

## **Introduction to the DCP Design Method for Low Volume Sealed Roads**

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## Purpose and Scope

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

## Presentation Outline

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

## Typical Design Methods

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

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

### BUT

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

The CBR test is notoriously inaccurate with low reproducibility.

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

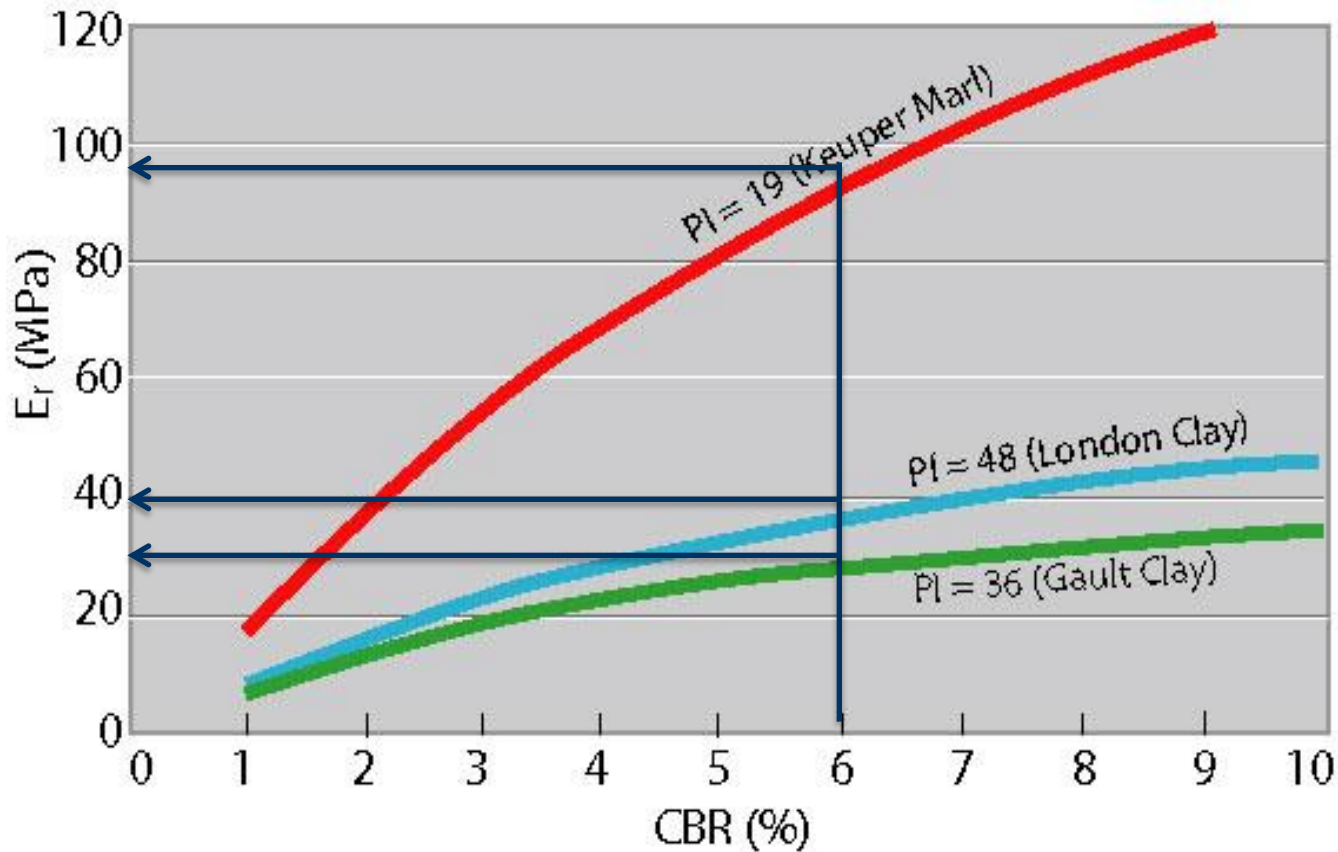
CBR	$\sigma$	95% confidence	Range
10	4	$\pm 8$	2 – 18
30	7	$\pm 14$	16 – 44
60	12	$\pm 24$	36 – 84
80?	16	$\pm 32$	58 – 122

## Accuracy of Common CBR Test

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

\* Lee, IK. White, W and Ingles, OG., 1983. Geotechnical Engineering. Pitman Books, Ltd., London.

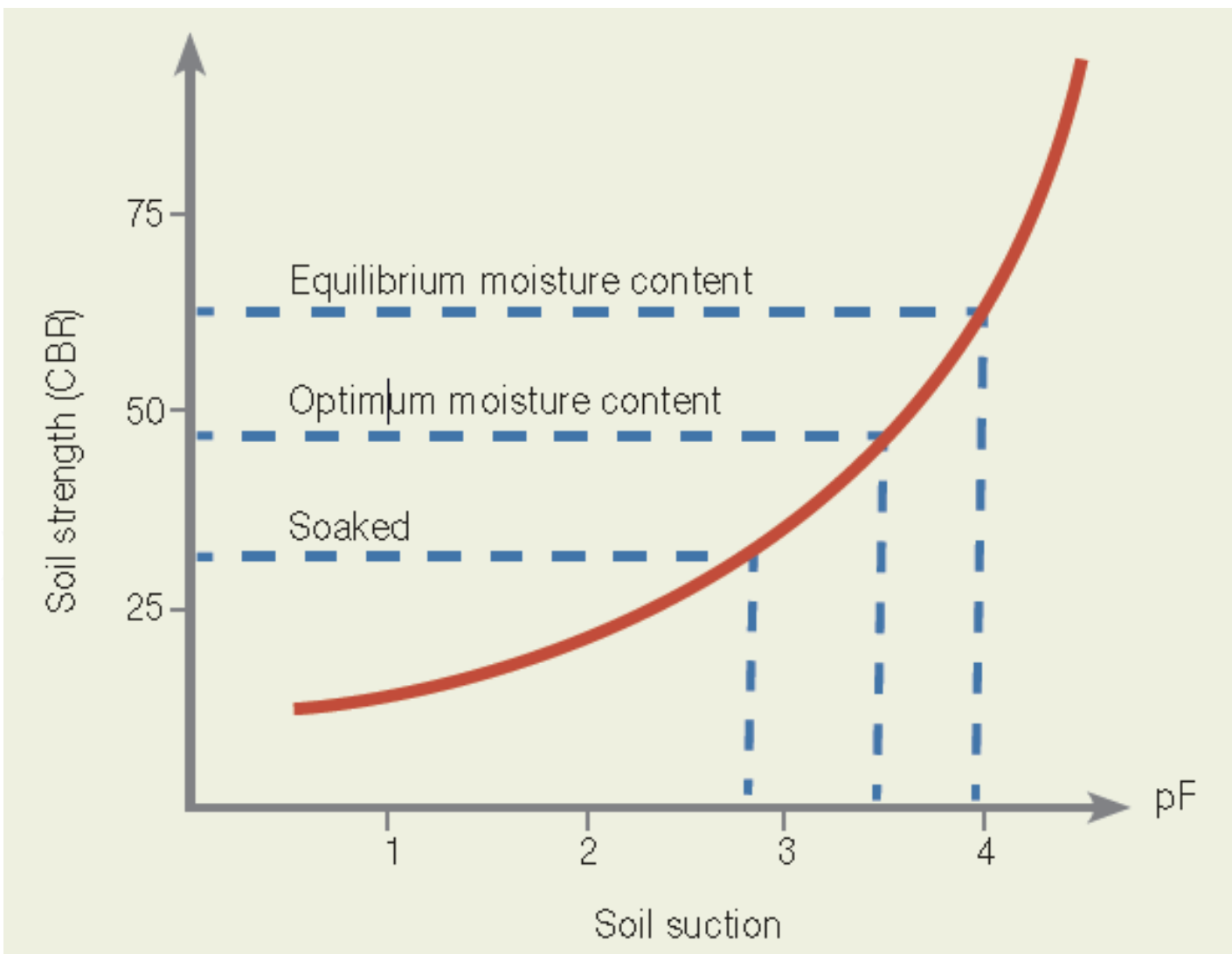
## CBR – Poor Correlation With Stiffness



