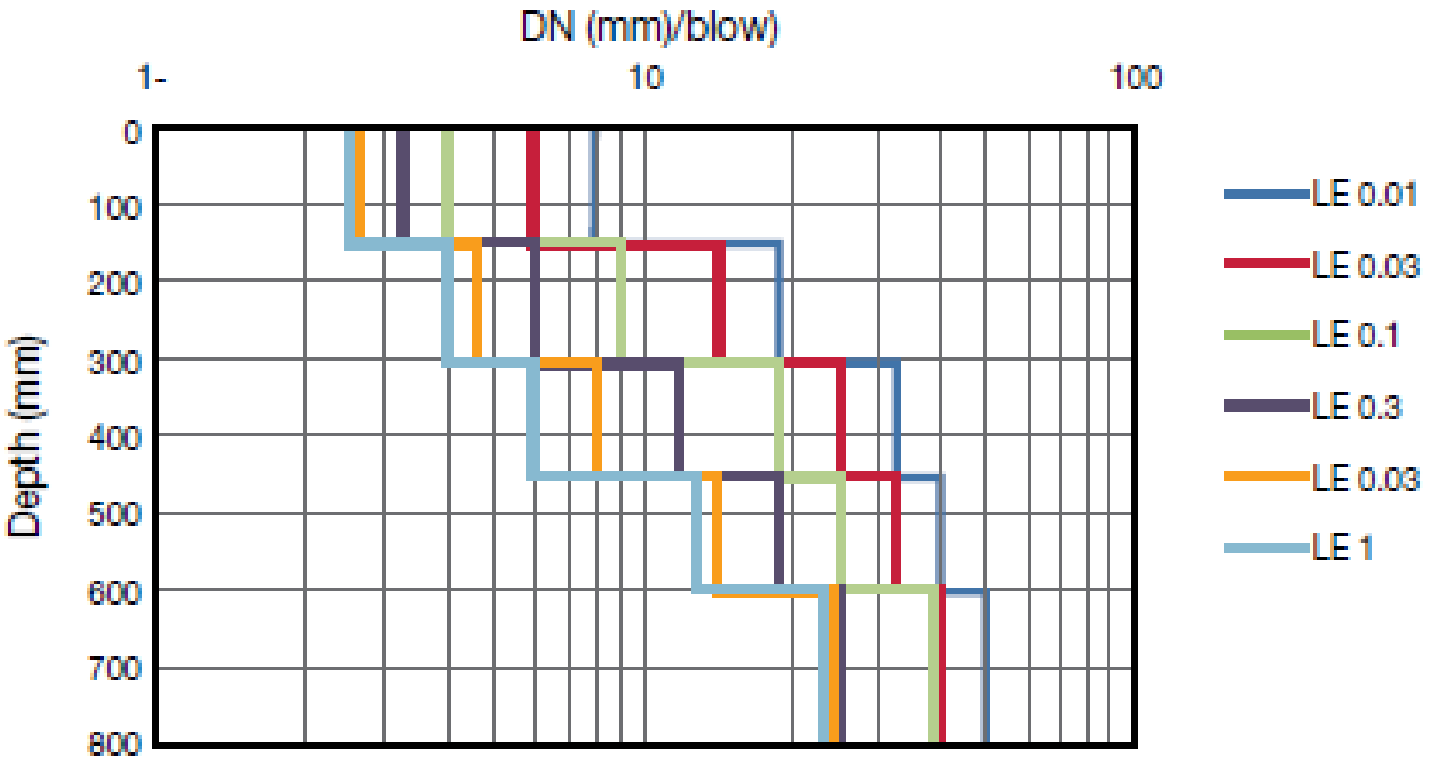
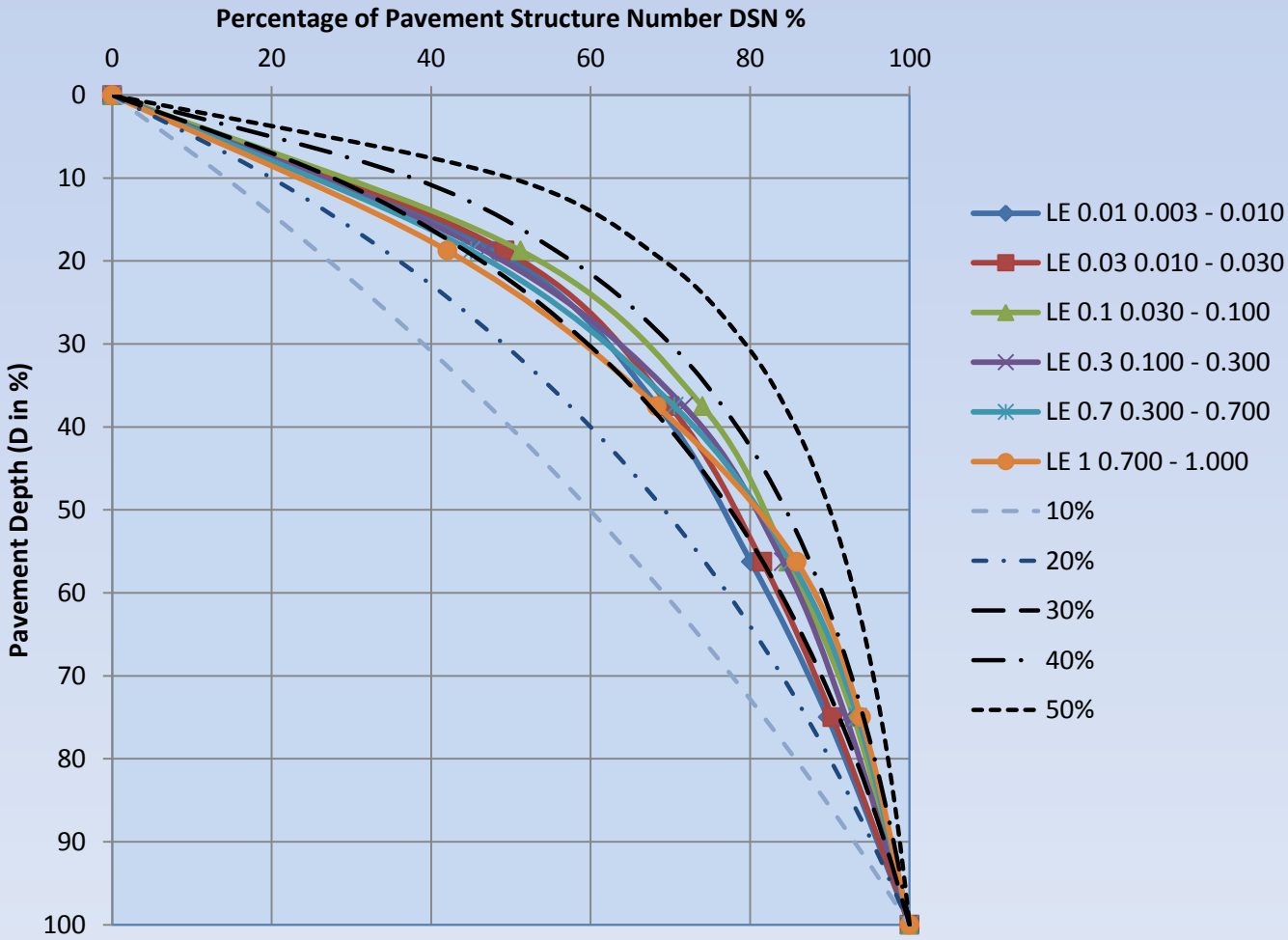


Figure 5-7: Layer Strength Diagram for various traffic classes

6 x Traffic Loading Curves (TLC) and structural balance..



ReCAP
Research for Community Access Partnership

"DCP DN Design Catalogue"-based on TLCs

UKaid
from the British people

Traffic Load Class (TLC) E80 x 10^6	TLC 0.01 0.003 – 0.010	TLC 0.03 0.010 – 0.030	TLC 0.1 0.030 – 0.100	TLC 0.3 0.100 – 0.300	TLC 0.7 0.300–0.700	TLC 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} (Blows)	≥ 39	≥ 52	≥ 73	≥ 100	≥ 128	≥ 143

{Experience largely based on LVR R&D, Page-Green, *et. al.*}

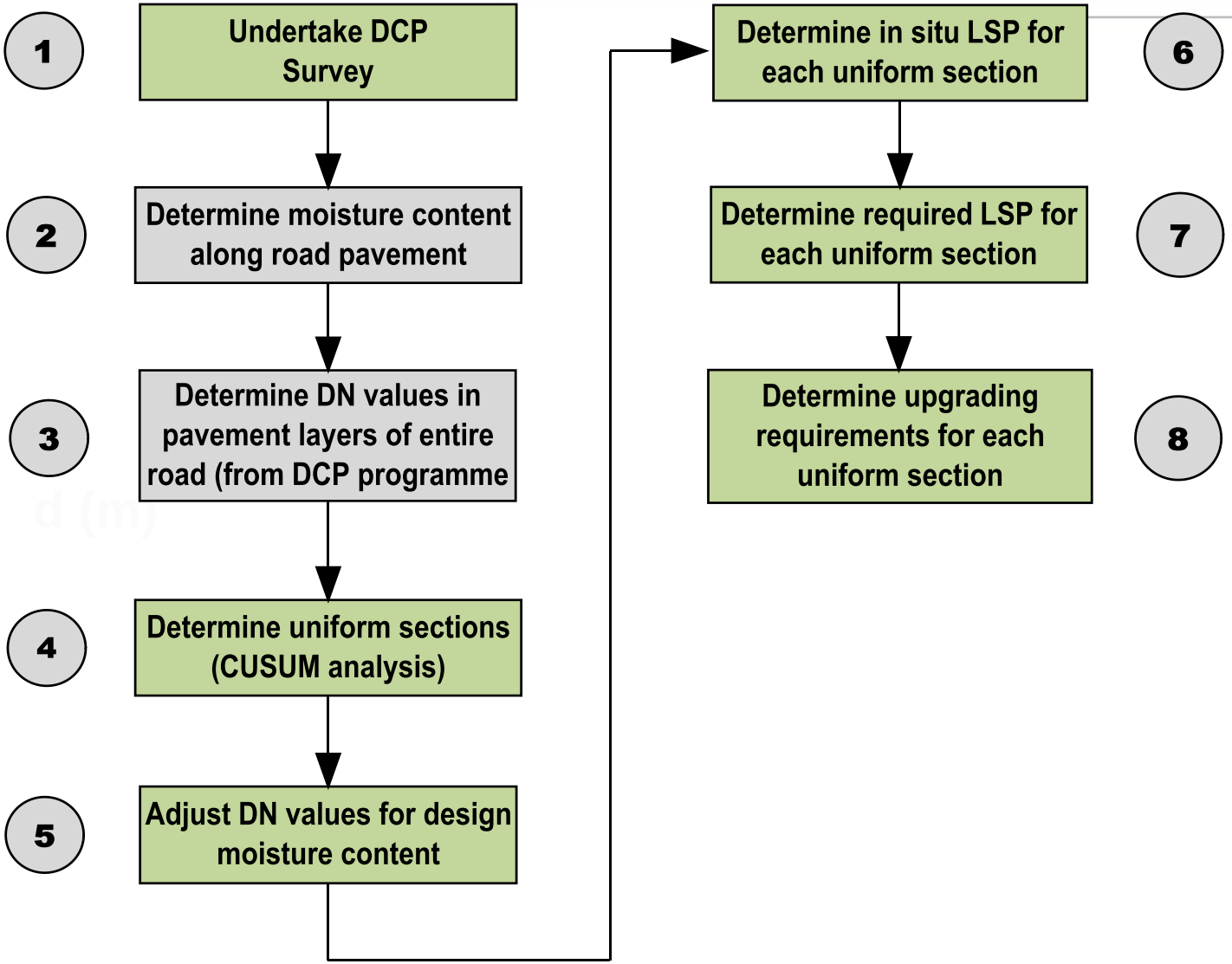
Presentation Outline

- Background
- Dynamic Cone Penetrometer (DCP) Pavement Design Principles
- **DCP Pavement Design Method/Process**
- AfCAP Low Volume Road (LVR) - DCP Pavement Software
- Summary & Conclusions

DCP Method of Design

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

8 Step DCP based Road Design Process



DCP Test Frequency..

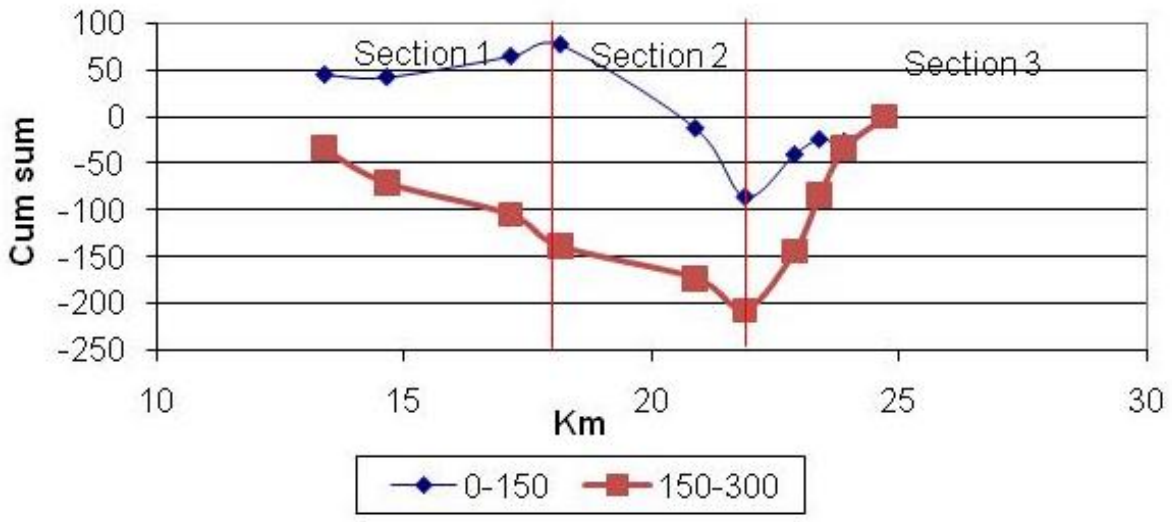
Road condition	Frequency of testing/km*
Uniform (low risk)	5
Non-uniform (medium risk)	10
Low-lying/distressed (high risk)	20

EXISTING (IN SITU) ROAD CONDITIONS

Firstly identify uniform sections

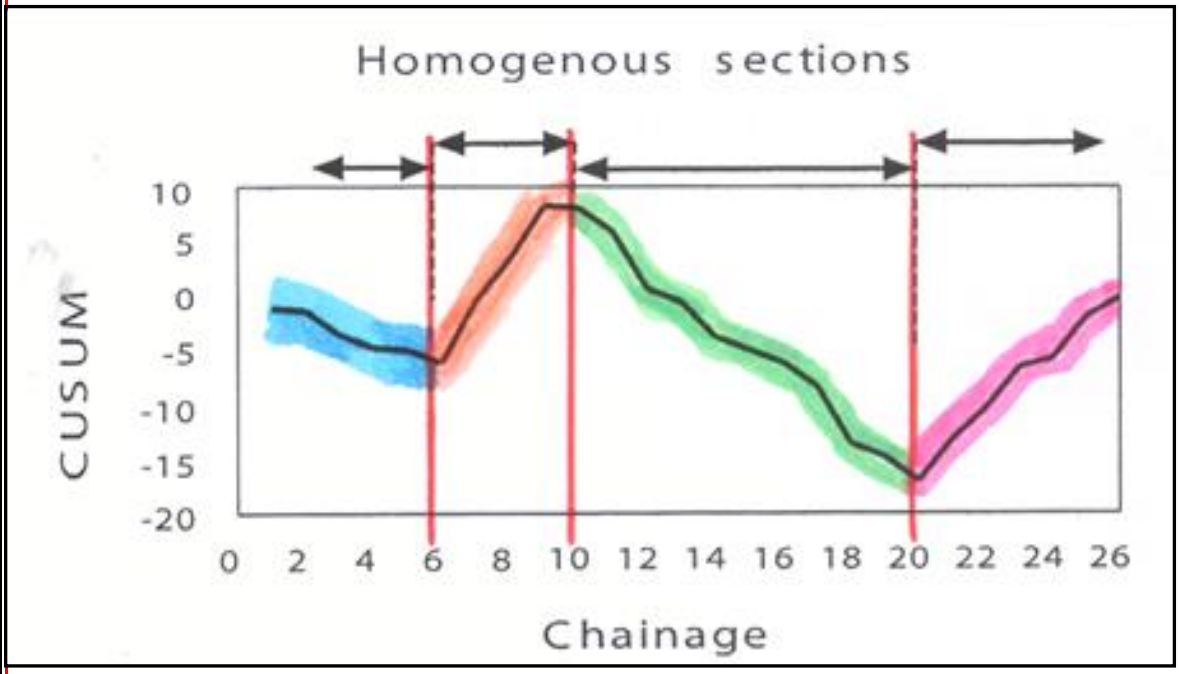
- Carry out DCP survey
- Use cumulative sum (CUSUM) technique to identify uniform sections
- Use for actual data (by depth) – any percentile (P)
- Don't have too many short sections

$$CUSUM = \Sigma (x_i - x_m)$$

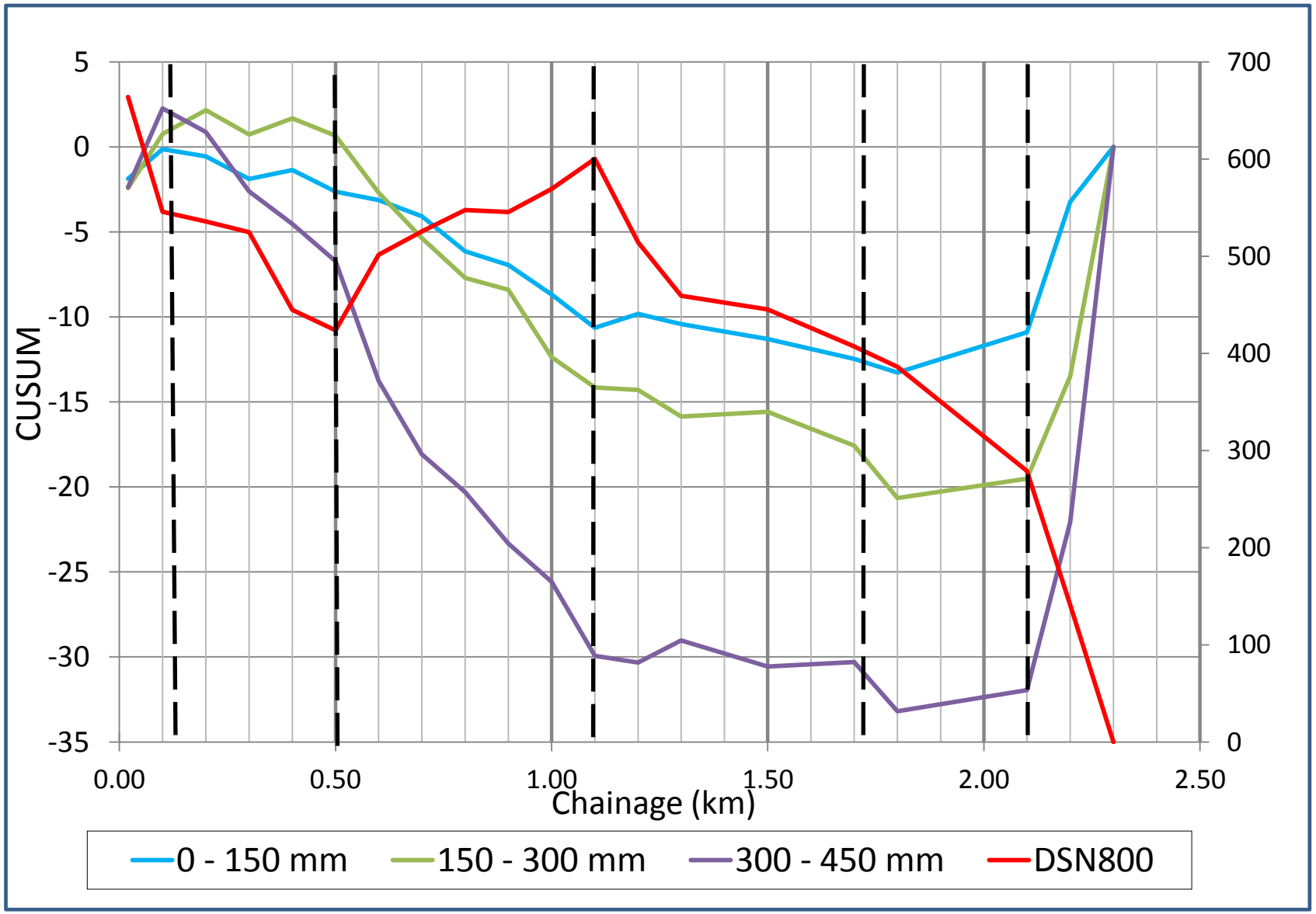


Determine Uniform Road Sections- CUSUM

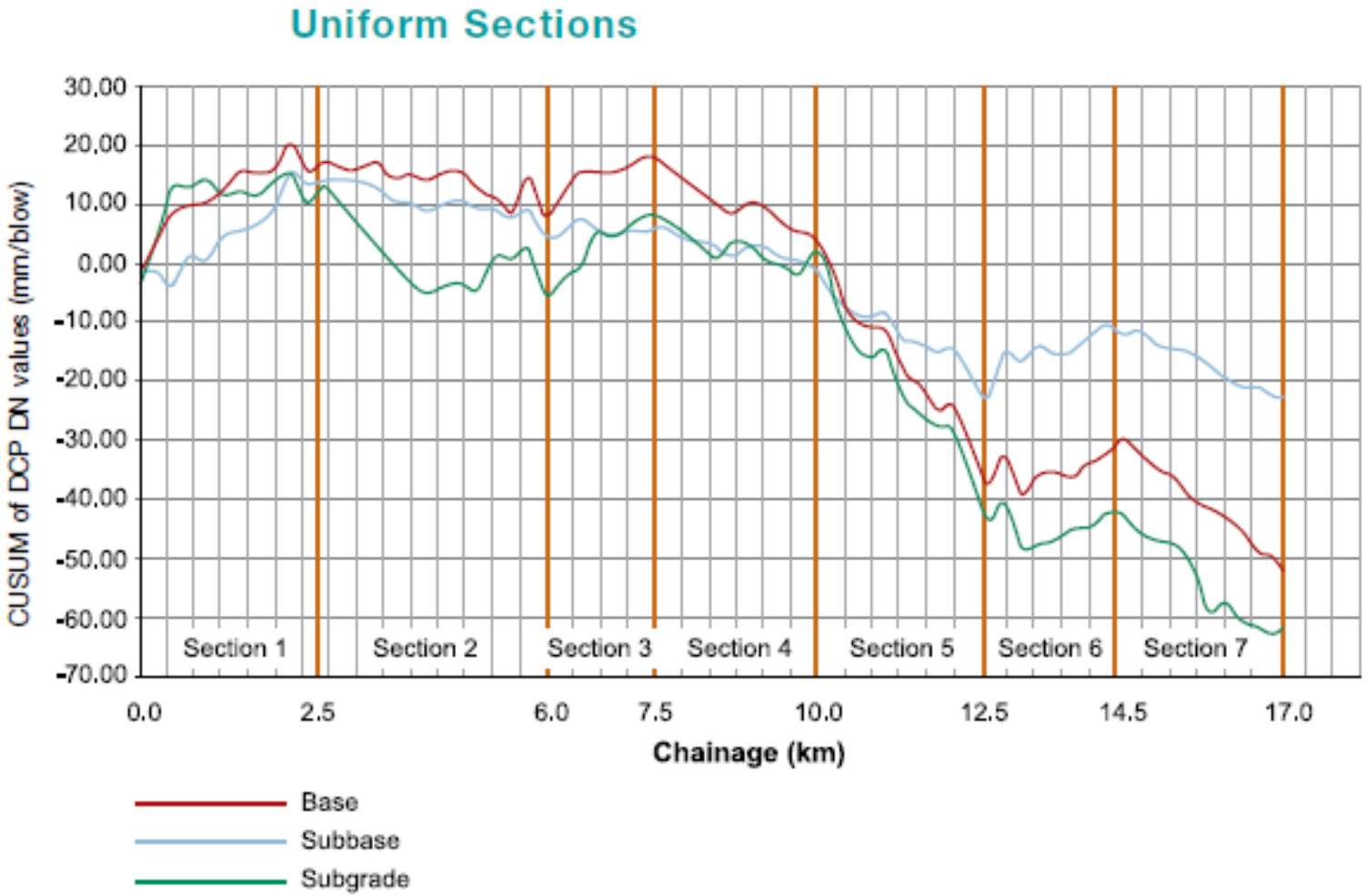
	B	C	
Chainage (Km)	Measured DCP (DN Value -mm/blow)	Difference from average (A-B)	CUSUM (Accumulated values of C)
1	14	-1.2	-1.2
2	13	-0.2	-1.4
3	15	-2.2	-3.6
4	14	-1.2	-4.8
5	13	-0.2	-5.0
6	14	-1.2	-6.2
7	7	5.8	-0.2
8	9	3.8	3.4
9	8	4.8	8.2
10	13	-0.2	8.0
11	15	-2.2	5.8
12	18	-5.2	0.6
13	14	-1.2	-0.6
14	16	-3.2	-3.8
15	14	-1.2	-5.0
16	14	-1.2	-6.2
17	15	-2.2	-8.4
18	18	-5.2	-13.6
19	14	-1.2	-14.8
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 = 12.8			



