5th Africa Transportation Technology Transfer (T2) Conference
Arusha, Tanzania, 21-25 November 2011

Design of Low Volume Roads

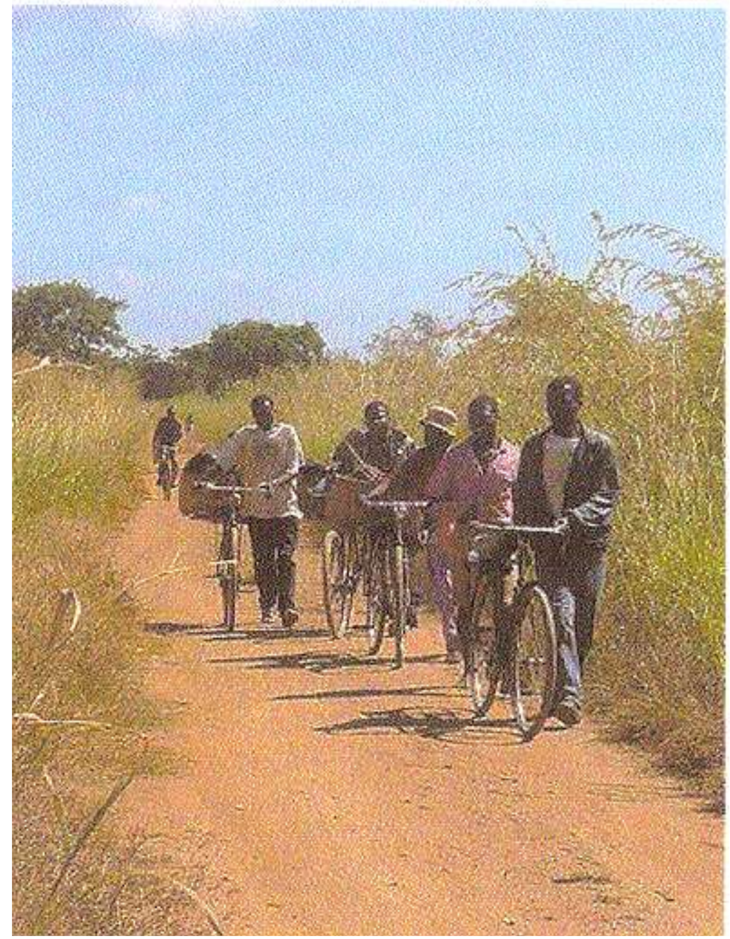
AFCAP Workshop on Rural Accessibility and Mobility

Mike Pinard
AFCAP Consultant

Outline of Presentation

- General Introduction
- Engineered Earth Roads
- Gravel Roads
- Low Volume Sealed Roads
- Performance Review of Malawi Low Volume Sealed Roads
- DCP Method of Pavement Design

Typical Means of Transport in Rural Areas



Lack of Reliable Access

Adverse impact on mobility

Lack of Reliable Access

Short sections of road in poor condition can benefit significantly from spot improvement works – attention to drainage.

The Message

Poverty is linked to poor access

- **Rural Economic and Social development in Africa needs commercial, educational, health and infrastructure initiatives that rely on GOOD PERMANENT ACCESS.**

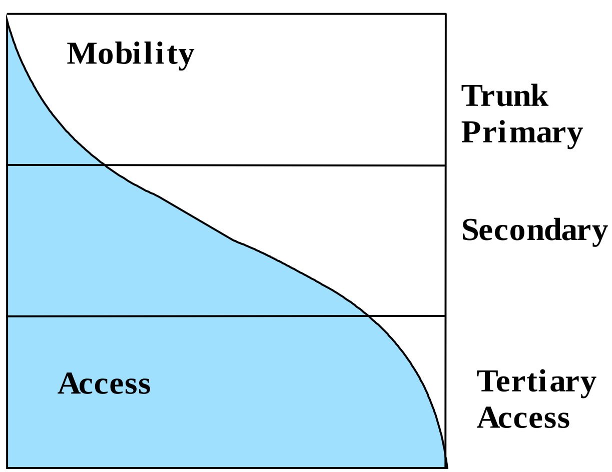
- **Unfortunately, poor access for millions in rural communities limits the effectiveness of these initiatives, because of:**
  - **unreliable travel or impassability, especially in the rains,**
  - **high unit transport costs for goods, services & people.**

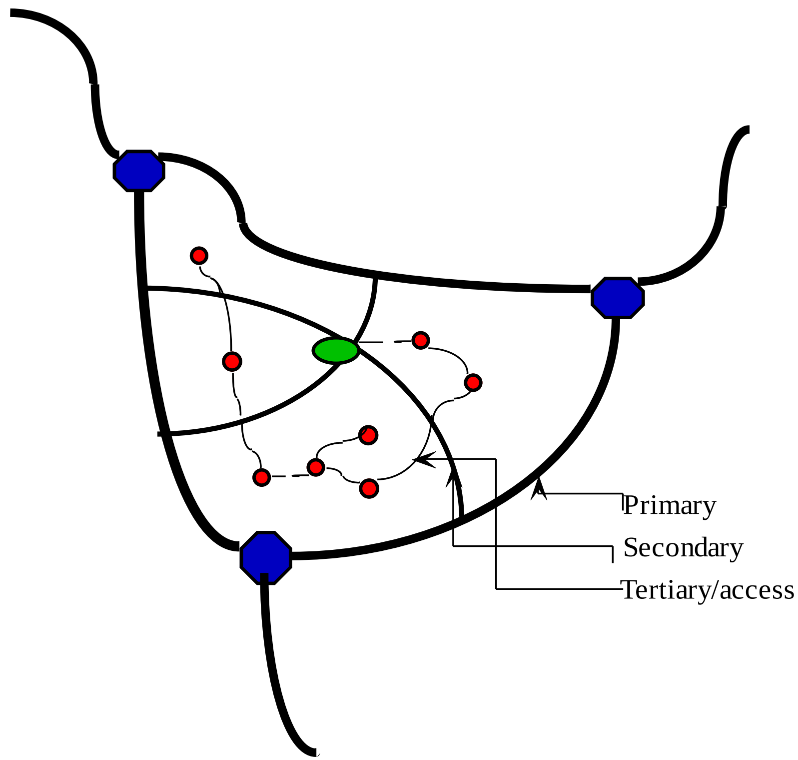
- ***Investment is discouraged by poor access.***
- ***Critical need to provide more reliable access in a more sustainable and affordable manner***

Definition of Low Volume Roads

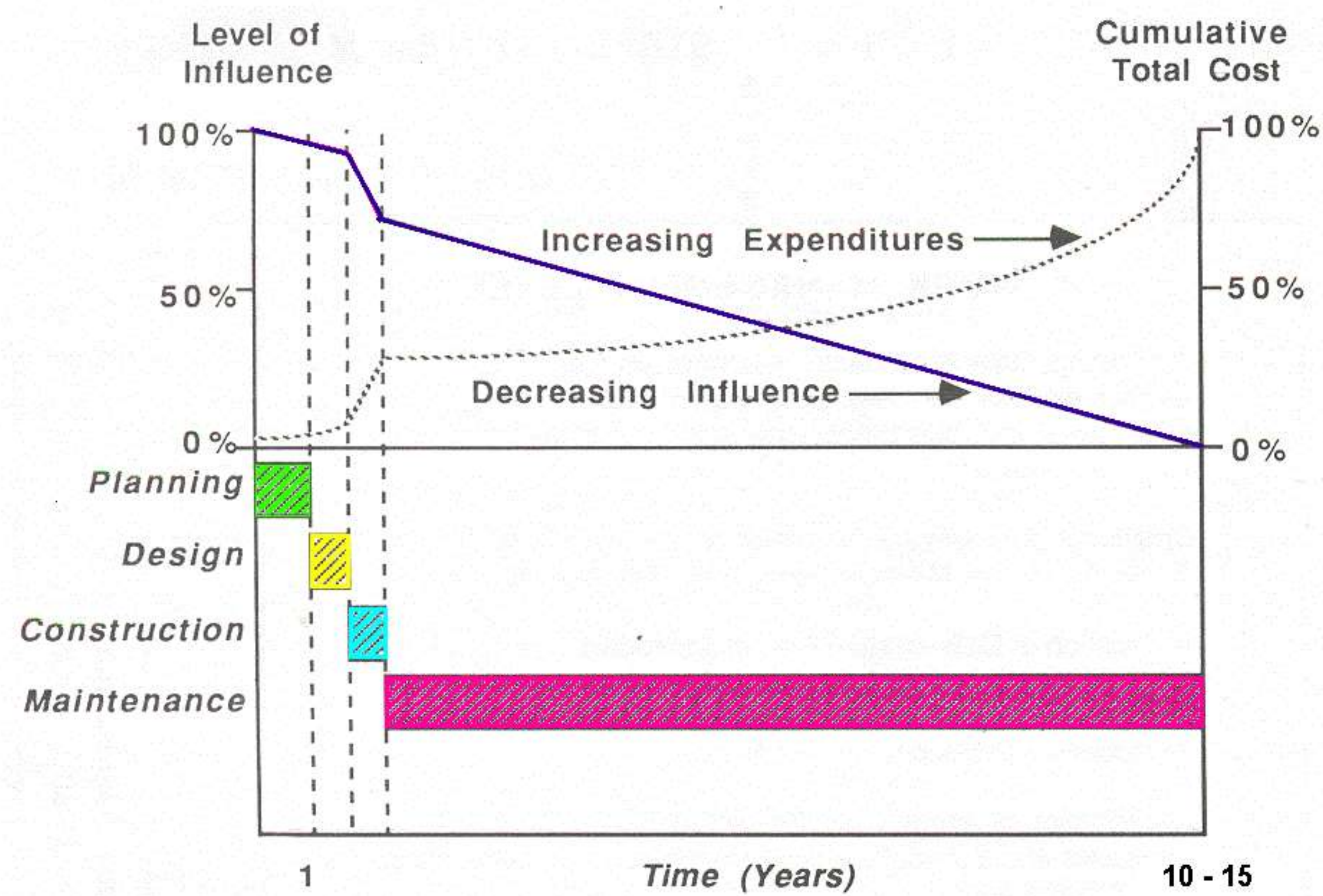
- Many kinds of low volume roads serving different functions – may be primary, secondary or tertiary/access and may fulfill an access or mobility function.

- One characteristic in general – they all carry relatively low volumes of traffic – typically less than 200 vpd or 1.0 MESA



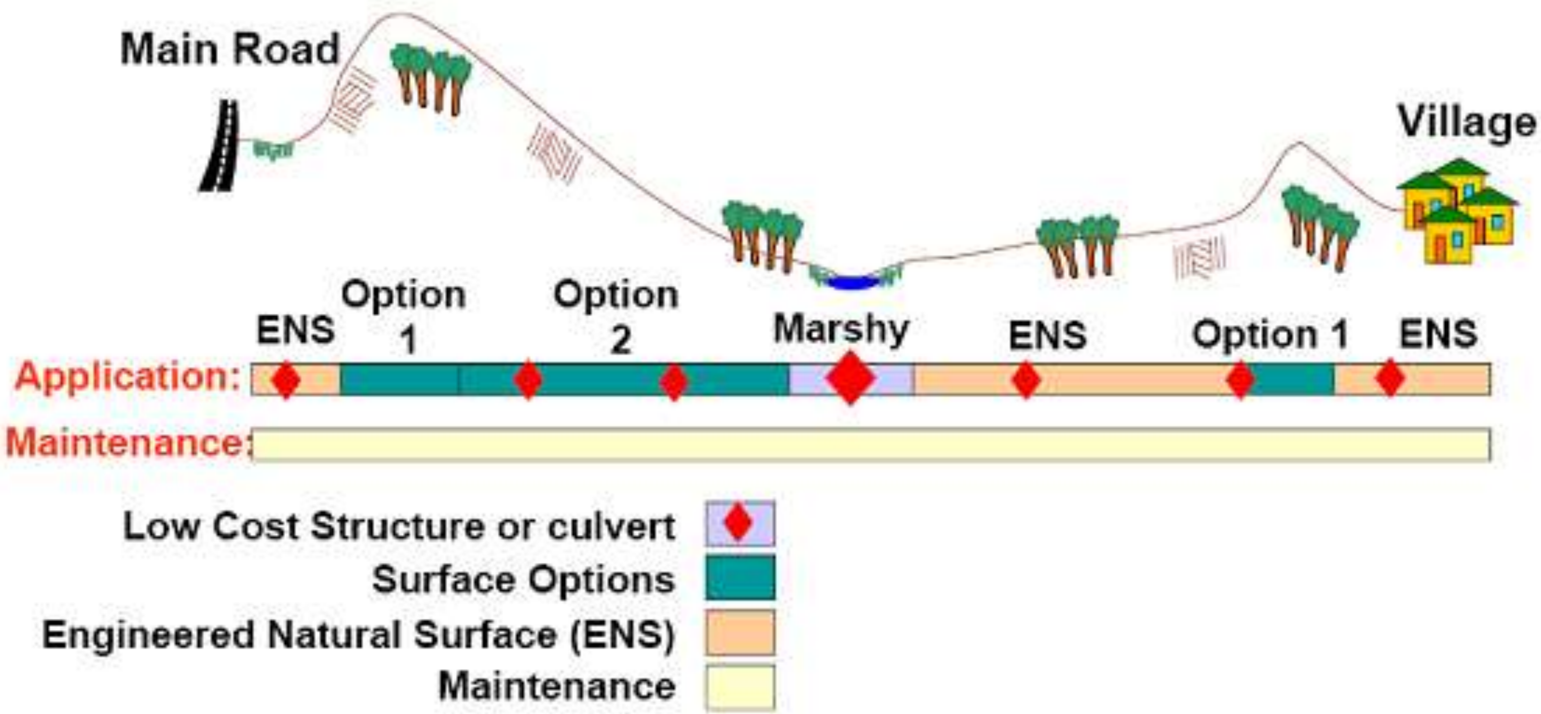


Main components of LVSR provision



Influence level of LVSR components on total cost

Targeted Intervention Approach



Environmentally optimised, context sensitive design

Using Local Materials

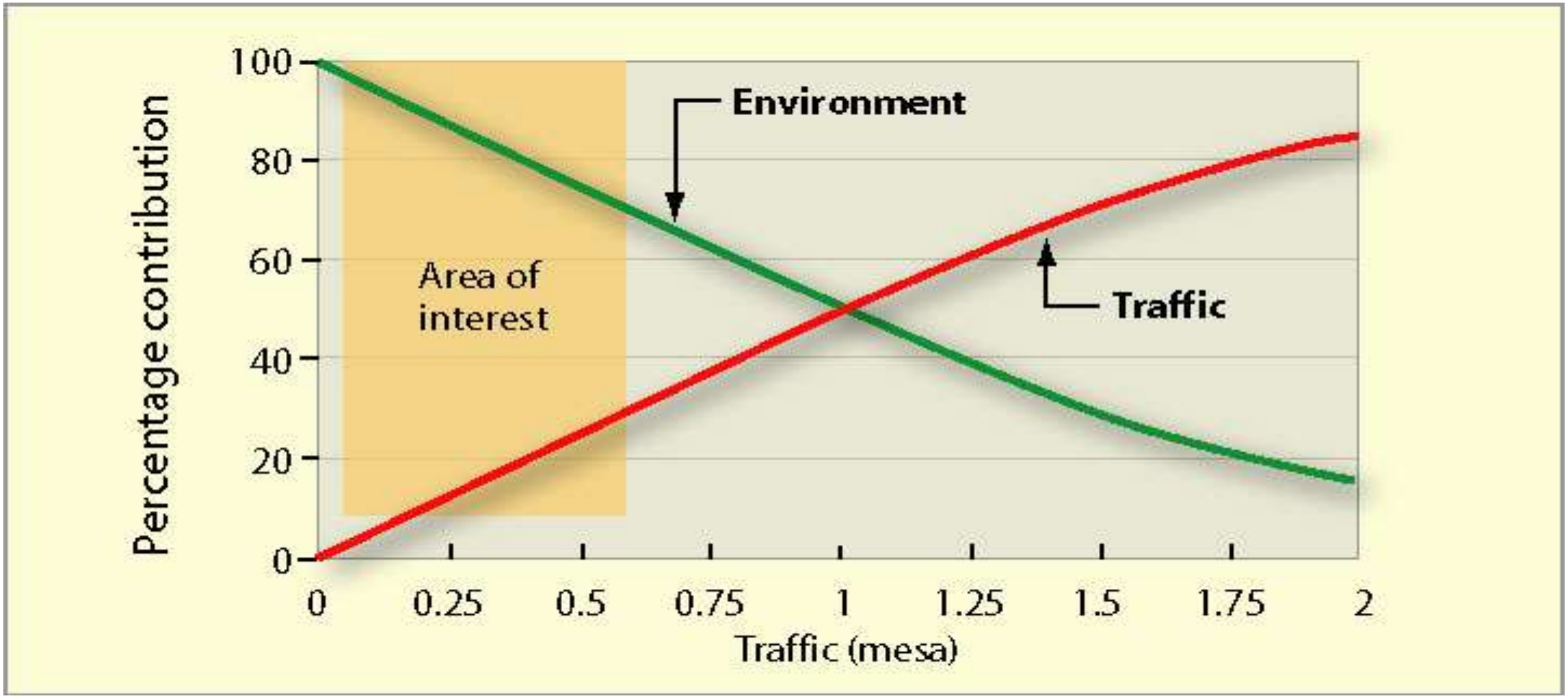
" The art of the roads engineer consists for a good part in utilising appropriate specifications that will make possible the use of materials he finds in the vicinity of the road works.