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

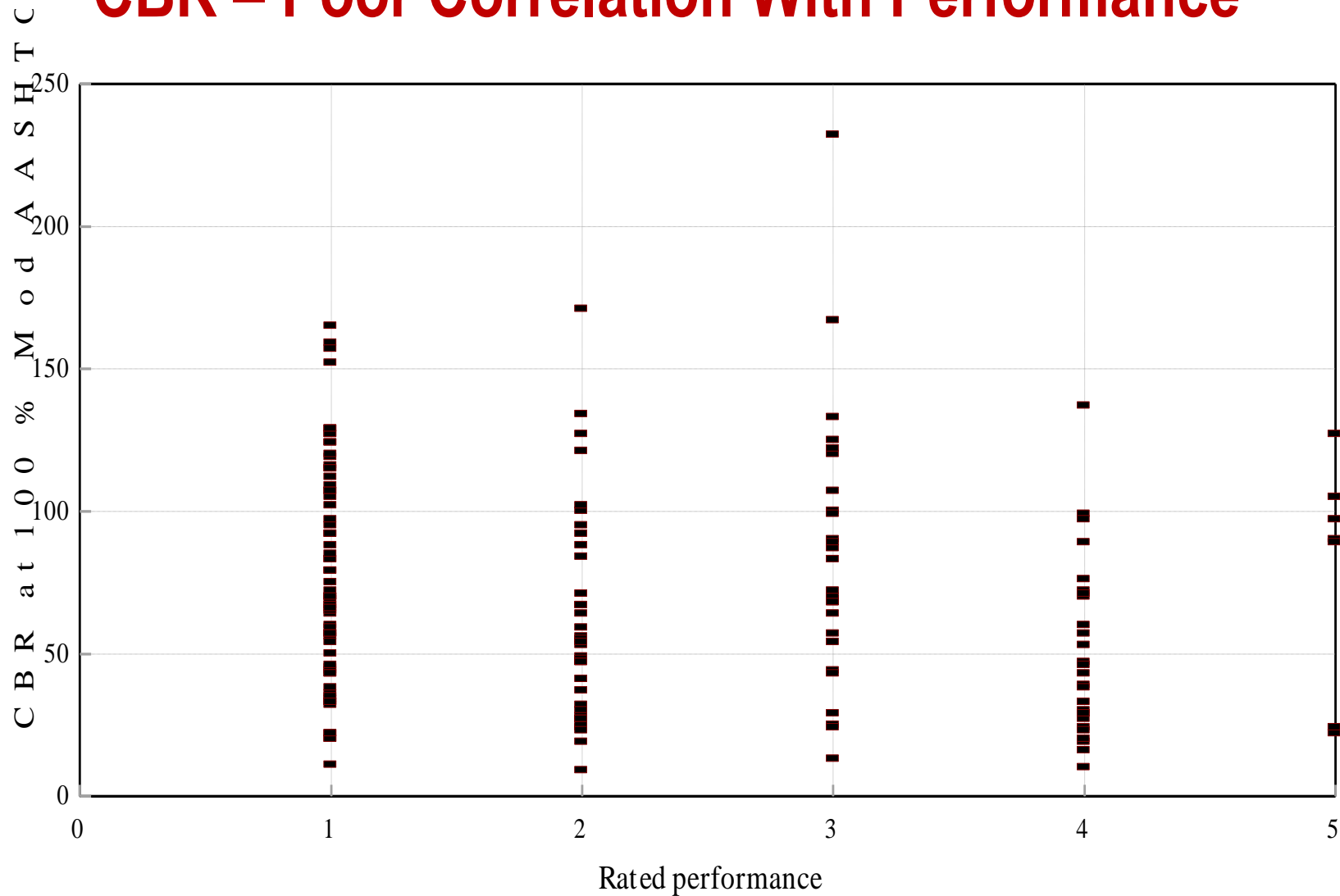
# AFCAP Is Soaked Strength Necessary ?

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

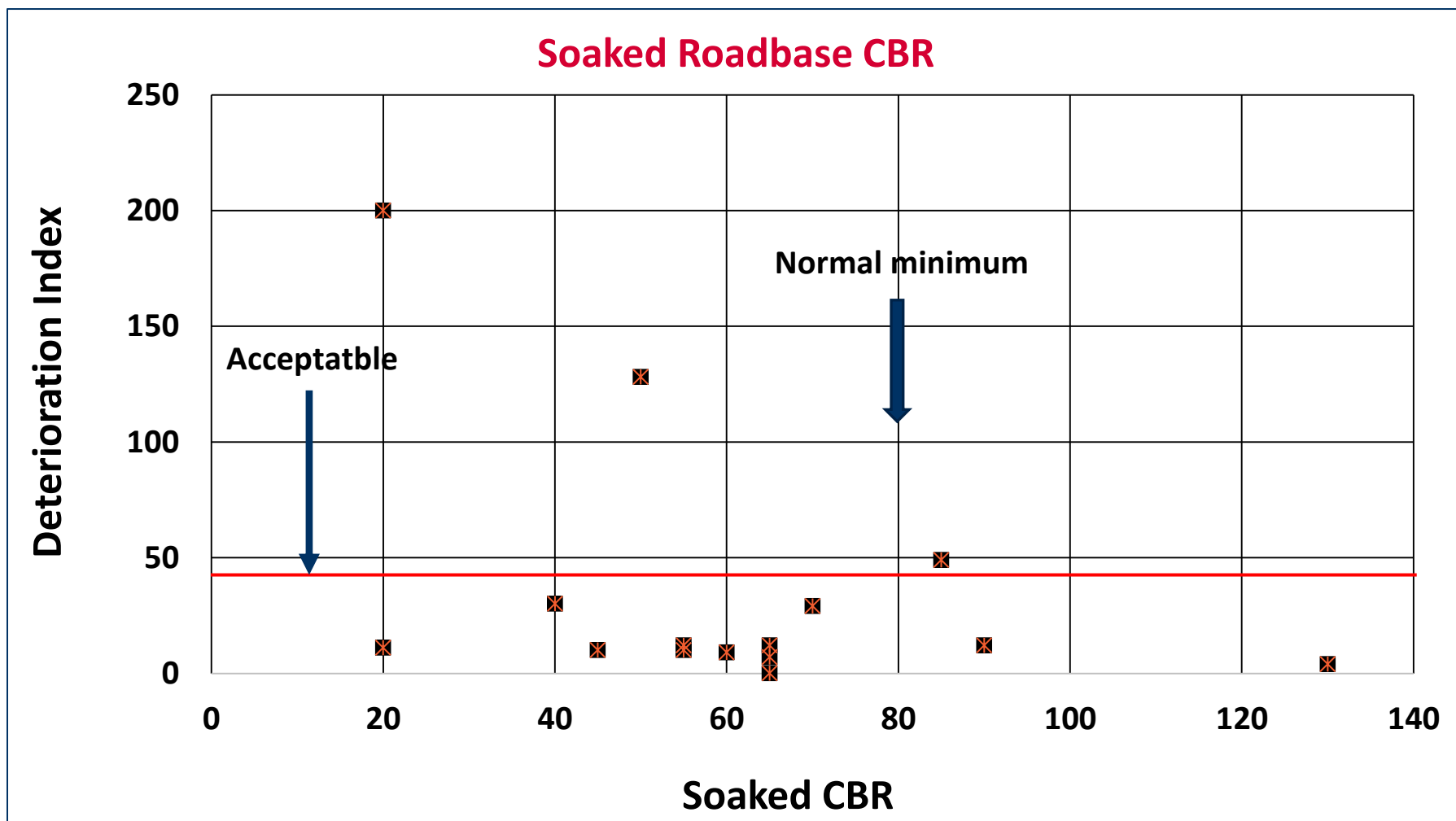


d (m)

