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Alternative Materials and Pavement Design Technologies for Low-volume Sealed Roads + Case Studies

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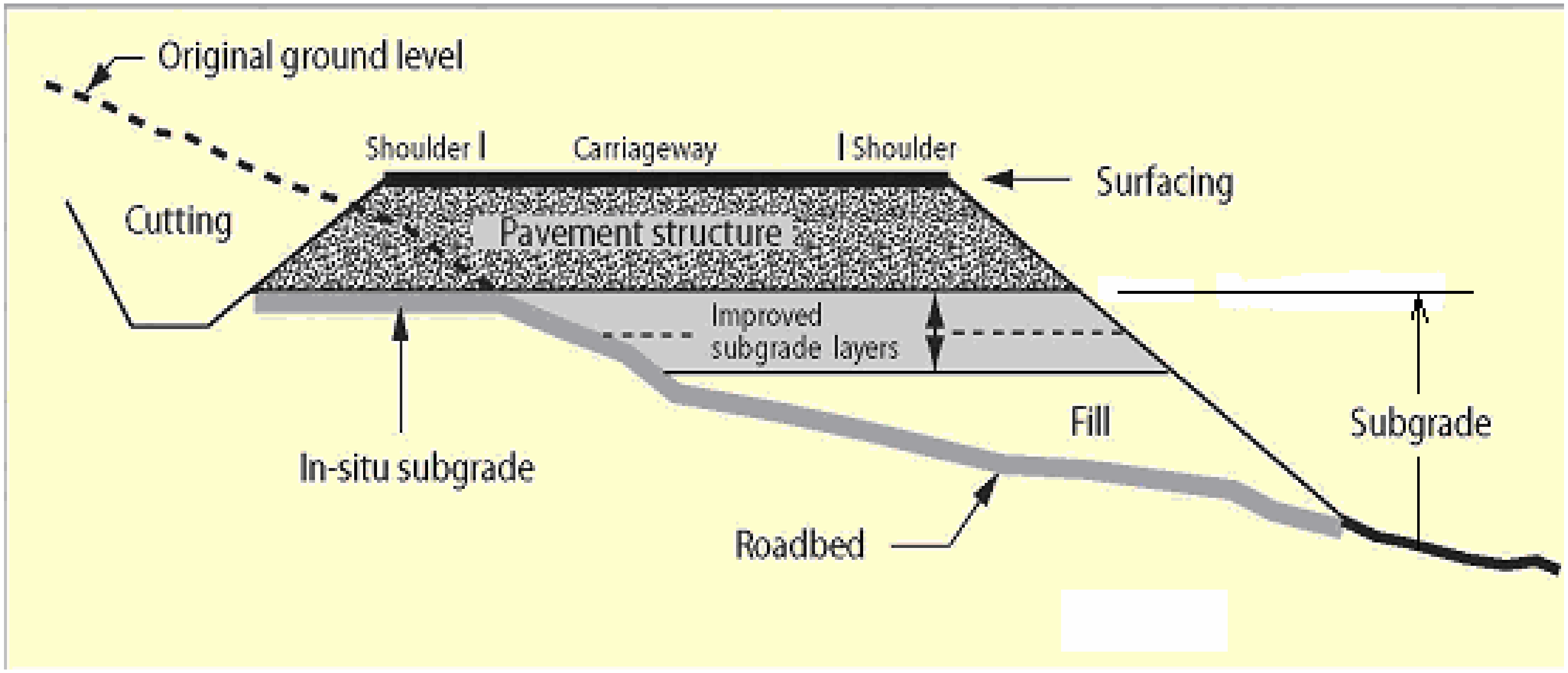
Outline of Presentation