Unfortunately, force of habit, inadequate specifications and lack of initiative have suppressed the use of local matereials and innovative construction technologies"

➔Consider materials' "fitness for purpose"

➔Make specification fit materials rather than materials fit specification

LVR Performance w.r.t Traffic and Environment



- Most design methods cater for relatively high volumes of traffic, typically > of 0.5 MESA over a 10–15 year design life with attention focused on load-associated distress.
- Most LVRs carry < 0.50 million ESAs over their design life so priority attention should be focused on ameliorating effects of the environment, particularly rainfall and temperature, on their performance

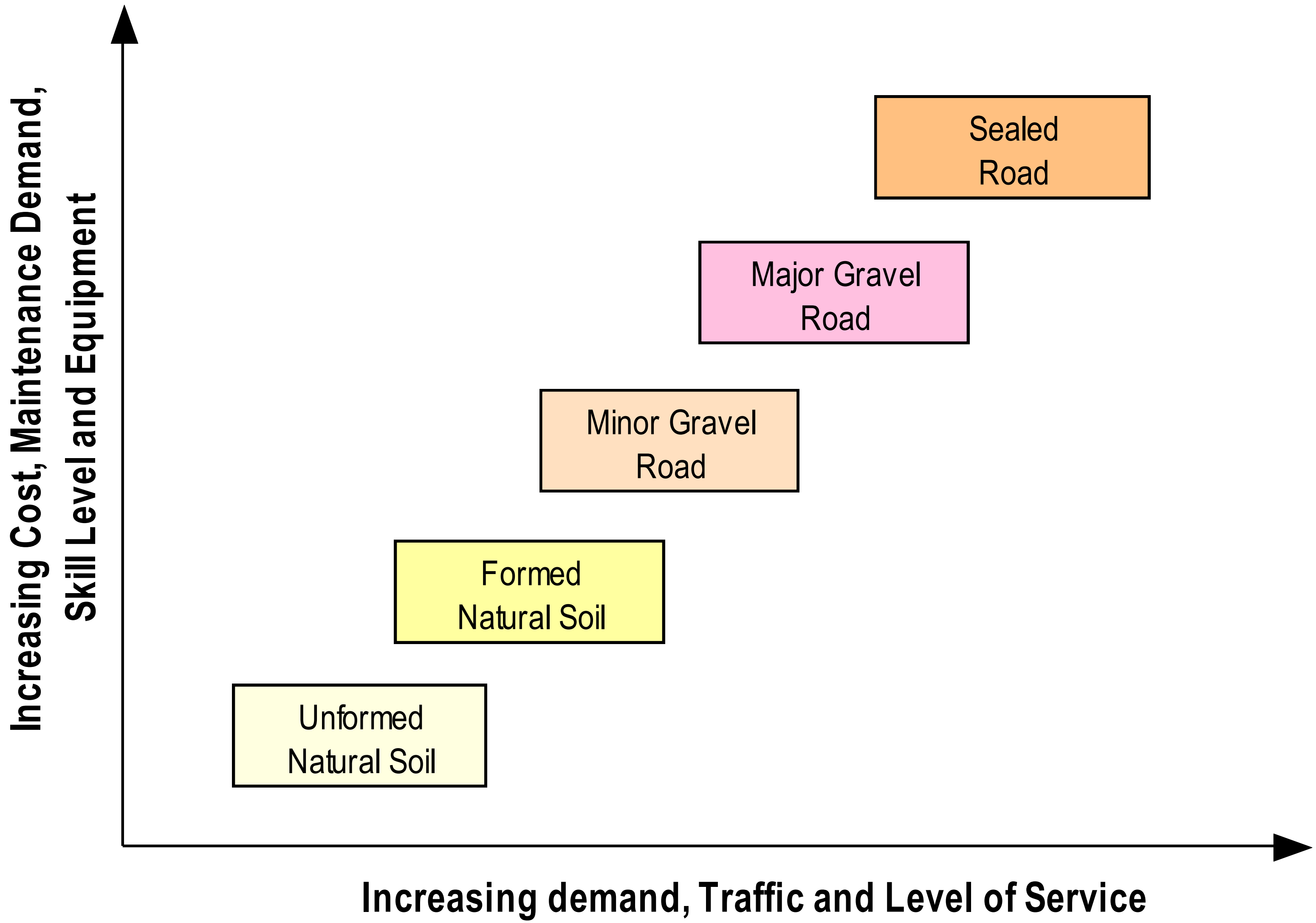
Guiding Philosophy

The successful engineering of a low volume road (earth, gravel, sealed) requires ingenuity, imagination and innovation. It entails "working with nature" and using locally available, non-standard materials and other resources in an optimal and environmentally sustainable manner.

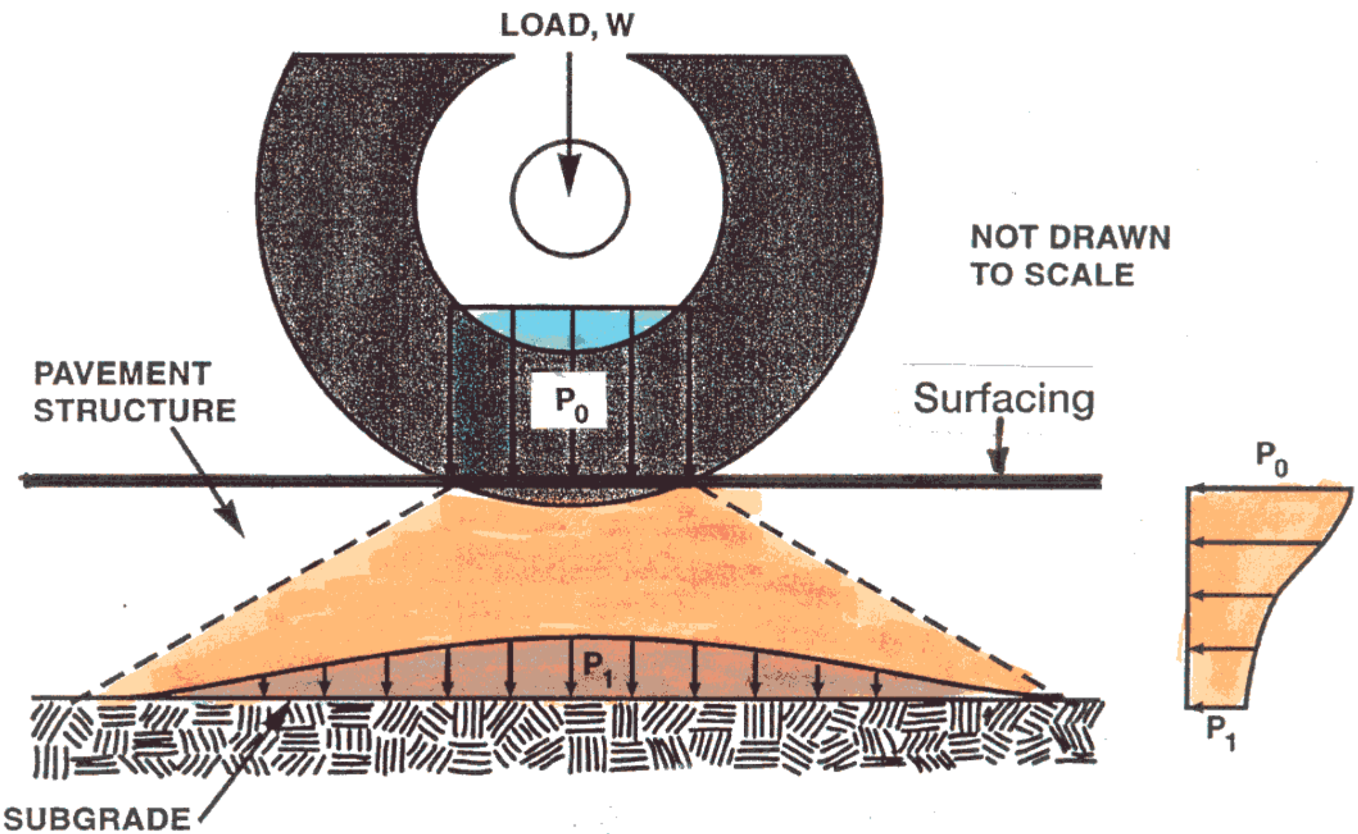
It will rely on planning, design, construction and maintenance techniques that maximize the involvement of local communities and contractors.

When properly engineered to an appropriate standard, a LVR will reduce transport costs and facilitate socio-economic growth and development and reduce poverty in the African region.

Upgrading steps of a typical LVR

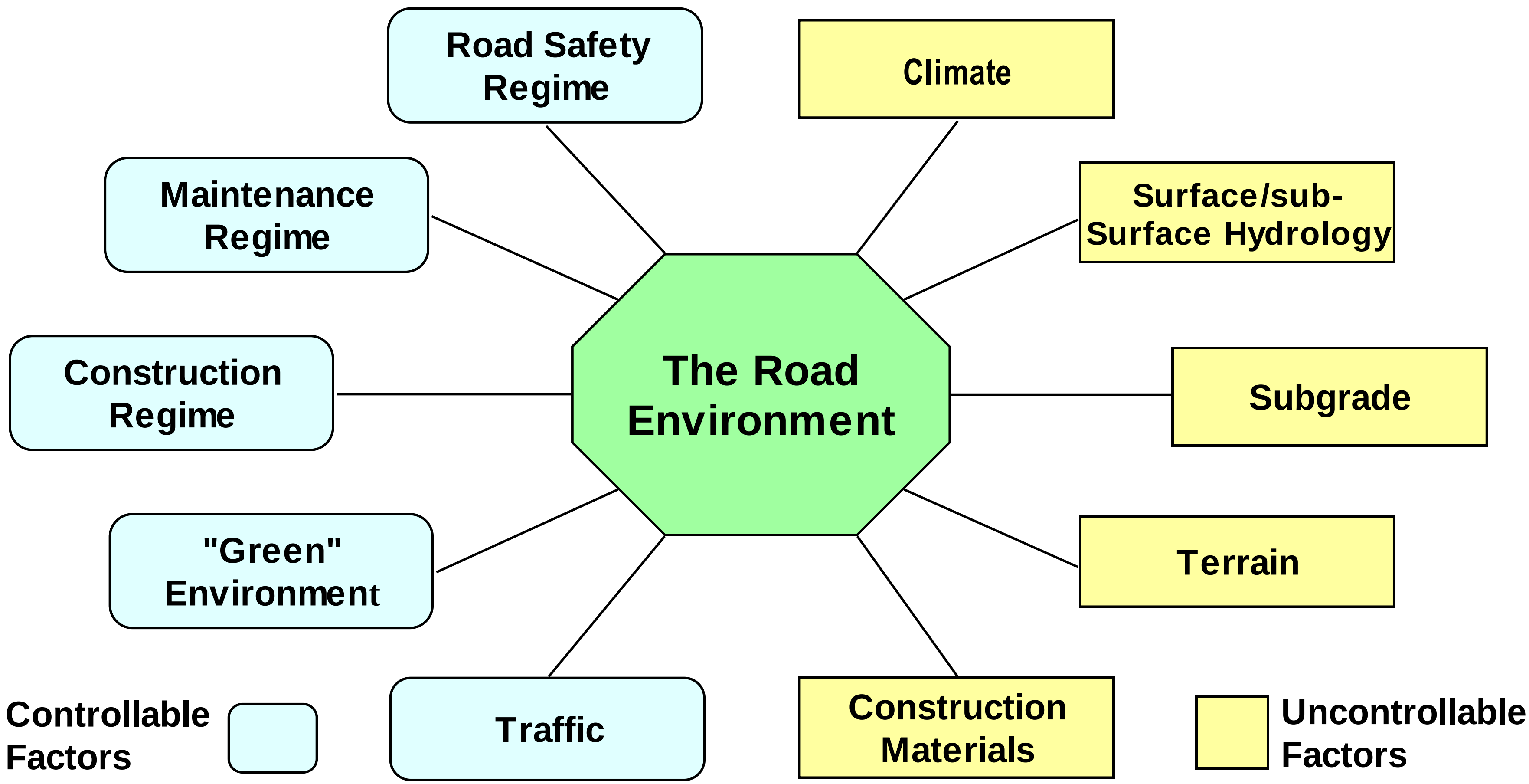


Fundamental Principle of Road Design



Wheel load transfer through pavement structure

Road Environment Factors



Pavement design process must be fully responsive to the road environment

Outline of Presentation

- General Introduction
- Engineered Earth Roads
- Gravel Roads
- Low Volume Sealed Roads
- Performance Review of Malawi Low Volume Sealed Roads
- DCP Method of Pavement Design

Types of Earth Roads

Unformed

Formed

Engineered Natural Surface (ENS)

Formation of Earth Roads

Manual excavation of side ditch material to form ENS camber (prior to spreading and compaction)

Formation of Earth Roads

Typically consist of excavated, in situ material from alongside alignment which is shaped to form a camber that is raised above ground level and includes side drains

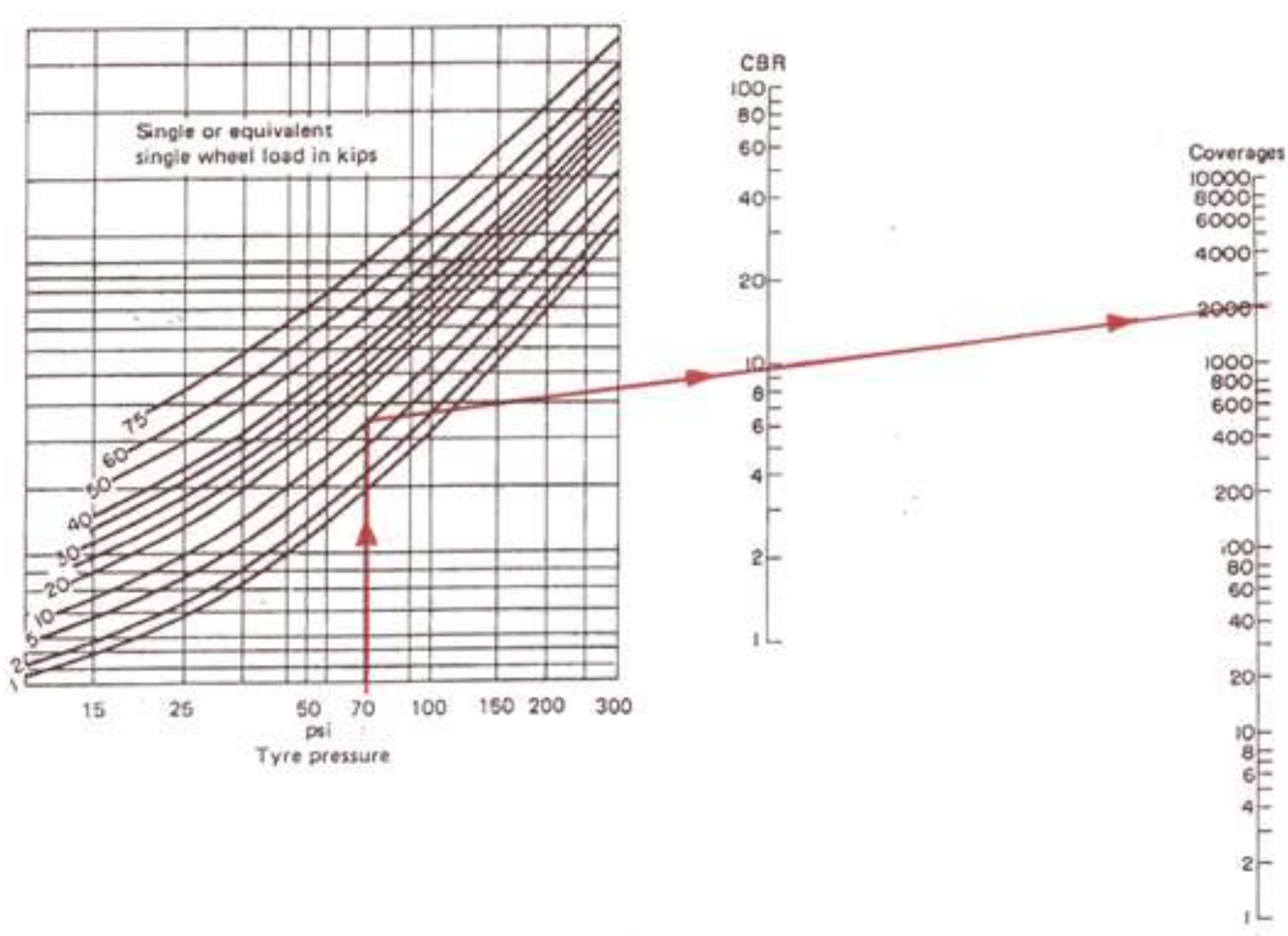
Performance of Earth Roads

Performance depends on:

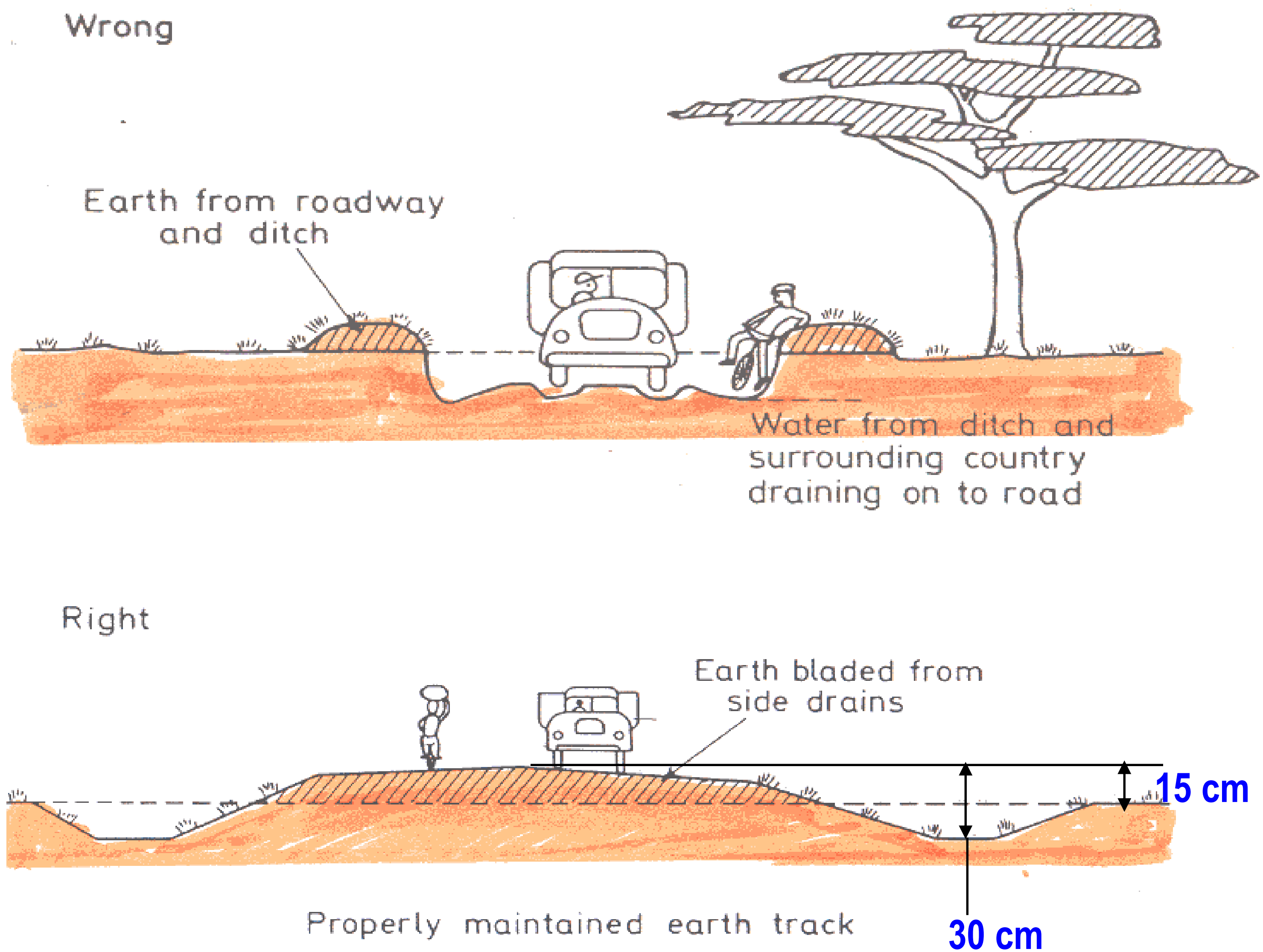
- Soil properties
- Rainfall (amount and intensity)
- Traffic (type, volume and tyre pressure)
- Longitudinal gradient
- Quality of drainage
- Level of water table

No formalised design method – too many variables that interact in a complex manner.