## CBR – Poor Correlation With Performance



South African Low Volume Road Investigation (CSIR)



## Mozambique Back-Analysis Project

## 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

## Presentation Outline

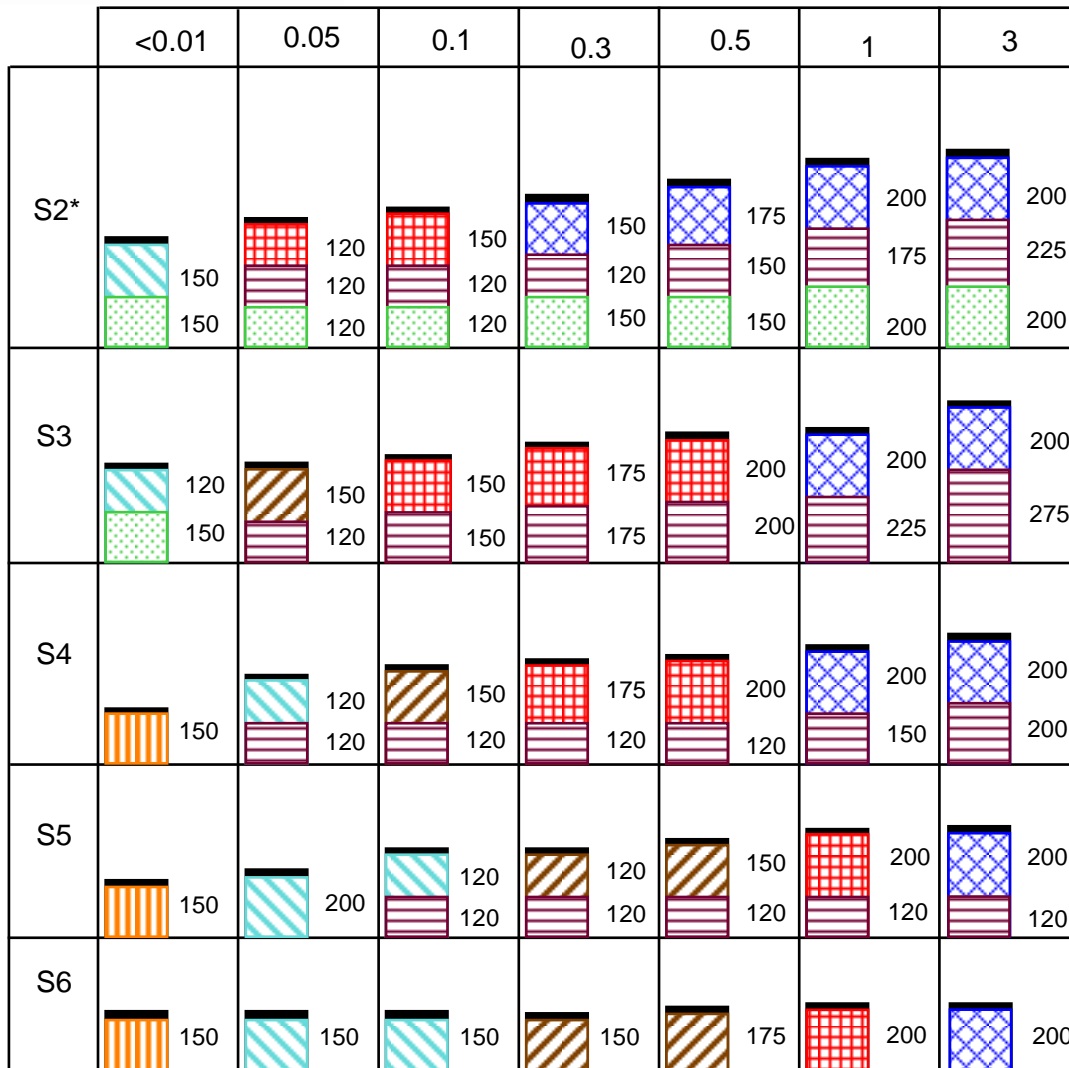
- Background
- **DCP Design Principles**
- DCP Design Method
- Summary and Conclusions

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

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

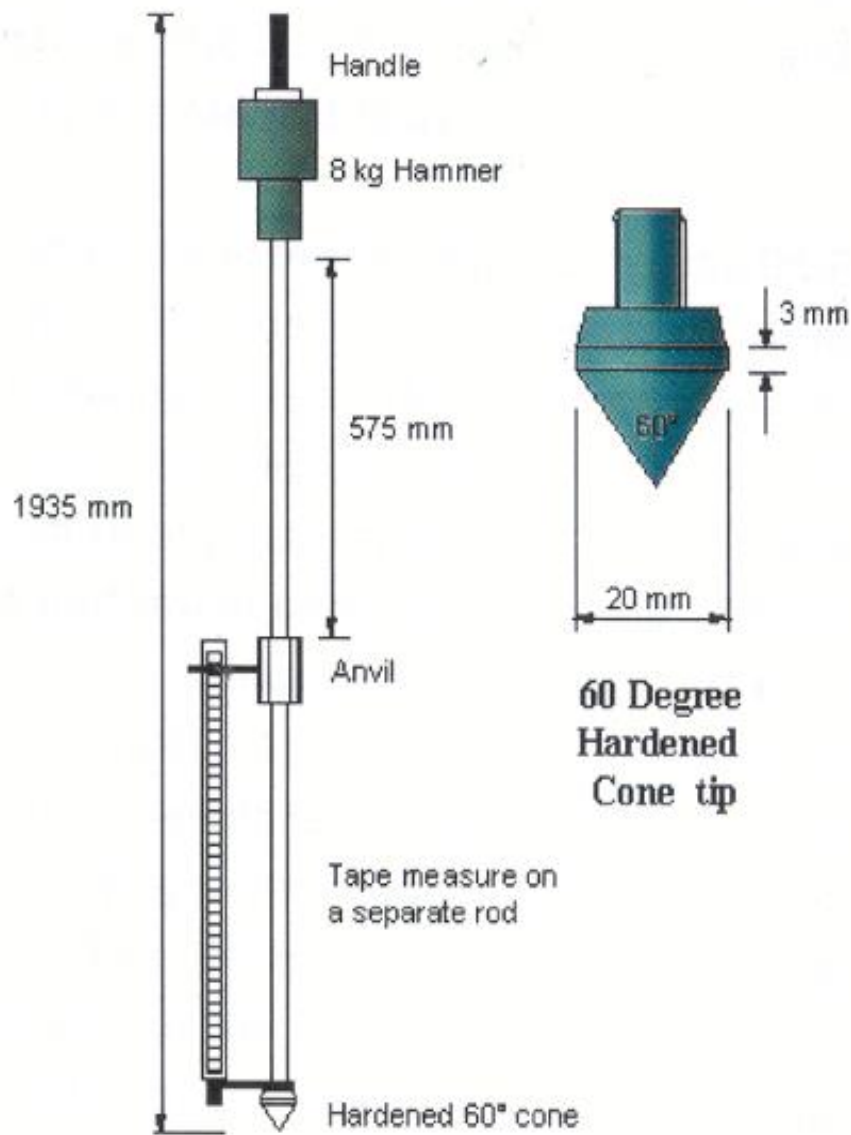
- Catalogue-based
  - DCP-CBR (TRL/SADC, CSIR)
  - DCP-DN (AFCAP)
    - ❖ AFCAP DCP Manual