Determine Uniform Sections based on CUSUM of DSN_{800}



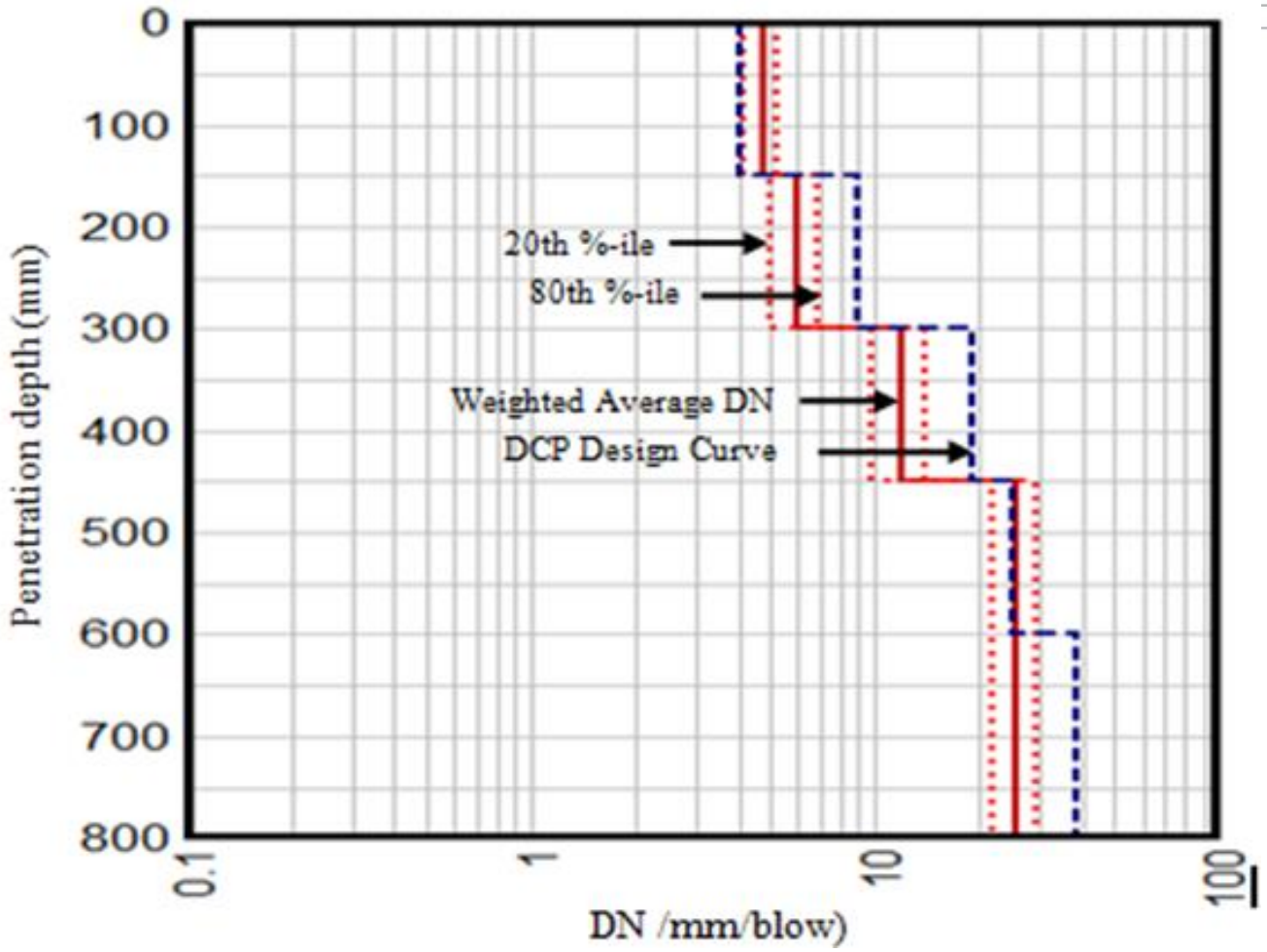
Determine Uniform Sections based on CUSUM of DN Values



Adjust DN Values for Moisture Environment

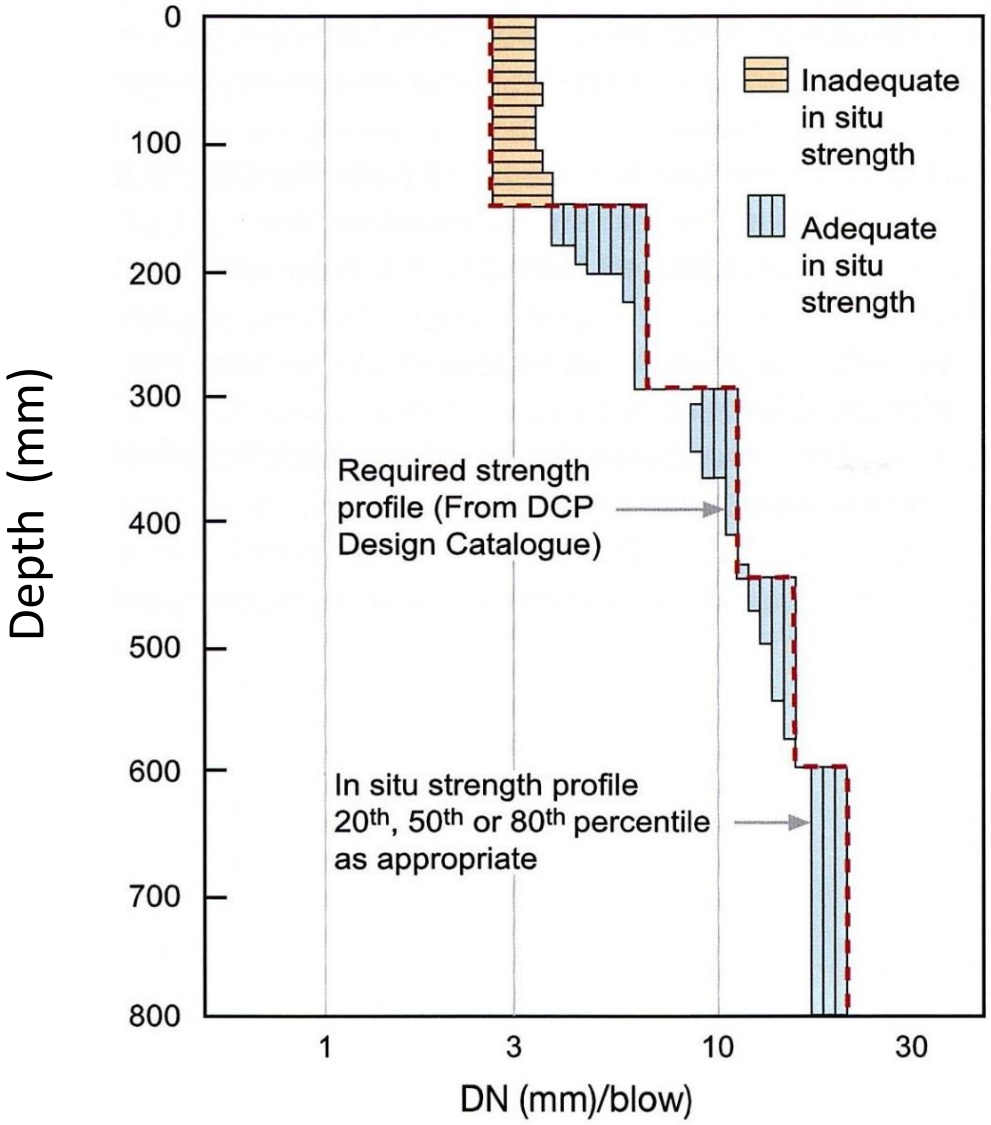
Chainage (km)	Point No	DN 0-150 (Base)	Percentile of minimum strength Profile (max. penetration rate – DN)		
			20th	50th (Mean)	80th
0.00	1	2.29	3.46	5.24	8.19
0.25	2	4.44			
0.50	3	2.00			
0.75	4	8.67			
1.00	5	3.75			
1.25	6	8.07			
1.50	7	5.11			
1.75	8	5.37			
2.00	9	6.60			
2.25	10	10.12			
Anticipated 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

Compare In Situ & Required LSD for Uniform Section

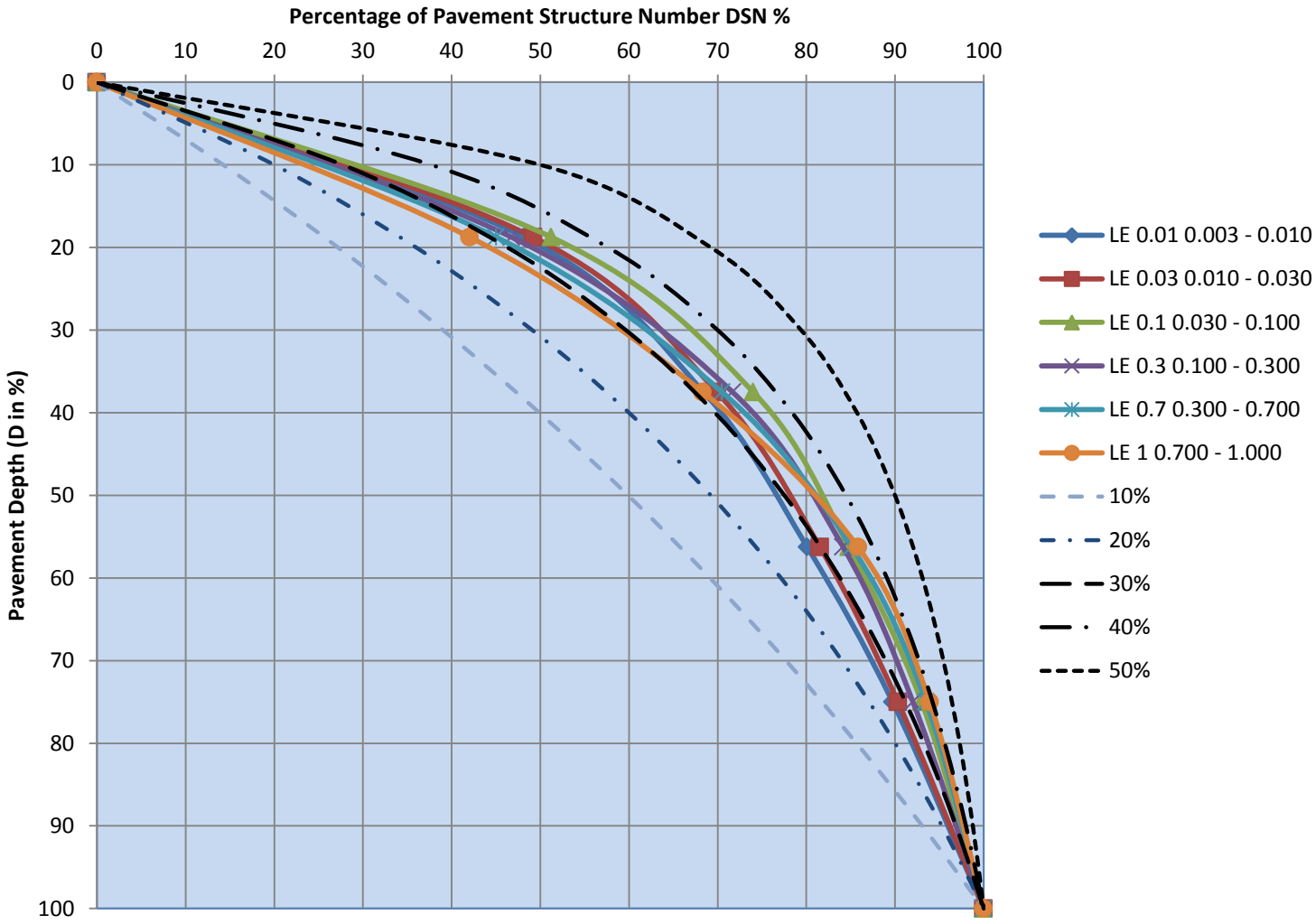


Layer strength diagram (LSD) for average analysis of uniform sections

Compare In Situ & Required LSD for Uniform Section



LSD=Layer Strength Diagram


Percentage of Pavement Structure Number DSN %
0
10
20
30
40
50
60
70
80
90
100
Pavement Depth (D in %)
0
10
20
30
40
50
60
70
80
90
100
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 0.700 - 1.000
10%
20%
30%
40%
50%

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.

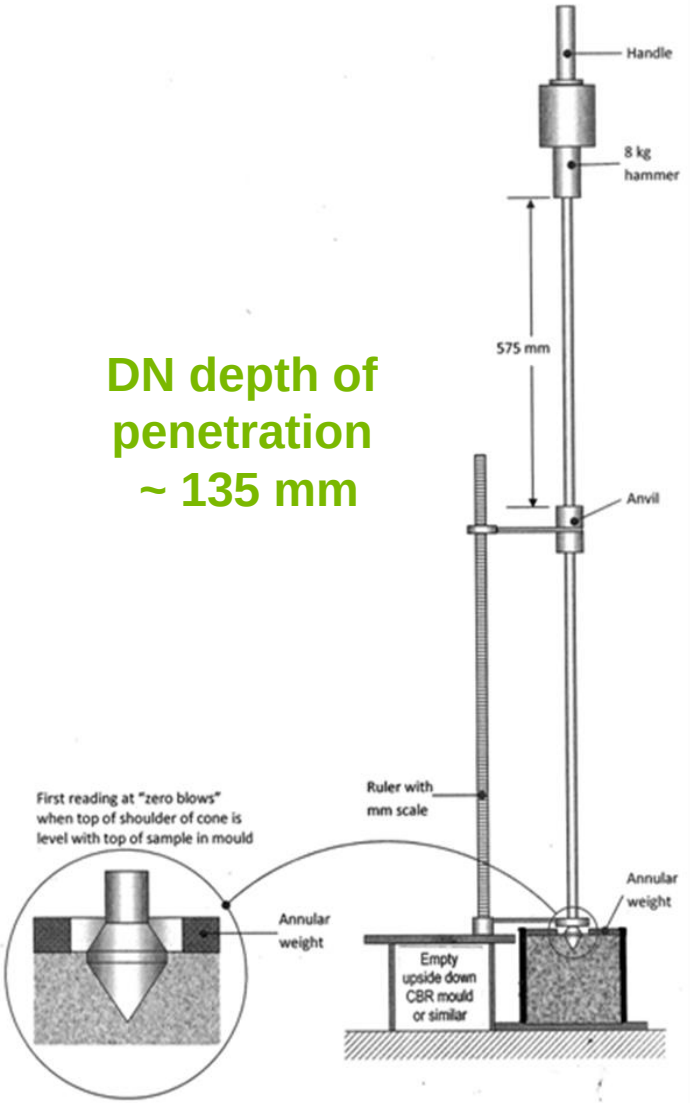
Material Selection

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

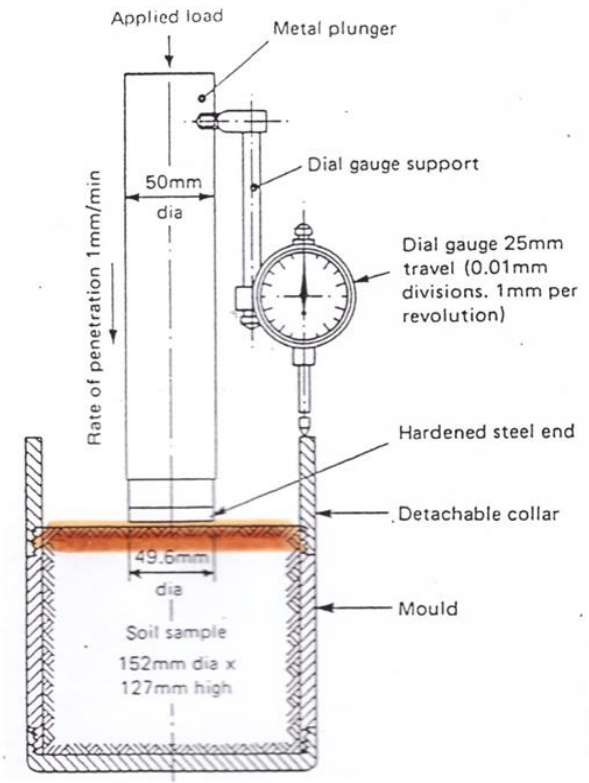
- **Provided design DN value is achieved, then in service performance indirectly takes account of actual grading and plasticity at given moisture and density which do not need to be separately specified.**
  - DN value provides is a composite measure of materials resistance to penetration (= shear strength)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

Determination of Laboratory DN Value

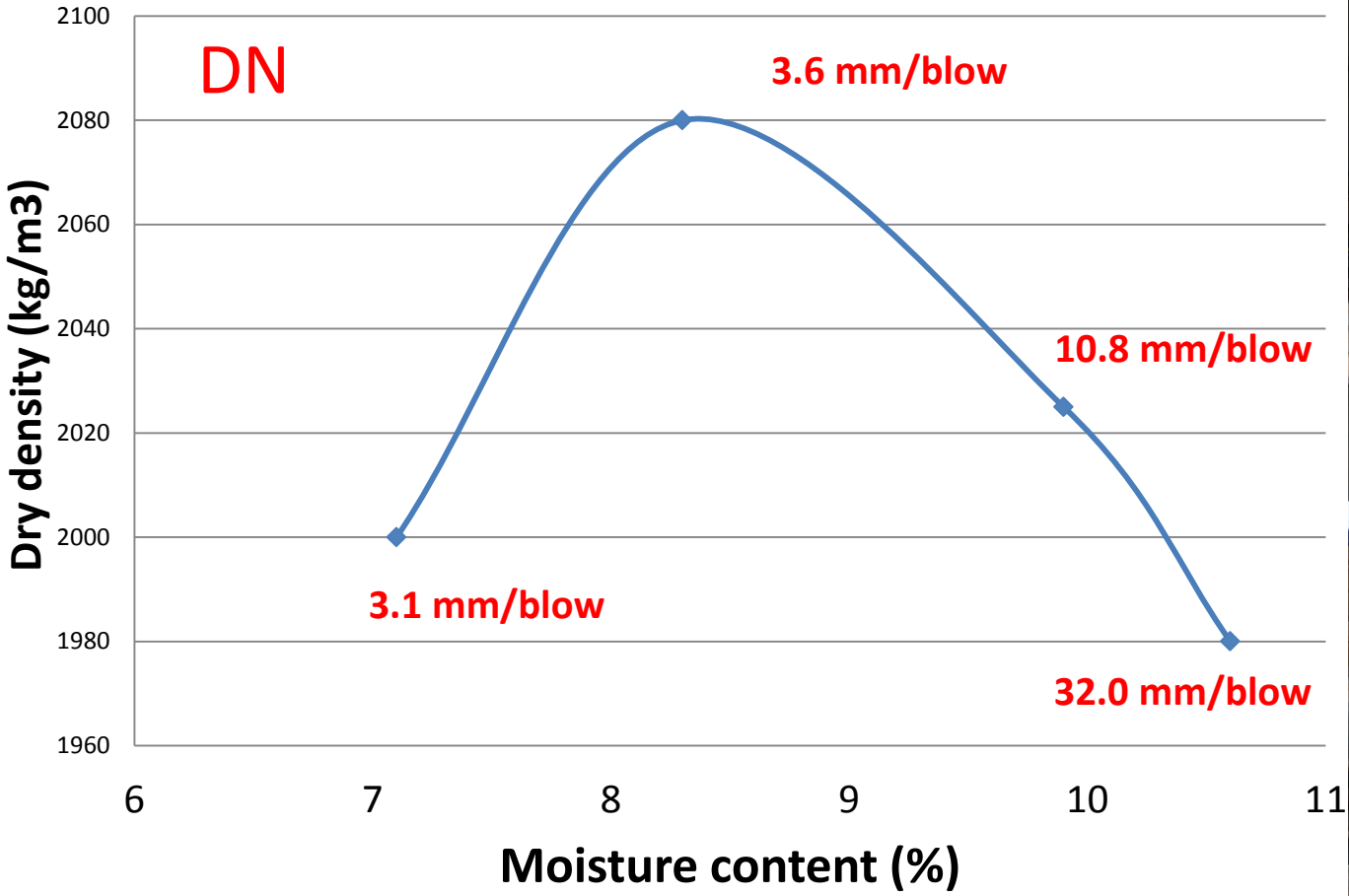
DN depth of penetration ~ 135 mm



CBR depth of penetration ~ 2.54/5.0 mm

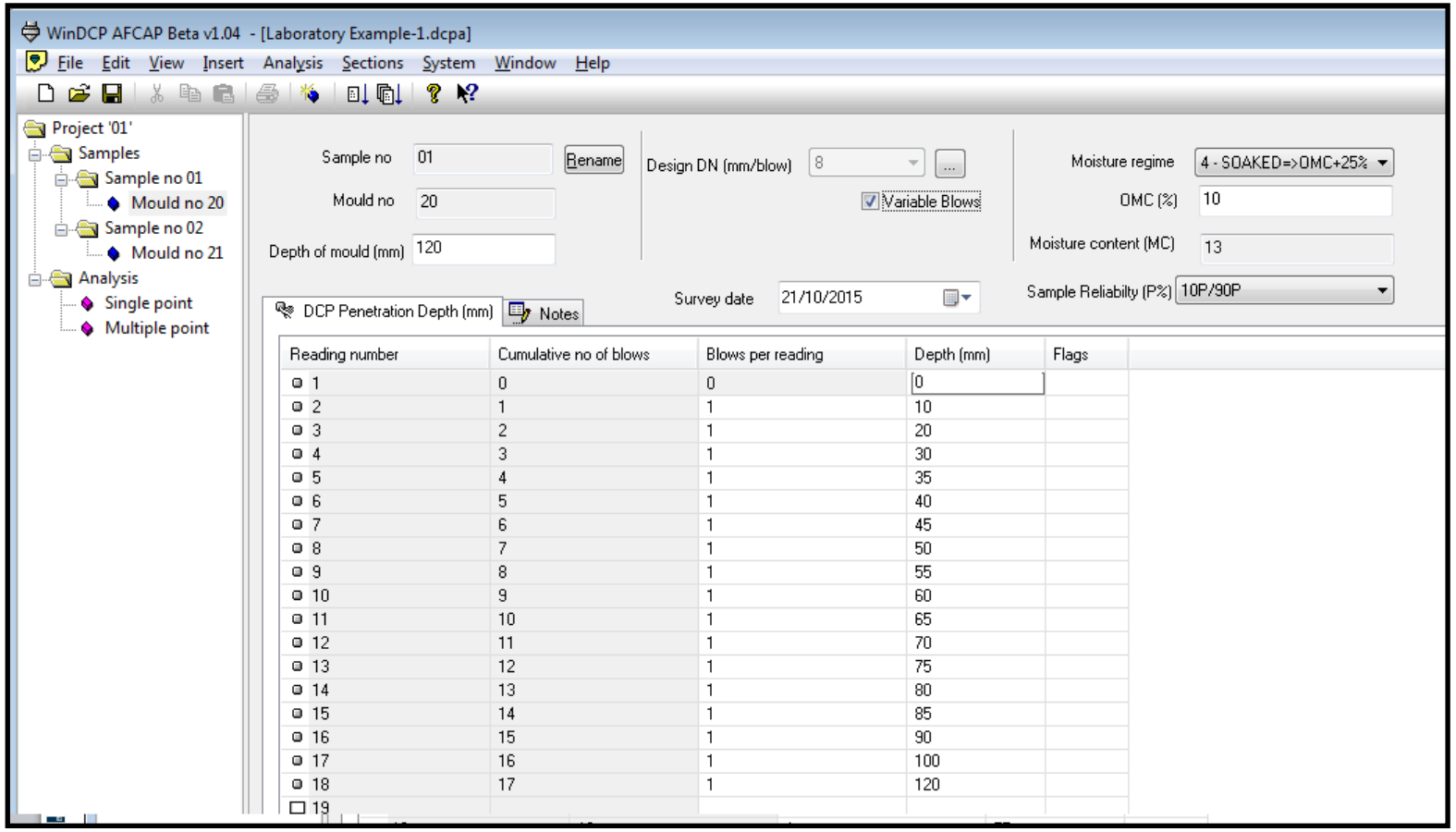


COMPACTION TEST (WITH DCP PENETRATION UNSOAKED)