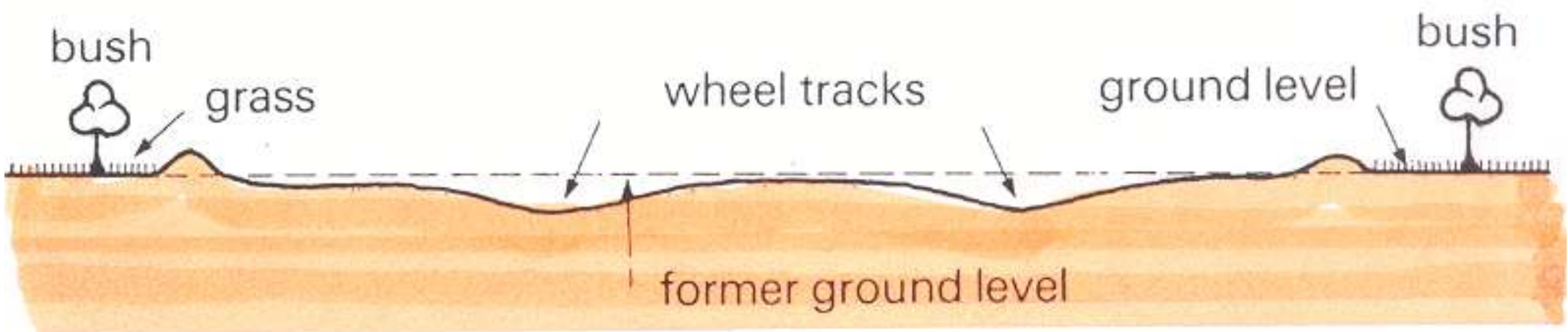
Relationship between load, repetition, tyre pressure and CBR for unsurfaced roads

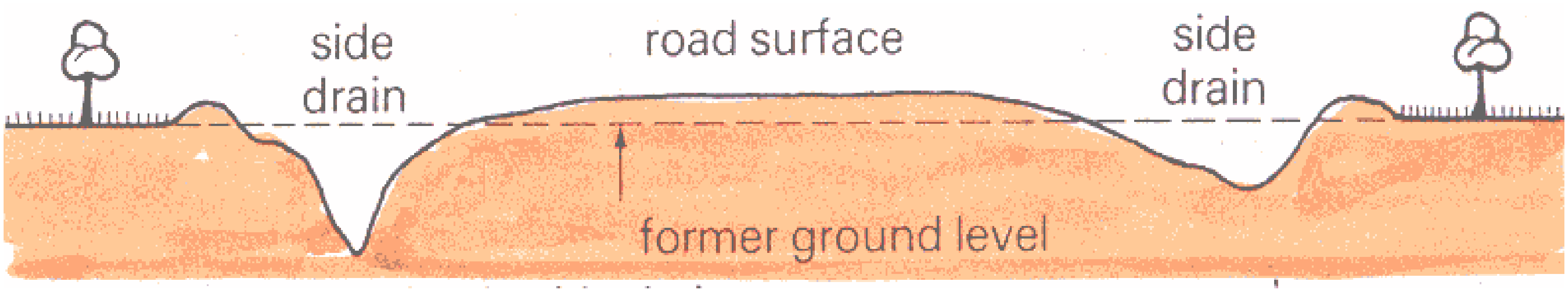


Construction of Earth Roads



Maintenance of Earth Roads





Outline of Presentation

- General Introduction
- Engineered Earth Roads
- **Gravel Roads**
- Low Volume Sealed Roads
- Performance Review of Malawi Low Volume Sealed Roads
- DCP Method of Pavement Design

Approach to Gravel Road Design

Major gravel roads in which the existing road may be eventually upgraded to a bituminous standard. This typically applies to roads which have a design AADT between 25-200.

- The subgrade materials should comply with the requirements of a low volume sealed road

- Only the wearing course would need replacement at intervals related to the expected annual gravel loss, and Geometry and drainage are upgraded to acceptable minimum levels during construction.

Approach to Gravel Road Design

Thickness Design - Major Gravel Roads - AADT 25 – 300)

The required gravel thickness, D, shall be determined as follows:

1. Determine the minimum subbase gravel thickness necessary to avoid excessive compressive strain in the subgrade (D_1). (Design catalogue)

[R1]

2. Determine the extra wearing course (WC) thickness (D_2) needed to compensate for the annual gravel loss (GL) under traffic during the period between regravelling operations (N). Thus $D_2 = N \times GL$.

3. Determine the total gravel thickness, D, by adding the above two thicknesses $D = (D_1 + D_2) = D_1 + N.GL$.

Design Catalogue -

Catalogue for major gravel roads – strong gravel (G45)

Subgrade Strength Class CBR (%)	Traffic Classes (esa x 10^6)				
	<0.01	0.01-0.1	0.1-0.3	0.3-0.5	0.5-1.0
S2 (3-4)	175	225	250	300	350
S3 (5-7)	150	200	225	250	300
S4 (8-14)	100	150	200	200	250
S5 (15-29)	100	125	150	175	200

Catalogue for major gravel roads – medium gravel (G30)

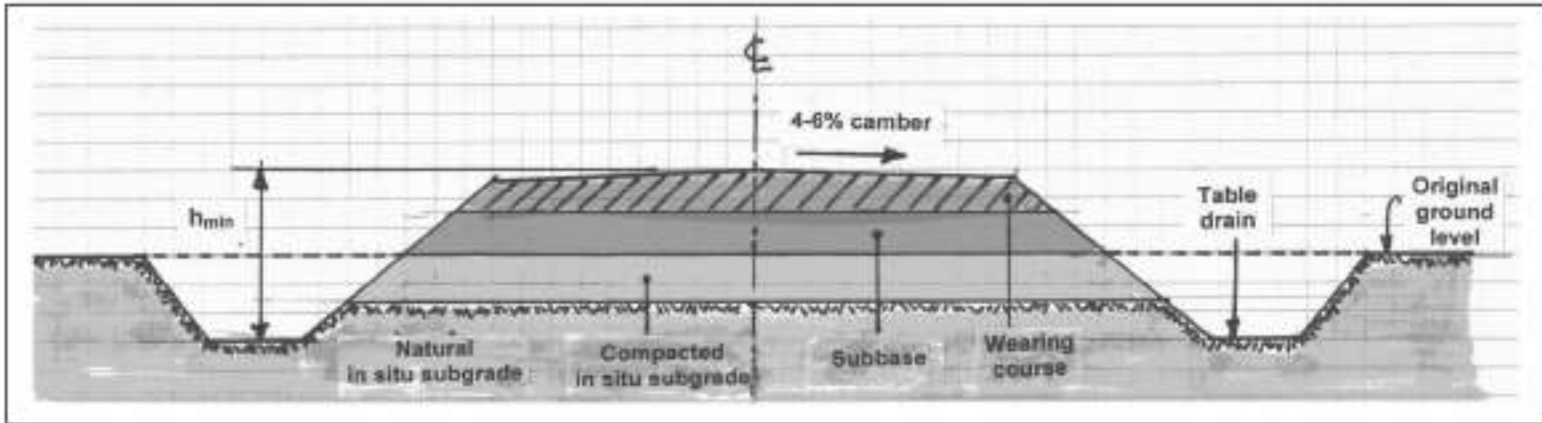
Subgrade Strength Class CBR (%)	Traffic Classes (esa x 10^6)				
	<0.01	0.01-0.1	0.1-0.3	0.3-0.5	0.5-1.0
S2 (3-4)	175	250	290	325	370
S3 (5-7)	150	200	250	275	325
S4 (8-14)	125	175	200	220	275
S5 (15-29)	100	100	150	175	200

Design Catalogue -

Catalogue for major gravel roads – weak gravel (G15)

Subgrade Strength Class CBR (%)	Traffic Classes (esa x 10^6)				
	<0.01	0.01-0.1	0.1-0.3	0.3-0.5	0.5-1.0
S2 (3-4)	225	325	375	NA	NA
S3 (5-7)	200	250	325	350	NA
S3 (5-7)	200	250	325	350	NA
S5 (15-29)	150[1]	150[1]	200[1]	200[1]	NA

Approach to Gravel Road Design



Typical gravel road x-section in flat terrain

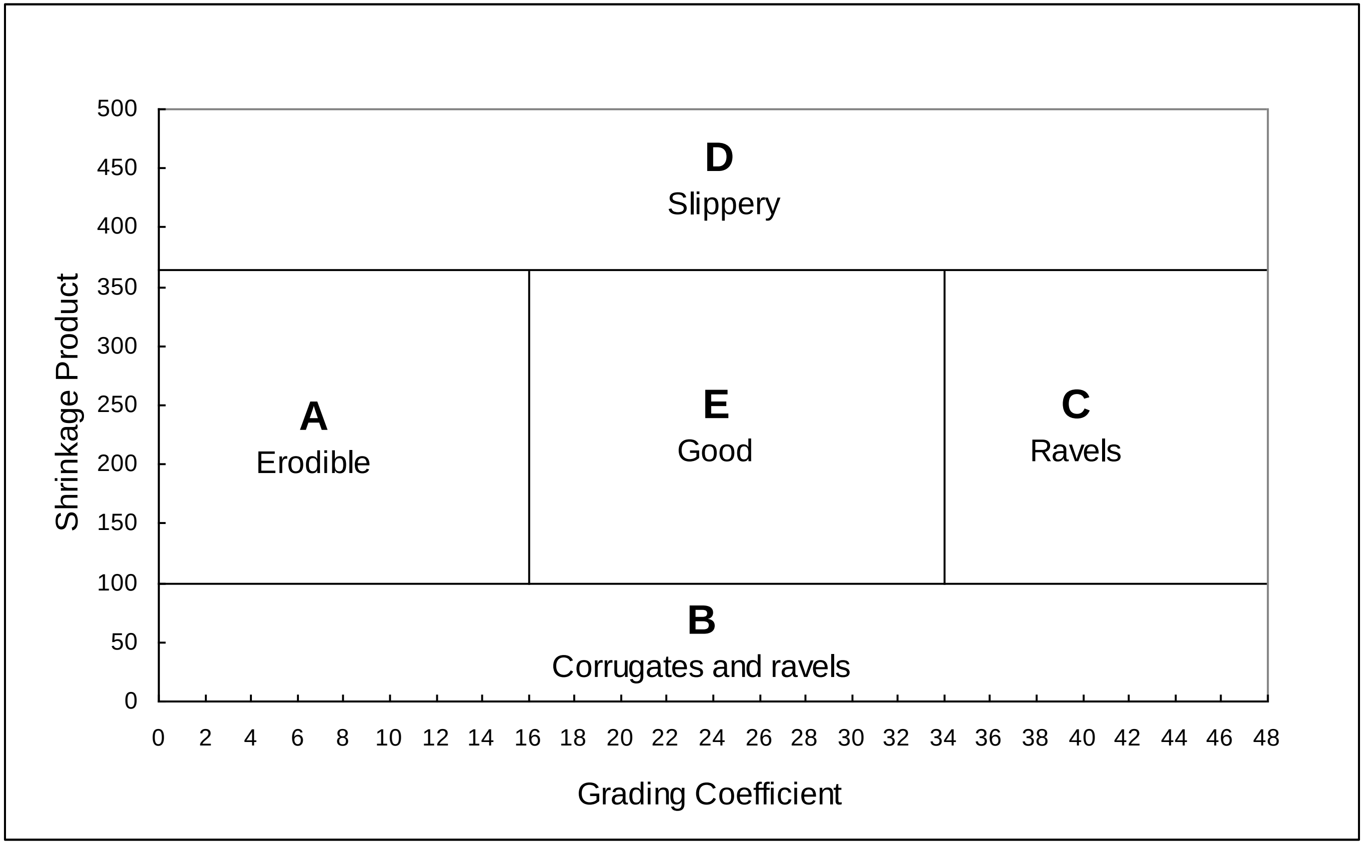
Road Class	Climate	
	Wet (N < 4)	Dry (N > 4)
	h_{min} (mm)	hmin (mm)
DC-1	350	250
DC-2	400	300
DC-3	450	350
DC-4	500	400

Required min height (hmin) between road crown and invert level of drain in relation to climate

Desirable Material Characteristics

- Skid resistance
- Smooth riding characteristics
- Cohesive properties
- Resistance to ravelling and scouring
- Wet and dry stability
  [R1]
- Low permeability
- Load spreading ability

Wearing Course Selection and Specifications



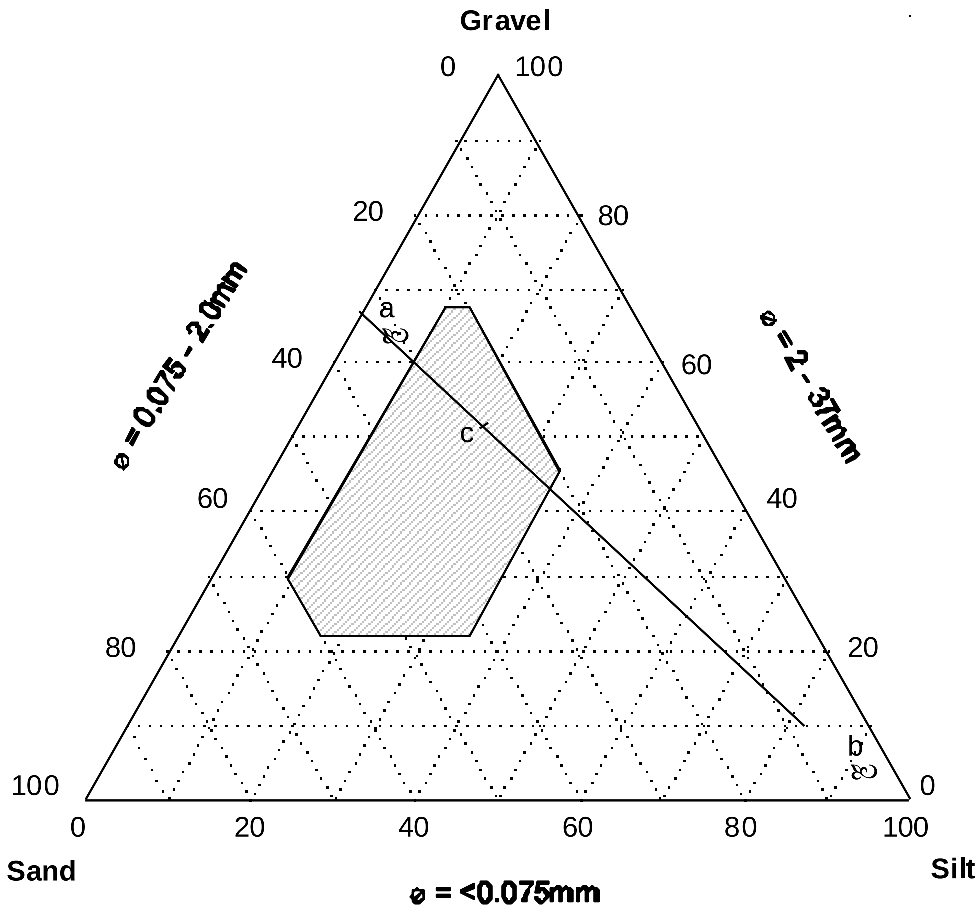
Material quality zones

Reducing Oversize

Grid roller

Rock buster

Blending of Materials



[R1]

Ternary diagram for blending gravel materials

Approach to Gravel Road Design

Minor gravel roads - existing road unlikely in the foreseeable future to be upgraded to a bituminous standard (AADT typically < 25 vpd)

- **The subgrade materials should not necessarily comply with the requirements of a low volume sealed road**
- **The full thickness of wearing course may not necessarily be provided initially with the remainder being provided at a later date.**
- **Drainage, but not necessarily geometry, is upgraded to acceptable minimum levels during construction.**

Outline of Presentation

- General Introduction
- Engineered Earth Roads
- Gravel Roads
- **Low Volume Sealed Roads**
- Performance Review of Malawi Low Volume Sealed Roads
- DCP Method of Pavement Design

Limitations of Gravel Roads

Traditionally Gravel is used for rural access roads.