# SADC/TRL DCP-CBR Pavement Design Catalogue



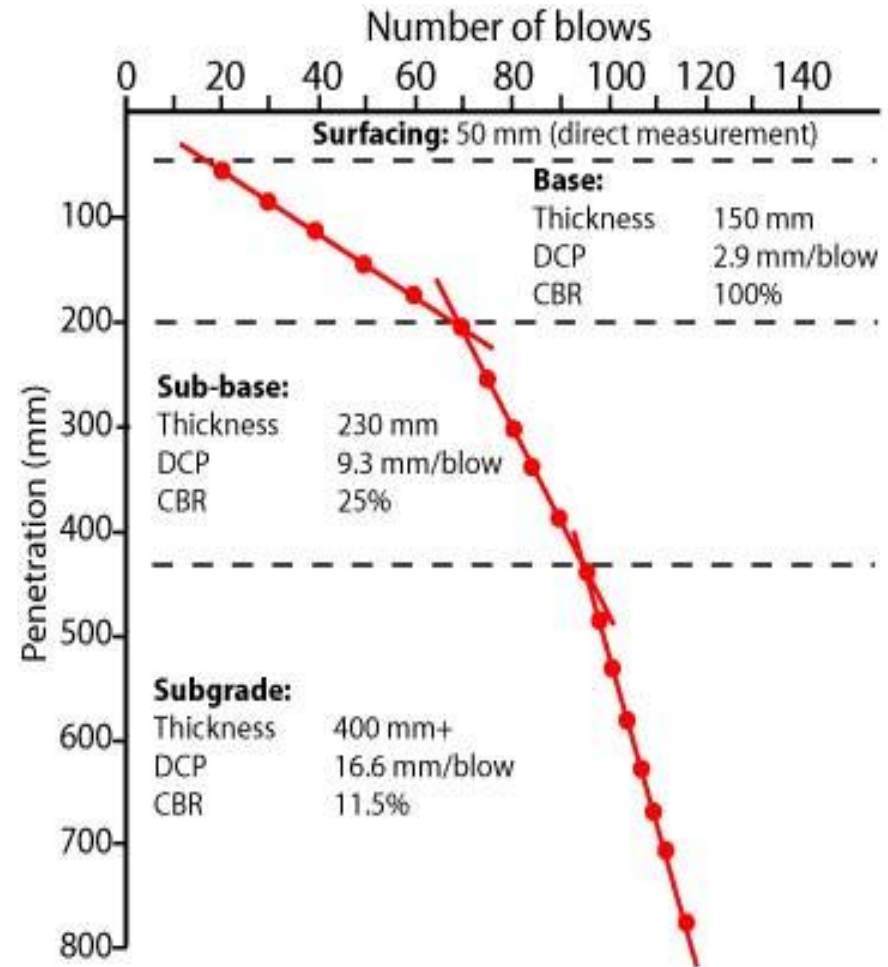
Note: \* Non-expansive subgrade

# AFCAP Dynamic Cone Penetrometer (DCP)



DCP test in process

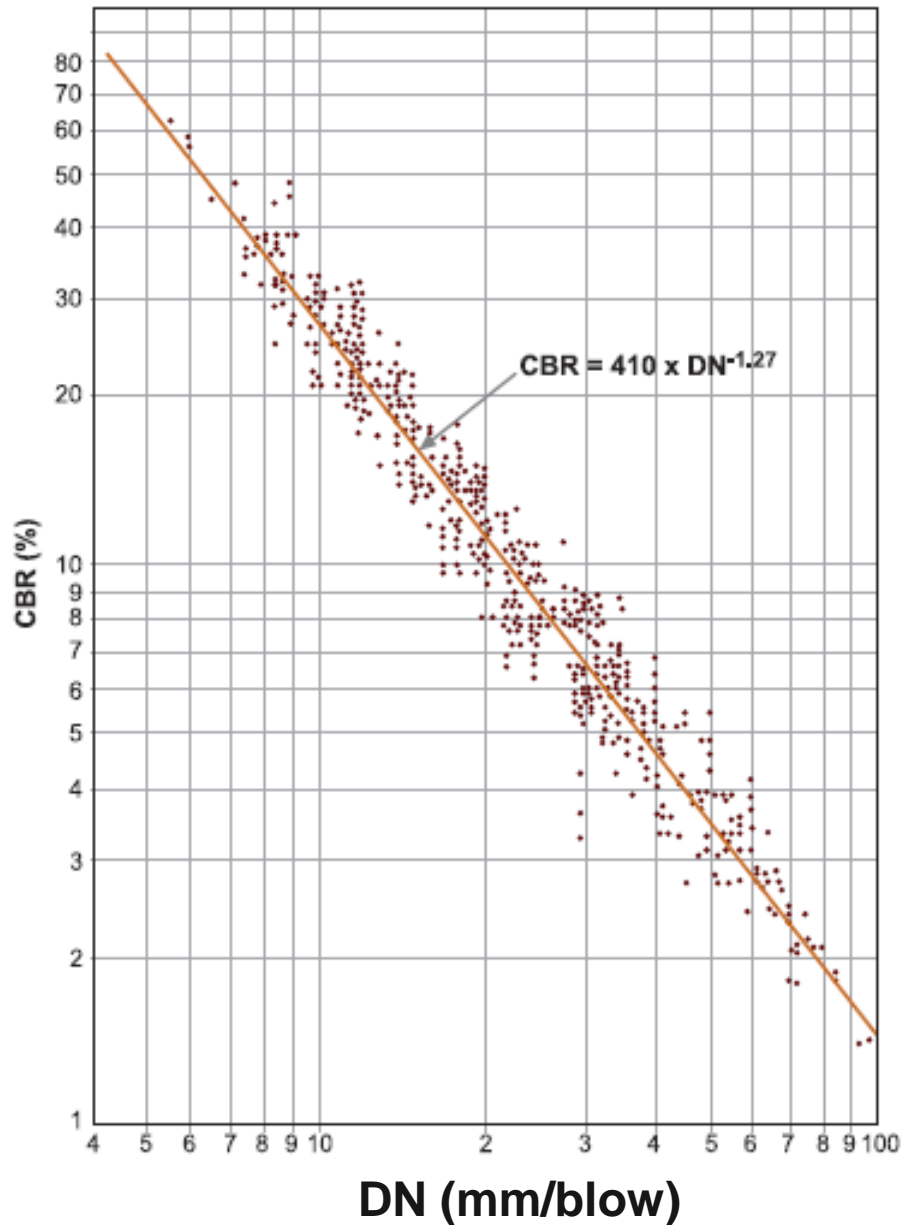
- Measures the weighted penetration per blow into a pavement through each of the different pavement layers
- Rate of penetration is a function of the in situ shear strength of the material at the in situ moisture content and density of the pavement layers at the time of testing.
- Profile in depth of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