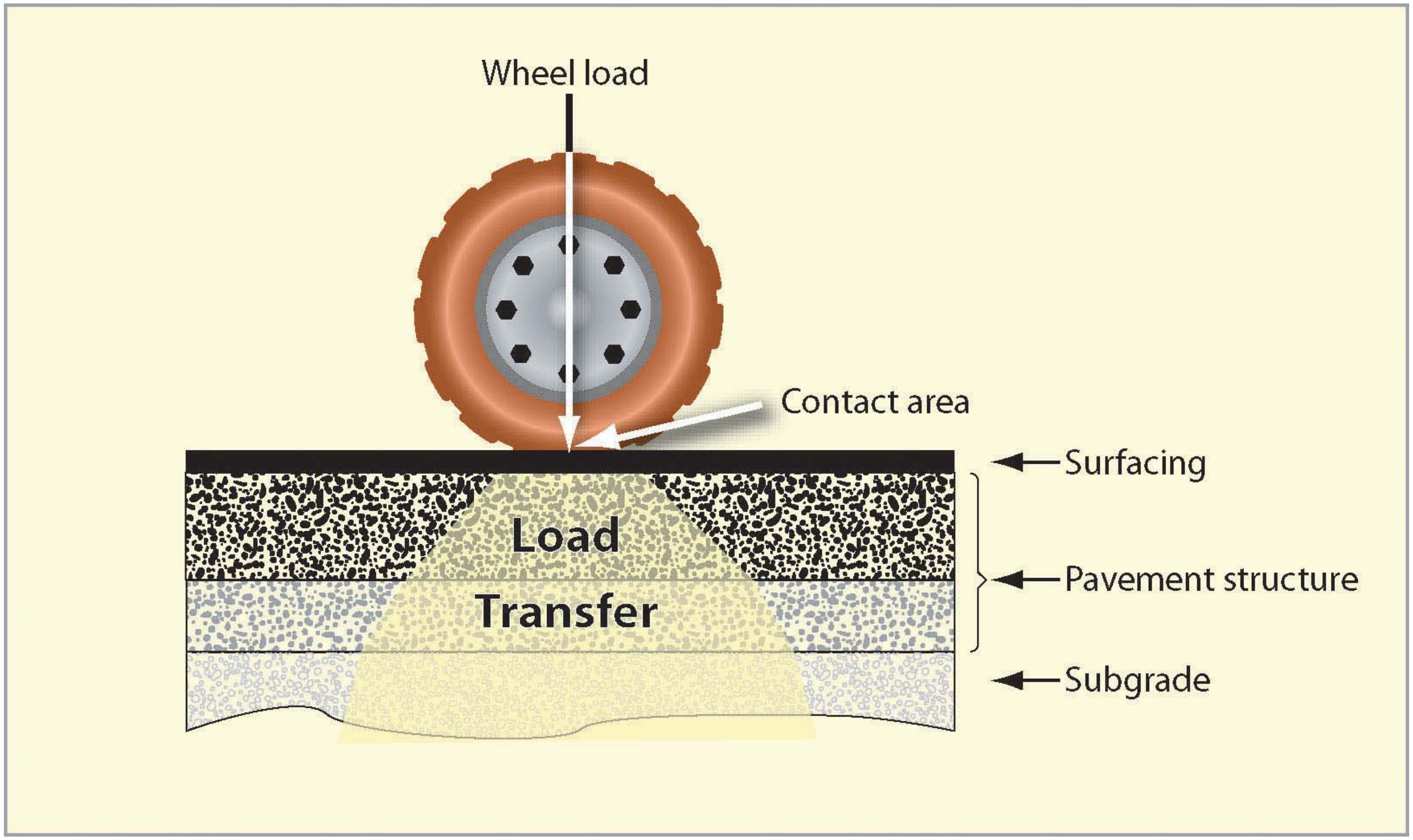
- Introduction
- Materials Issues
- Pavement design issues
- Other issues