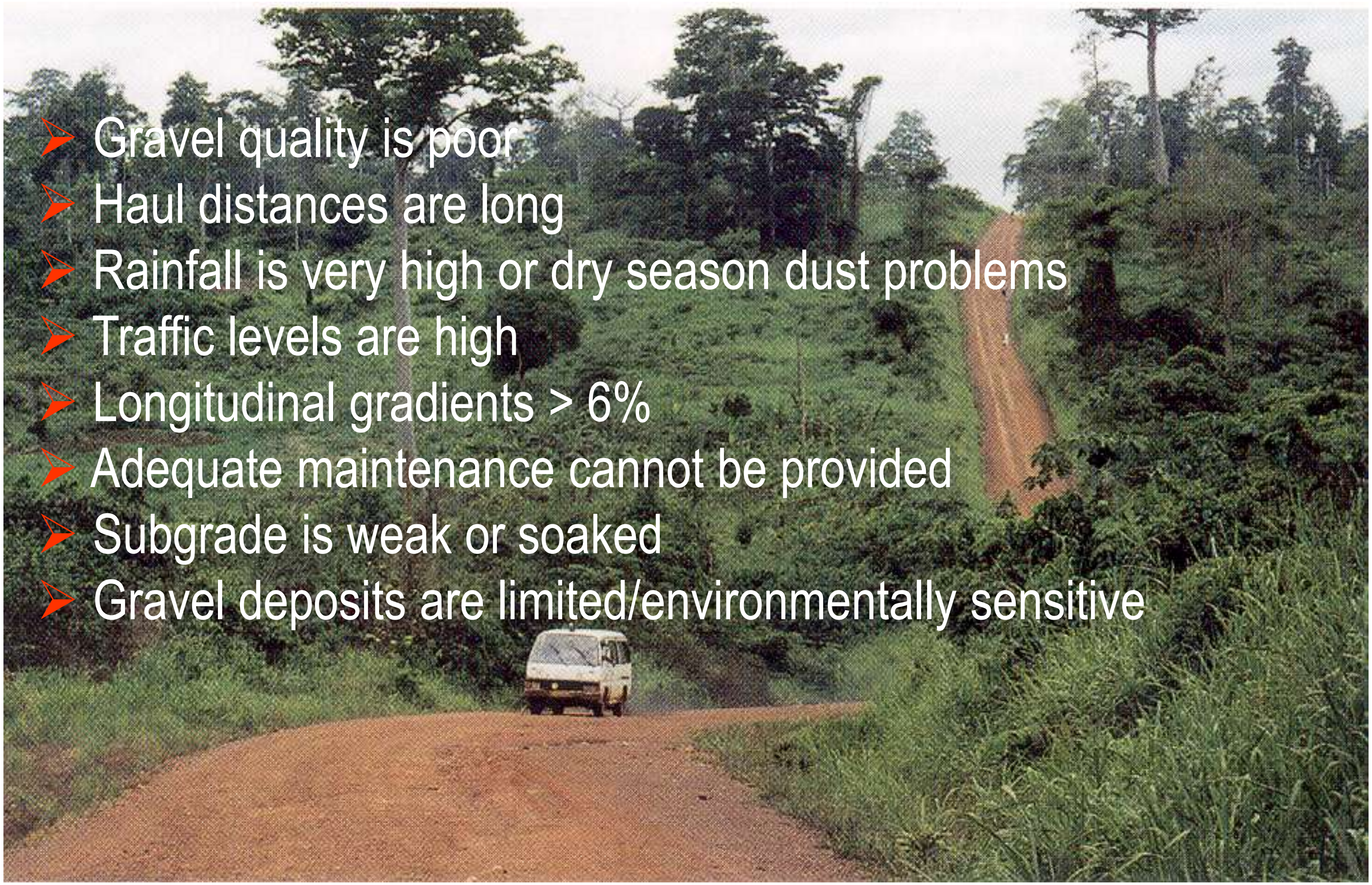
However:

- They are low (initial) cost and relatively easy to construct

- 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 regravel.

……….SENSIBLE??? NO!!!

Limitations of Gravel Roads (Cont'd)



- Gravel quality is poor
- 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

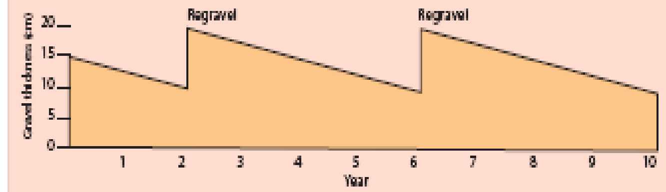
Why low volume sealed roads?

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

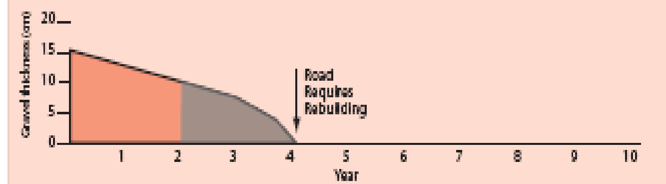
Unpaved roads: Require continuous use of a non-renewable resource – gravel. This is inherently unsustainable and environmentally damaging. Is this sustainable? NO!

Approx. 175 million cu.m "consumed" annually in SADC region for gravelling purposes

Maintaining Gravel Roads–The Reality



(a) Gravel thickness with preventative maintenance (timely regravelling).



(b) Gravel thickness without preventative maintenance (no timely re-gravelling).

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

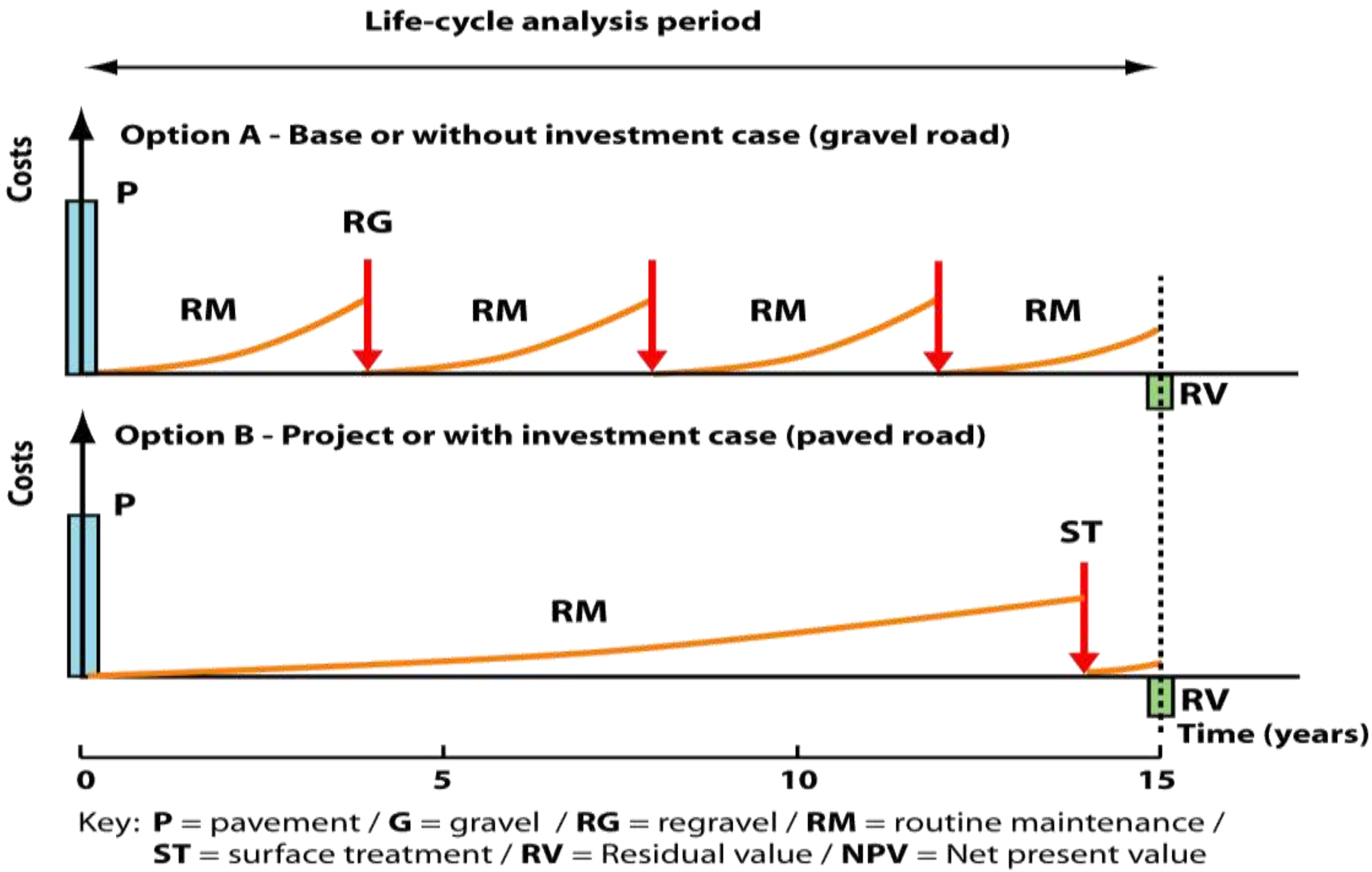
The Message

- 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.
- These techniques are ideal for use by SMEs.

Sealed Road Challenge

- Not possible to upgrade all unsealed roads
- However, many thousands of km of rural access roads carrying light traffic that could be justifiably upgraded using “low-cost” seals coupled with appropriate standards and specs.

Life-Cycle Costs: Gravel vs LVSR



In many cases NPV_B < NPV_A

Outline of Presentation

- General Introduction
- Engineered Earth Roads
- Gravel Roads
- Low Volume Sealed Roads
- **Performance Review of Malawi Low Volume Sealed Roads**
- DCP Method of Pavement Design

Motivation for Project

- Malawi public road network – 15,451km
  - Unpaved - 75%
  - Additional but not classified (unpaved) – 9,500km
  - Characteristics of unpaved roads
    - Seasonal accessibility problems
    - Longer travel times
    - High VOC
    - High maintenance cost
    - Depletion of non-renewable resource (gravel)-unsustainable
    - Environmentally unfriendly

Motivation for Project

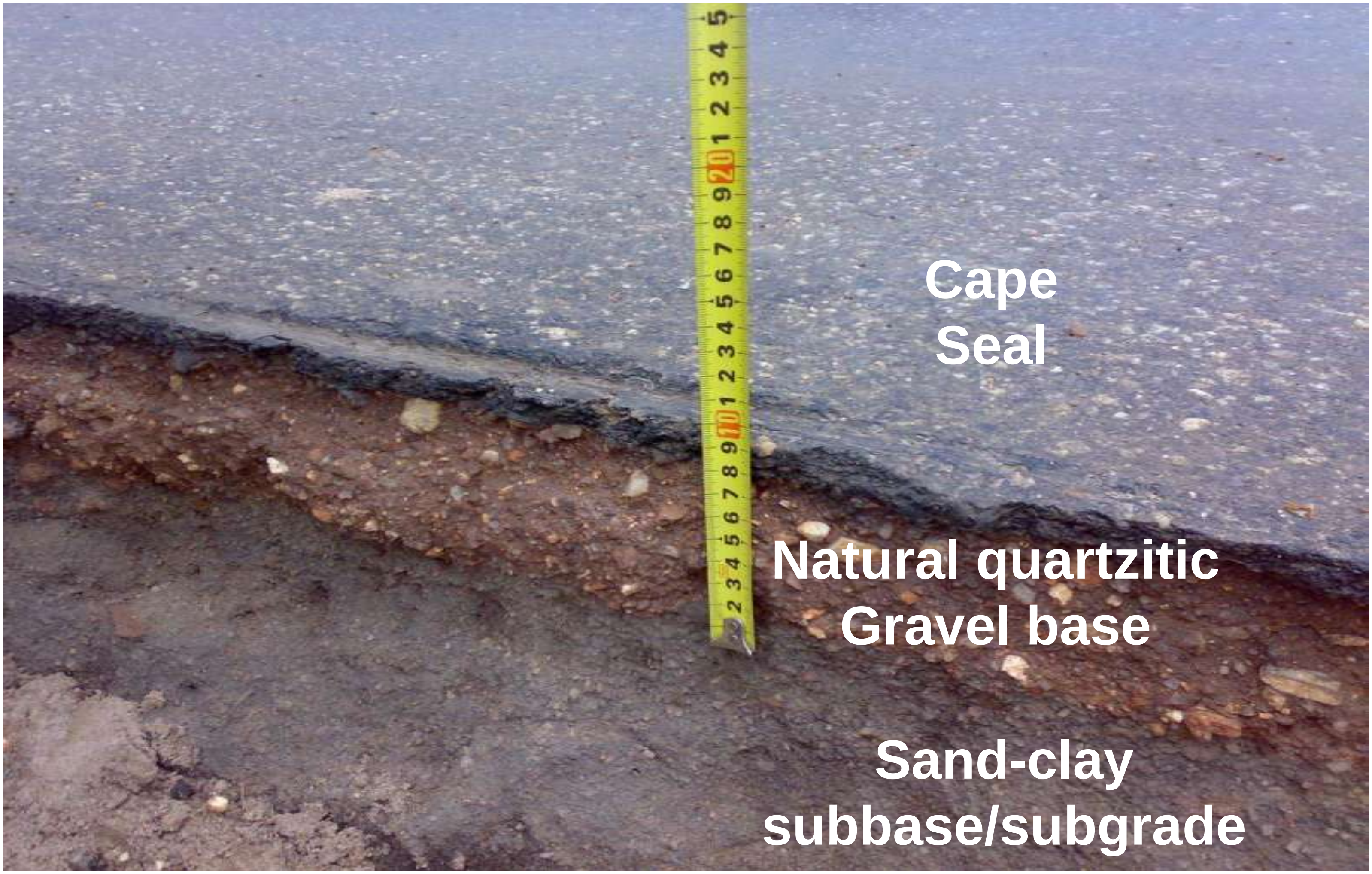
- **Why paved roads?**
  - Cheaper in terms of both
    - Recurrent maintenance cost
    - Life cycle cost
  - More sustainable than unpaved roads
  - Stimulate social and economic growth
- **BUT initial capital investment cost relatively high *using traditional standards and specs***
- **Are there not alternative ways of providing paved roads?**

YES!! BASED ON A LOW VOLUME/LIGHTLY TRAFFIC SEALED ROADS APPROACH TAKING ACCOUNT OF PERFORMANCE BASED ON RESEARCH CARRIED OUT IN MALAWI AND OTHER COUNTRIES IN SOUTHERN AFRICA

Motivation for Project

- LVSRs in Malawi date back to more than 20 years
  - No proper records in place – need for quantification
  - Discovered through rehabilitation works
- Recent LVSRs – a total of about 20km constructed
  - Have taken advantage
    - Old age of existing earth roads (>20 years) – CONSOLIDATED PAVEMENTS
    - Reasonably engineered alignments
  - Simplistic approach adopted
    - Grade/rehabilitate without affecting the existing pavement and alignment – varying widths for different roads
    - Place gravel (even "marginal" with CBR_s +/- 50%) compacted to 98% MDD
    - Surface (Cape seal)
    - Use of simplified bidding documentation

Example of Long-standing LVSR – Lilongwe A47 Road



After 20 years in use – 6.5m wide and little maintenance

Example of Long-Standing LVSR – Nyika National Park

After 15 years in service: 4m wide and little maintenance

Example of Malawi LVSR – Dowa Road

After 6 years in service – 4m wide and little maintenance

Example of Malawi LVSR – Ntchisi Road

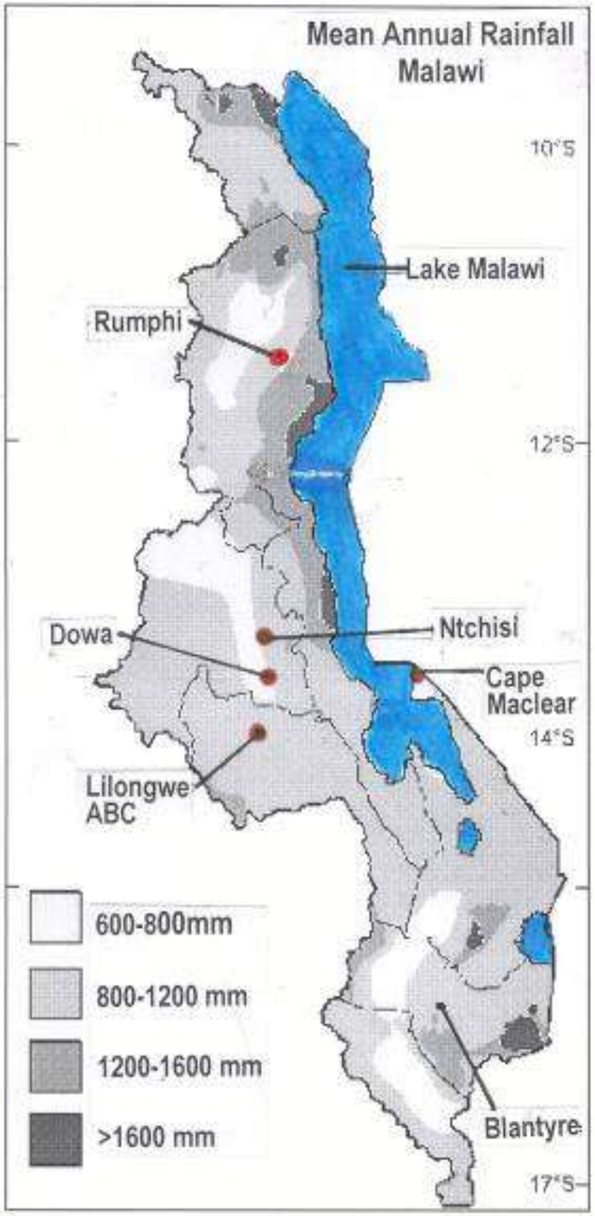
After 9 years in service – 5m wide, little maintenance, excellent condition

Motivation for Project

- NRA needs design standards and specs that are appropriate to LVRs which should reflect historical experience and be acceptable to political decision makers, local consultants and contractors.
  - Requested AFCAP to assist with a Performance Review of Design Standards and Technical Specs used on Low Volume Sealed roads in Malawi.
- Project expected to contribute to greater awareness of need for appropriate design standards for LVRs and benefits to local economy.
- Intention is to gain support amongst key decision makers for a subsequent project to develop an official design manual and standard specs for construction of LVRS.