- Extensive DCP testing was carried out in conjunction with Heavy Vehicle Simulator (HVS) testing of various roads.
  - Allowed further correlations and developments, e.g. relationships between actual road performance and DCP results



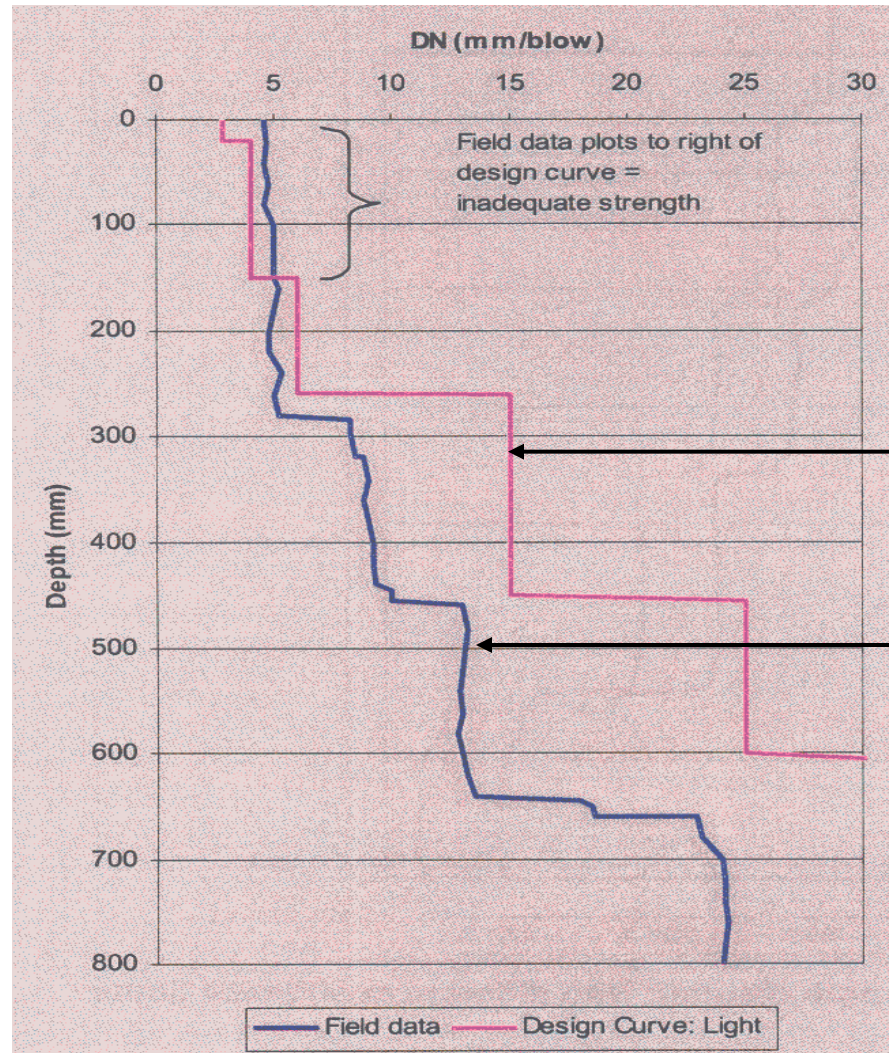
# Relationship between DN and CBR



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

- 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 sytrench profile

# AFCAP Integration of In Situ and Required Strength Profiles



Required strength profile

In situ strength profile

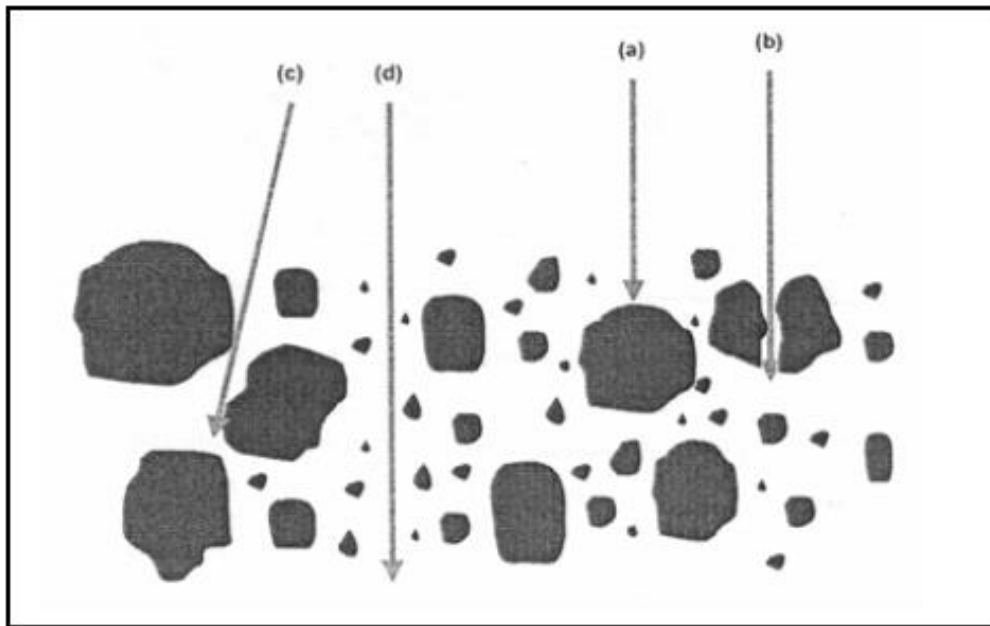
Traffic Class E80 x 10 <sup>6</sup>	LE 0.01 0.003 – 0.010	LE 0.03 0.010 – 0.030	LE 0.1 0.030 – 0.100	LE 0.3 0.100 – 0.300	LE 0.7 0.300–0.700	LE 1.0 0.700 – 1.0
0- 150mm Base ≥ 98% MAASHTO	DN ≤ 8	DN ≤ 5.9	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.6	DN ≤ 2.5
150-300 mm Subbase ≥ 95% MAASHTO	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	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

## 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



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;