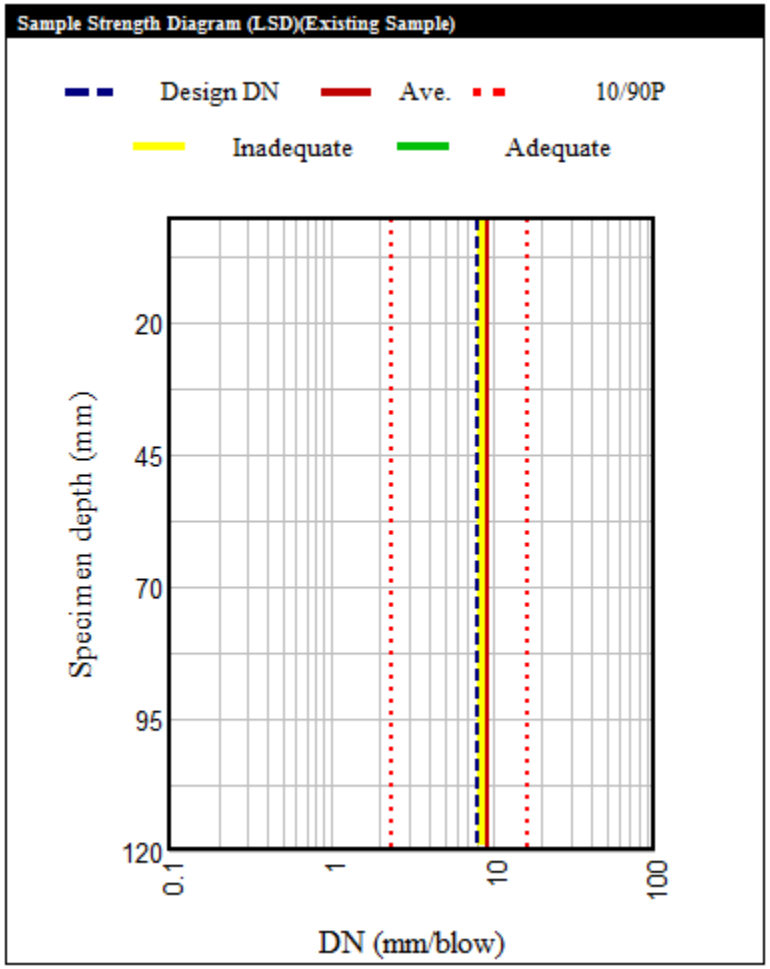


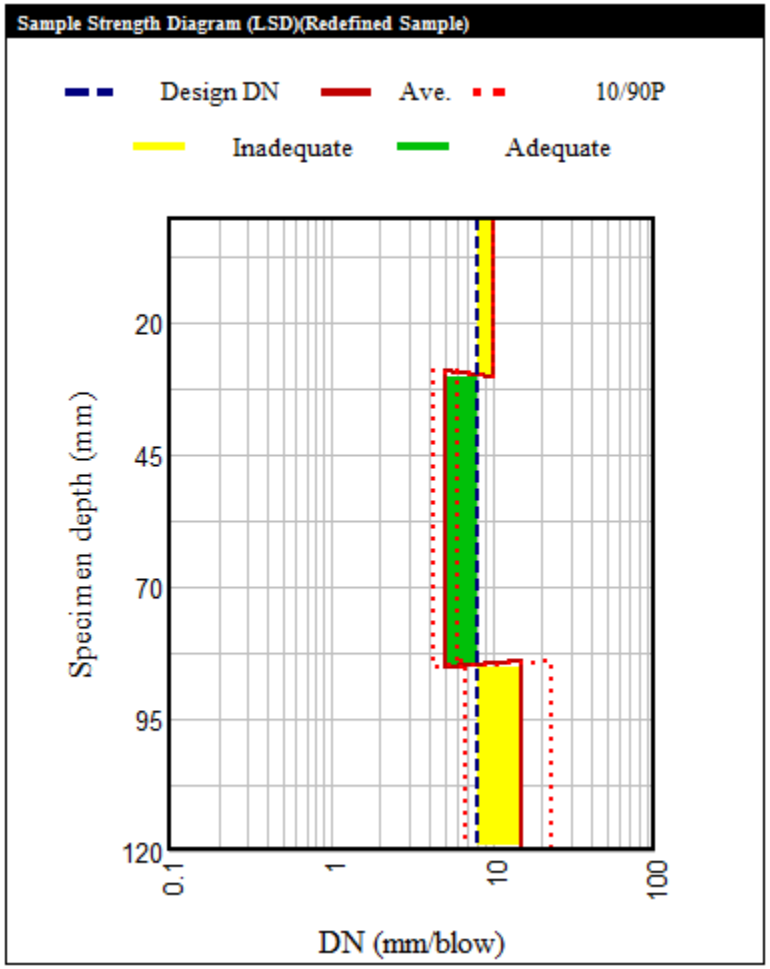
Paige-Green, ~2009

Laboratory DN Project – Samples Tree

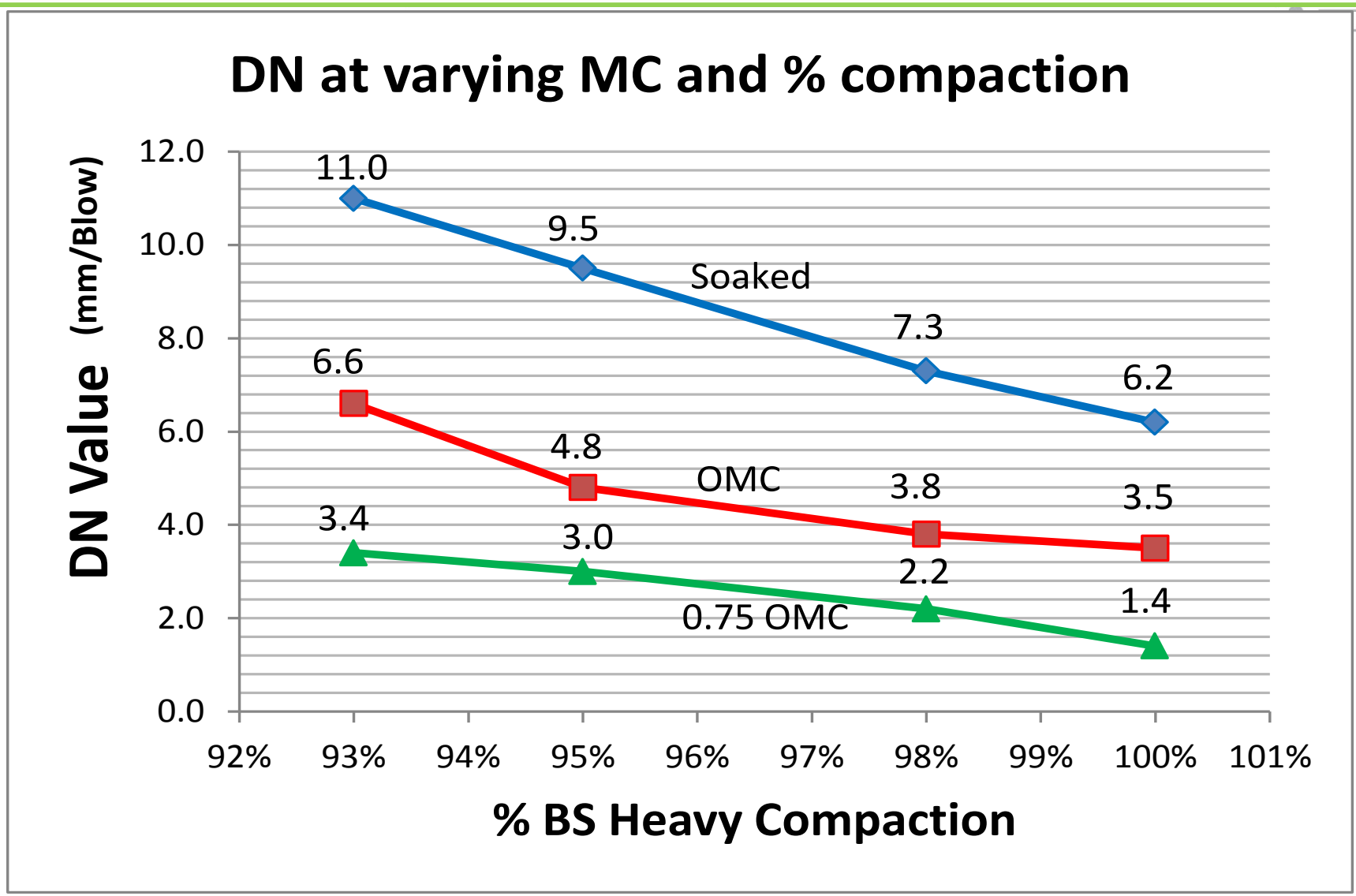


Laboratory DN Project – Analysis LSD:





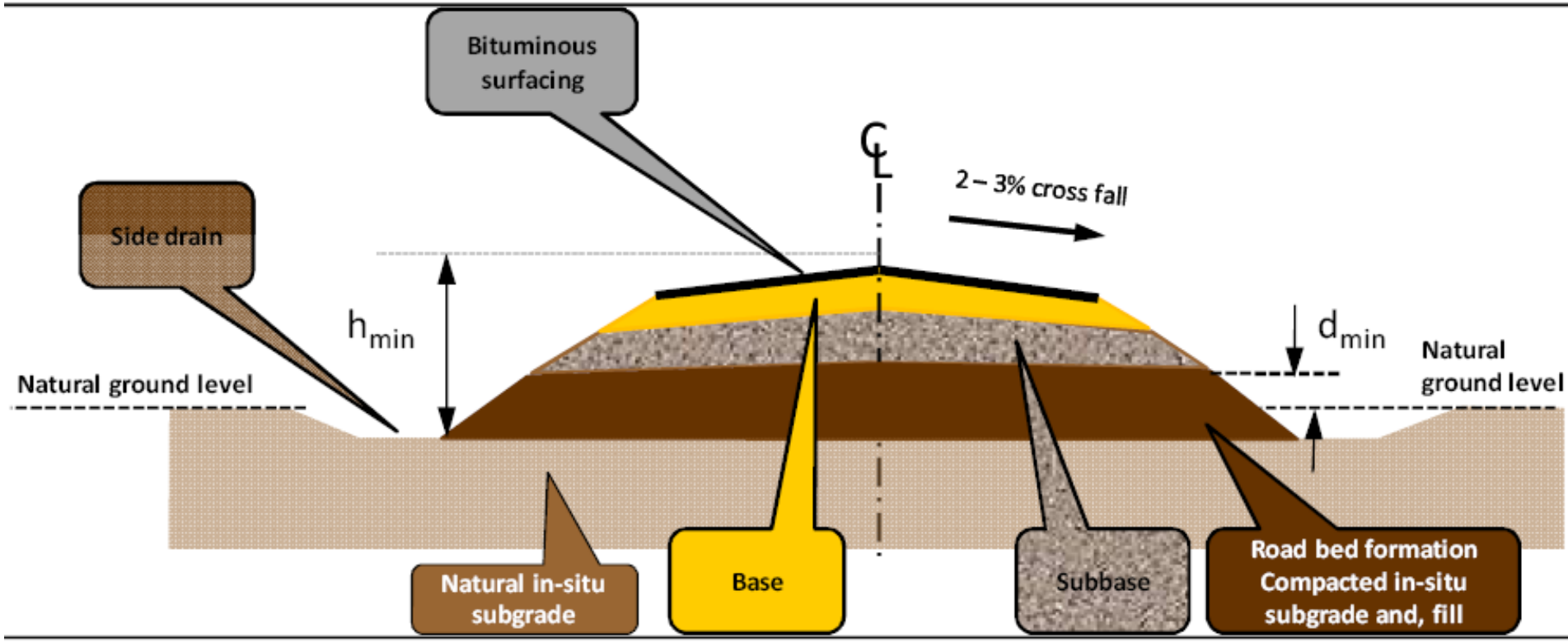
DN/Density/Moisture Relationship



Optimisation of local moisture conditions

Ensure adequate drainage:

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



Moisture

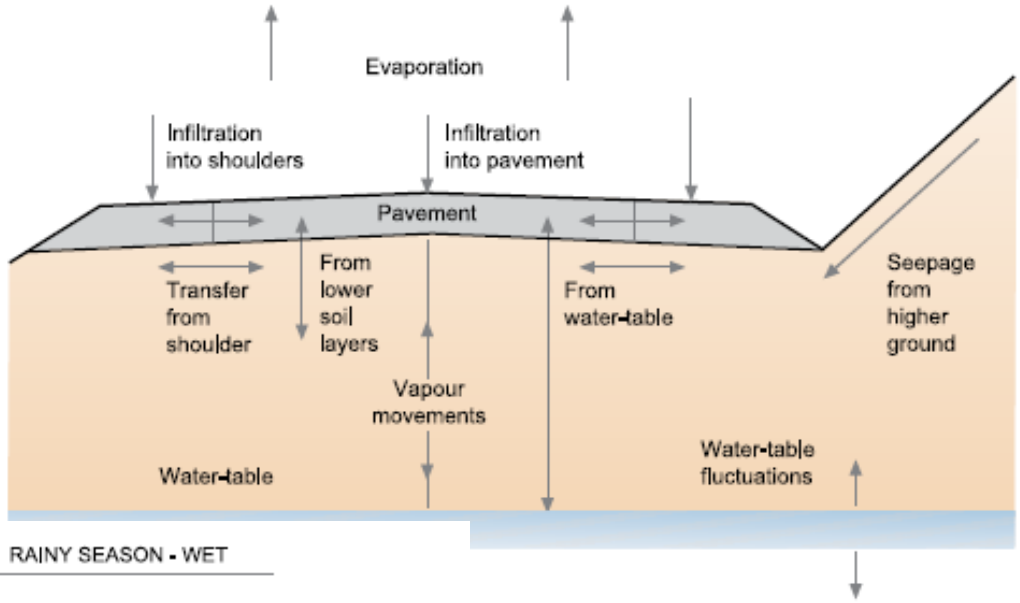
- Moisture effects influence DCP results enormously (NB)
- Needs to be taken into account
- OWT is normally most variable – wetter in rainy season, drier in dry season – lag
- CL should be at about equilibrium moisture content (EMC)

MOISTURE REGIME

- Testing should preferably be carried out during (or towards the end of) the wet season
- This is not always possible
- Need to assess the moisture regime at the time of the DCP survey (SurMR) in relation to the likely worst (wettest) condition (SerMR)

Environment/Moisture ...

Severe erosion of road side slopes in high rainfall areas.



ments in pavements and subgrades

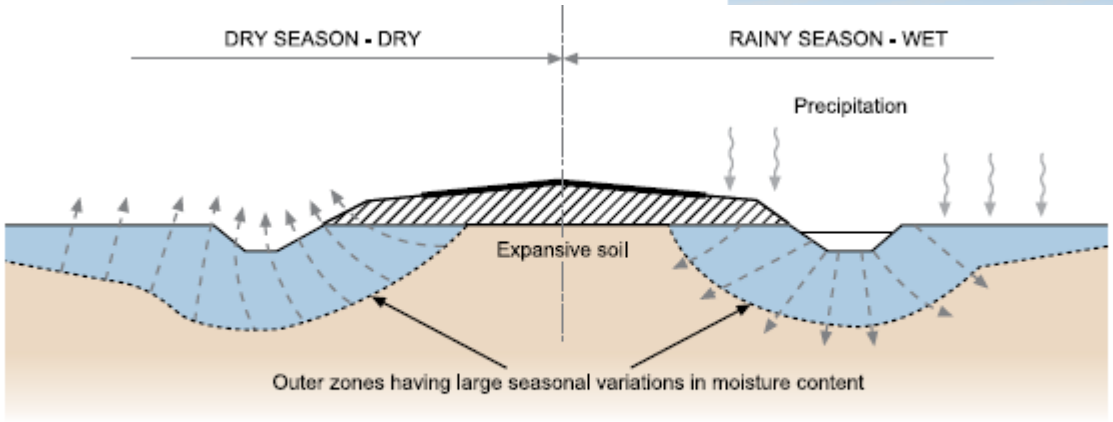


Figure 5-1: Moisture movements in expansive soils under a paved road

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

MESA: Million Equivalent Standard Axles

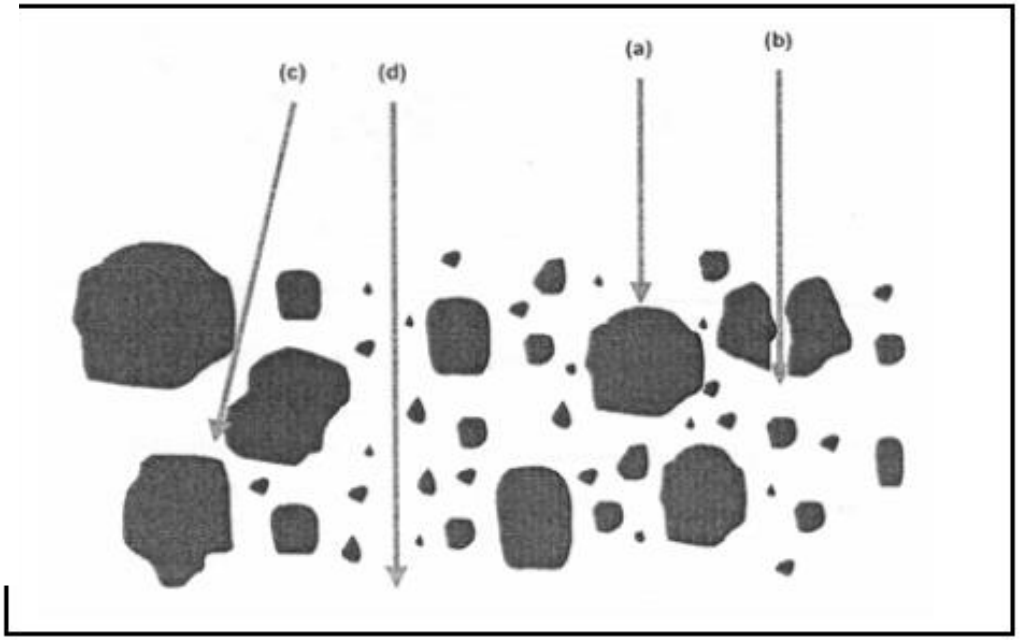
Typical DCP effects with large stones in pavement layer/structure:

(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 (or very low DN);

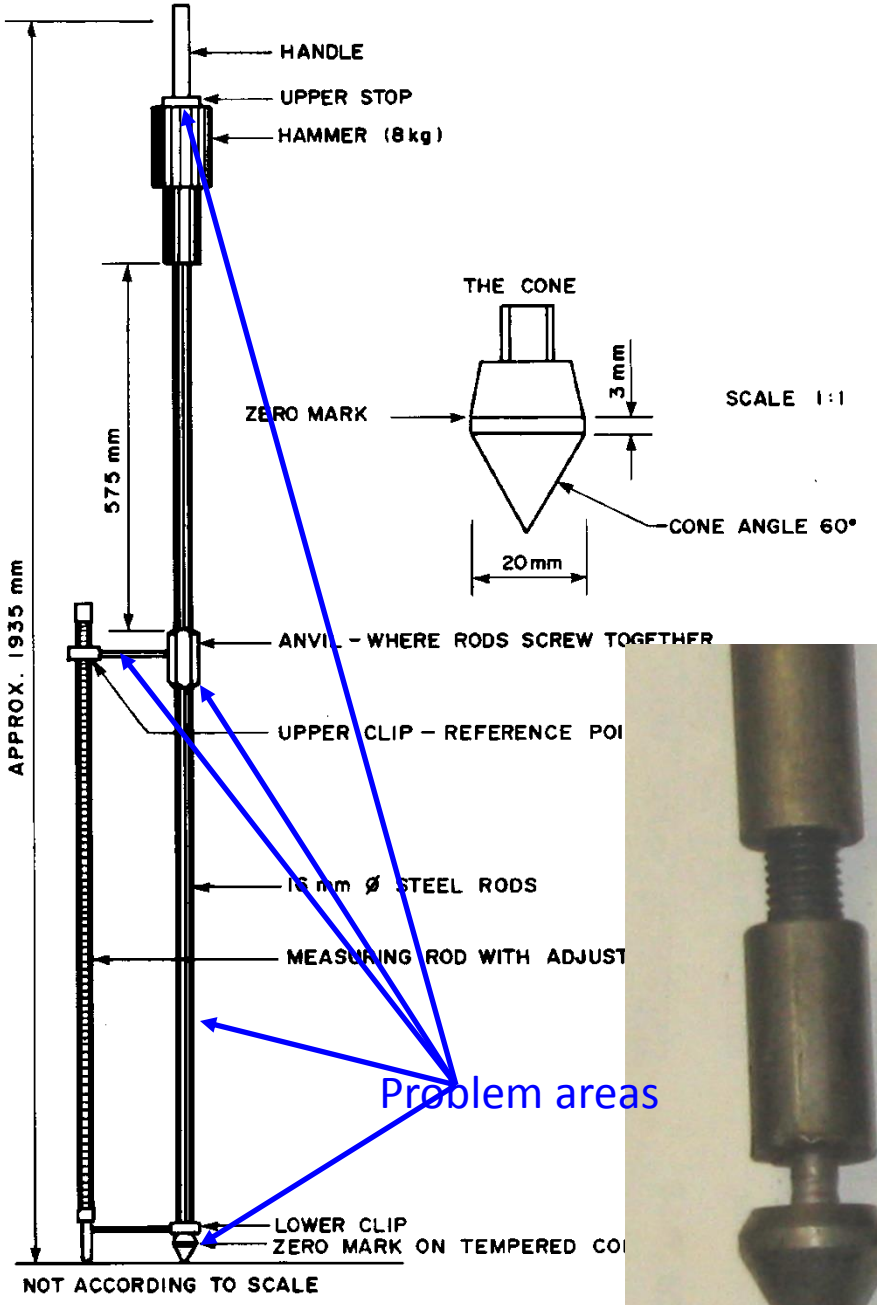
(c) Cone tries to push stone aside. Result is high DSN_{800} because of side friction generated on cone shaft;

(d) Usually provides a normal result;



STONES..

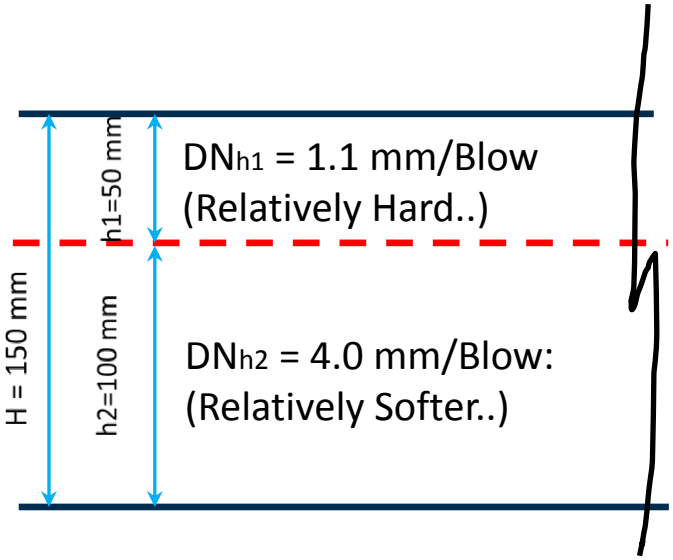
- DCP cone may strike a large stone:
  - Stone breaks
  - Cone deflected
  - Refusal
- Consequences:
  - OK for 1st case
  - Start again for others



Problem areas

DCP Cone tips…, check wear and tear..

Weighted Average vs Normal Average - DCP Penetration Rates (DN)



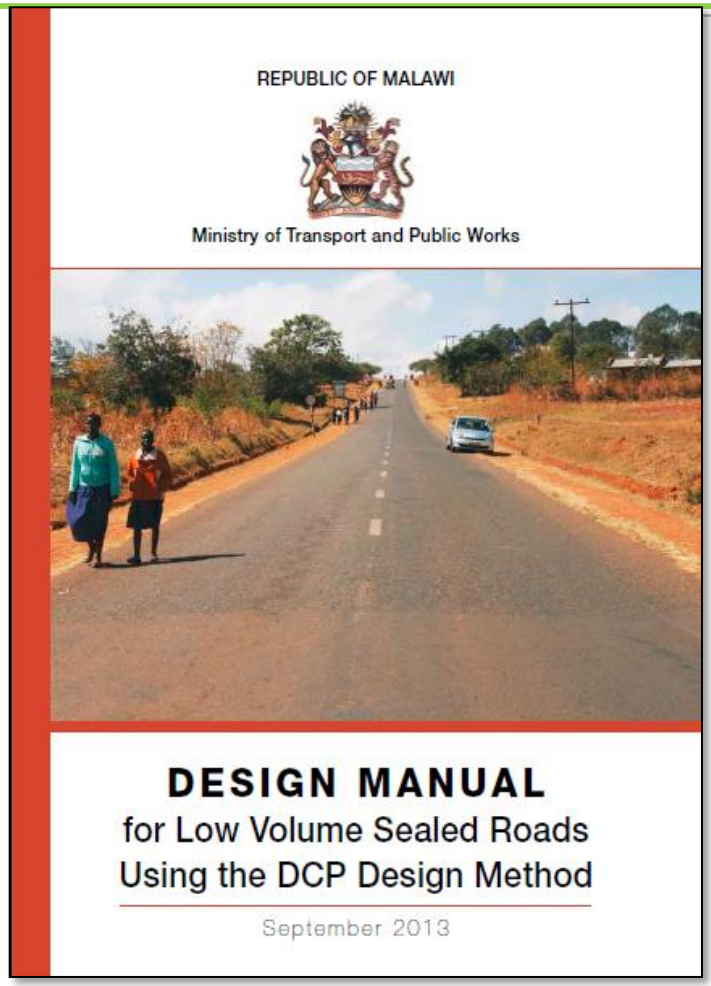
Normal Ave:
= (1.1 + 4.0)/2
= 2.55 m/blow

Weighted Ave (..Linearly by H):
= [(1.1*50mm) + (4.0*100mm)]/150mm
= **3.03 mm/blow**

~ = 20 % increase in DN …(Risk) !.