Location of Road Sections Investigated

Description	Typical Mean Annual Rainfall	Weinert N Value	Thornthwaite Mositure index (I_m)
Arid	< 250mm	5+	< -40
Semi-arid	250 - 500mm	4 – 5	-20 to -40
Semi-arid to sub-tropical	500 - 1000	2 – 4	0 to +20
Humid tropical	> 1000mm	< 2	+20 to +100



Overall Scoping of Project

Stage 1

Preliminary Activities

- Stakeholder sensitisation meetings
- Desk study of historical projects
- Field visits to select sites
- Development of field investigation and laboratory testing programme
- Establishment of investigation procedures
- Determination of traffic loading

Inception Report

Stage 2

Field Investigations

- Visual condition
- Side drainage
- Rut measurements
- DCP measurements
- IDD and in situ MC measurements
- Bulk sampling for lab testing

Preliminary Fieldwork Report

Stage 3

Laboratory Testing

- Classification
  - grading
  - Atterberg Limits
  - Linear shrinkage
- Compaction
  - MDD/OMC
- Strength
  - CBR (soaked, OMC, 0.75 OMC)

Final Fieldwork Report

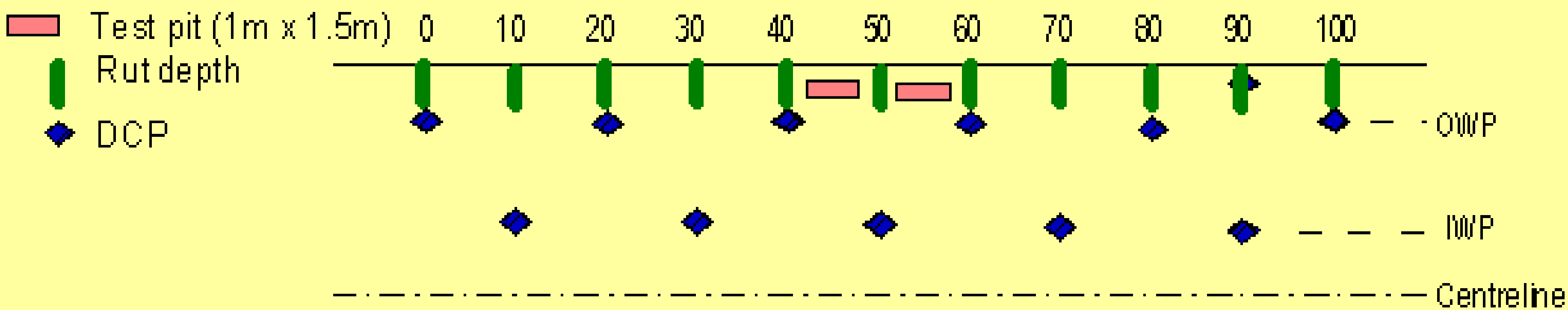
Stage 4

Analysis and Reporting

- Analysis of results
- Recommendations for LVSRs
- standards and specifications

Final Project Report

Overview of Field and Lab Testing



Notes:

(1) Testing to be undertaken in one lane only (more heavily trafficked lane)

(2) 3 No. IDDs and 3 No. moisture contents to be taken in each test pit in each pavement layer

(3) Outermost DCP measurements to be 50 cms from edge of surfacing

(4) DCP penetration to 800 mm

(5) Rut depths with 2 m straight edge in inner wheel path (IWP) and outer wheel path (OWP)

Overview of Field Investigations

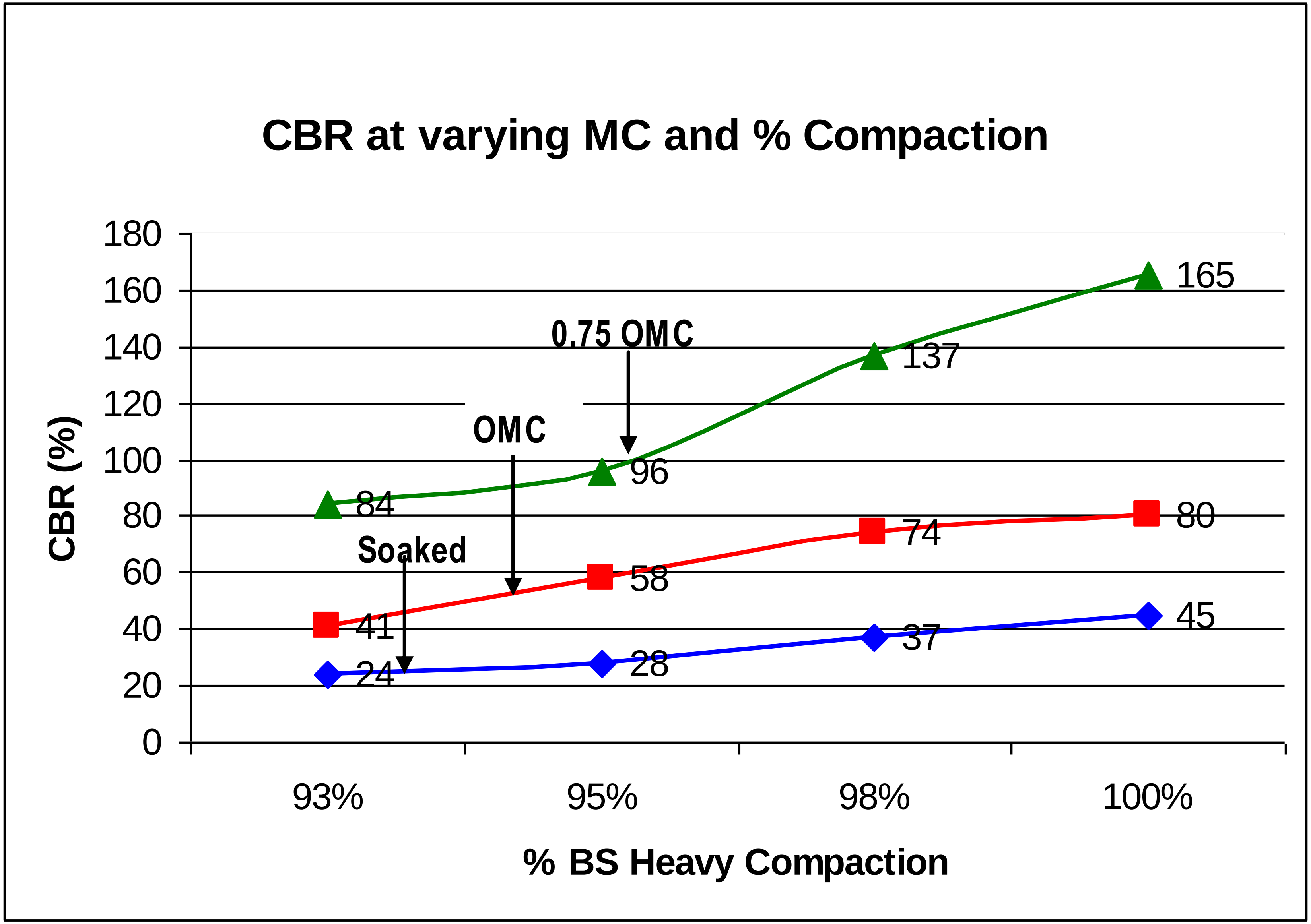
IDD testing by sand replacement method

Sampling of base course material

Overview of Field Investigations

Pavement profile showing base (+/- 150mm) and subbase/ subgrade layers

Results: CBR at Varying MC and Density



Results: Classification Tests

Road Section	Pavement Layer	Soil Parameter									
		P425		P075		Max. LL		Max. PI		Max. PM	
		Value	ORN31	Value	ORN31	Value	ORN31	Value	ORN31	Value	ORN31
Ntchisi (School)	Base SB/SG	46 80	10 – 30 10 - 60	30 52	5 - 15 5 - 25	36 38	- 35– 55[1]	16 19	6 6 – 20[2]	736 1520	90 -
Ntchisi (Hospital)	Base SB/SG	61 82	10 – 30 10 - 60	36 52	5 - 15 5 - 25	33 42	- 35 - 55	16 19	6 6 – 20[2]	976 9.3	90 -
Ntchisi (Standard	Base Subbase Subgrade	47 54 59	10 – 30 10 – 60 -	17 30 31	5 - 15 5 – 25 -	NP 30 35	- 35 – 55 -	NP 14 18	6 6 – 20[2] -	- 756 1062	90 - -
Dowa	Base SB/SG	41 80	10 – 30 10 - 60	29 45	5 - 15 5 - 25	43 34	- 35 - 55	17 13	6 6 – 20[2]	697 1040	90 -
Rumphi	Base SB/SG	31 43	10 – 30 10 - 60	15 22	5 - 15 5 - 25	32 NP	- 35 - 55	18 NP	6 6 – 20[2]	558 -	90 -
Cape Maclear	Base SB/SG	37 29	10 – 30 10 - 60	19 21	5 - 15 5 - 25	24 35	- 35 - 55	14 16	6 6 – 20[2]	518 464	90 -

Results generally are non-compliant with traditional (ORN 31) specifications

Results: Field MC/Optimum MC Ratio

Road Section	Pavement Layer	Relative Compaction (%)	FMC/OMC		
			Location	Wet Season	Dry Season
Ntchisi (School)	Base SB/SG	96.7 94.4	OWP IWP OWP IWP	0.76 0.27? 1.02 0.79	0.62 0.91 0.91 1.07
Ntchisi (Hospital)	Base SB/SG	97.3 98.9	OWP IWP OWP IWP	- - - -	0.94 1.05 0.95 1.10
Ntchisi (Standard)	Base SB SG	96.6 99.8 90.3	OWP IWP OWP IWP OWP IWP	0.82 0.46 0.85 0.73 1.36 1.24	0.79 0.86 1.08 1.14 1.42 1.47
Dowa	Base SB/SG	96.3 93.3	OWP IWP OWP IWP	0.56 0.44 0.95 0.84	0.67 0.86 0.71 0.74

DCP Results

Pavement Type (DCP Category)								
Deep			Shallow			Inverted		
Well balanced (WBD)	Averagely balanced (ABD)	Poorly balanced (PBD)	Well balanced (WBS)	Averagely balanced (ABS)	Poorly balanced (PBS)	Well balanced (WBI)	Averagely balanced (ABI)	Poorly balanced (PBI)

Road Section	DSN_{800}	Pavement Balance	Ave DCP CBR		80%ile minimum DN		Est.Traffic (MESA)*
			0-150 mm	150-800mm	0-150mm	150-800mm	
Ntchisi	94	ABD	45	20	9.2	22.2	0.03
Dowa	129	WBD	47	30	9.0	14.0	0.24
Rumphi	272	ABI	123	57	6.0	7.8	0.14
C. Maclear	174	WBD	97	28	5.0	11.6	0.06

Road Drainage - Variable

Brick-lined drain on longitudinal gradient of peri-urban section of the Ntchisi (school) road. Example of Satisfactory drainage

Poorly drained section of the Ntchisi (school) road. Example of poor drainage.

Functional Performance-Excellent!

Photo: Ntchisi road (school) - constructed in 2002
Condition: Good/sound

Photo: Dowa road – constructed in 2004
Condition: Good/sound

Pavement Structure Comparisons

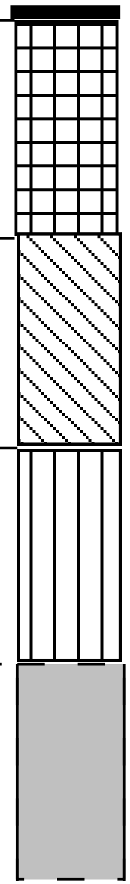
Bituminous surface treatment

Base: 150mm natural gravel
CBR >80% soaked @ 98% MDD
PI < 6
Grading enveloppe: Yes

Subbase: 150mm natural garvel
CBR > 30% (at emc) @95% MDD
PI: 6-20 (climate dependent)

Subgrade: 150mm natural gravel
CBR: > 15% (at emc) @ 93% MDD
PI: N/A

In situ material

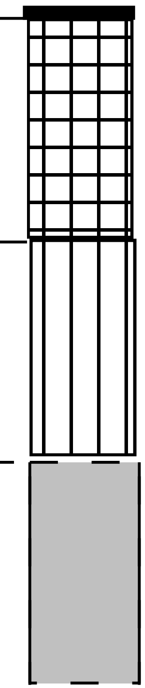


Bituminous surface treatment

Base: 150mm natural gravel
CBR >50% soaked @ 98% MDD
PI < 16
Grading enveloppe: No

Subbase/subgrade (original surface)
CBR > 30% at EMC after proof rolling
PI: N/S)

In situ subgrade material



Typical 2-layer LVR pavement structure : Ntchisi (school) road

Typical traditional 3-layer pavement structure (left) and 2-layer LVR structure (right)

Technical and Construction Cost Comparisons

LVR construction

Standard construction

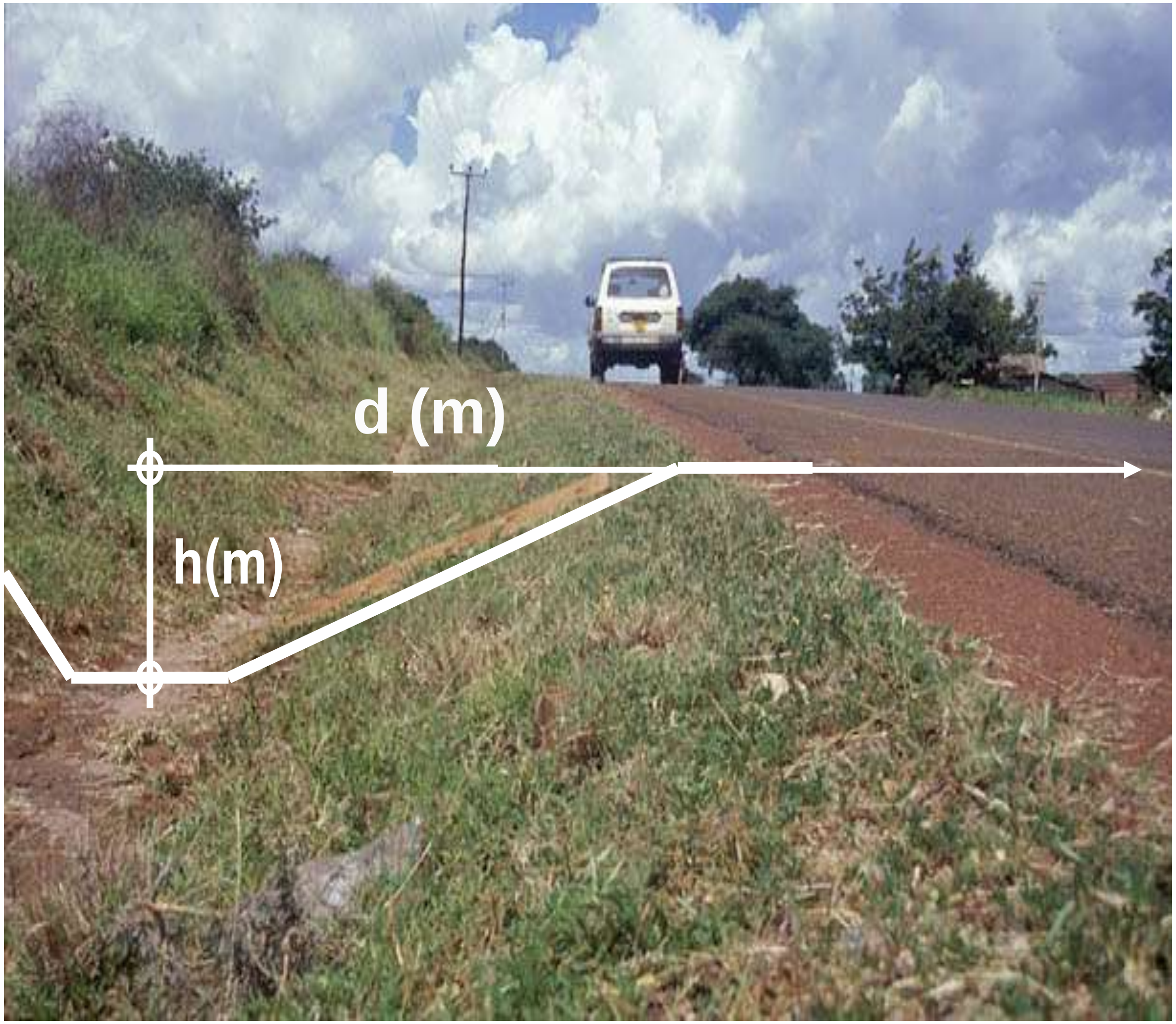
Cost Comparison
LVSR versus Standard Construction

Road Design Standard	Construction Cost (US$)	Cost Difference (%)
LVR	150,000	-
Class I	300,000	100
Class II	500,000	233

Key Requirements for Good Performance

- Moisture control through effective drainage
  - Sealing shoulders
  - Meeting minimum Drainage Factor
- Retention of existing, traffic-consolidated and moulded pavement structure as much as possible
  - Benefit of deep, well-balanced pavement less prone to overloading
- Compacting base materials to “refusal” with heaviest plant available
  - Reduces permeability and susceptibility to moisture ingress
  - Increases pavement life
- Tightly controlled construction quality
- Effective overload control

Effective Drainage



- Sealed shoulders reduce/ eliminate lateral moisture penetration under carriageway

Drainage Factor DF = d x h	Classification
< 2.5	Very poor
2.6 – 5.0	Poor
5.1 – 7.5	Moderate
>7.5 or free draining	Good

Example of a well-drained pavement (DF > 7.5)