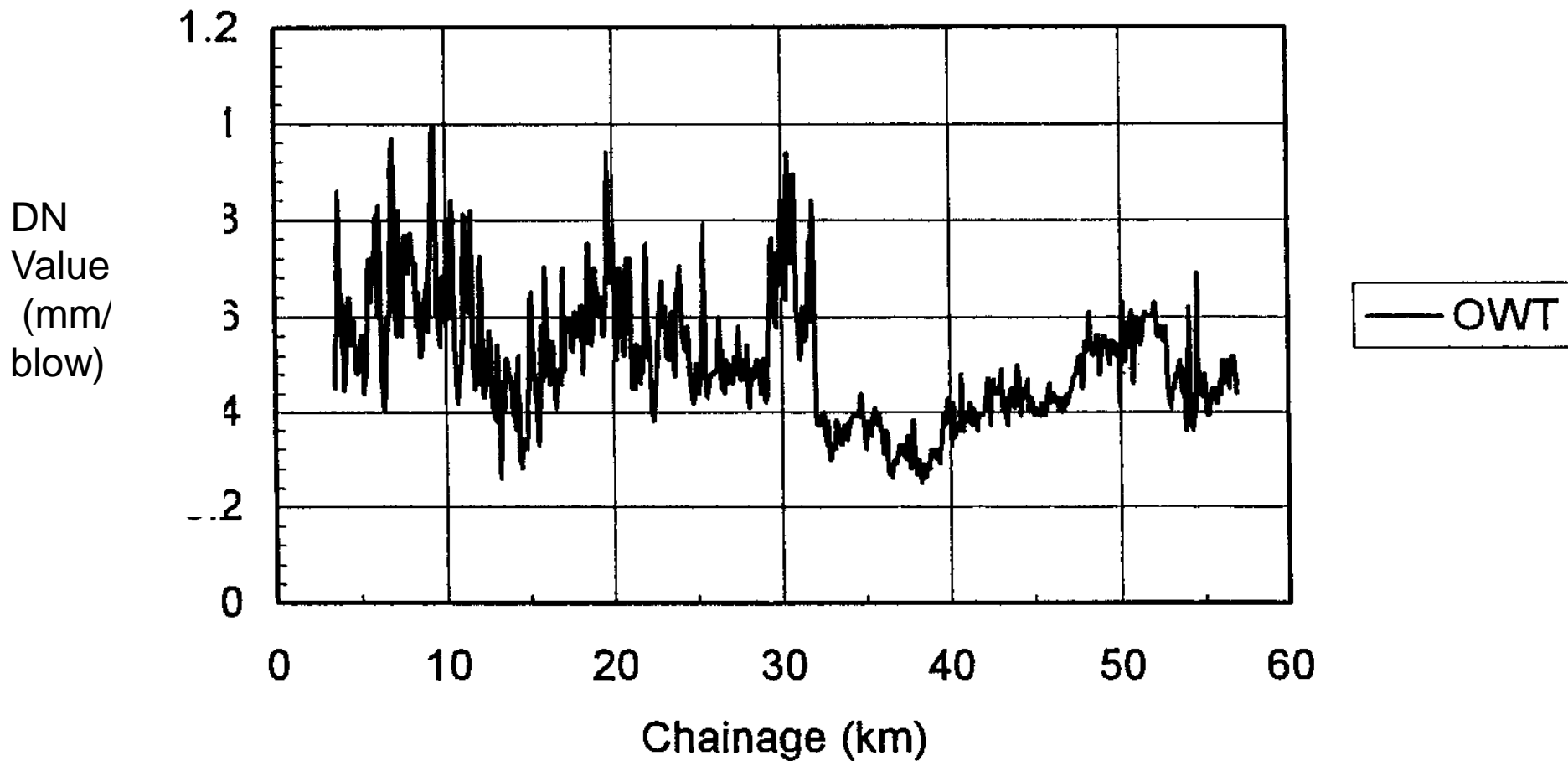
(c) cone tries to push stone aside. Result is high because of side friction generated on cone shaft;

(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.

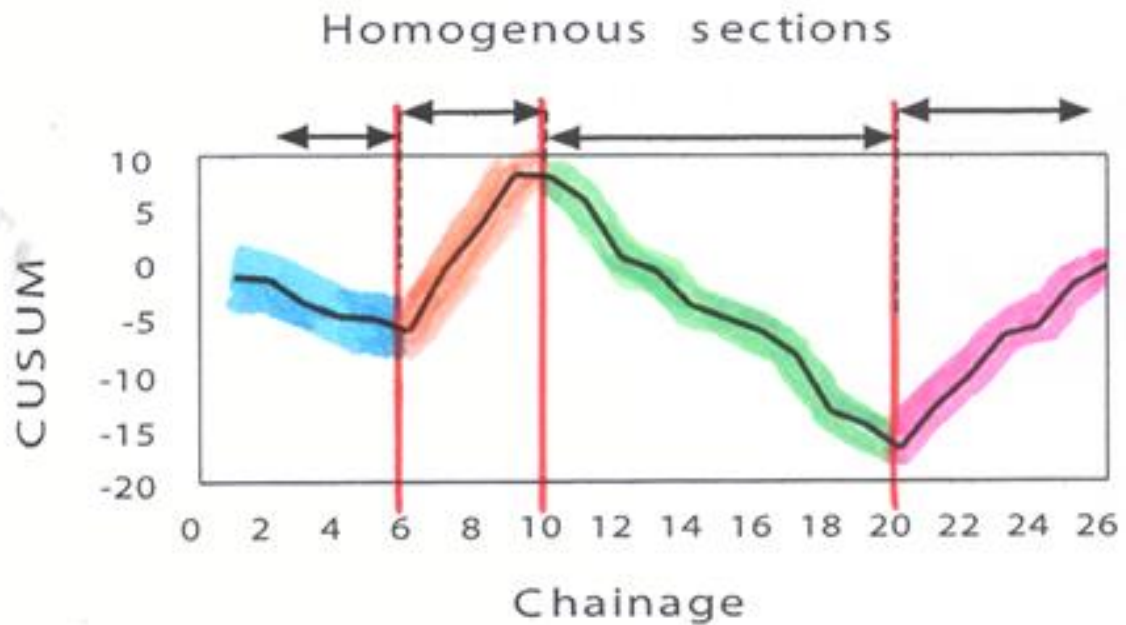
## Step 6 – Obtain DN Values Along Road



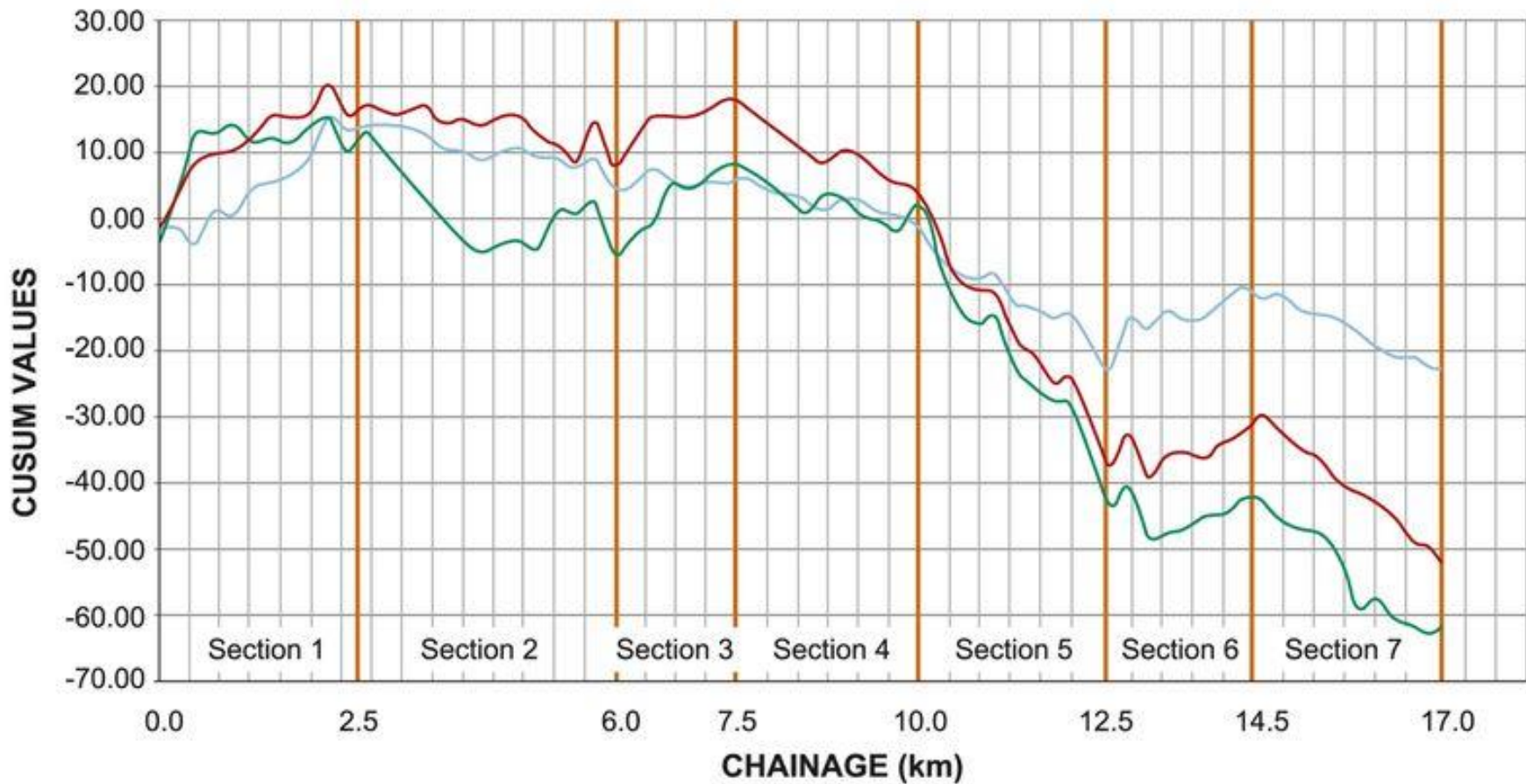
DCP provides a good “picture” of in situ ground conditions