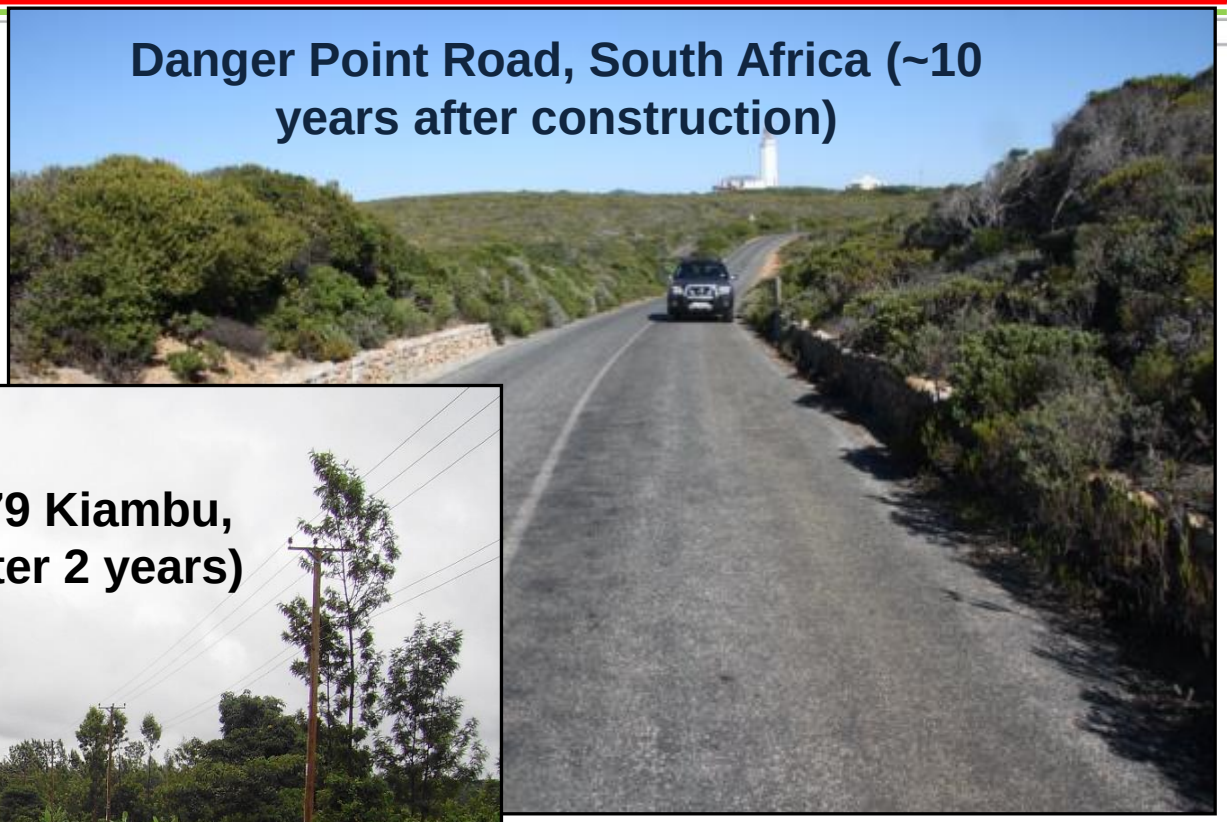
..until new research proof otherwise…

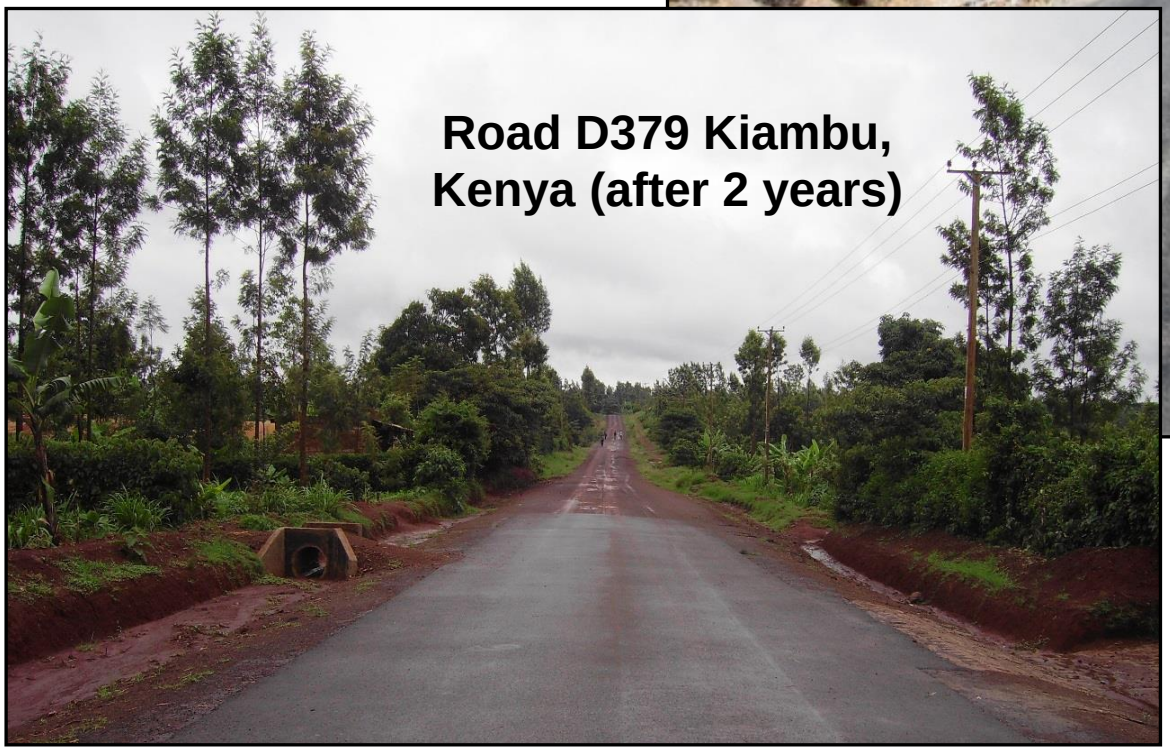
DCP Design Manual: Malawian Example



- Builds on pioneering work done in RSA, UK and Australia)
- Reduced reliance on conventional testing
- Supports an existing design approach
- Demonstration projects so far in Kenya and DRC and Tanzania.

Examples of DCP Designed Roads..



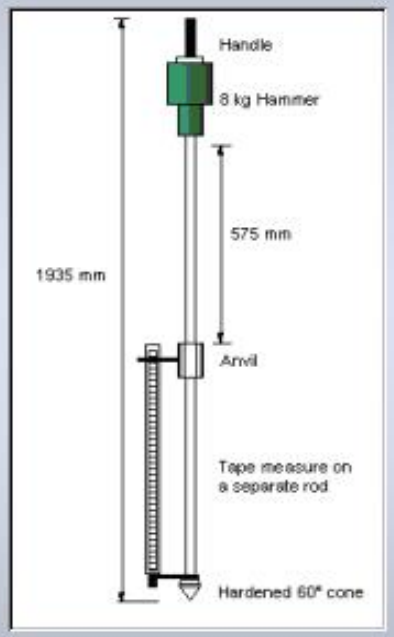


Presentation Outline

- Background
- Dynamic Cone Penetrometer (DCP) Pavement Design Principles
- DCP Pavement Design Method
- AfCAP Low Volume Road (LVR) - DCP Pavement Software
- Summary & Conclusions

AfCAP LVR-DCP v1.03_ 2016

About DCP



our future through science

AfCAP LVR-DCP v1.03

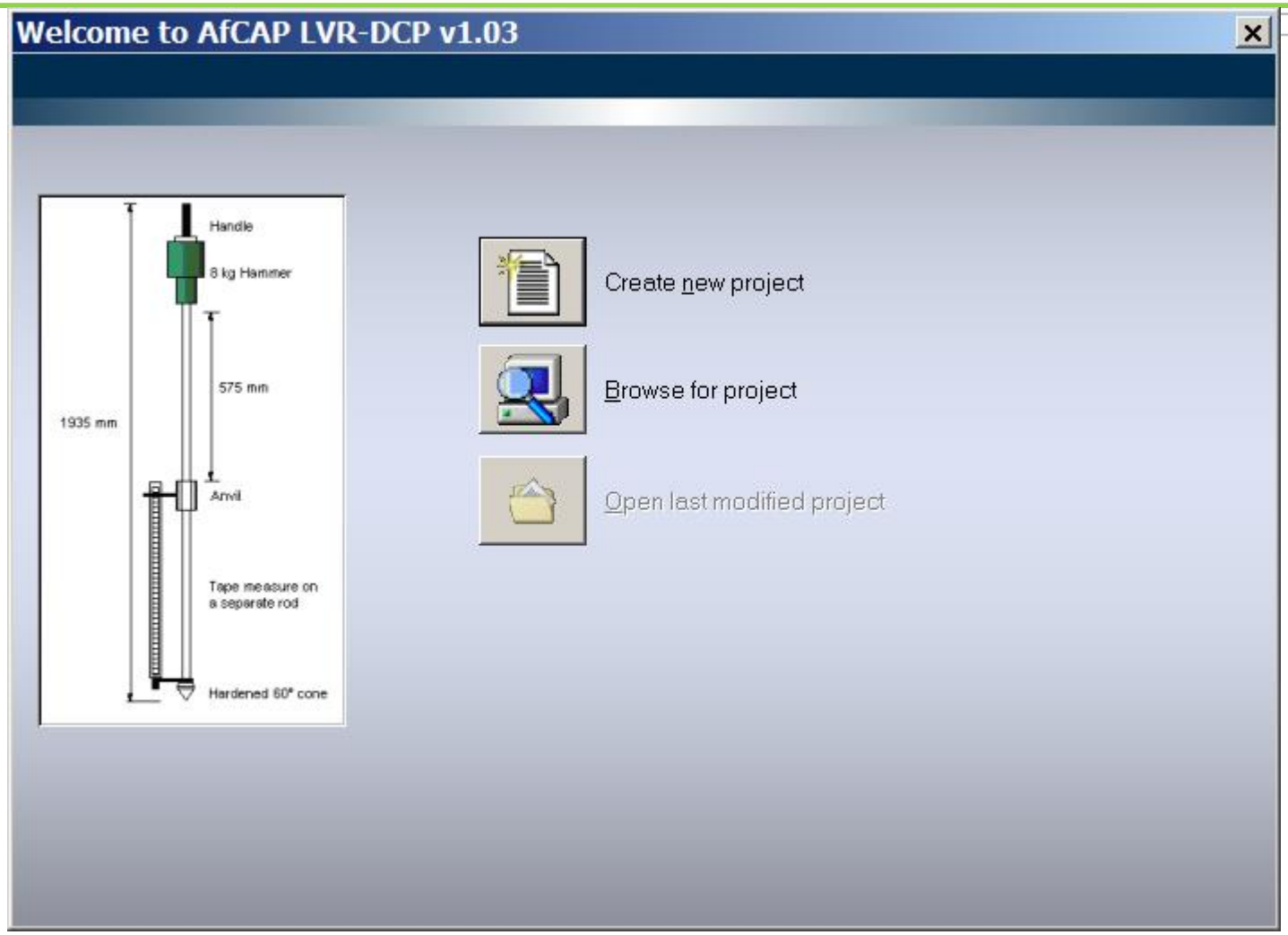
Copyright (C) 1998-2016 CSIR/WNNR

Build date: Jul 8 2016

WARNING: This program is protected by copyright law and international treaties. Unauthorized reproduction or distribution of this program, or any portion of it, may result in severe civil and criminal penalties, and will be prosecuted to the maximum extent possible under law.

OK

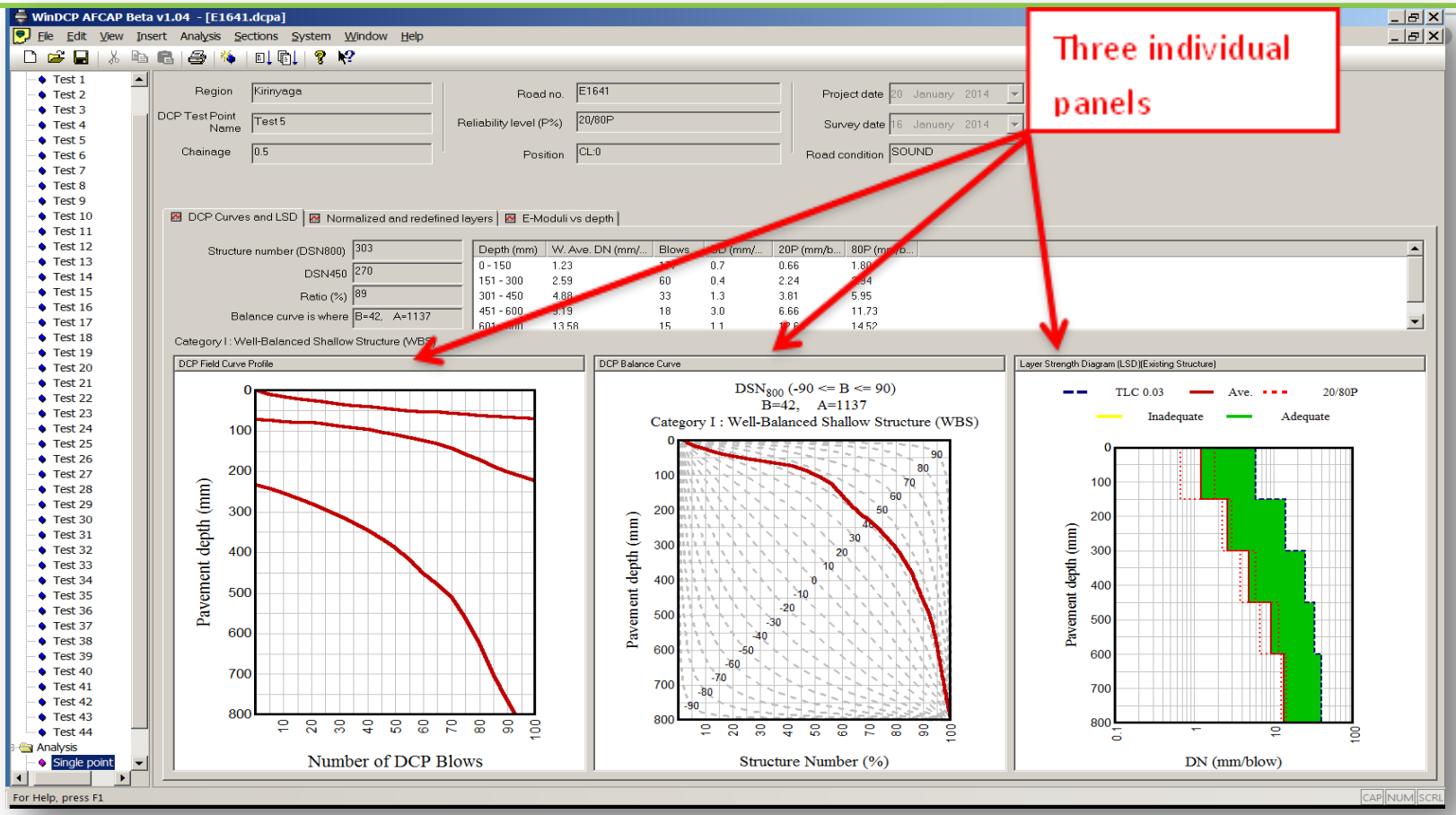
AfCAP Low Volume Road (LVR) - DCP Software v1.03_ 2016



Select “Field” for DCP field data

ReCAP
Research for Community Access Partnership

UKaid
from the British people



CSIR
our future through science

DCP Single Analysis

ReCAP Research for Community Access Partnership

UKaid from the British people

AfCAP LVR-DCP v1.03 - [D201.dcpa]

File Edit View Insert Analysis Sections System Window Help

Project 'D201'
- DCP Test Points
  - DCP 0.0
  - DCP 0.5
  - DCP 1.0
  - DCP 1.5
  - DCP 2.0
  - DCP 2.7
  - DCP 3.0
  - DCP 3.5
  - DCP 4.0
  - DCP 4.5
  - DCP 5.0
  - DCP 5.5
  - DCP 6.0
  - DCP 6.5
  - DCP 7.0
  - DCP 7.5
  - DCP 8.0
  - DCP 8.5
  - DCP 9.0
  - DCP 9.5
  - DCP 10.0
  - DCP 10.5
- Analysis
  - Single point
  - Multiple point
  - Homogeneous s

Region	NWP Matplataneng	Road no.	D201	Project date	22 March 2016
DCP Test Point Name	DCP 0.0	Reliability level (P%)	15/85P	Survey date	15 March 2016
Chainage	0	Position	CL:4	Road condition	WARNING

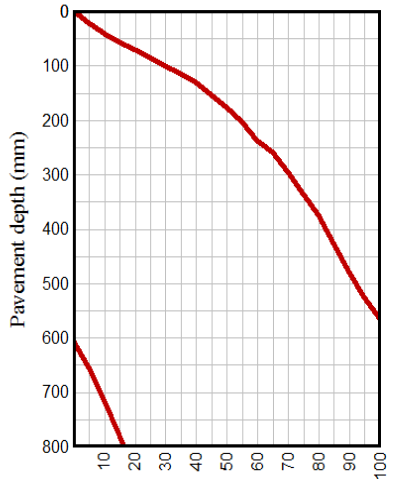
DCP Curves and LSD | Normalized and redefined layers | E-Moduli vs depth

Structure number (DSN800)	121
DSN450	87
Ratio (%)	72
Balance curve is where	B=19, A=1050

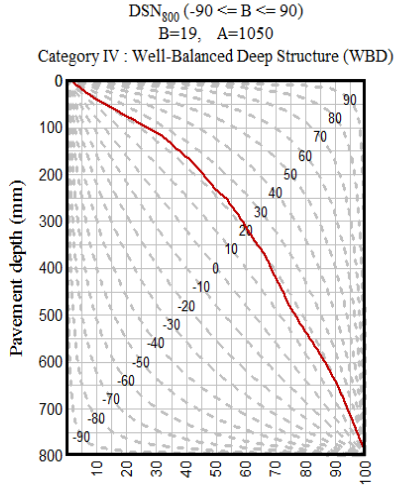
Depth (mm)	W. Ave. DN (mm/...	Blows	SD (mm/...	15P (mm/b...	85P (mm/b...
0 - 180	3.70	51	0.8	2.90	4.49
181 - 400	7.31	32	1.5	5.75	8.87
401 - 800	10.59	39	1.9	8.66	12.53

Category IV : Well-Balanced Deep Structure (WBD)

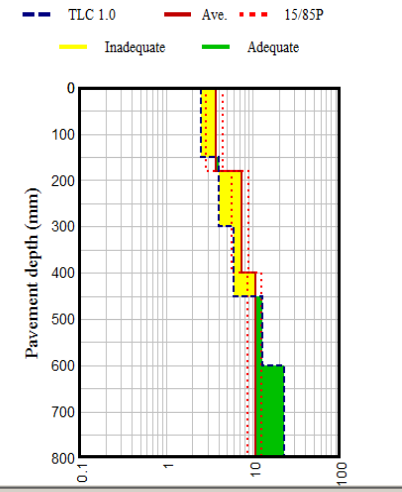
DCP Field Curve Profile



DCP Balance Curve



Layer Strength Diagram (LSD)(Existing Structure)



For Help, press F1

CAP NUM SCRL

DCP Multiple Point Analysis

ReCAP Research for Community Access Partnership

UKaid from the British people

AfCAP LVR-DCP v1.03 - [D201.dcpa]

File Edit View Insert Analysis Sections System Window Help

Project 'D201'
- DCP Test Points
  - DCP 0.0
  - DCP 0.5
  - DCP 1.0
  - DCP 1.5
  - DCP 2.0
  - DCP 2.7
  - DCP 3.0
  - DCP 3.5
  - DCP 4.0
  - DCP 4.5
  - DCP 5.0
  - DCP 5.5
  - DCP 6.0
  - DCP 6.5
  - DCP 7.0
  - DCP 7.5
  - DCP 8.0
  - DCP 8.5
  - DCP 9.0
  - DCP 9.5
  - DCP 10.0
  - DCP 10.5
- Analysis
  - Single point
  - Multiple point
  - Homogeneous s

Region	NWP Matplataneng	Road no.	D201	Project date	22 March 2016
DCP Test Point Name	Multiple point analysis	Reliability level (P%)	20/80P	Survey date	30 December 1899
Chainage	–	Position	–	Road condition	

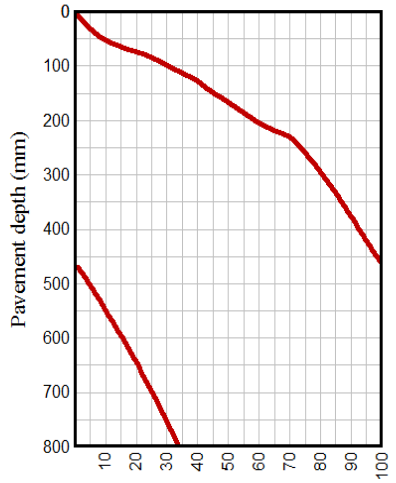
DCP Curves and LSD | Normalized and redefined layers | E-Moduli vs depth

Structure number (DSN800)	134
DSN450	98
Ratio (%)	73
Balance curve is where	B=16, A=1075

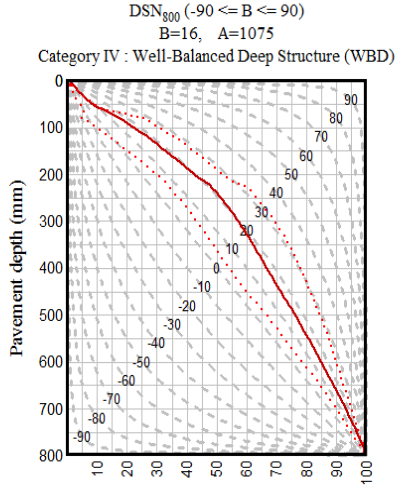
Depth (mm)	W. Ave. DN (mm/...	Blows	SD (mm/...	20P (mm/b...	80P (mm/b...
0 - 180	6.16	53	1.2	5.12	7.19
181 - 400	8.60	39	1.7	7.21	10.00
401 - 800	12.85	41	0.7	12.26	13.44

Category IV : Well-Balanced Deep Structure (WBD)

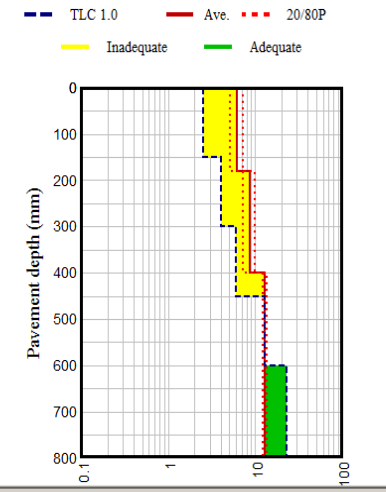
DCP Field Curve Profile



DCP Balance Curve



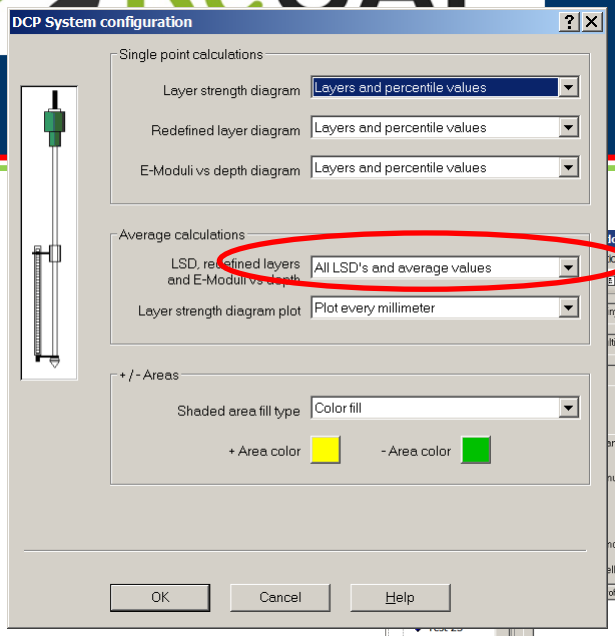
Layer Strength Diagram (LSD)(Existing Structure)