Ideal Cross-Section

- 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

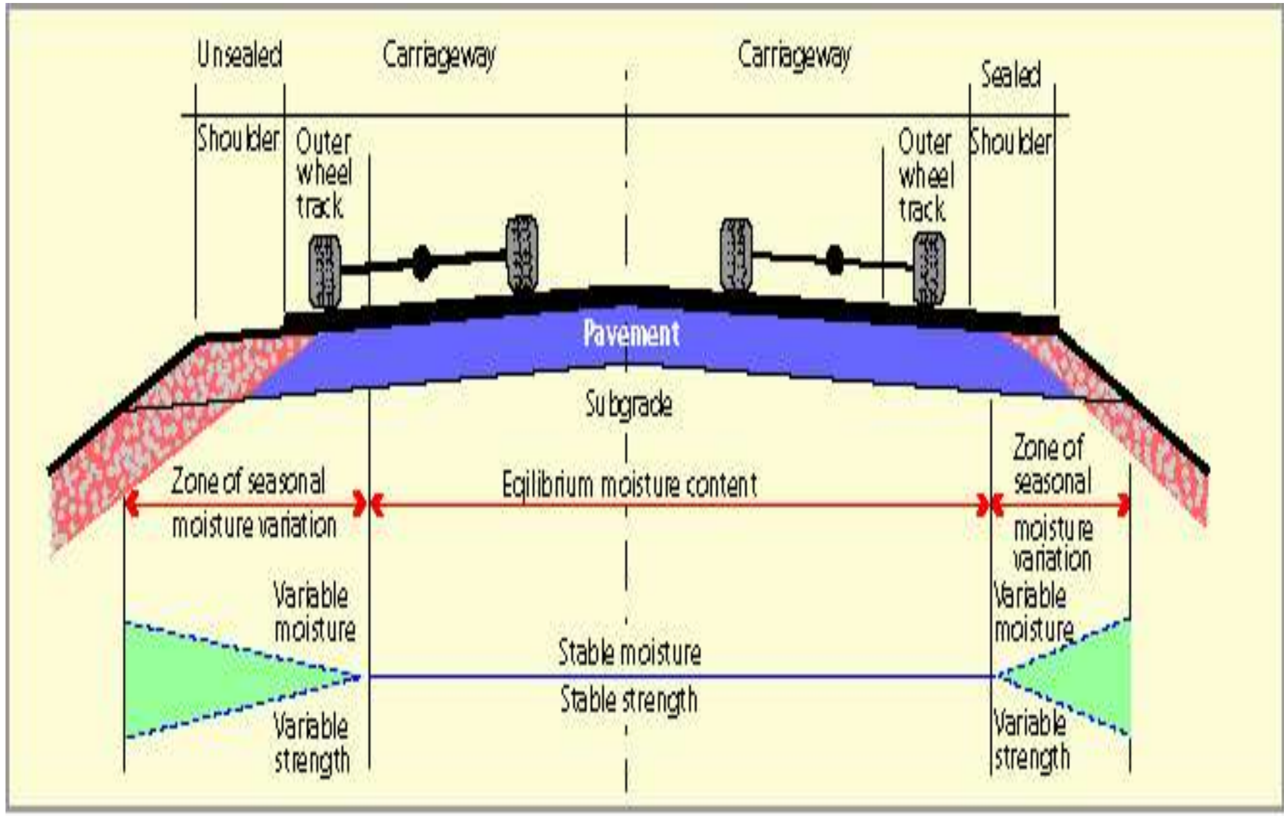
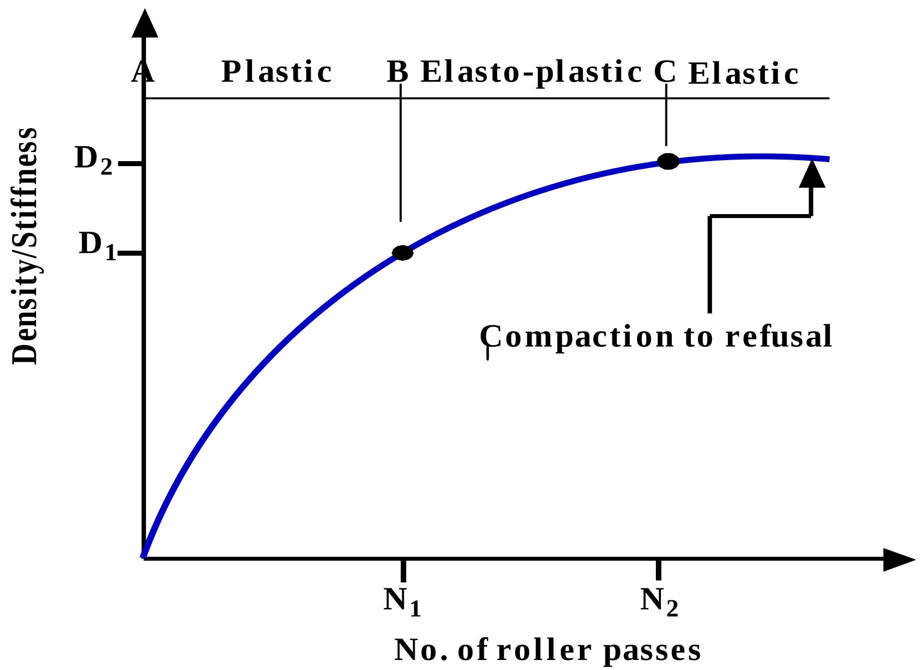
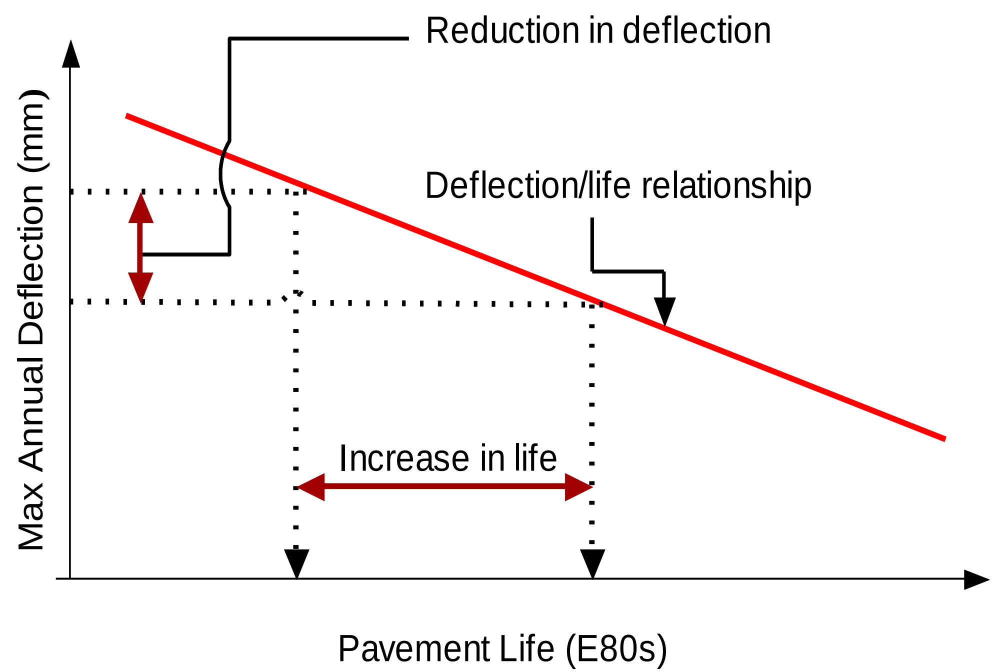


Figure 5.11

Moisture zones in a LVSR

Benefits of Compaction to "Refusal"





Compaction to "refusal"

Deflection/life relationship

Level of compaction in pavement layers influences pavement life – increasing compactive effort is generally economically justified

Outline of Presentation

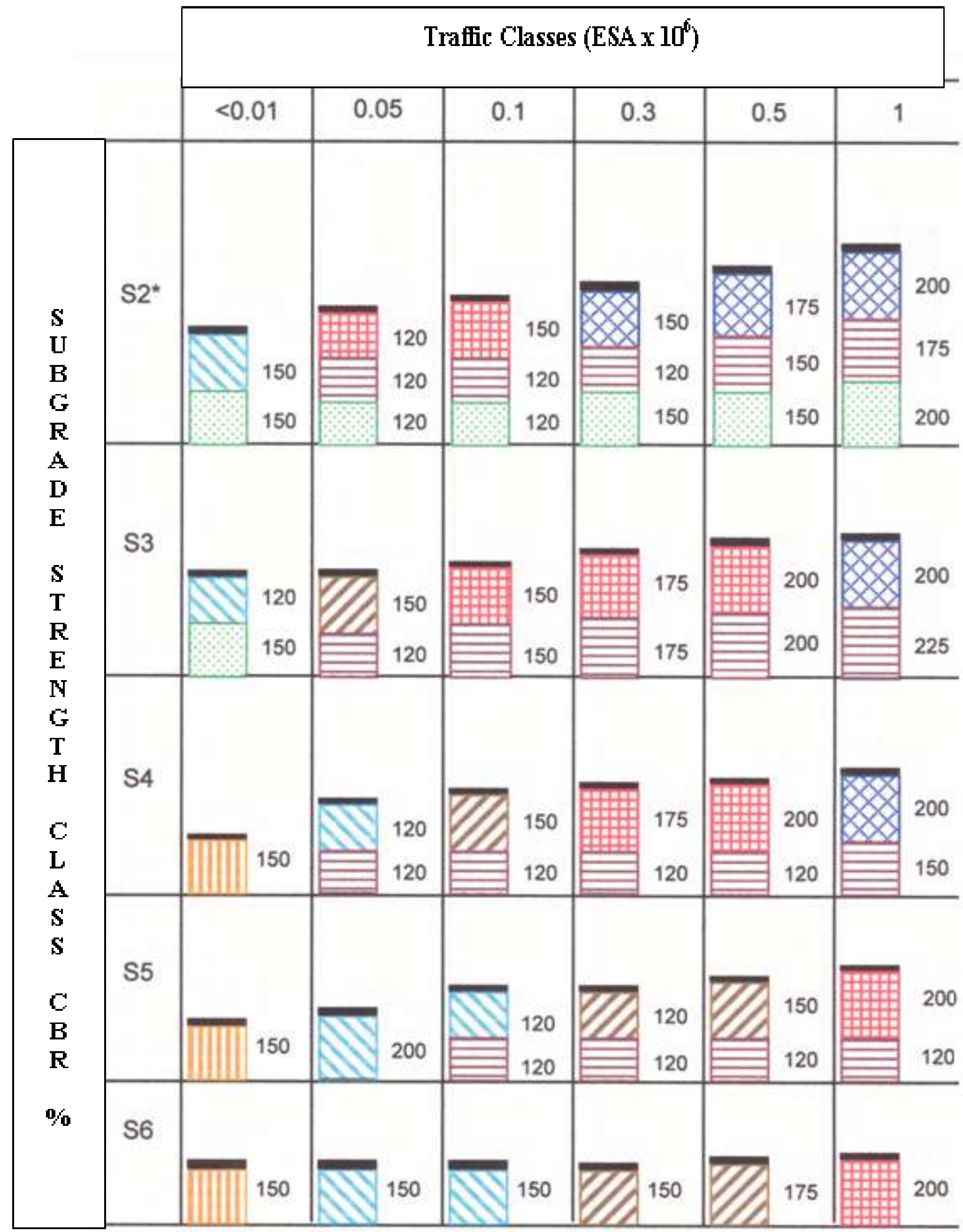
- General Introduction
- Engineered Earth Roads
- Gravel Roads
- Low Volume Sealed Roads
- Performance Review of Malawi Low Volume Sealed Roads
- **DCP Method of Pavement Design**

Pavement Design Methods

- Numerous pavement design methods used in practice
  - CBR cover curve
  - AASHTO structural number
  - Mechanistic-empirical
  - Catalogue
    - Lab CBR based (e.g. TRL ORN 31, TRL/SADC, TRH 4)
    - DCP based (e.g. Kleyn et al)
      - easiest design method to use
      - theoretical work already undertaken
      - different structures presented in catalogue form for various combinations of traffic loading and subgrade conditions

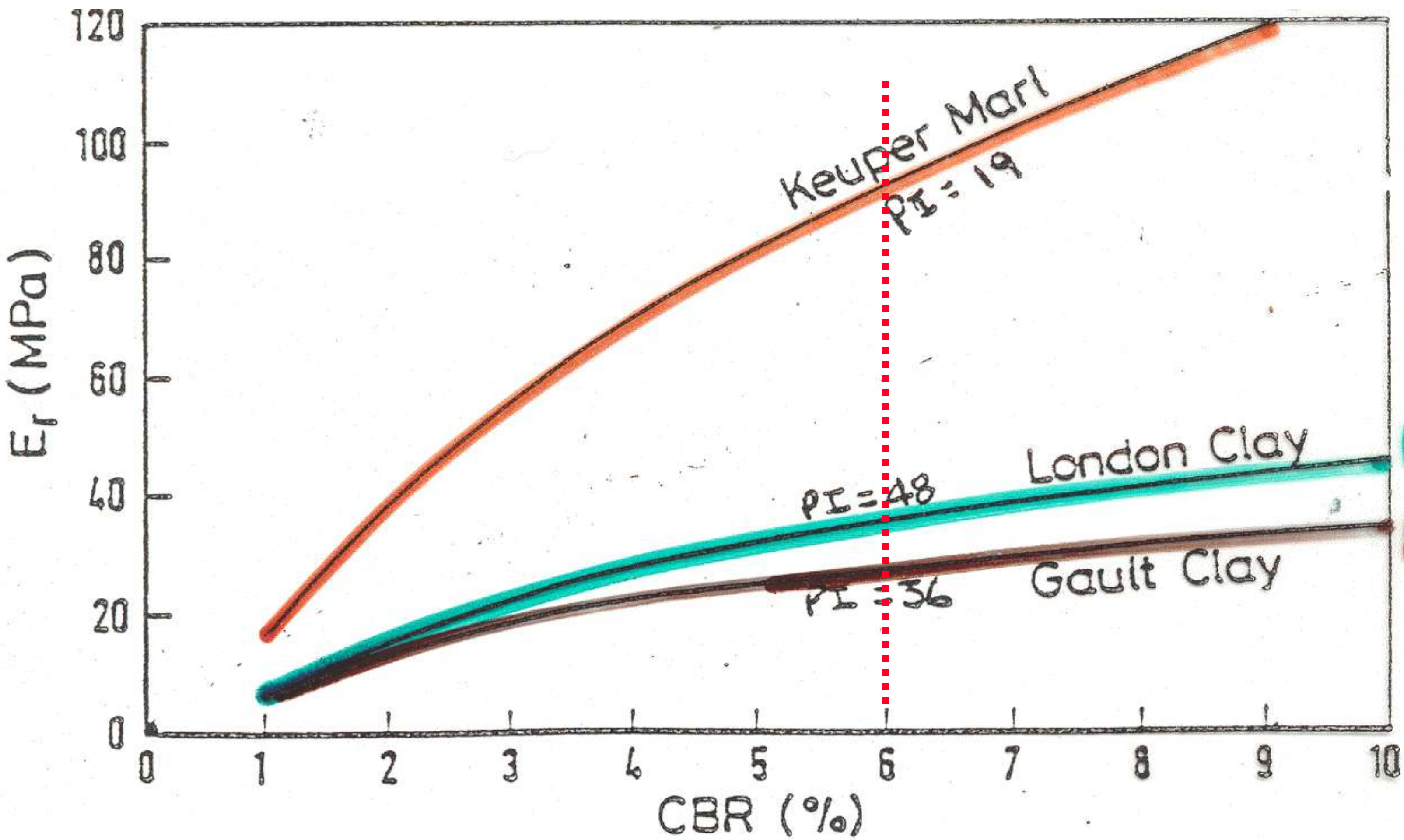
TRL/SADC Lab CBR-based Design Method

S2 = 3-4
S3 = 5-7
S4 = 8-14
S5 = 15-29
S6 = 30+



Pavement Catalogue N < 4

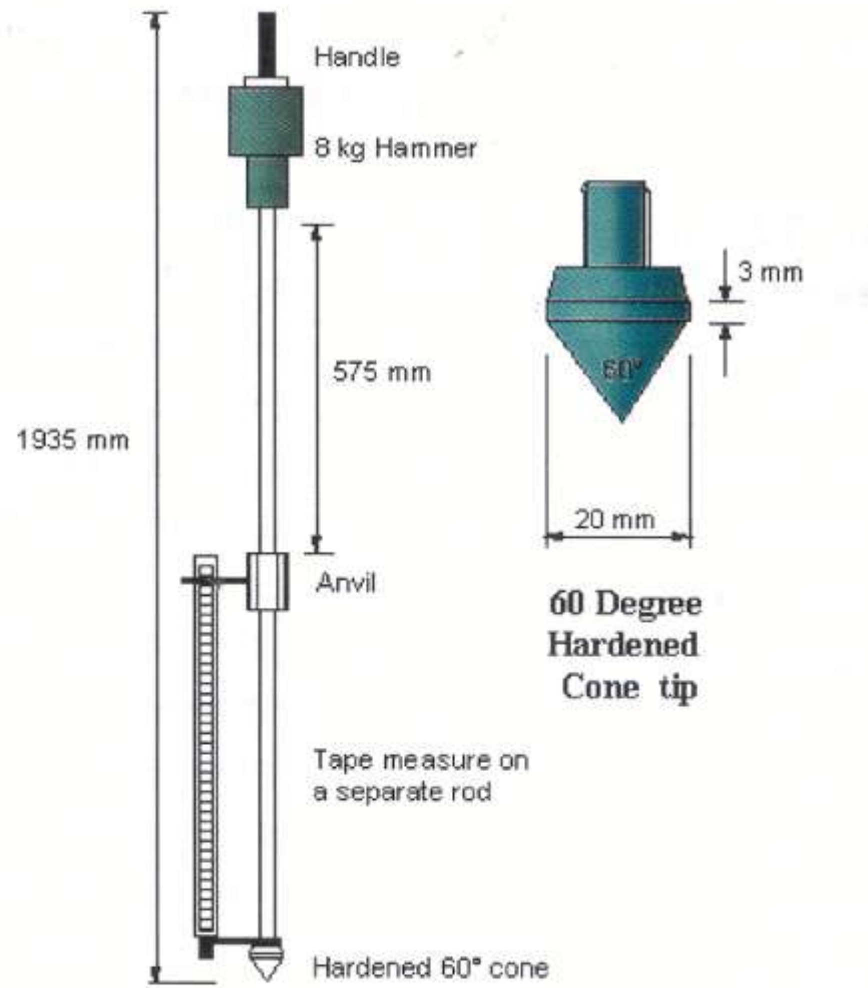
CBR Test method vs performance



Overview of Presentation

- Malawi LVSR Project
  - Motivation for the project
  - Investigations Carried Out
  - Findings and Conclusions
- Pavement Design Methods
  - Lab CBR-based methods
  - DCP based method
    - Application to Upgrading Low Volume Roads