# AFCAP Step 7 – Determine Uniform Sections

Chainage (Km)	B Measured DCP (DN Value -mm/blow)	C 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
<b>Average: A = 12.6</b>			



# AFCAP Step 7 – Determine Uniform Sections



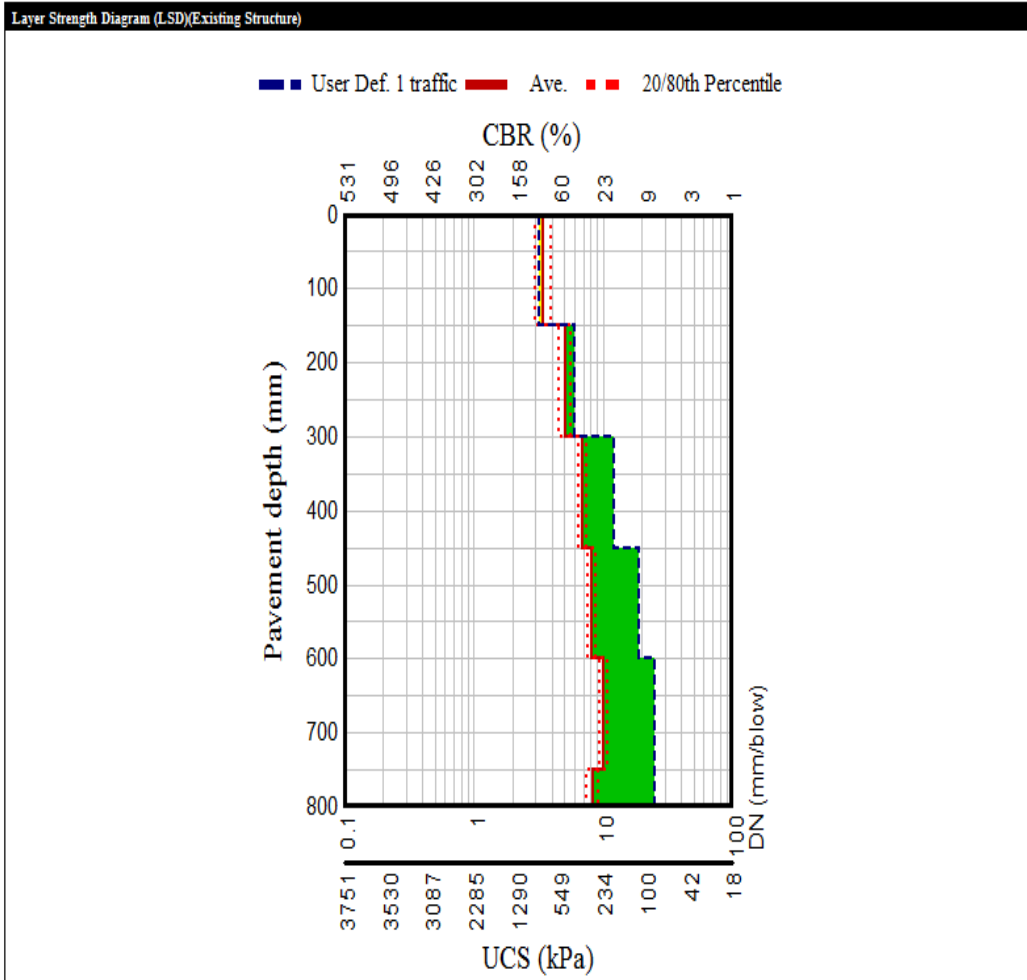
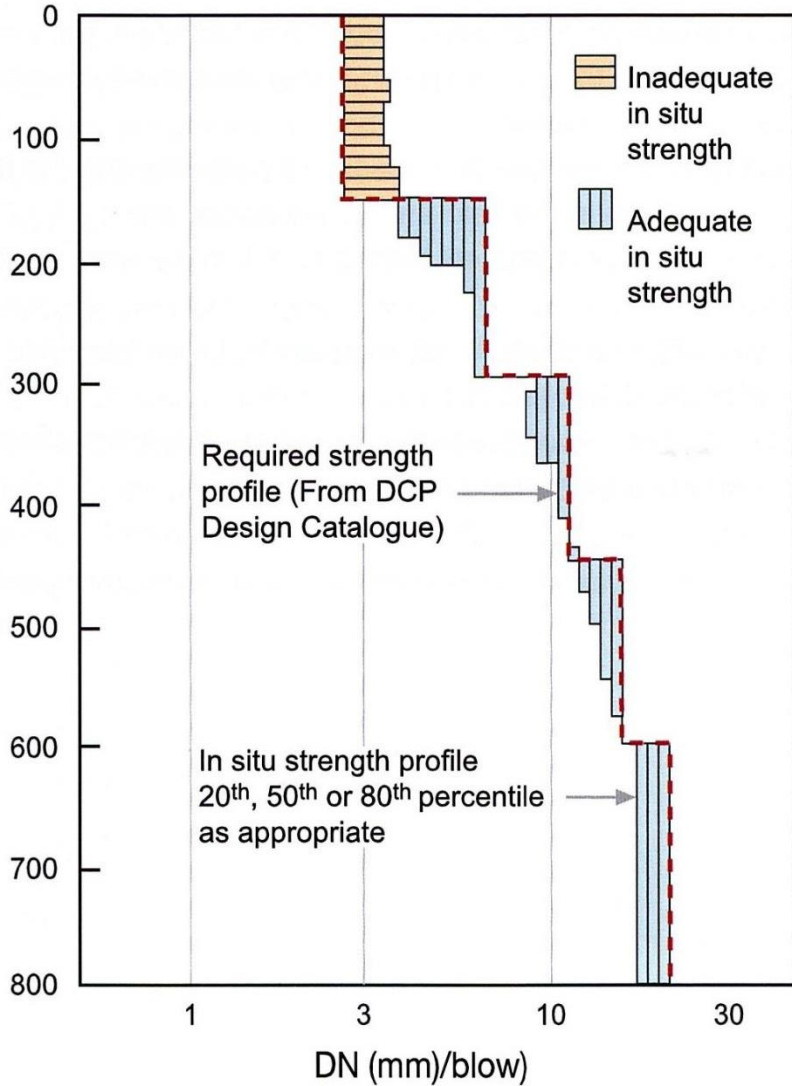
- Base
- Subbase
- Subgrade



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



Computer printout

# Determine Upgrading Requirements (Cont'd)

- **Reworking the existing layer**

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

- **Replacing the existing layer**

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

- **Augmenting the existing layer**

- if material quality (DN value) is adequate but the layer thickness is inadequate, then imported material of appropriate quality will need to be imported to make up required thickness prior to compaction.