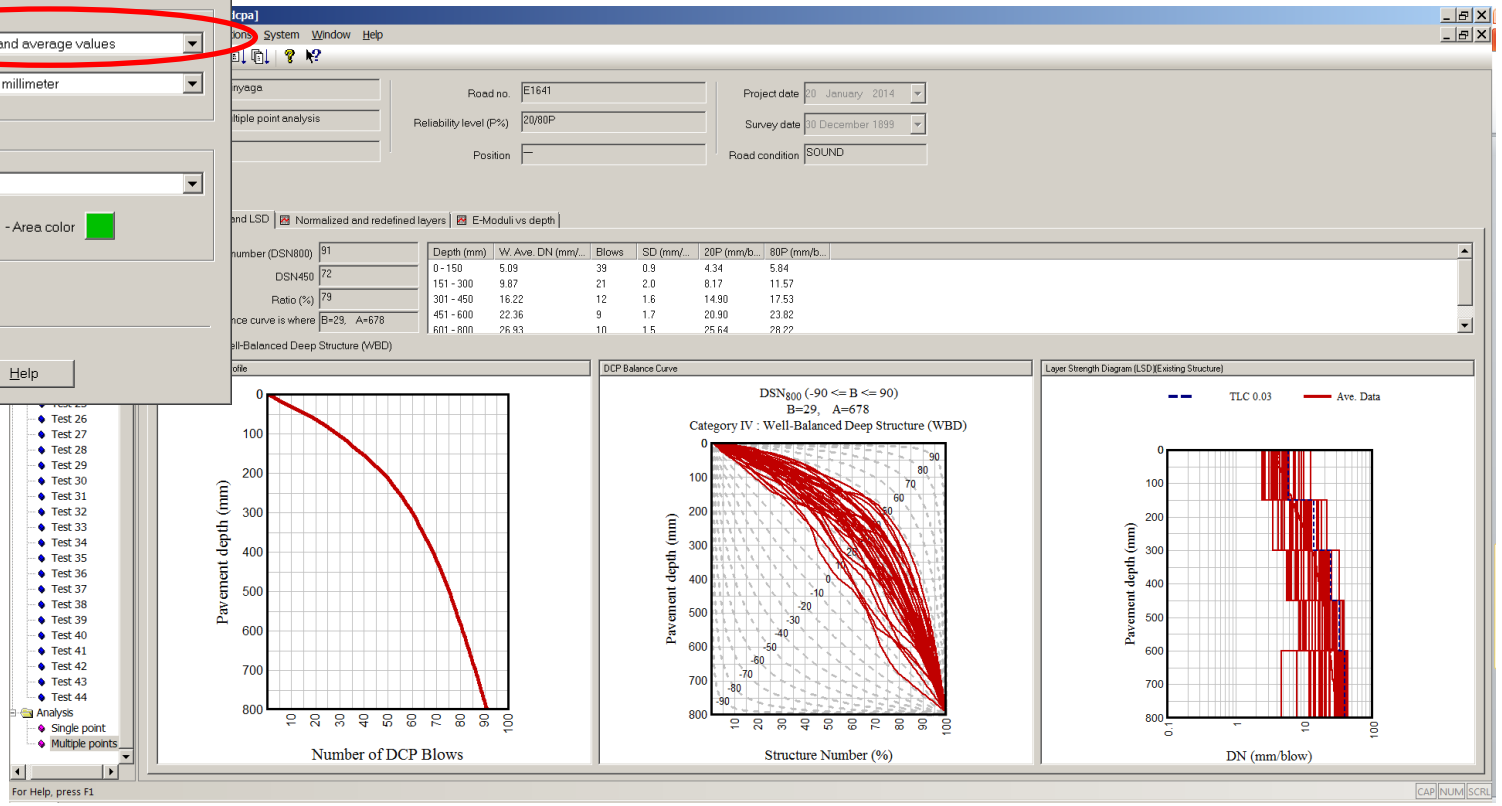


For Help, press F1

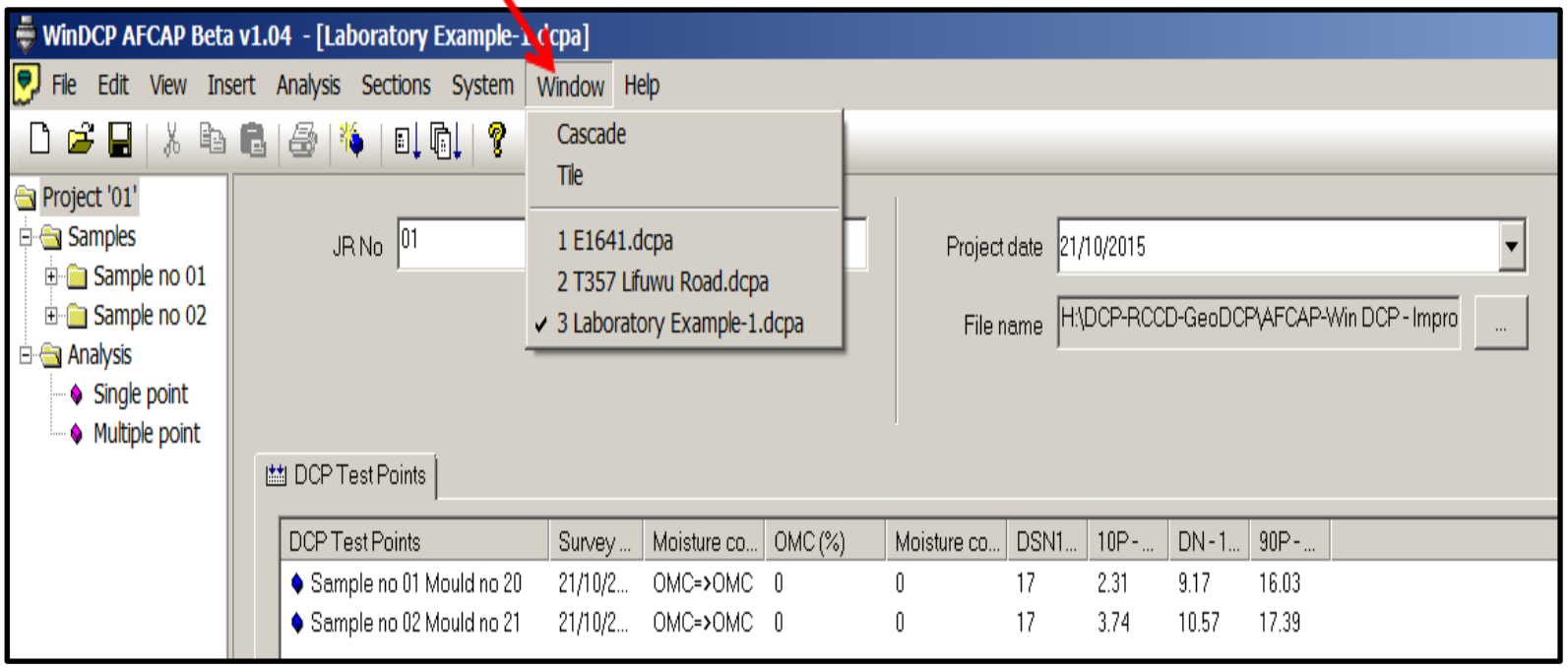
CAP NUM SCRL

Multiple Point Analysis and Percentile Selection



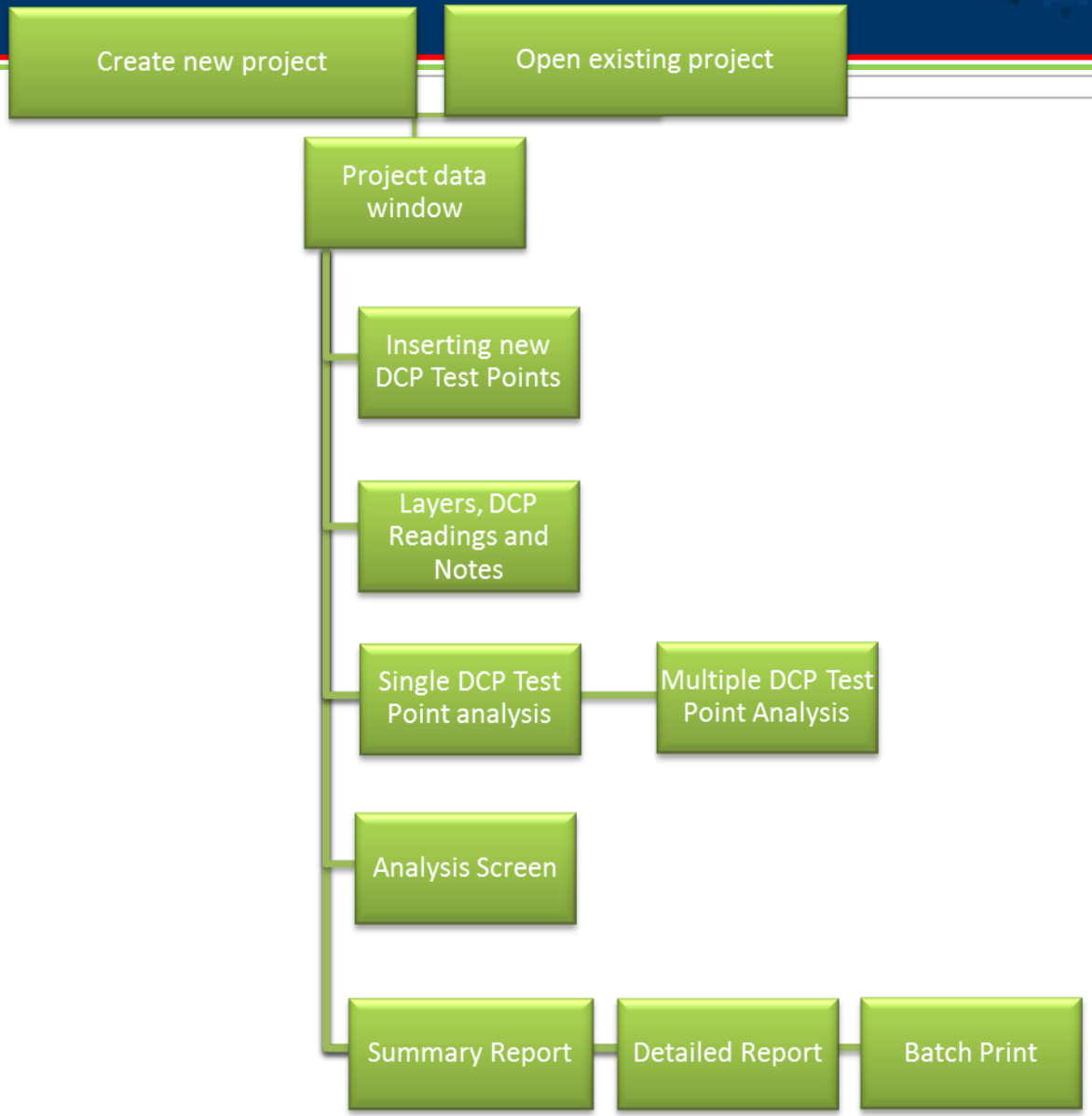


Option for Laboratory DN analysis..

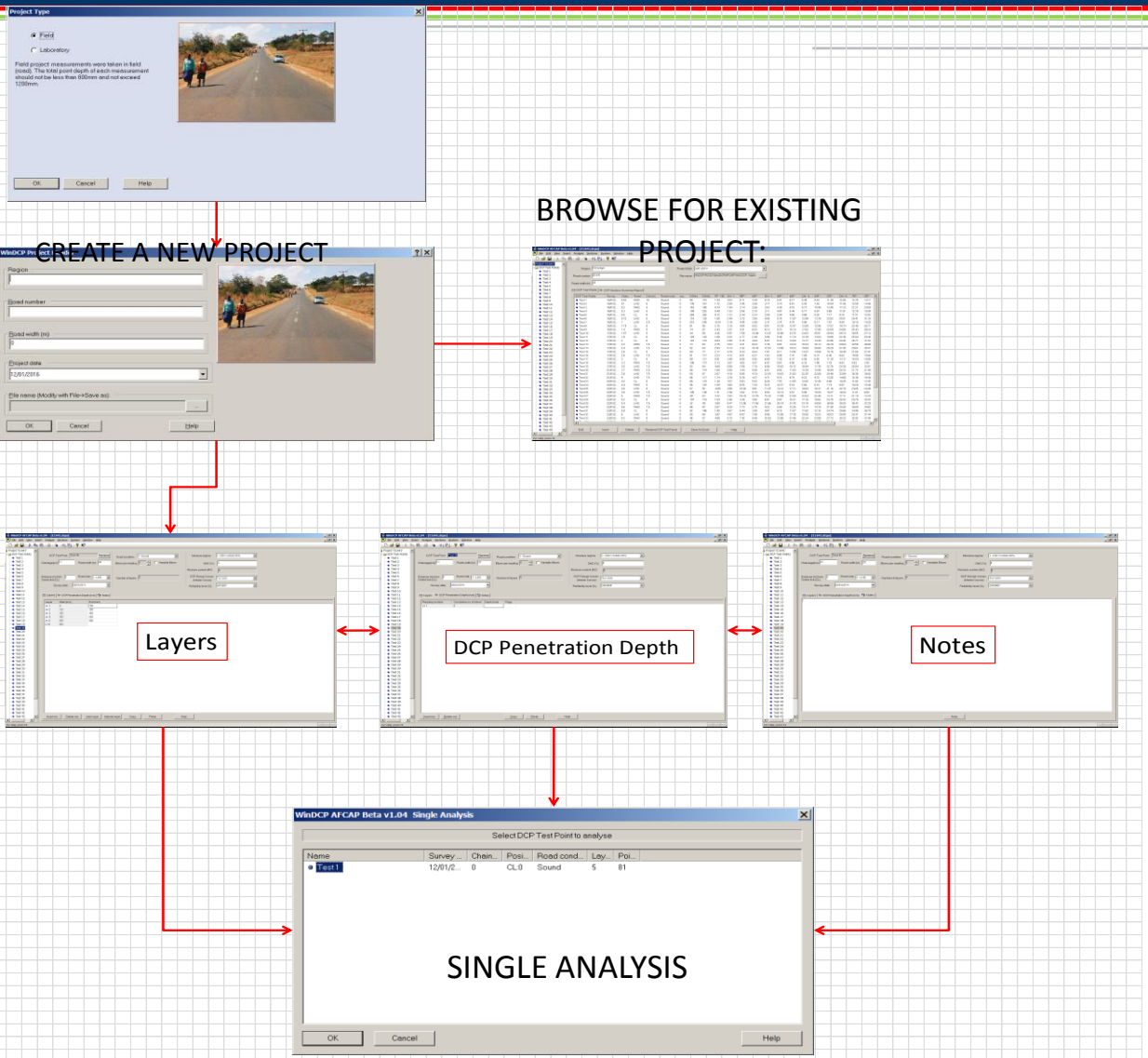


Flowchart_1": DCP Project

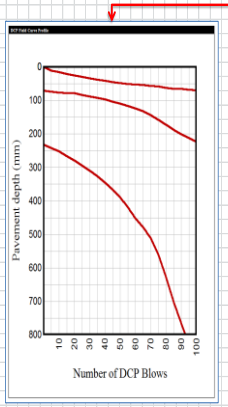
DCP Project:

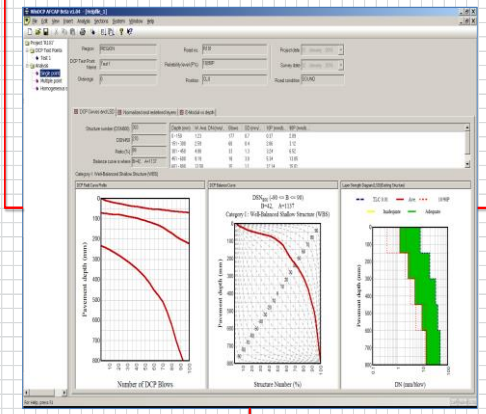


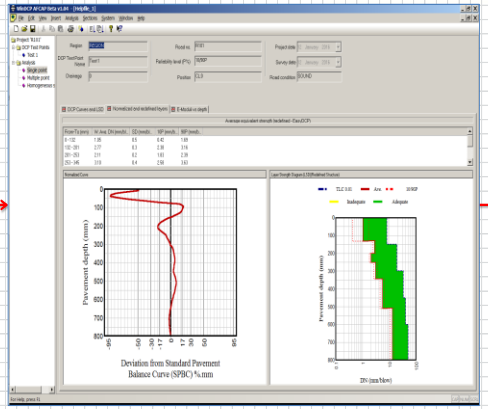
START DCP ANALYSIS

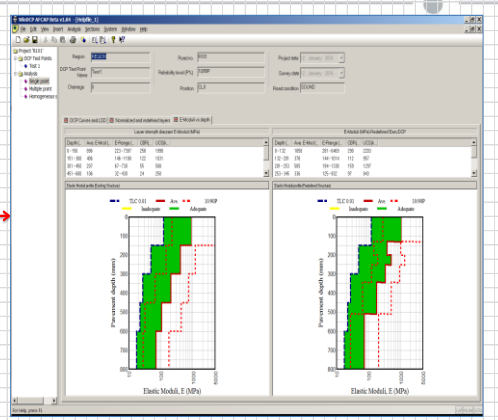


SINGLE POINT DCP ANALYSIS



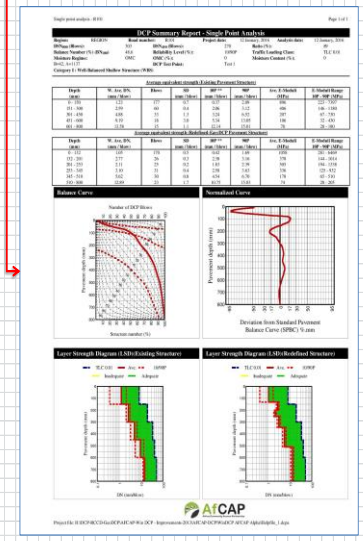


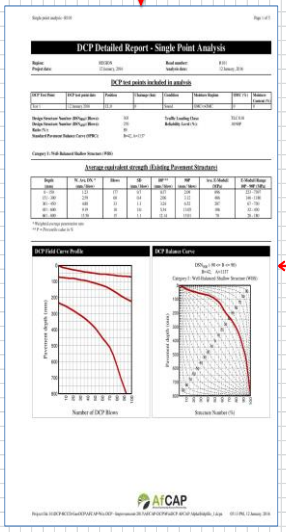


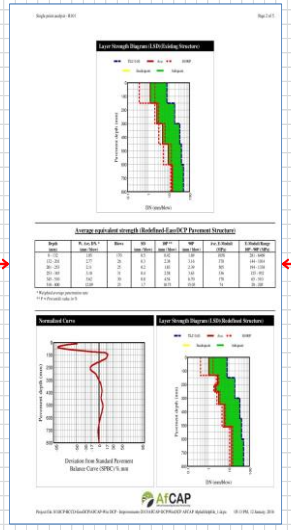


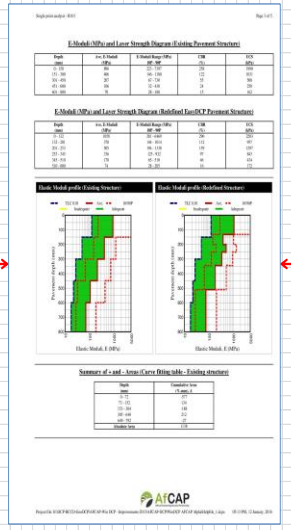
Summary Report

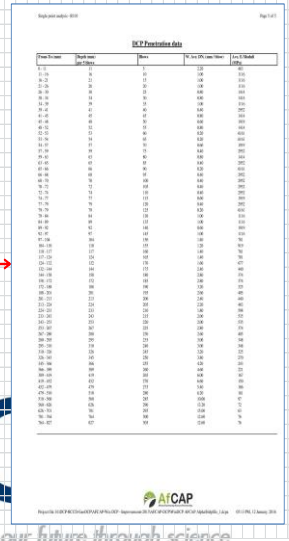
Detail Report











DCP Summary Report" – one page report (as in EasyDCP)

Multiple point analysis

Page 1 of 1

DCP Summary Report - Multiple Point Analysis

Region: Kirinyaga **Road number:** E1641 **Project date:** 20 January, 2014 **Analysis date:** 07 January, 2016

DSN_{800} (Blows): 108 **DSN_{450} (Blows):** 89 **Ratio (%):** 83

Balance Number (%) (BN_{100}) 47.0 **Reliability Level (%):** 20/80P **Traffic Loading Class:** TLC 0.03

B=31, A=544 **DCP Test Point:** Section 1 km 0+000 to 4+800

Category IV : Well-Balanced Deep Structure (WBD)

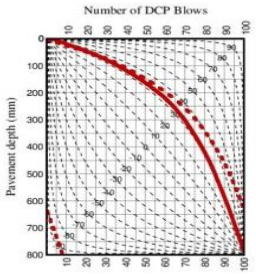
Average equivalent strength (Existing Pavement Structure)

Depth (mm)	W. Ave. DN. (mm / blow)	Blows	SD (mm / blow)	20P ** (mm / blow)	80P (mm / blow)	Ave. E-Moduli (MPa)	E-Moduli Range 20P - 80P (MPa)
0 - 150	4.49	50	0.8	3.81	5.16	227	104 - 508
151 - 300	8.75	25	1.8	7.23	10.28	111	50 - 257
301 - 450	15.00	14	1.7	13.59	16.42	63	30 - 132
451 - 600	21.41	9	1.9	19.80	23.01	43	21 - 88
601 - 800	26.26	10	1.4	25.11	27.40	35	18 - 69

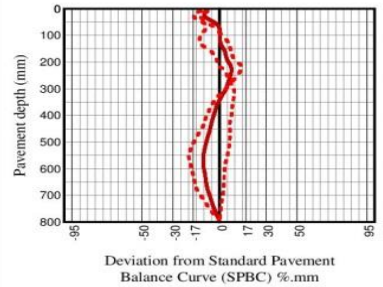
Average equivalent strength (Redefined-EasyDCP Pavement Structure)

Depth (mm)	W. Ave. DN. (mm / blow)	Blows	SD (mm / blow)	20P ** (mm / blow)	80P (mm / blow)	Ave. E-Moduli (MPa)	E-Moduli Range 20P - 80P (MPa)
0 - 80	3.82	32	0.3	3.61	4.03	269	135 - 538
80 - 160	5.36	20	0.5	4.91	5.80	188	92 - 388
160 - 230	7.40	13	0.7	6.80	8.00	133	65 - 275
230 - 310	10.69	11	1.0	9.87	11.51	90	44 - 185
310 - 460	15.38	13	1.6	14.01	16.75	61	30 - 127
460 - 620	21.92	9	1.7	20.47	23.38	42	21 - 85
620 - 800	26.54	9	1.1	25.59	27.48	34	18 - 67

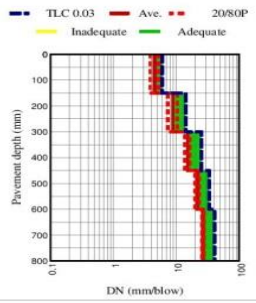
Balance Curve



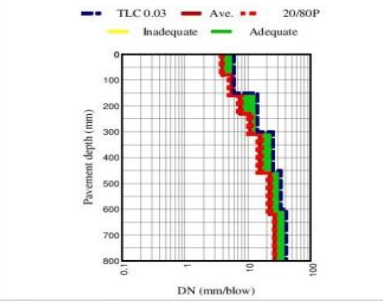
Normalized Curve



Layer Strength Diagram (LSD)(Existing Structure)



Layer Strength Diagram (LSD)(Redefined Structure)



AfCAP

Project file: H:\DCP-RCCD-GeoDCP\AFCAP-Win DCP - Improvements-2013\AFCAP-DCP\WinDCP AFCAP Alpha\E1641.dcpa

DCP Category Classification

DCP Summary Report - Single Point Analysis

Region:	Kirinyaga	**Road number:**	E1641	**Project date:**	20 January, 2014	**Analysis date:**	07 January, 2016
DSN_{800} (Blows):	246	**DSN_{450} (Blows):**	216			**Ratio (%):**	88
Balance Number (%) (BN_{100})	51.3	**Reliability Level (%):**	20/80P			**Traffic Loading Class:**	TLC 0.03
Moisture Regime:	OMC	**OMC (%):**	0			**Moisture Content (%):**	0
B=40, A=1243		**DCP Test Point:**	Test 7				

Category II : Averagely Balanced Shallow Structure(ABS)

Re-Defined layers: EasyDCP

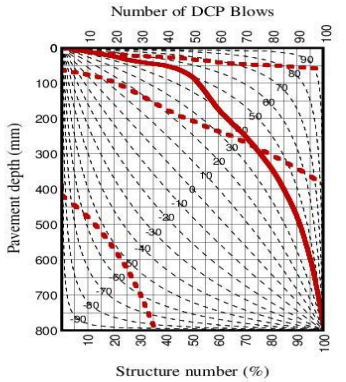
Average equivalent strength (Existing Pavement Structure)

Depth (mm)	W. Ave. DN. (mm / blow)	Blows	SD (mm / blow)	20P ** (mm / blow)	80P (mm / blow)	Ave. E-Moduli (MPa)	E-Moduli Range 20P - 80P (MPa)
0 - 150	2.10	139	1.4	0.90	3.30	507	166 - 2342
151 - 300	3.37	45	0.5	2.99	3.75	307	146 - 658
301 - 450	4.96	31	0.8	4.25	5.67	204	94 - 452
451 - 600	9.04	17	1.6	7.70	10.37	108	49 - 241
601 - 800	15.79	13	2.4	13.80	17.78	60	28 - 130

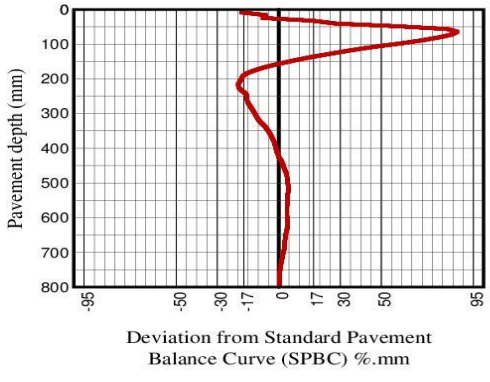
Average equivalent strength (Redefined-EasyDCP Pavement Structure)

Depth (mm)	W. Ave. DN. (mm / blow)	Blows	SD (mm / blow)	20P ** (mm / blow)	80P (mm / blow)	Ave. E-Moduli (MPa)	E-Moduli Range 20P - 80P (MPa)
0 - 75	0.83	115	0.4	0.50	1.16	1361	508 - 4360
75 - 363	3.52	86	0.6	2.99	4.04	294	134 - 658
363 - 519	6.39	25	1.1	5.50	7.29	156	72 - 344
519 - 800	14.22	21	3.2	11.56	16.89	67	29 - 156

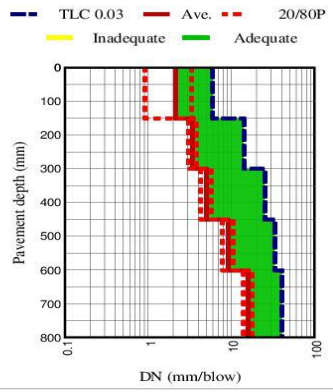
Balance Curve



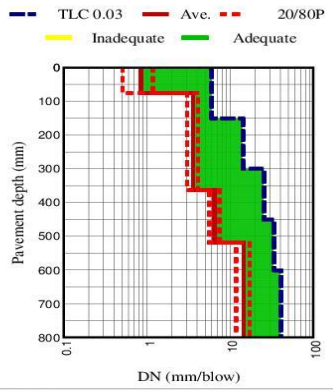
Normalized Curve



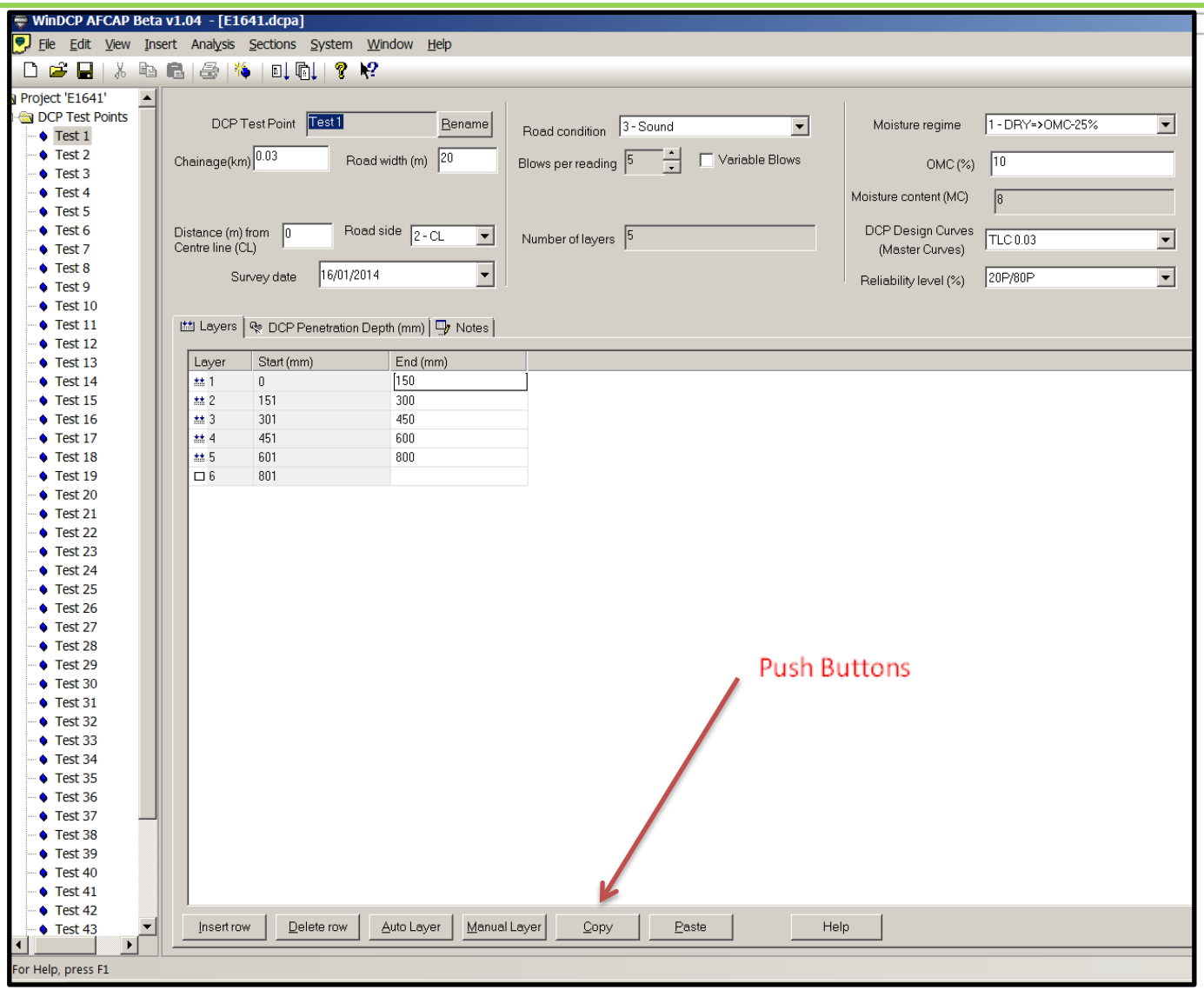
Layer Strength Diagram (LSD)(Existing Structure)



Layer Strength Diagram (LSD)(Redefined Structure)



Various “Push” buttons:..