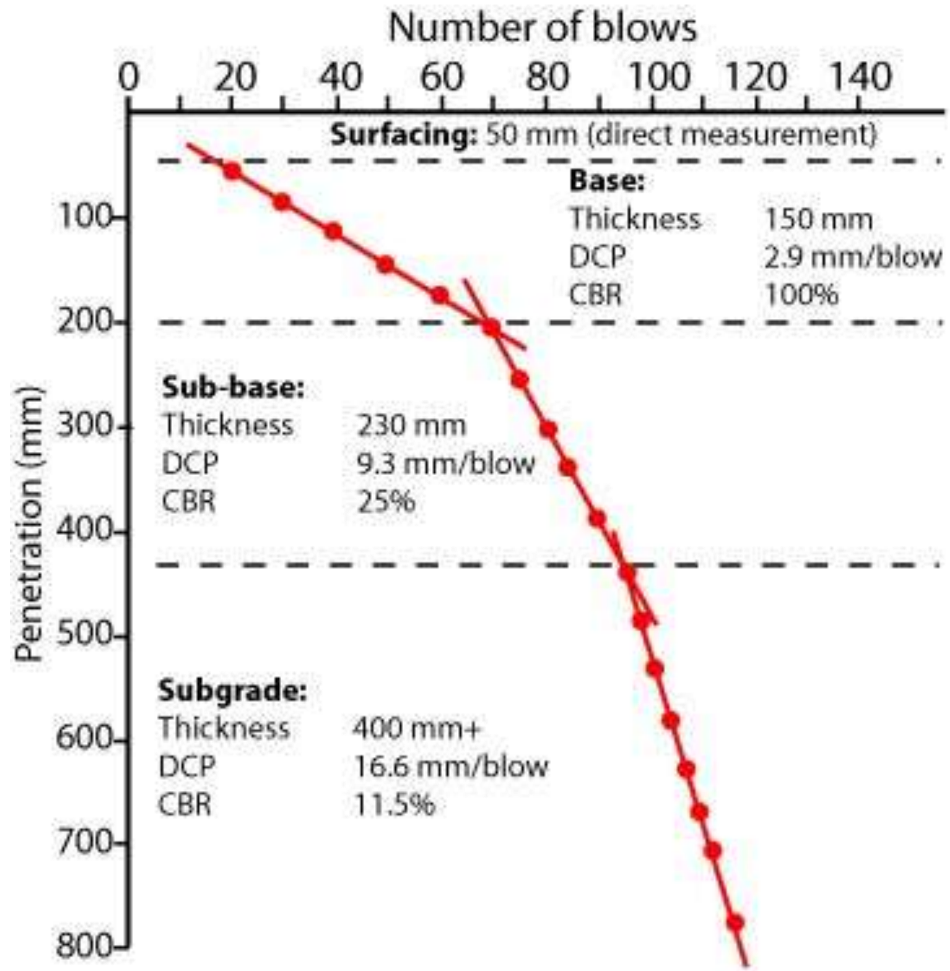
Dynamic Cone Penetrometer (DCP)



The Dynamic Cone Penetrometer

DCP Test and Output

DCP test in process



Typical DCP plot

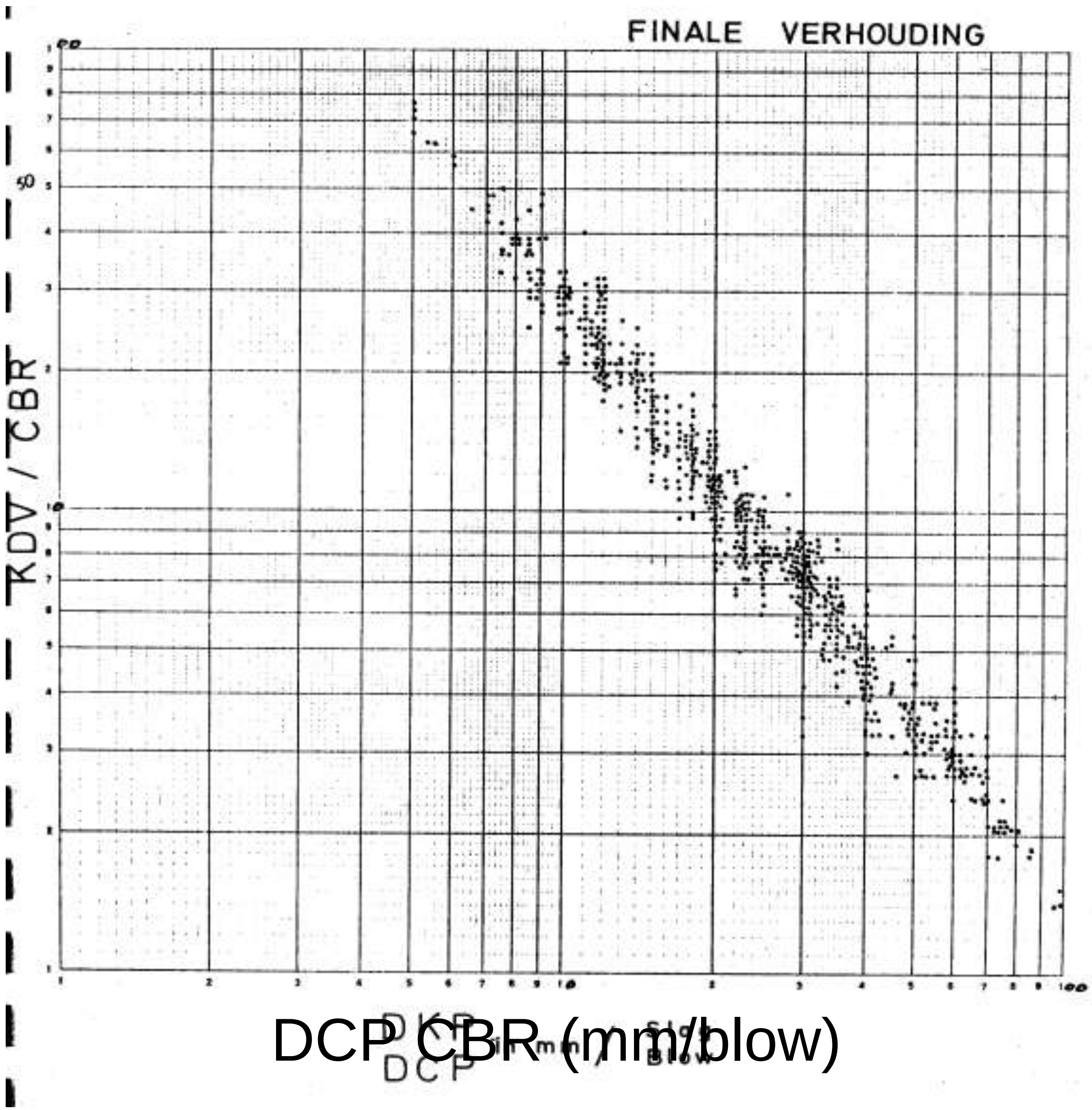
DCP Advantages and Disadvantages

- **Advantages of DCP**
  - Low cost
  - Robust
  - Quick and easy (many tests)
  - Non-destructive (almost)
  - Tests in situ condition (density, moisture, stress conditions) to a depth of 800 mm
- **Disadvantages of DCP**
  - Affected by stones
  - Affected by poor testing technique
  - More than one variable (density, moisture, material type)
  - *Outweighed by advantages*

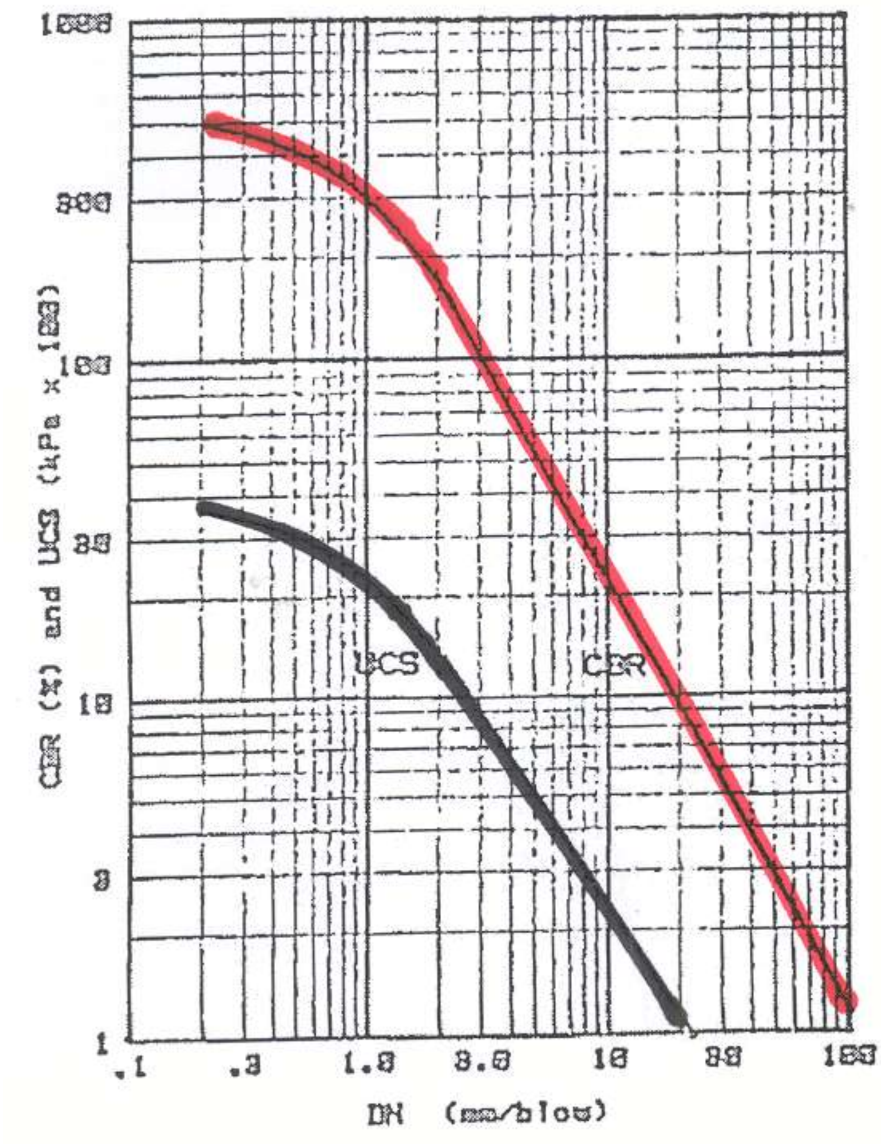
DCP – CBR Correlations

- **Initially, correlation models developed for both natural and stabilized materials based on comparative field DCP and lab CBR results**
- **Subsequent DCP testing carried out in conjunction with Heavy Vehicle Simulator (HVS) testing of various roads and allowed further correlations:**
  - **between actual road performance and DCP results**
  - **between cone penetration rate (DN) and CBR (%) and UCS (kPa)**

DCP – CBR Relationship



Relationship Between DN, CBR & UCS



If DN > 2 mm/blow

CBR = 410 x DN-1.27

(or Log CBR = 2.61 –1.27 log (DN)

If DN ≤ 2 mm/blow

CBR = (66.66xDN2)-(330xDN)+ 563.33

UCS = 2900 x DN-1.09

or UCS = 15 x CBR0.88

Effect of Moisture on DCP CBR

- Moisture content at time of testing is extremely important
- Correlations have been developed for making a general correction
  - Ignore density and material type

DCP CBR-Lab Soaked CBR Correlation

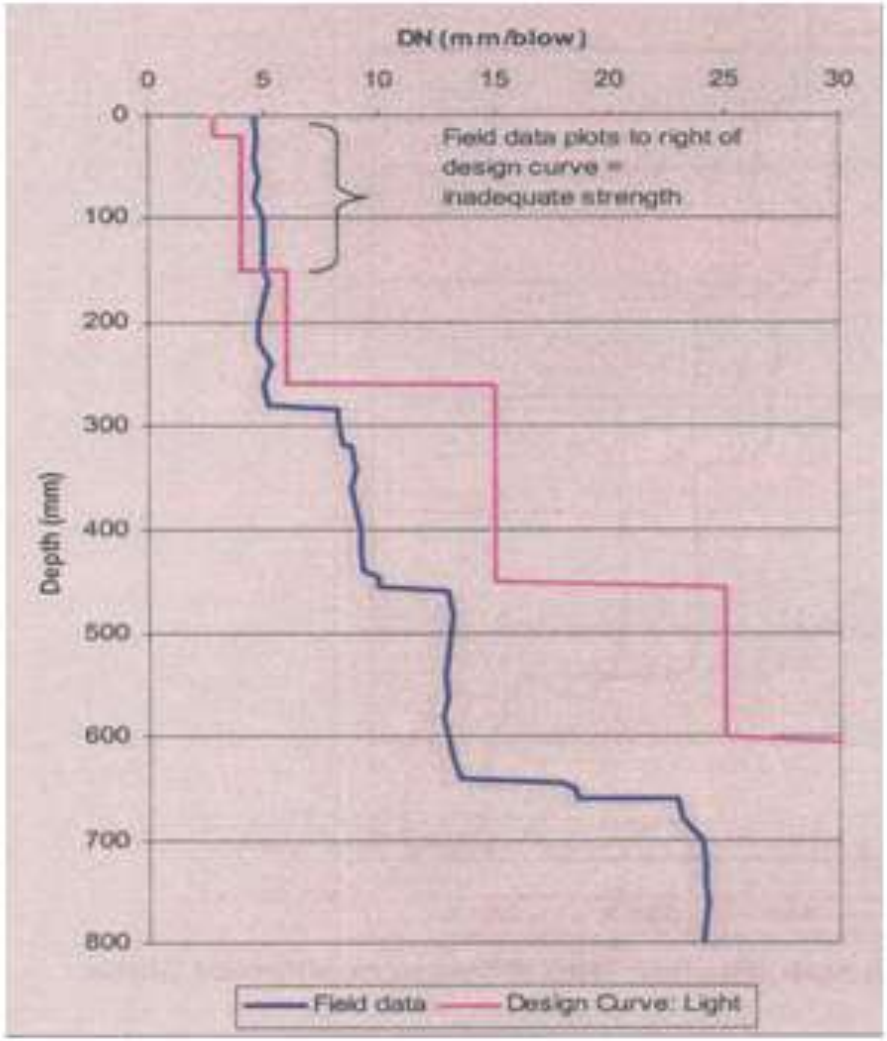
Material Classification	Soaked CBR (%)	Approximate Field DCP-CBR: Unsealed Road					
		Subgrade		Wearing Course			
		Wet Climate	Dry Climate	Very Dry State	Dry State	Moderate State	Damp State
G4 (80)	80			318	228	164	117
G5 (45)	45			244	175	126	90
G6 (25)	25	59	65	186	234	96	69
G7 (15)	15	45	50	147	106	76	54
G8 (10)	10	38	43				
G9 (7)	7	33	37				
G10 (3)	3	20	24				

Note: Moisture contents expressed as ratios of in situ Mod AASHTO OMC as follows: Very dry=0.25; Dry=0.5; Moderate=0.75; Damp=1.0

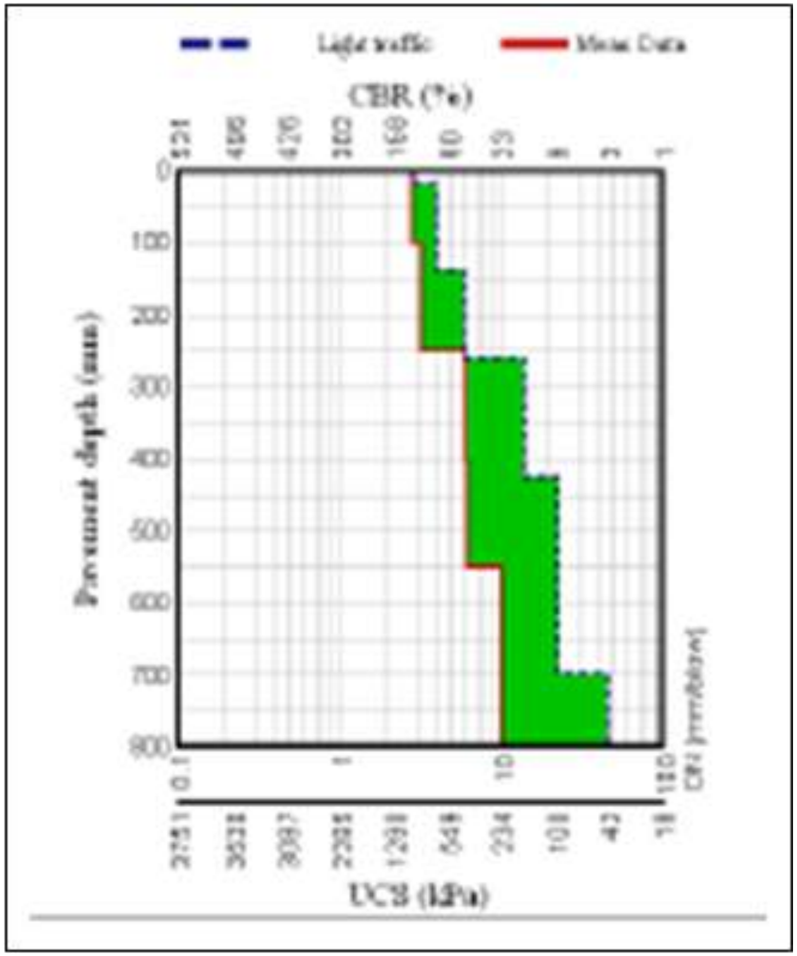
Pavement Design Methods

- DCP design method
  - Based on comprehensive method of designing lightly trafficked roads using DCP
  - Provides a light, well-balanced pavement structure for specific design traffic categories summarised in a catalogue
  - Design strength profile integrated with in situ soil strength and strength profile to optimally utilise in situ material strength

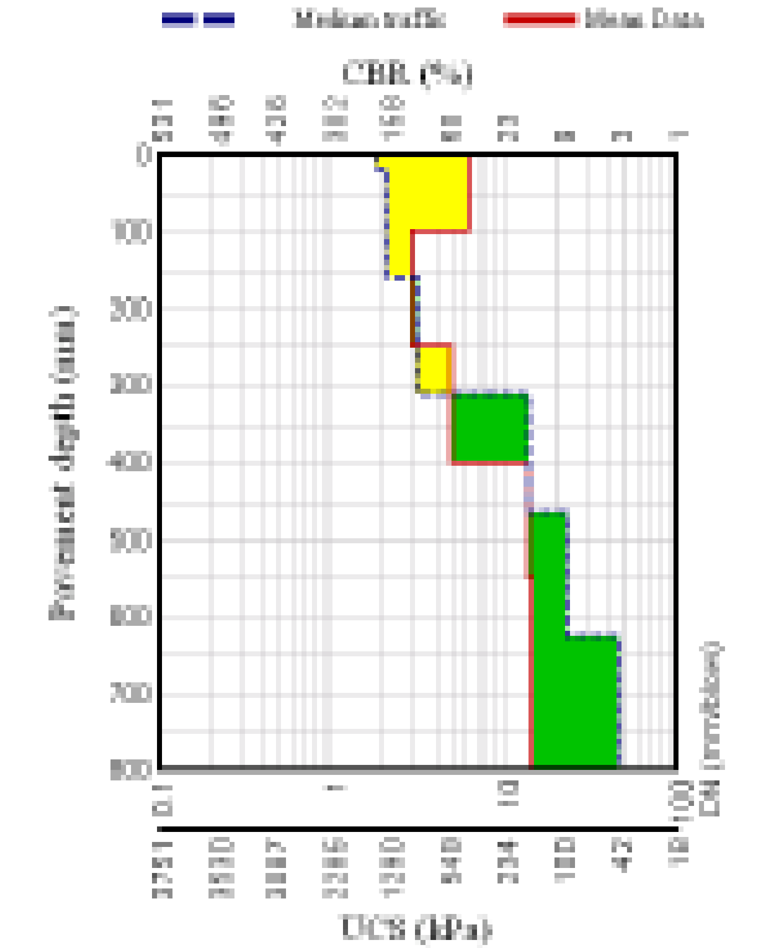
DCP Profile: Field data vs Design Curve



DCP Profiles – In situ vs Required



Pavement structure with adequate strength for lightly trafficked (< 0.2 M esa)