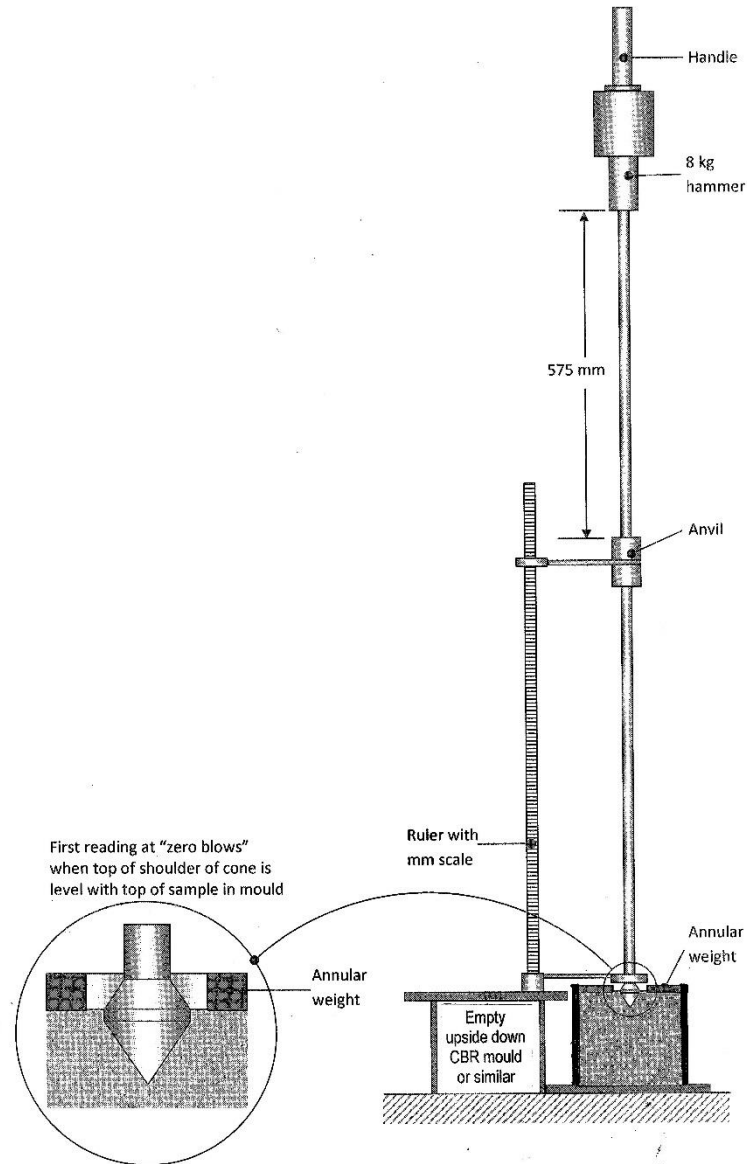
# Material Selection

- **DN value serves as criterion for selecting materials to be used in upper/base layer of LVSR pavement**
- **Provided design DN value is achieved, then in service performance indirectly takes account of actual grading and plasticity at given moisture and density which do not need to be separately specified.**
  - **DN value provides is a composite measure of materials resistance to penetration (= shear strength) at given moisture and density and is effected by material grading and plasticity.**

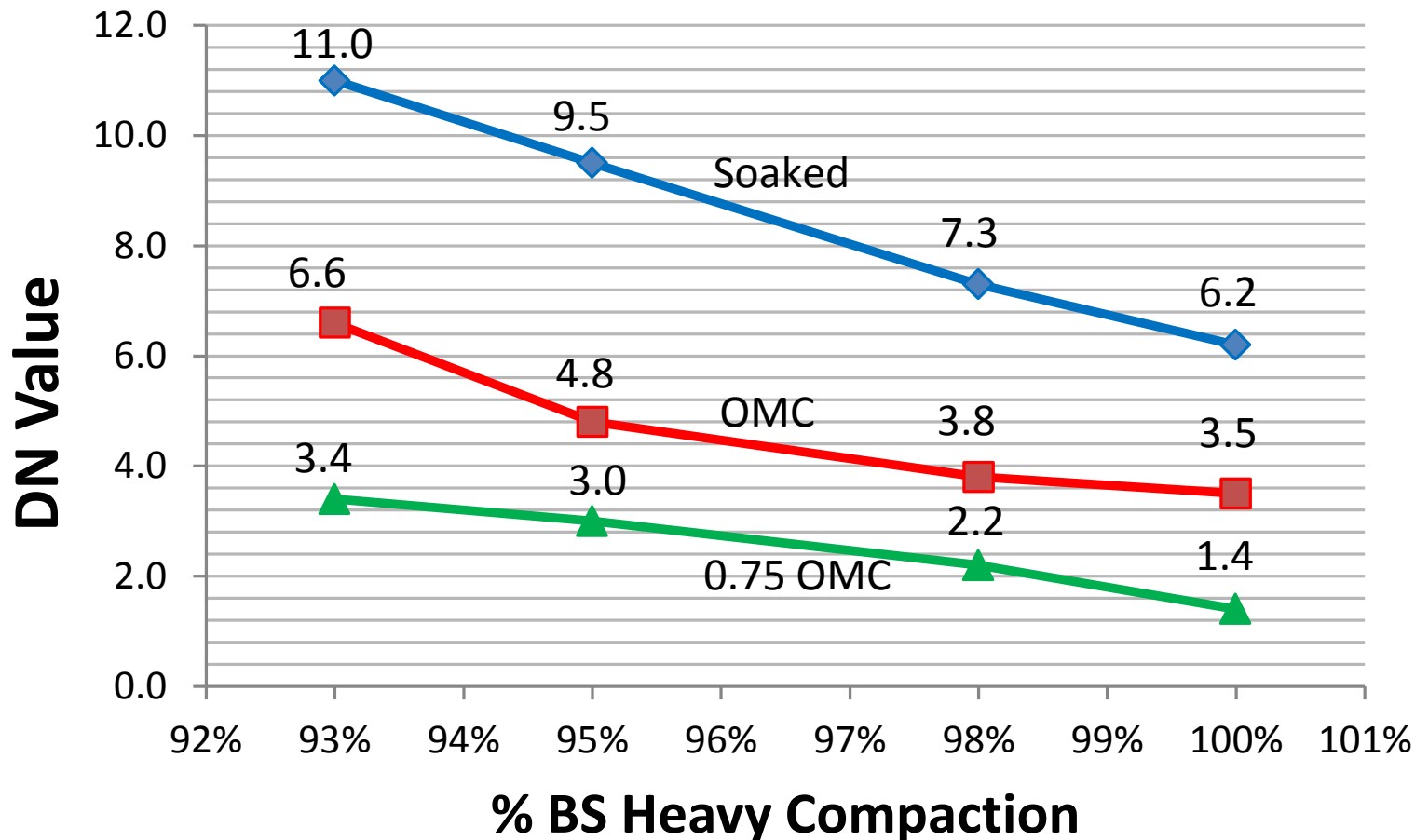
$DN = h/r$  where:

$h$  = depth of  
CBR mould

$r$  = total number  
of blows to  
reach depth  $h$



## DN at varying MC and % compaction



# AFCAP Examples of DCP Designed Roads

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



Road D379 Kiambu, Kenya (after 2 years)



- 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 existing 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**