"Manual" Fitting of layers/sub-layers..

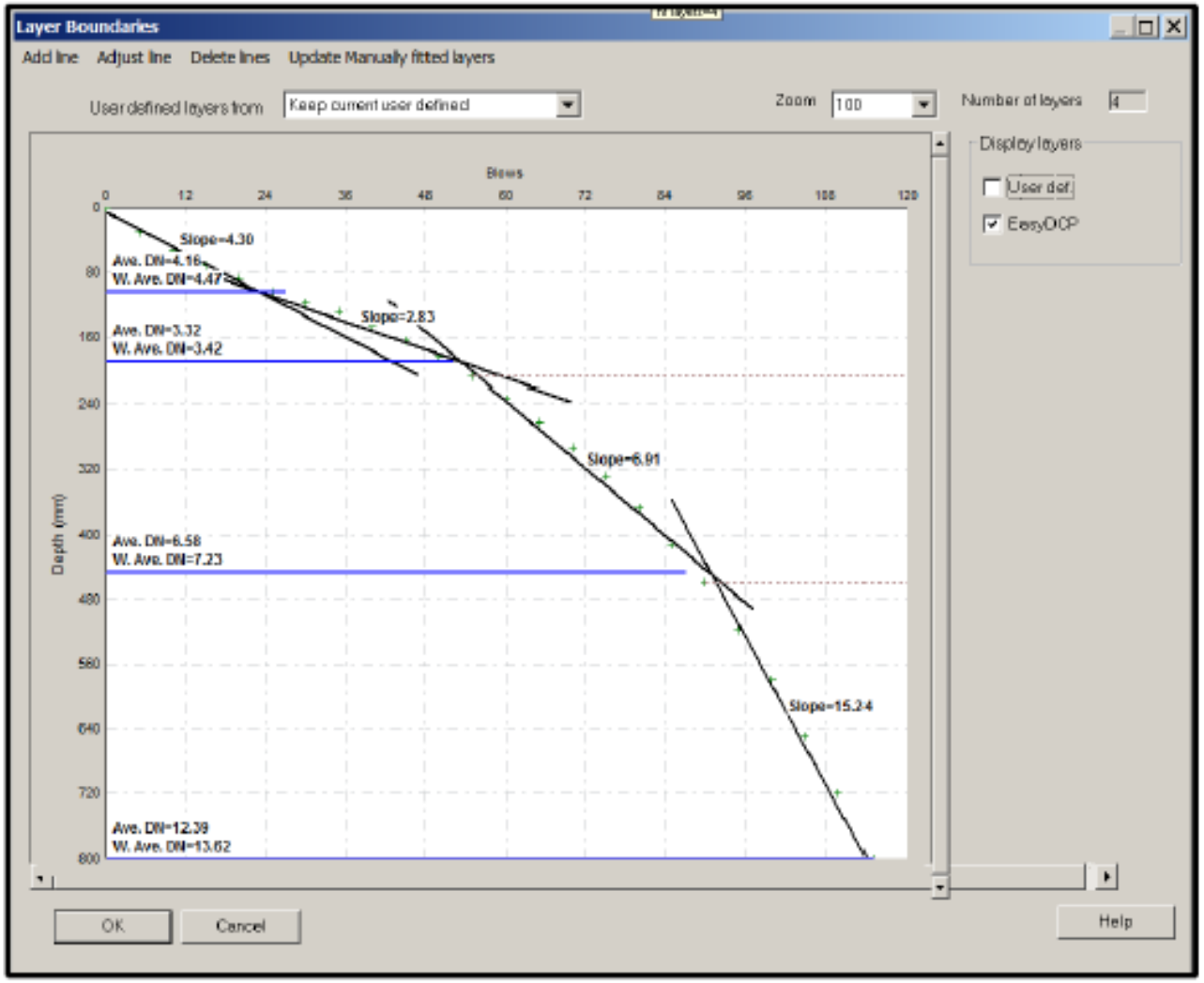
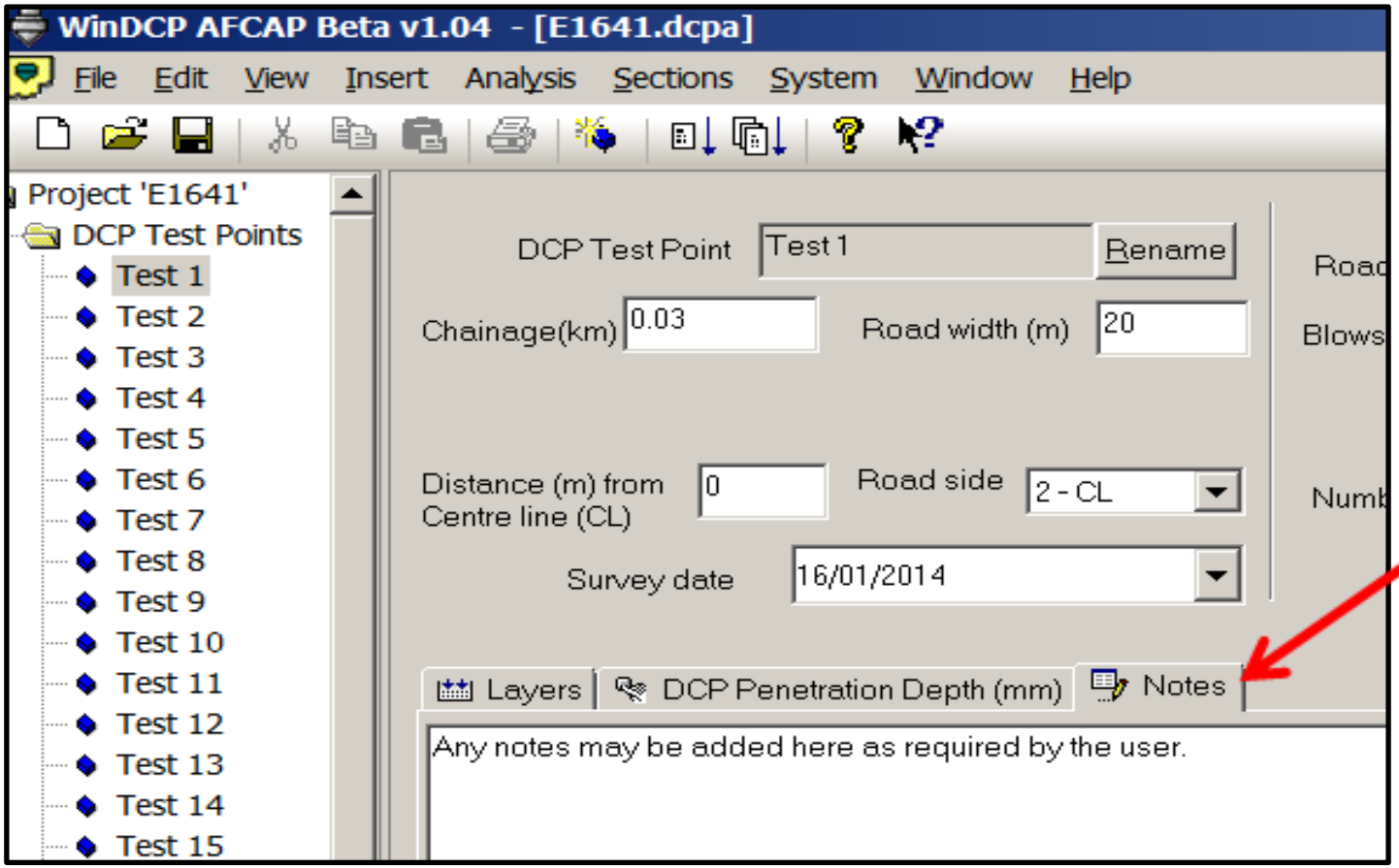


Figure 28. Manual layer fitting menu for layer boundaries to be defined. Note: EasyDCP auto re-defined layers also shown here by the broken lines.

Option to include your own "Notes":

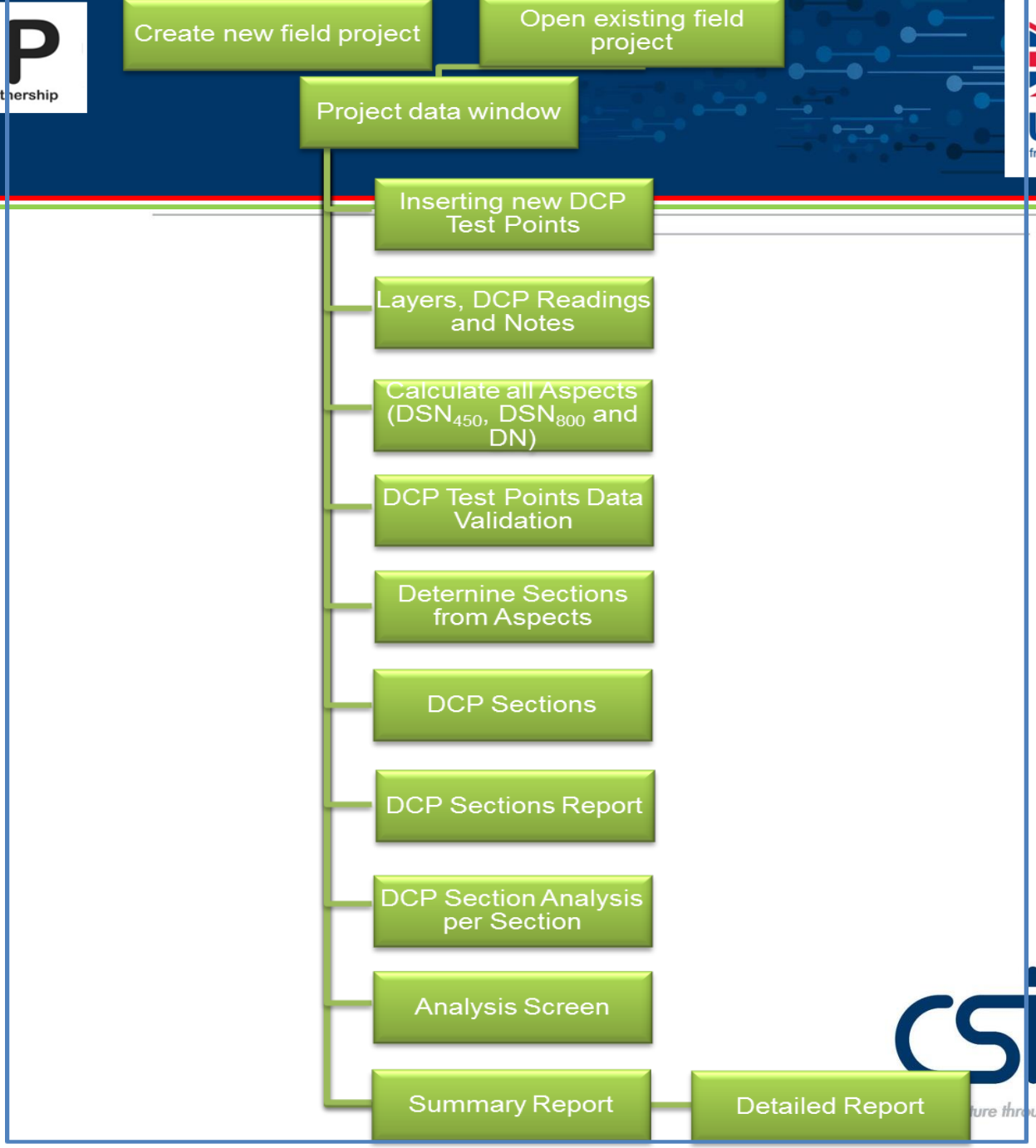


ReCAP
Research for Community Access Partnership

UKaid
from the British people

Flowchart_2":

DCP Sections:



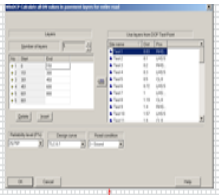
CSIR
ure through science

Sectioning the project:

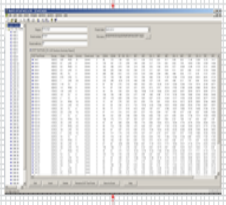
There are two stages to divide a project in “Homogeneous Sections”:

- **Stage 1:** The DCP Project is sectioned using each of the DCP “Aspects” from “DSN_{450}/DSN_{800}” (or DN) per layer which are deemed to be significant by User;
- **Stage 2:** The DCP Sections from Stage 1 are compared and DCP Sections defined which best combine the single DCP parameter sections – USER DEFINED, BASED ON YOUR EXPERIENCE..

Calculate all DN and DSN_{800} values

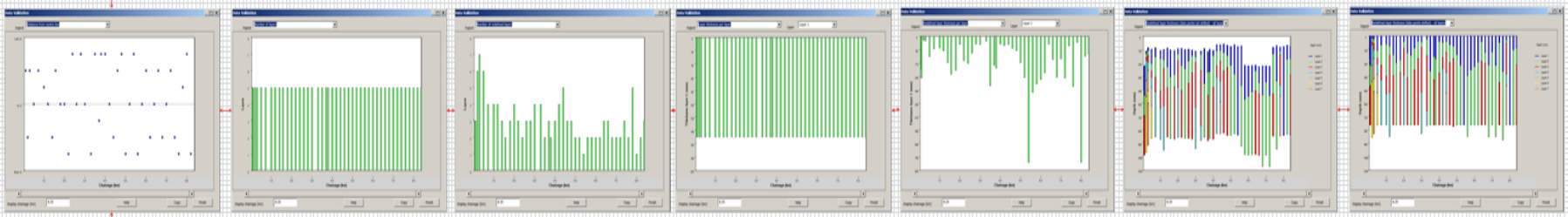


Calculate all DN and DSN800 values Set P-values and TLC:

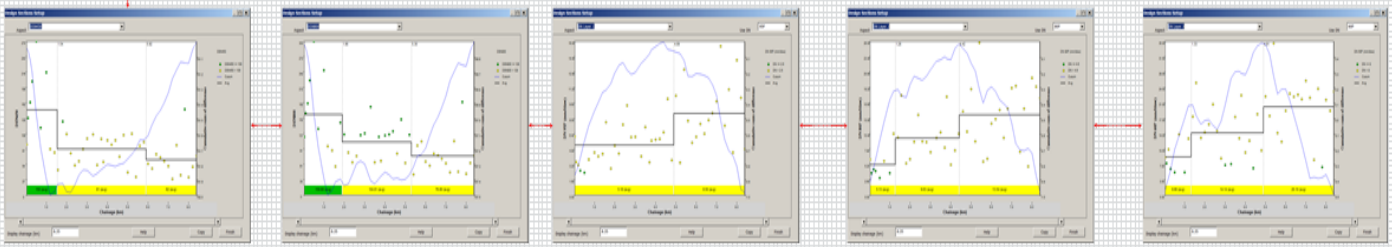


DCP TEST POINTS:

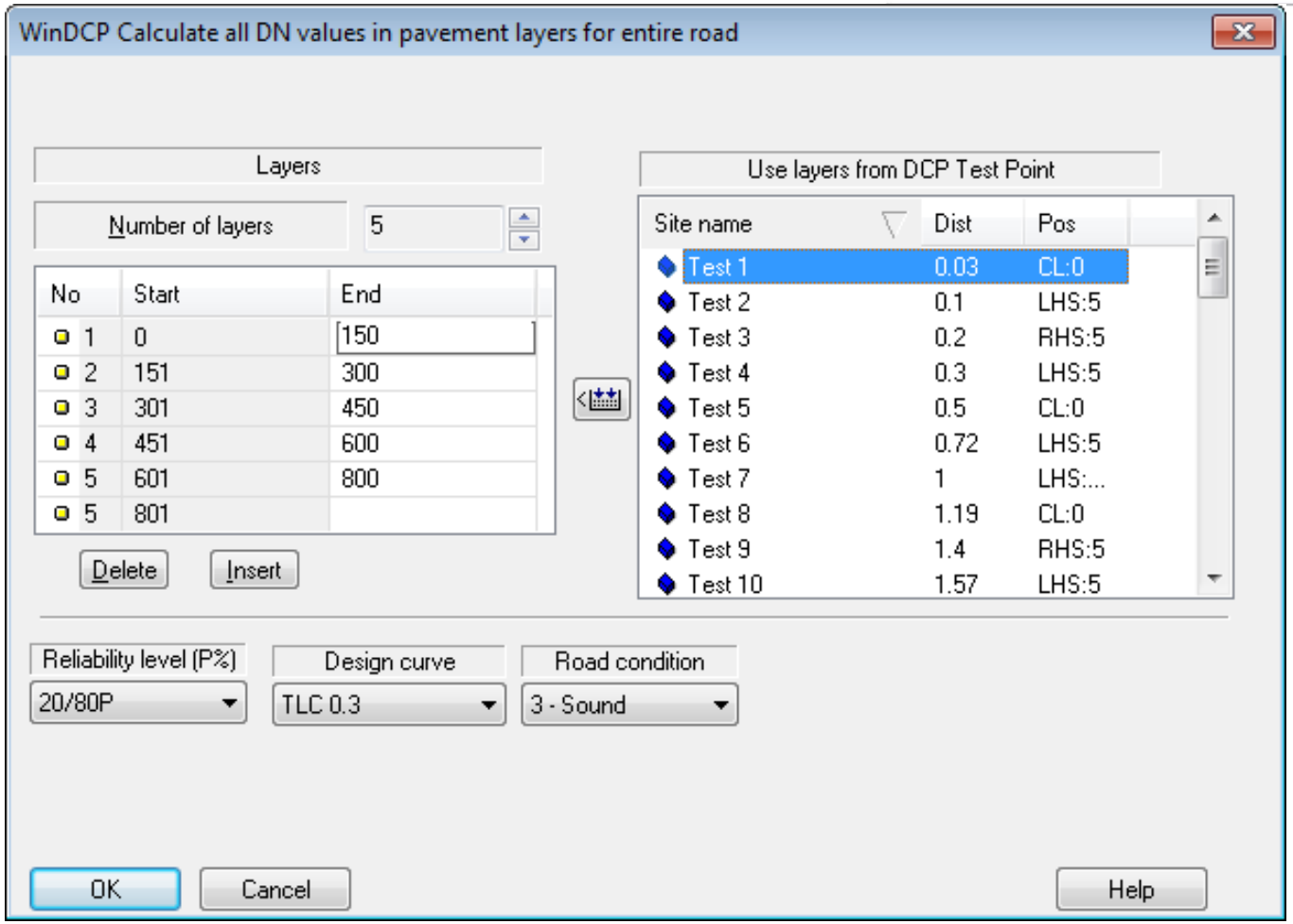
DCP TEST POINT DATA VALIDATION:



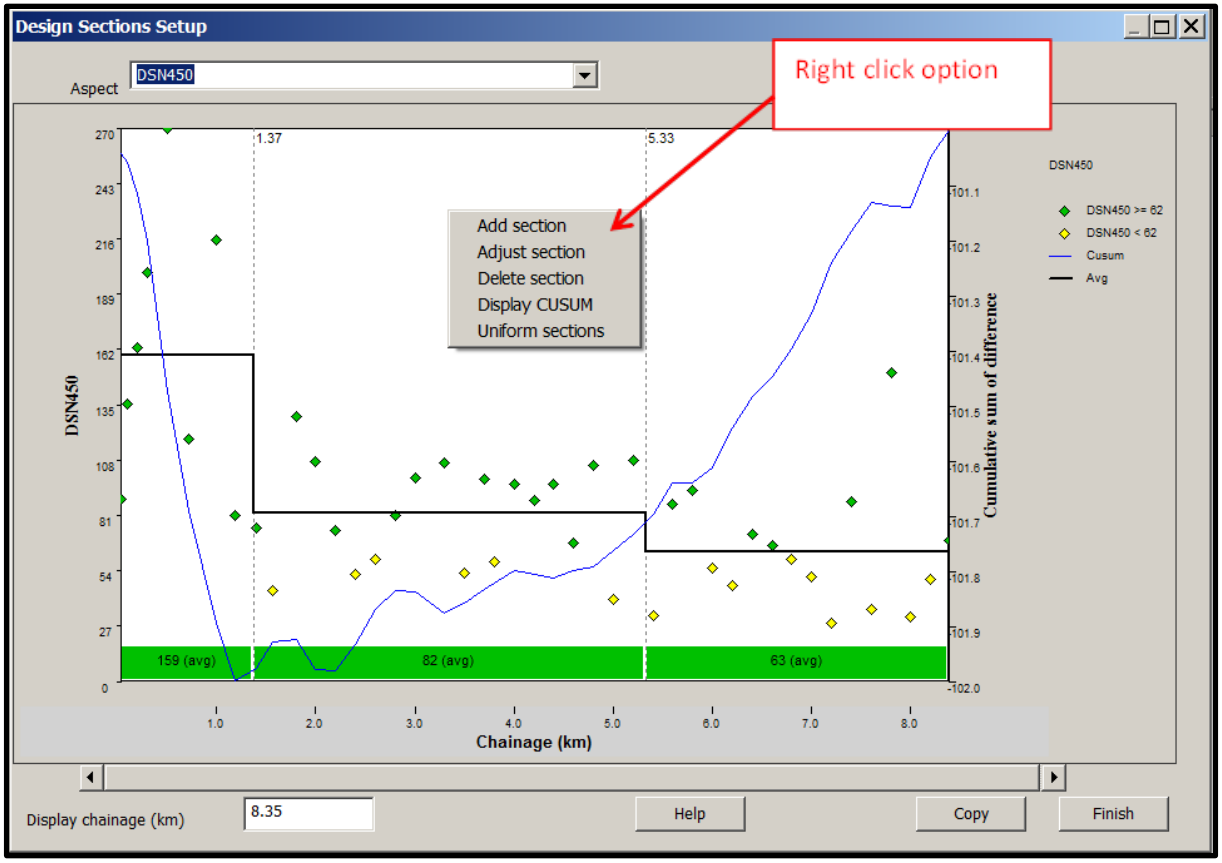
DESIGN SECTION SET-UP:



New Report Table- calculate all ASPECTS:



DETERMINE UNIFORM ROAD SECTIONS



New Report Table - report on project screen...

The calculated DN and DSN800 values are now displayed on the project screen. Press Save As Excel to save to xlsx.