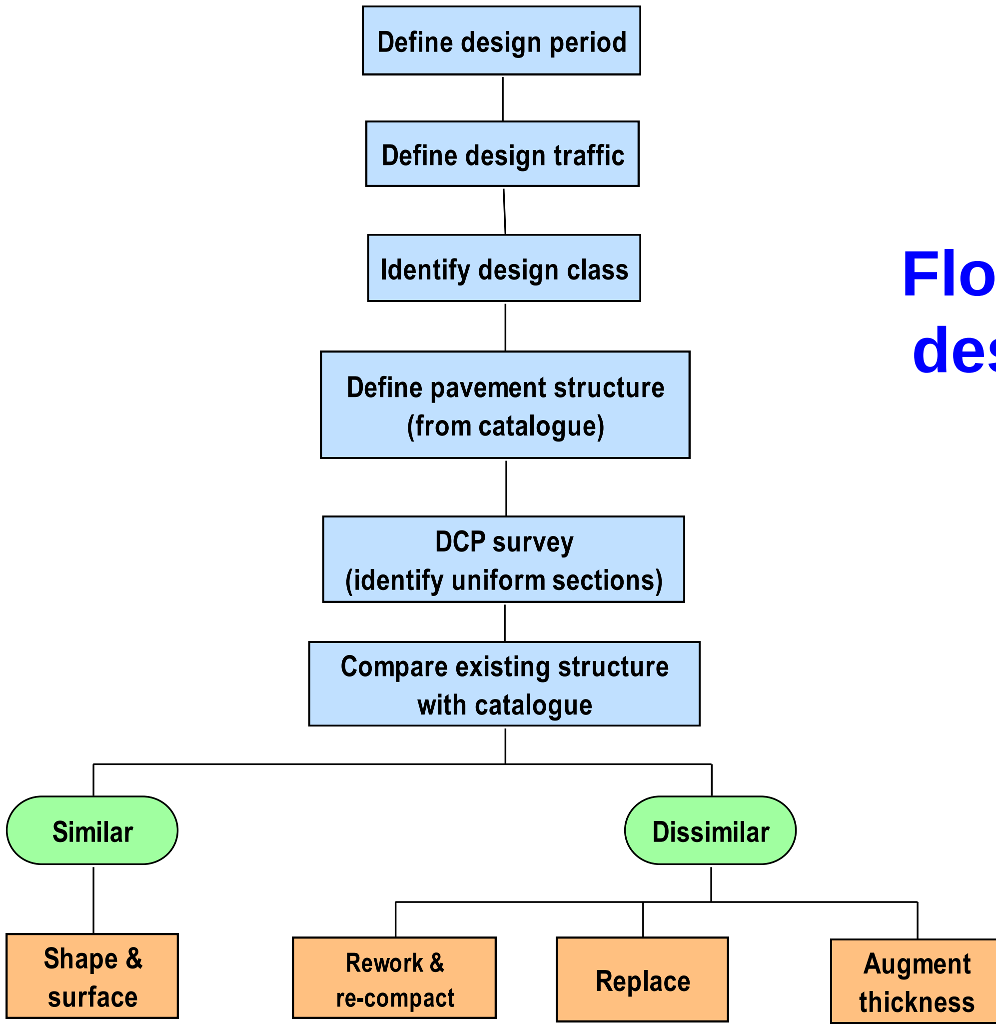


Pavement structure with insufficient structural strength in upper 300mm for medium traffic (0.2 – 0.8M esa)

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 – General Design Procedure

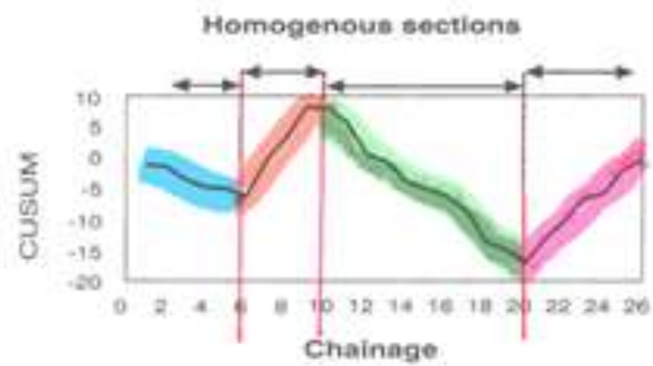


Flow diagram of design process

DCP Uniform Sections

	B	C	
Chainage [Km]	Rutting measured [mm]	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	-0,4
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		

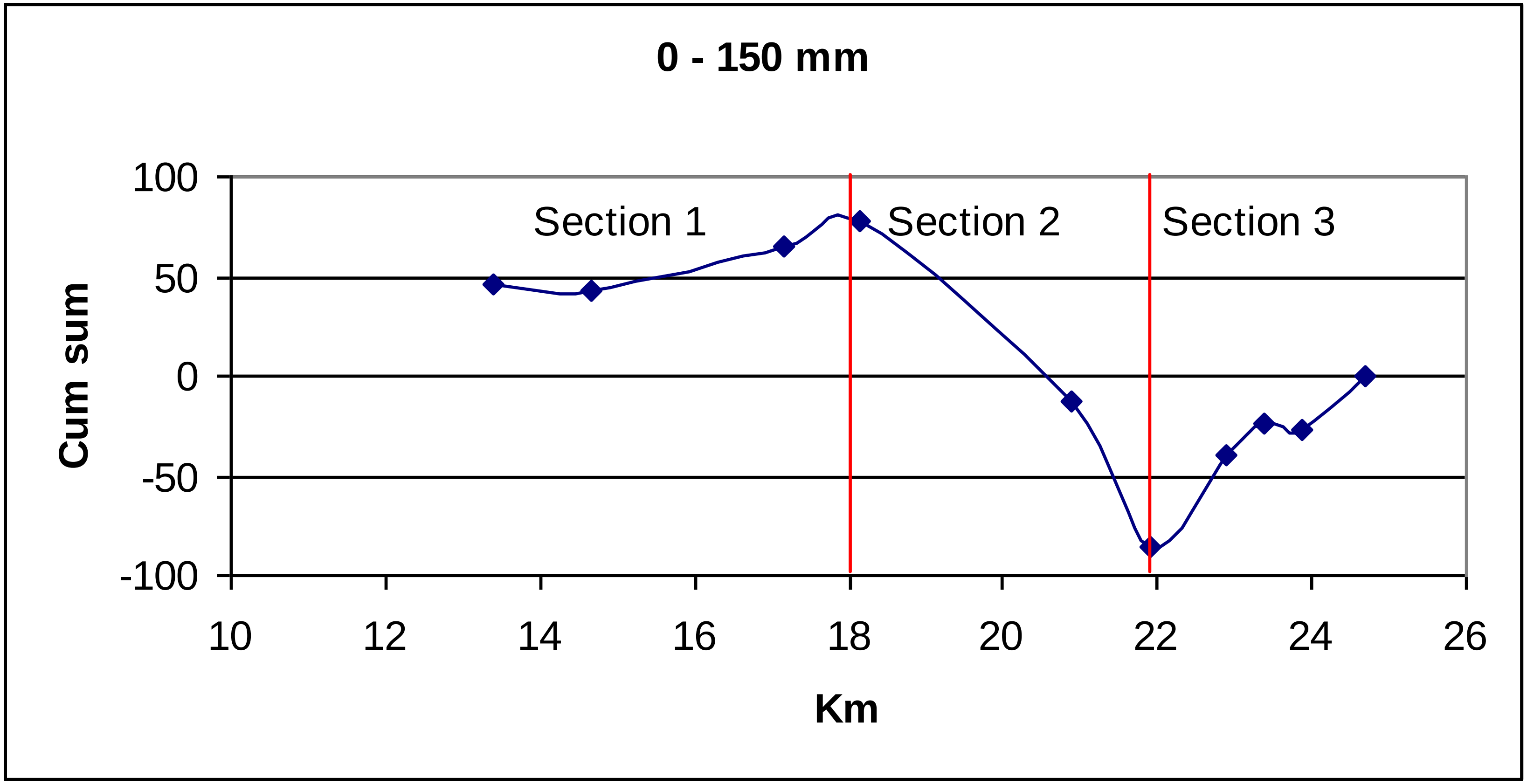
Plotting of CUSUM against Chainage



Interpretation of data:

A change of slope indicates change of conditions along the data. Four distinct homogenous sections can be seen in the above chart.

DCP Uniform Sections



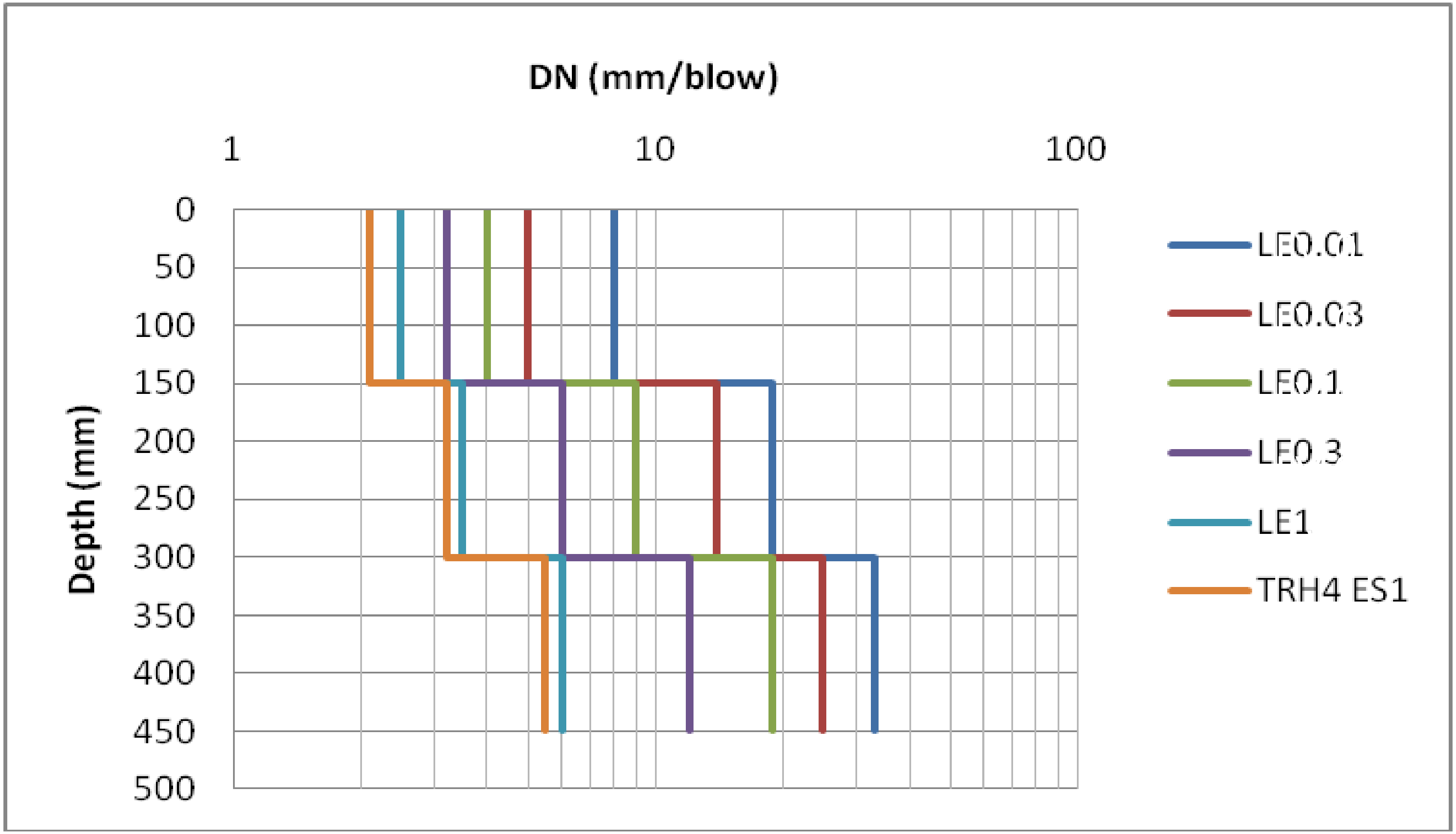
Example of Cumulative Sum plot of DCP strengths between 0 and 150 mm depth.

DCP Pavement Design Catalogue-Sealed Roads

Pavement Class E80 x 10^6	LV 0.01 0.003 – 0.010	LV 0.03 0.010 – 0.030	LV 0.1 0.030 – 0.100	LV 0.3 0.100 – 0.300	LV 1.0 0.300 – 1.000
Base 150 mm ≥ 98% BSH	DN ≤ 8	DN ≤ 5	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.5
Subbase 150 mm ≥ 95% BSH	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 3.5
Selected 150 mm ≥ 93% BSH	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 6

DCP design curves for various design traffic classes

DCP Pavement Design Catalogue-Sealed Roads



Required DCP strength profile for different traffic categories

Conclusions

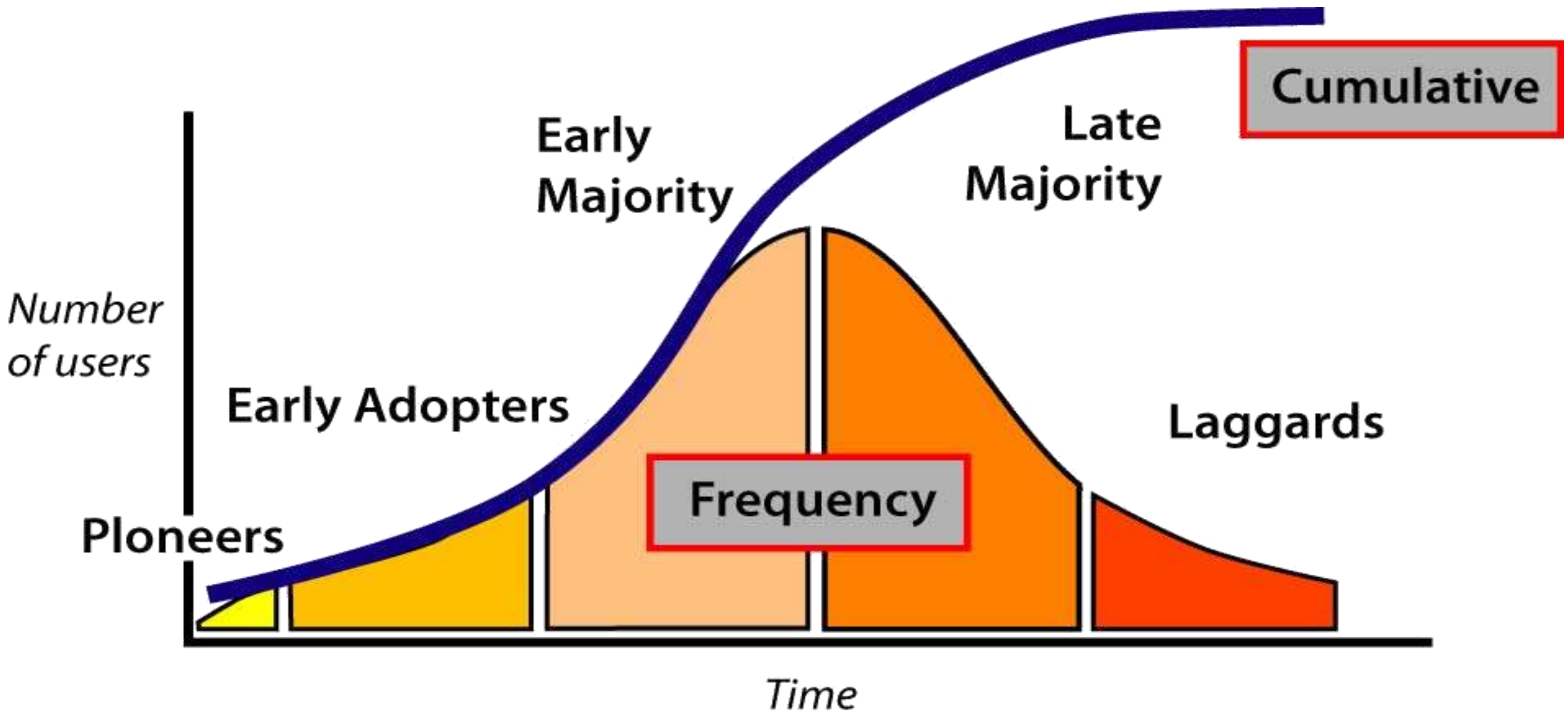
- Analysis of DCP data from unpaved sections indicate that the DCP design relatively closely predicts performance.
- Validity of back-analysis depends strongly on accuracy of traffic counts and moisture conditions assumed at time of DCP survey.
- DCP can provide all the necessary inputs for low volume road pavement design e.g. layer thicknesses, strengths, seasonal moisture changes, but:
  - Need to understand the interactions
  - Apply engineering judgement and experience

Summary

- Make use of the in situ structure as far as possible
- Existing gravel road has been compacted by traffic

DO NOT DISTURB UNNECESSARILY !!

DCP Design – Quo Vadis???



- Very difficult to make progress without making change
- Research shows that when 20 – 25% of a target population has adopted a new paradigm, the whole process becomes self-sustaining.


The End!
Thanks you for your attention