Pavement design and materials

Pavement structure terms

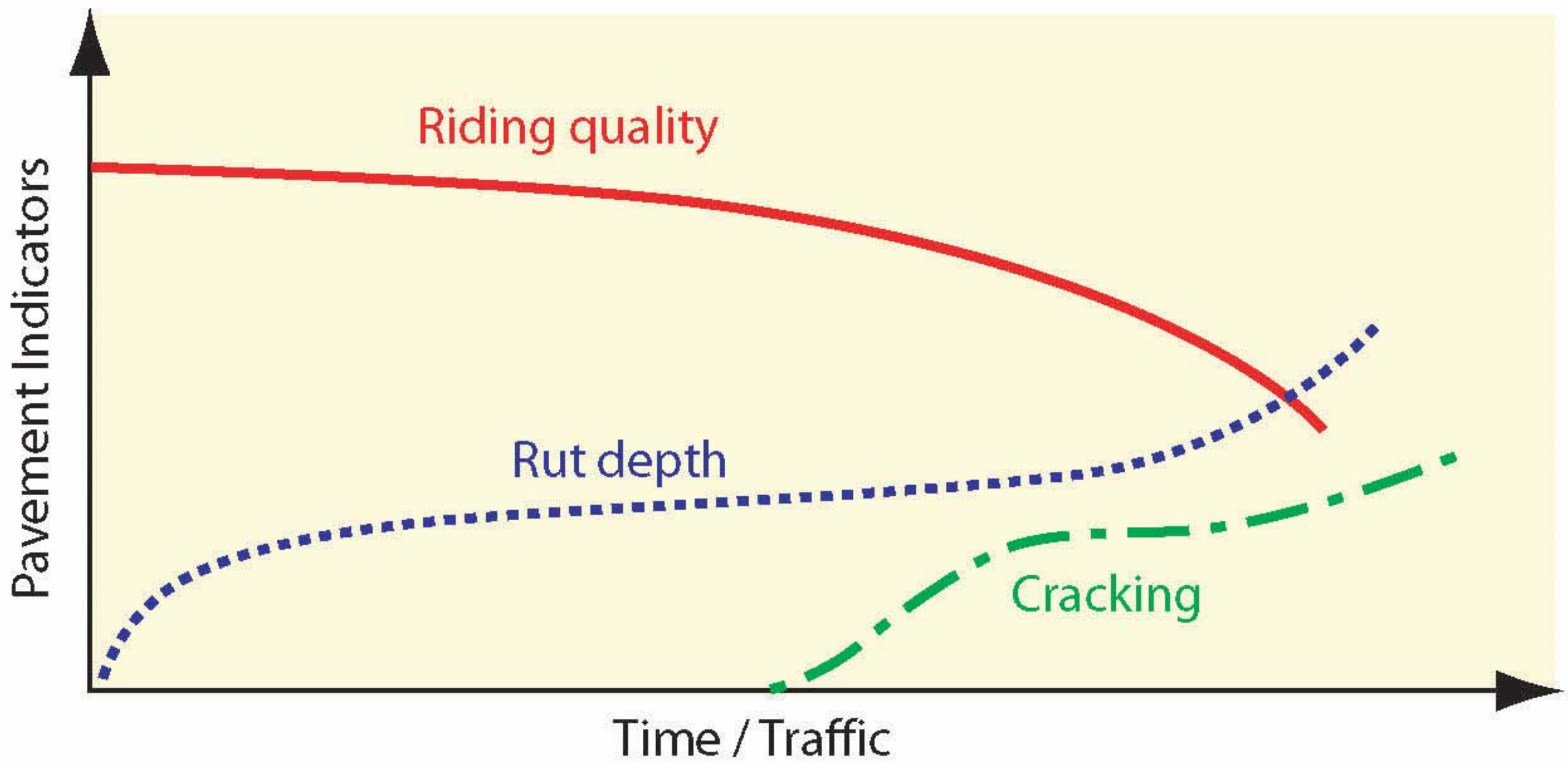


Requirements of Pavement structure



Spread of wheel load through pavement structure

Pavement performance



Generalised pavement behaviour characteristics and indicators

Examples

Challenge of Using Natural Gravels

- Materials typically make up 70% of total cost of LVSR
- 90% of problems occurring on LVSRs are materials related
- Overwhelming need to be knowledgeable about use of local materials
  - Tend to be variable and moisture sensitive – require use of appropriate designs, construction techniques and drainage measures
  - Standard methods of test (e.g. CBR) often do not provide true assessment of performance
  - Conventional specs apply to “ideal” materials and preclude use of many natural gravels (grading, plasticity, strength)
- **Local road building materials often “non-standard”compared with temperate climate materials. Disparagingly referred to as “marginal”, “low cost”, etc.**
- Regional research work has allowed revised specs to be derived for major groups of natural gravel materials found in region.

Examples

Materials Options

Pavement design and materials

The challenge

- Existing pavement design methods cater to relatively high volumes of traffic with damaging effect quantified in terms of esa. In contrast, main factors controlling deterioration of LVRs are dominated by *the local road environment and details of design (drainage), construction and maintenance practice.*
- Conventional specs apply to “ideal” materials
- Standard methods of test do not always give a true assessment of performance of local materials

Pavement design and materials

Materials and specs

- **SADC road building materials mostly derived from weathering and pedogenesis**
- **Each group has a characteristic range of properties and potential problems which should be taken into account by test methods and specs**
- **Conventional specs often unnecessarily restrictive and can result in costly failures as well as over-conservative , uneconomic designs**
- **Specs tied directly to test methods used in carrying out research work – dangerous to mix.**

Traditional specifications for base gravels typically specify a soaked CBR @ 98% MAASHO of 80%, PI of <6 and adherence to a tight grading envelope. However, research in the region has shown that when due consideration is given to factors such as traffic, subgrade strength, drainage, pavement cross-section, etc, substantial relaxations can be made on selection criteria with significant cost savings

Pavement design and materials

Using local materials

“ The art of the roads engineer consists for a good part in utilising 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 (“resource based” specs)