DCP Test Points | DCP Sections Summary Report

DCP Test Points	Survey date	Chainag...	Road Si...	Dist (m) fr...	Road condition	Layers	DSN450	DSN800	20P - 150	DN - 150	80P - 150
Test 1	16/01/2014	0.03	CL	0	Sound	5	88	115	2.96	4.03	5.10
Test 2	16/01/2014	0.1	LHS	5	Sound	5	135	161	2.14	2.58	3.03
Test 3	16/01/2014	0.2	RHS	5	Sound	5	163	180	1.32	1.94	2.55
Test 4	16/01/2014	0.3	LHS	5	Sound	5	199	225	1.00	1.53	2.05
Test 5	16/01/2014	0.5	CL	0	Sound	5	269	302	0.66	1.23	1.80
Test 6	16/01/2014	0.72	LHS	5	Sound	5	118	130	1.73	2.40	3.08
Test 7	16/01/2014	1	LHS	2.5	Sound	5	215	245	0.90	2.10	3.30
Test 8	16/01/2014	1.19	CL	0	Sound	5	81	96	2.61	3.10	3.59
Test 9	16/01/2014	1.4	RHS	5	Sound	5	74	87	2.89	3.37	3.85
Test 10	17/01/2014	1.57	LHS	5	Sound	5	44	56	5.14	5.97	6.79
Test 11	17/01/2014	1.8	CL	0	Sound	5	129	142	1.95	2.22	2.50
Test 12	17/01/2014	2	CL	0	Sound	5	107	119	1.89	2.99	4.10
Test 13	17/01/2014	2.2	RHS	7.5	Sound	5	73	83	3.13	3.53	3.93
Test 14	17/01/2014	2.4	LHS	7.5	Sound	5	52	64	4.00	5.13	6.25

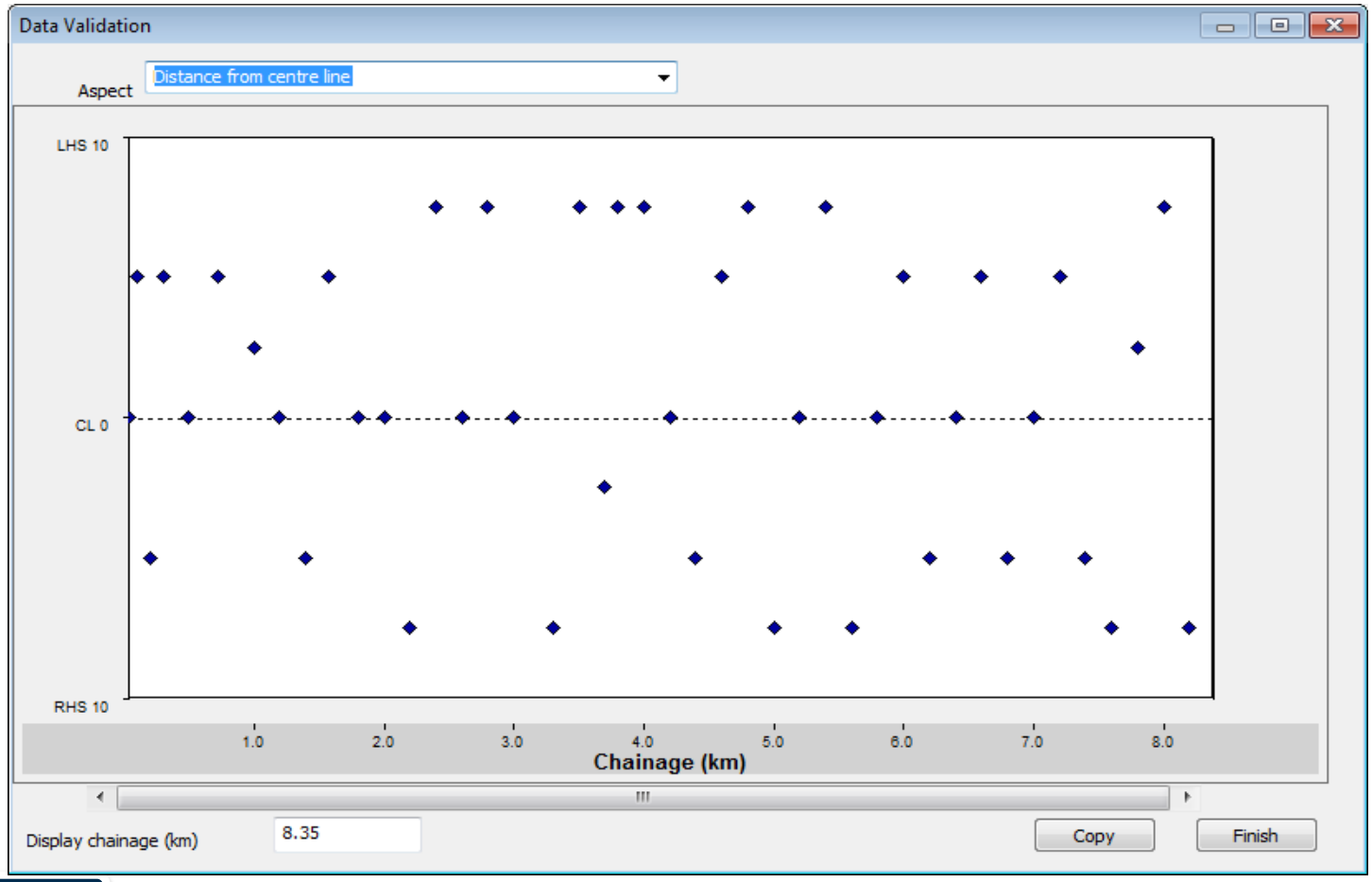
New Report Table – or Save As *.xlsx

The results can now be viewed in Excel xlsx

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Averages from	Weighted Average												
Percentiles from	Normal Distribution												
													Weighte
DCP Test Point nr	DCP Test Point Name	Survey date	Distance (km)	Road Side	Distance (m) from centre line	DSN450	DSN800	0-150 mm			151-300 mm		
								20P	Mean	80P	20P	Mean	80P
1	Test 1	16/01/2014	0.03	CL	0	88	115	2.960	4.030	5.100	4.380	5.190	6.010
2	Test 2	16/01/2014	0.1	LHS	5	135	161	2.140	2.580	3.030	2.600	3.170	3.740
3	Test 3	16/01/2014	0.2	RHS	5	163	180	1.320	1.940	2.550	2.660	3.530	4.390
4	Test 4	16/01/2014	0.3	LHS	5	199	225	1.000	1.530	2.050	2.150	3.110	4.070
5	Test 5	16/01/2014	0.5	CL	0	269	302	0.660	1.230	1.800	2.240	2.590	2.940
6	Test 6	16/01/2014	0.72	LHS	5	118	130	1.730	2.400	3.080	3.560	4.660	5.760
7	Test 7	16/01/2014	1	LHS	2.5	215	245	0.900	2.100	3.300	2.990	3.370	3.750
8	Test 8	16/01/2014	1.19	CL	0	81	96	2.610	3.100	3.590	6.630	8.510	10.390
9	Test 9	16/01/2014	1.4	RHS	5	74	87	2.890	3.370	3.850	6.530	8.130	9.730

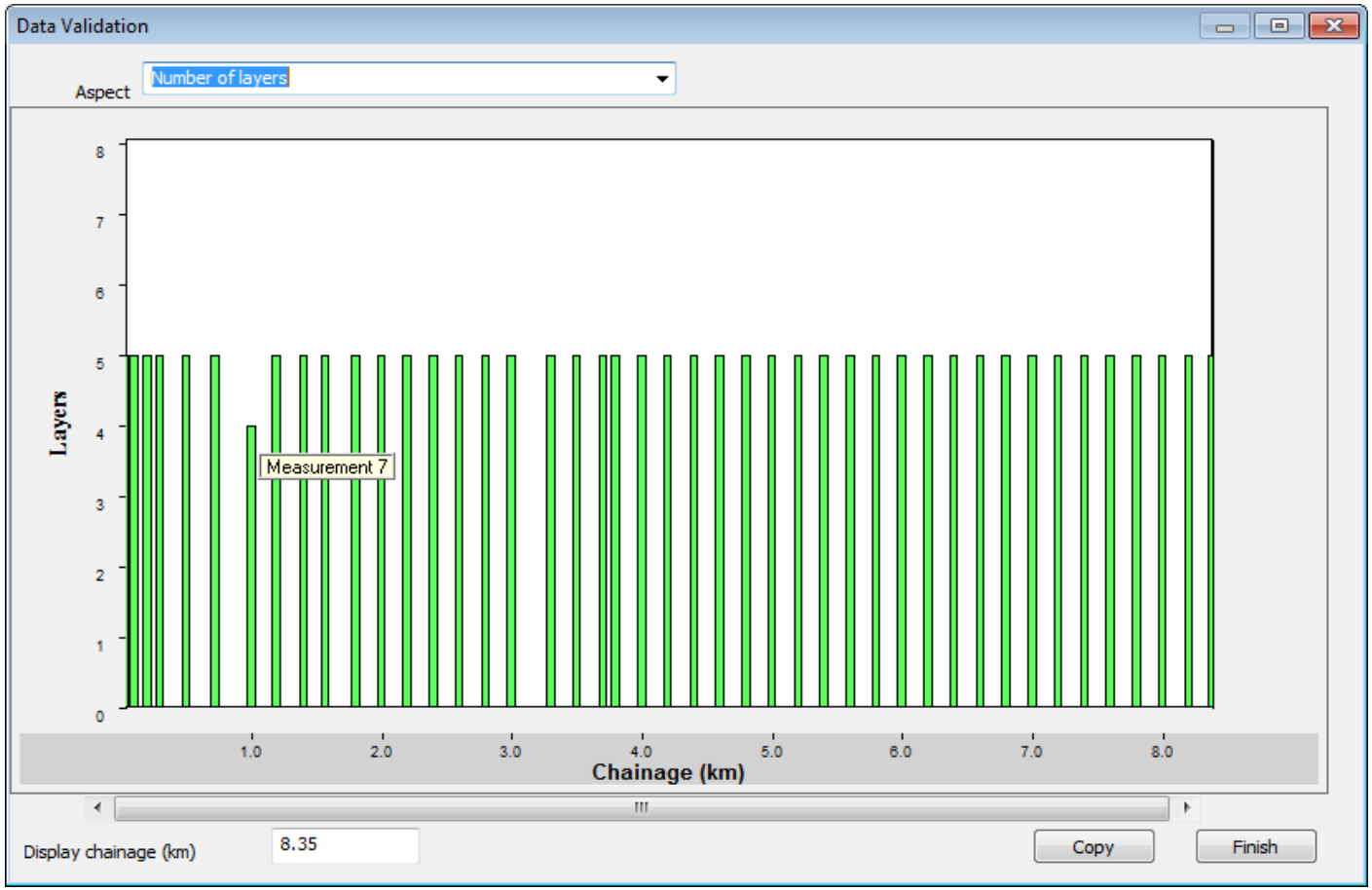
Newly added: Aspect 1: DCP Measurement Layout validation

Example 1: Plot of DCP Measurements along Chainage – Aspect: "Distance from centre line":



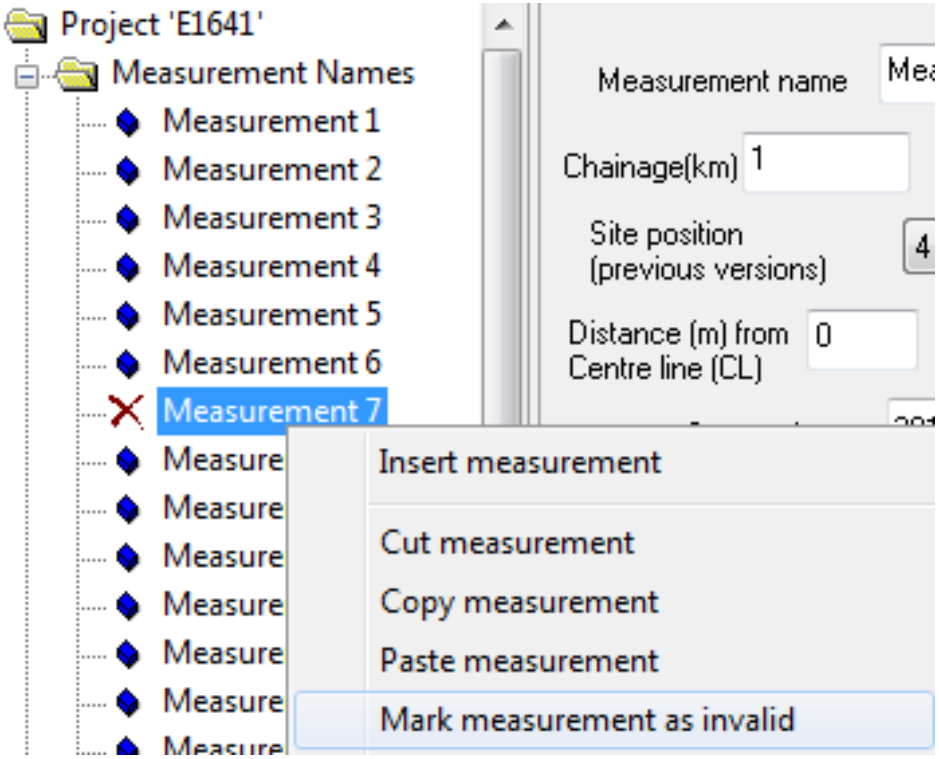
Newly added: Aspect: "Number of layers"

Example 2: Plot of DCP Measurements along Chainage – Aspect: "Number of layers":



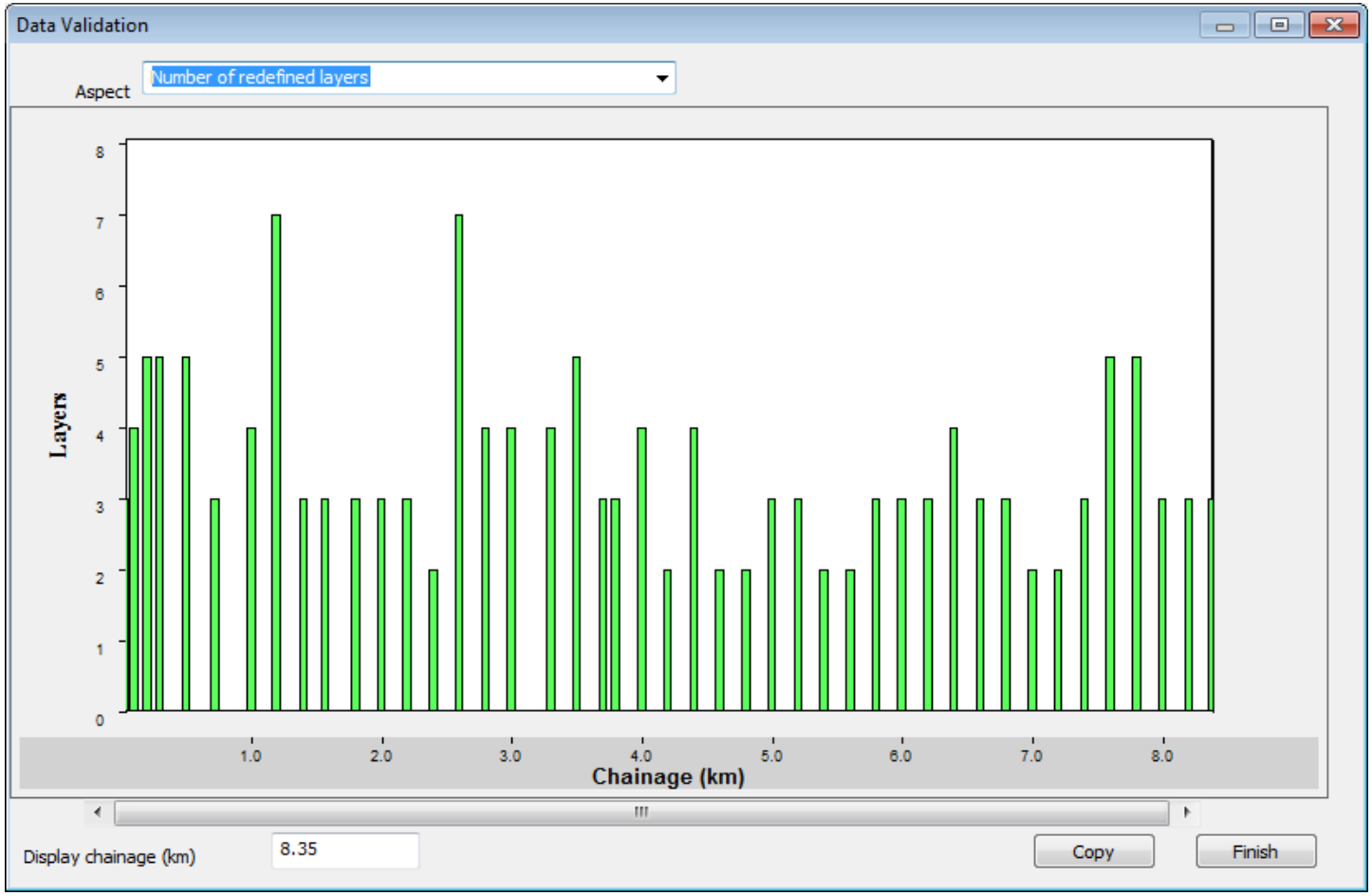
Newly added: Aspect: "Delete Outliers"

- Outlier measurements can be deleted from the project or marked as invalid. Measurements marked as invalid will not be included in the homogeneous section analysis but is not deleted from the project.



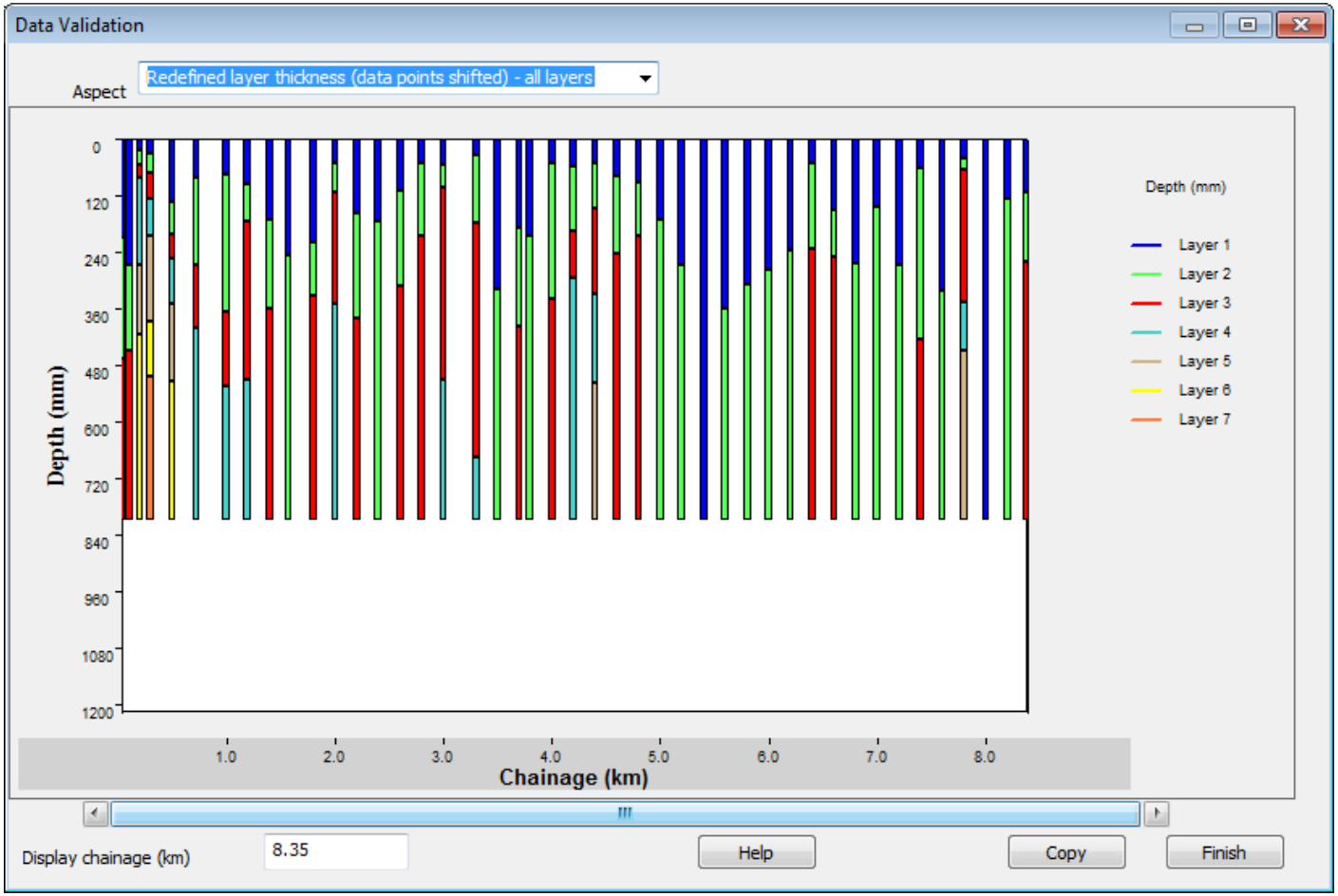
Newly added: Aspect: "Number of redefined layers"

Example 3: Plot of DCP Measurements along Chainage – Aspect: "Number of redefined layers"



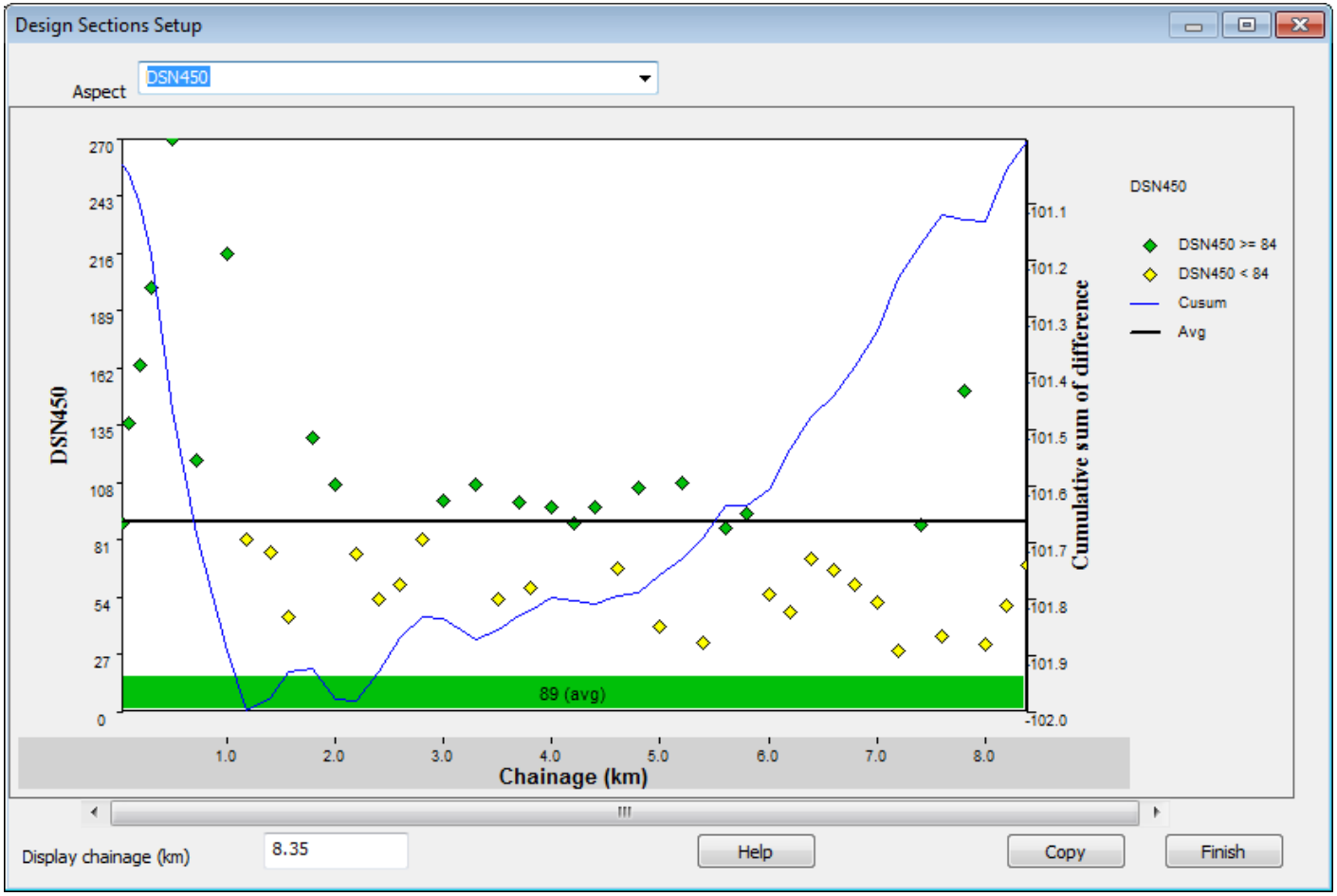
Newly added: Aspect: "Redefined layer depths"

Example 4: Plot of DCP Measurements along Chainage – Aspect: "Redefined layer thicknesses or depths"



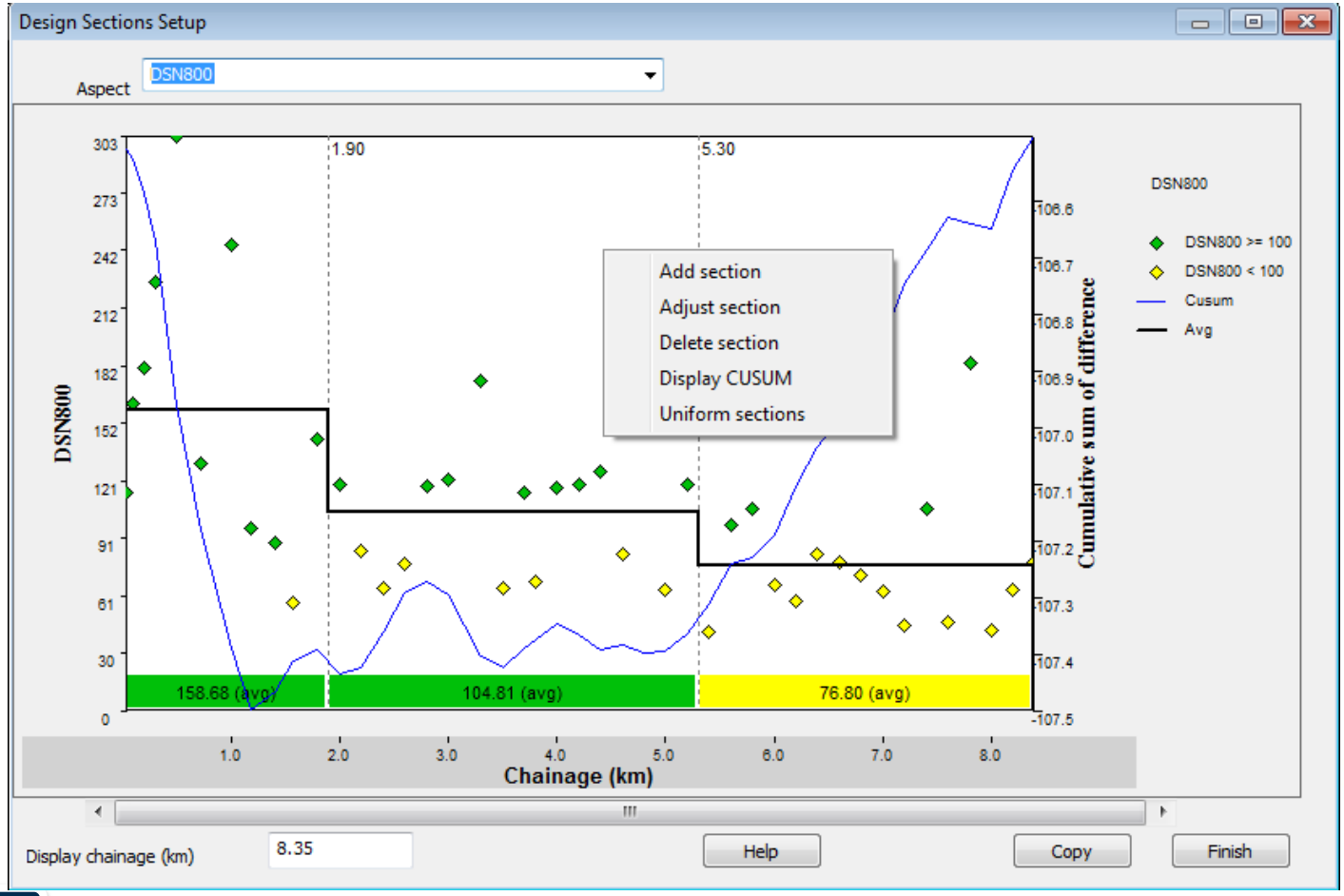
CUSUMS –Design Sections Setup:

By Aspect: "DSN_{450}":



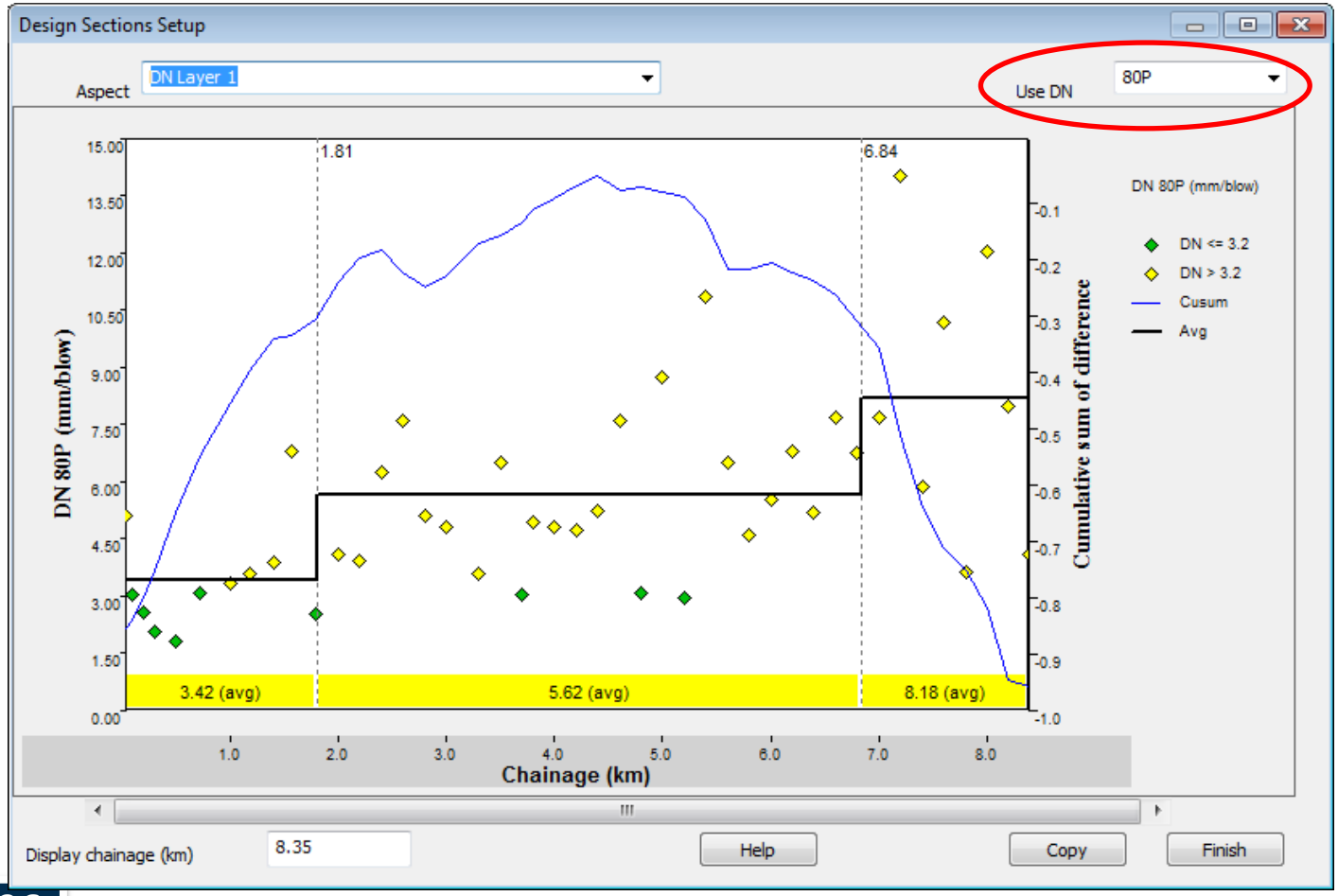
CUSUMS – Design DCP Sections (Stage 1)

By Aspect: "DSN_{800}" & Sections along Chainage (by Right Click):



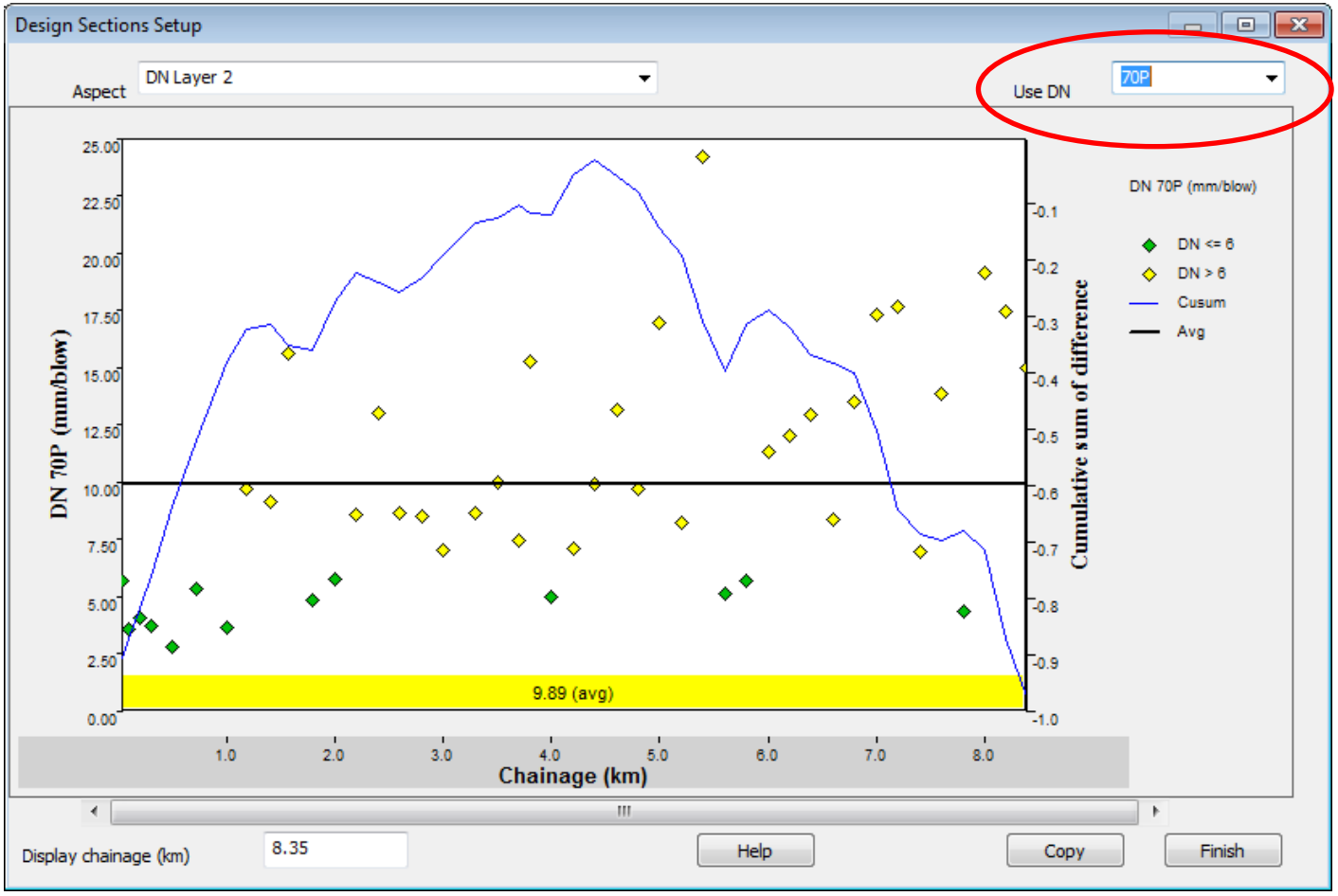
CUSUMS – Design DCP Sections (Stage 1)

By Aspect: “Layer 1” & Sections along Chainage (by Right Click):



CUSUMS – Design DCP Sections (Stage 1)

By Aspect: “Layer 2” & Sections along Chainage (by Right Click):



identify localised problem spots or sections, most often related to drainage problems, for which specific measures must be taken without affecting the overall design.

- Layer Strength Diagrams (LSD) with weighted average DN values for each 150 mm in-situ layers down to a depth of 800 mm used to determine the appropriate design intervention.
- Easy identification of uniform sections for optimised pavement design based on representative average DN values for each layer, adjusted for expected long-term pavement moisture regime.
- Assessment of the attained pavement balance against ideal pavement balance curves;
- A laboratory test module for testing and evaluating the strength of imported pavement materials.
- Pre-defined report formats.

The AfCAP LVR-DCP package is well suited for road practitioners and trainees.

Although the software automates many of the procedures that could otherwise have been performed using an Excel spreadsheet, and thus makes it possible for the designer to quickly and easily evaluate different design options, it must be emphasised that the AfCAP LVR DCP software is only a tool and is no substitute for sound engineering judgement, which must always be exercised by the designer.

Join the LVR DCP Software User Forum

Your registration will give you access to a professionally moderated, online LVR DCP Software User Forum, in which you can share your experience in using the software with peers and where you can ask your questions to a team of specialists.

If you have already registered, please login to the Forum **here**.

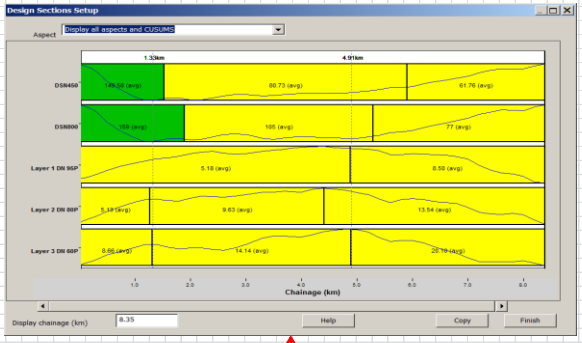
For further reading

CSIR (2016), Improvements to the WinDCP software for Pavement Design for Low Volume Roads

Hongve, J. and E. Mukandila (2016), Training and Application of the DCP-DN Pavement Design Method in Ghana

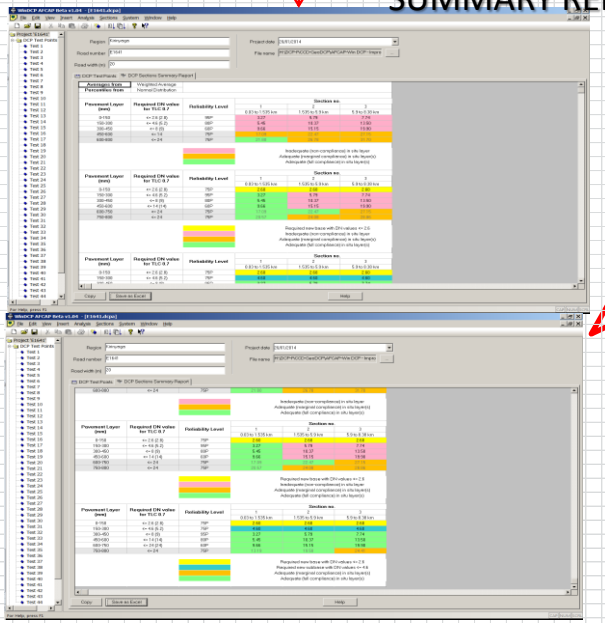
Hongve, J. and E. Mukandila (2016), Implementation of Technical Audit and Training of a New Batch of Local Practitioners in the DCP-DN Pavement Design Method in Malawi

DCP TEST: FINAL OUTPUT: UNIFORM ROAD SECTIONS: RESULTS



DCP TEST ASPECTS:

DCP SECTIONS SUMMARY REPORT



Averages from	Weighted Average
Percentiles from	Normal Distribution

Pavement Layer (mm)	Required DN value for TLC 0.7	Reliability Level	Section no. 1 (0.03 to 1.535 km)	Section no. 2 (1.535 to 5.9 km)	Section no. 3 (5.9 to 8.38 km)
0-150	<= 2.6 (2.8)	95P	3.27	5.79	7.74
150-300	<= 4.6 (5.2)	80P	5.45	10.37	13.50
300-450	<= 8 (9)	60P	9.66	15.15	19.90
450-600	<= 14	75P	17.09	22.47	27.15
600-800	<= 24	75P	21.80	26.78	31.70

Inadequate (non-compliance) in situ layer
Adequate (marginal compliance) in situ layer(s)
Adequate (full compliance) in situ layer(s)

Pavement Layer (mm)	Required DN value for TLC 0.7	Reliability Level	Section no. 1 (0.03 to 1.535 km)	Section no. 2 (1.535 to 5.9 km)	Section no. 3 (5.9 to 8.38 km)
0-150	<= 2.6 (2.8)	75P	2.60	2.60	2.60
150-300	<= 4.6 (5.2)	95P	3.27	5.79	7.74
300-450	<= 8 (9)	80P	5.45	10.37	13.50
450-600	<= 14 (14)	60P	9.66	15.15	19.90
600-750	<= 24	75P	17.09	22.47	27.15
750-800	<= 24	75P	20.57	24.08	28.86

Required new base with DN values <= 2.6
Inadequate (non-compliance) in situ layer
Adequate (marginal compliance) in situ layer(s)
Adequate (full compliance) in situ layer(s)

Pavement Layer (mm)	Required DN value for TLC 0.7	Reliability Level	Section no. 1 (0.03 to 1.535 km)	Section no. 2 (1.535 to 5.9 km)	Section no. 3 (5.9 to 8.38 km)
0-150	<= 2.6 (2.8)	75P	2.60	2.60	2.60
150-300	<= 4.6 (5.2)	75P	4.60	4.60	4.60
300-450	<= 8 (9)	95P	3.27	5.79	7.74
450-600	<= 14 (14)	80P	5.45	10.37	13.50
600-750	<= 24 (24)	60P	9.66	15.15	19.90
750-800	<= 24	75P	13.19	19.58	24.41

Required new base with DN values <= 2.6
Required new subbase with DN values <= 4.6
Adequate (marginal compliance) in situ layer(s)
Adequate (full compliance) in situ layer(s)

DCP TEST: FINAL OUTPUT: UNIFORM ROAD SECTIONS: RESULTS

ReCAP Research for Community Access Partnership

UKaid from the British people

AfCAP LVR-DCP v1.03 - [E1641.dcpa]

File Edit View Insert Analysis Sections System Window Help

Project 'E1641'

DCP Test Points

- Test 1
- Test 2
- Test 3
- Test 4
- Test 5
- Test 6
- Test 7
- Test 8
- Test 9
- Test 10
- Test 11
- Test 12
- Test 13
- Test 14
- Test 15
- Test 16
- Test 17
- Test 18
- Test 19
- Test 20
- Test 21
- Test 22
- Test 23
- Test 24
- Test 25
- Test 26
- Test 27
- Test 28
- Test 29
- Test 30
- Test 31
- Test 32
- Test 33
- Test 34
- Test 35
- Test 36
- Test 37
- Test 38

Region: Kirinyaga

Road number: E1641

Project date: 20/01/2014

File name: H:\DCP_LVR_AFCAP-Win DCP - Improvements_s ...

DCP Test Points | DCP Sections Report

Averages from	Weighted Average
Percentiles from	Normal Distribution

Pavement Layer (mm)	Required DN value for TLC 0.3	Section no. 1 (0.03 to 1.27 km)	2 (1.27 to 2.645 km)	3 (2.645 to 4.845 km)	4 (4.845 to 7.13 km)	5 (7.13 to 8.38 km)
0-150	<= 3.2 (3.5)	2.8 (80P)	4.7 (80P)	4.6 (80P)	6.0 (80P)	8.0 (80P)
150-300	<= 6 (6.9)	5.3 (90P)	11 (90P)	11 (90P)	14 (90P)	14 (90P)
300-450	<= 12 (14)	10 (90P)	20 (90P)	13 (90P)	24 (90P)	19 (90P)
450-600	<= 19	18 (90P)	29 (90P)	18 (90P)	31 (90P)	25 (90P)
600-800	<= 25	22 (90P)	33 (90P)	21 (90P)	34 (90P)	33 (90P)

Inadequate (non-compliance) in situ layer

Adequate (marginal compliance) in situ layer(s) that need to be improved

Adequate (full compliance) in situ layer(s)

Pavement Layer (mm)	Required DN value for TLC 0.3	Section no. 1 (0.03 to 1.27 km)	2 (1.27 to 2.645 km)	3 (2.645 to 4.845 km)	4 (4.845 to 7.13 km)	5 (7.13 to 8.38 km)
0-150	<= 3.2 (3.5)	2.8 (80P)	3.2	3.2	3.2	3.2
150-300	<= 6 (6.9)	5.3 (90P)	4.7 (80P)	4.6 (80P)	6.0 (80P)	6.0
300-450	<= 12 (14)	10 (90P)	11 (90P)	11 (90P)	14 (90P)	8.0 (80P)
450-600	<= 19	18 (90P)	20 (90P)	13 (90P)	24 (90P)	14 (90P)
600-800	<= 25	22 (90P)	30 (90P)	18 (90P)	32 (90P)	21 (90P)

New base added with DN values <= 3.2

New subbase added with DN values <= 6

Inadequate (non-compliance) in situ layer

Adequate (marginal compliance) in situ layer(s) that need to be improved

Adequate (full compliance) in situ layer(s)

Software Help File (SHF):

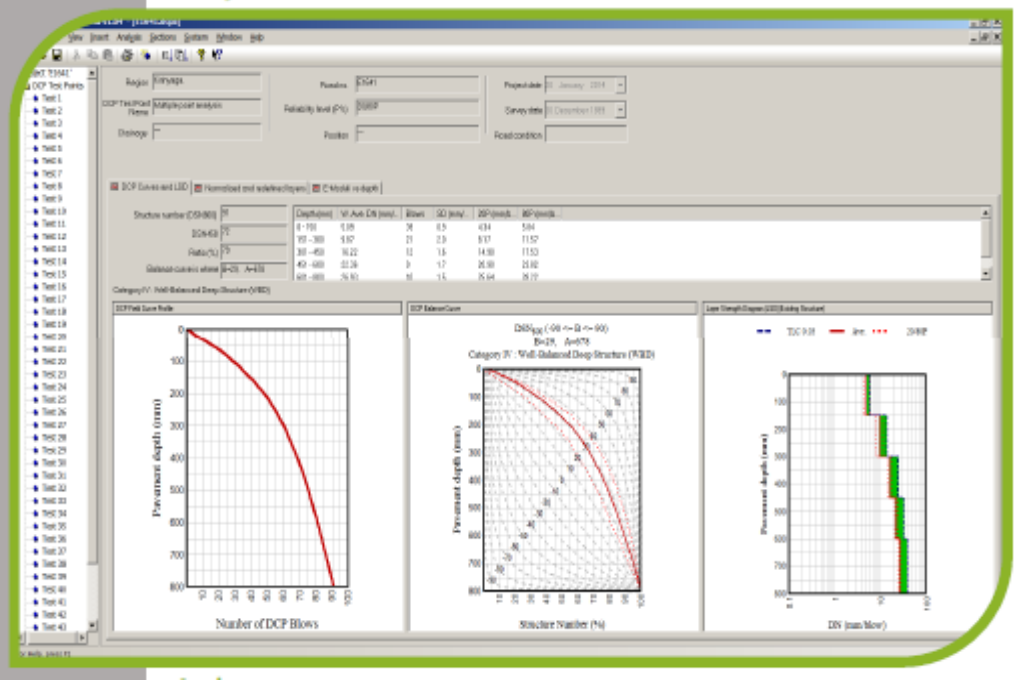
AfCAP
Africa Community Access Partnership

UKaid
from the British people

User Manual/Help file:

WinDCP AfCAP Beta v1.04

Project subtitle: Final Draft



CSIR
our future through science

Software Availability: Free from AfCAP..

Free AfCAP LVR-DCP Software Available From:

Home Page: http://research4cap.org
GoTo: Resources → Low Volume Roads DCP Software

Registration for LVR DCP Software and User Forum:
http://research4cap.org/SitePages/LVRDCPSoftware.aspx

Presentation Outline

- Background
- Dynamic Cone Penetrometer (DCP) Pavement Design Principles
- DCP Pavement Design Method
- AfCAP Low Volume Road (LVR) - DCP Pavement Software
- Summary & Conclusions

Summary of DCP Method-Strengths (1)

- 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.

Summary of DCP Method-Strengths (2)

- 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. *(Possibility for measuring every blow usually effective);*
- 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.

ReCAP
Research for Community Access Partnership

UKaid
from the British people

Thank You !

Free AfCAP LVR-DCP Software From:

Home Page: http://research4cap.org
GoTo: Resources → Low Volume Roads DCP Software

Registration for LVR DCP Software and User Forum:
http://research4cap.org/SitePages/LVRDCPSoftware.aspx

CSIR
our future through science

ReCAP
Research for Community Access Partnership

LVR-DCP-Software

Home
LVR Forum
LVR Members
Site Contents
EDIT LINKS

Download your copy of the LVR DCP Software

The AfCAP LVR DCP v1.00 Software and a software helpfile (SHF) are freely available for practitioners. Please follow the steps belo

Please verify your system meets with the requirements to be able to download and run the software:

- Supported operating systems: Windows 7, 8 and 10
- AFCAP LVR-DCP requires a computer with the following minimum capabilities:
- 32-bit (x86) or 64-bit (x64) processors
- Dual-core, 2-GHz or faster processor
- 2 GB of RAM
- File is 28Mb approx.

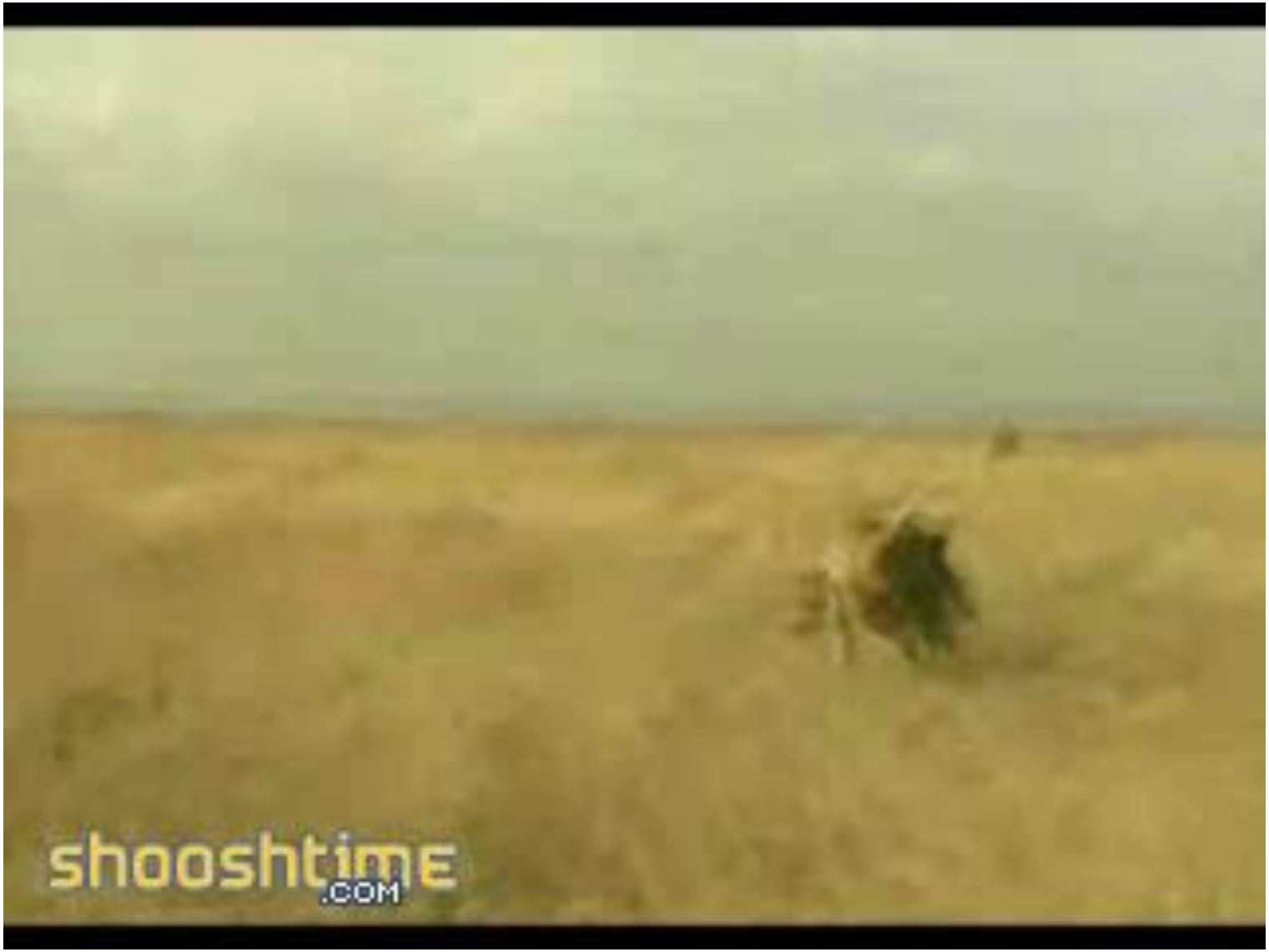
DOWNLOAD NOW

How do I decompress the files I download from your site?

Our files are compressed using WinZip and have the .zip file suffix. Users who download compressed files will have to decompres

Windows

Windows XP and later have a built-in decompression tool that decompresses .zip files. Users with earlier Windows versions may n


shooshtime
.com