Pavement material characteristics

- **Material strength derived from combination of:**

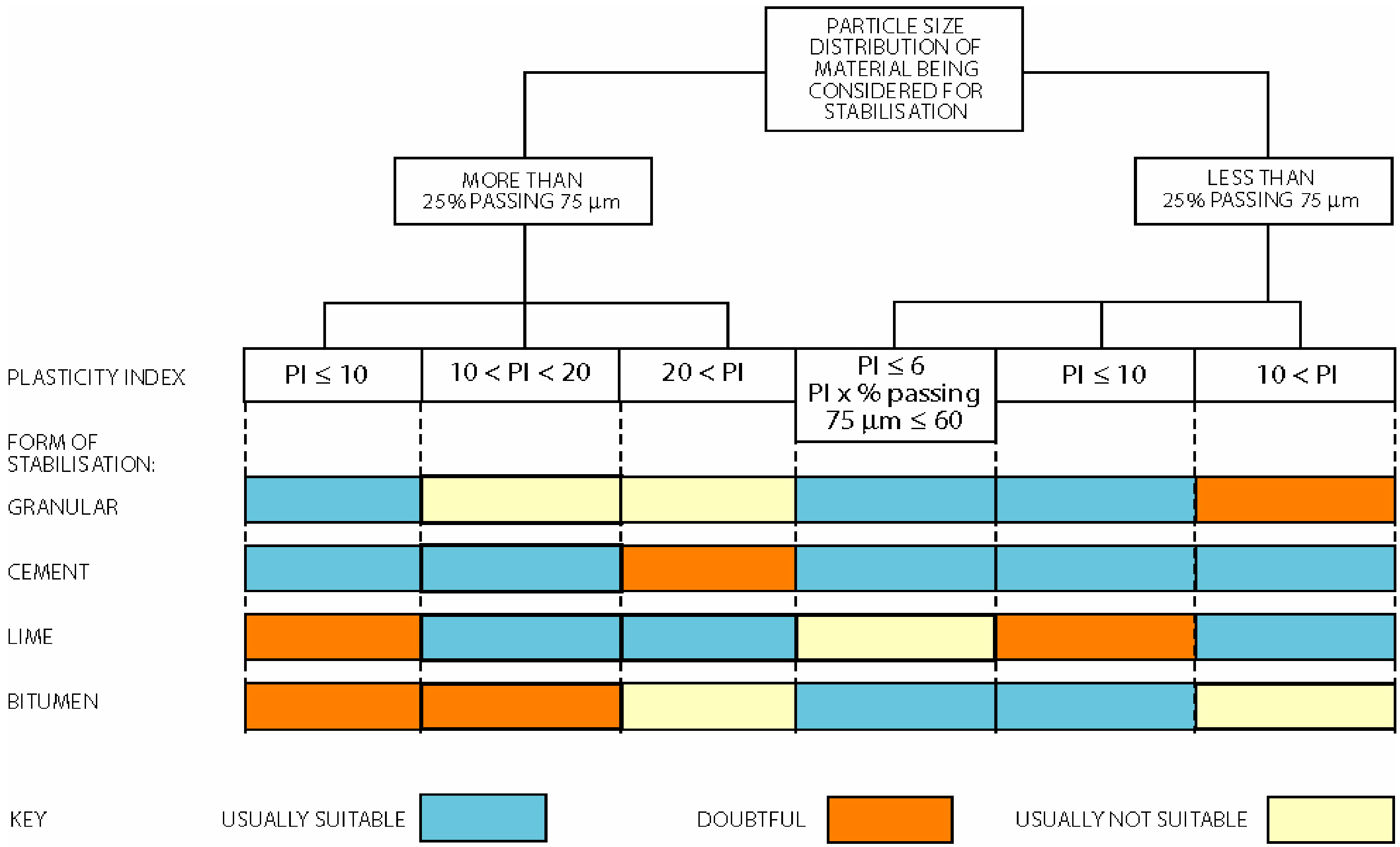
- cohesive effects
- soil suction
- physio-chemical (stab) forces
- inter-particle friction

- **Material selection influenced by:**

- traffic loading
- environment
- material properties (plastic mod)
- pavement configuration

Parameter	Pavement Type			
	Unbound			Bound
	Unprocessed	Processed	Highly processed	Very highly processed
Material Types	As-dug gravel	Screened gravel	Crushed rock	Stabilised gravel
Variability	High	Decreases		Low
Plastic Modulus	High	Decreases		Low
Development of shear strength	Cohesion and suction.	Cohesion, suction and some particle interlock.	Particle interlock.	Particle interlock and chemical bonding.
Susceptibility to moisture	High	Decreases		Low
Design philosophy	Material strength maintained only in a dry state.	Selection criteria reduces volume of moisture sensitive, soft and poorly graded gravels		Material strength maintained even in wetter state.
Appropriate use	Low traffic loading in very dry environment.	Traffic loading increases, environment becomes wetter		High traffic loading in wetter environments.
Cost	Low	Increases	High	High
Maintenance reliability	High	Decreases		Low

Guide to Method of Stabilisation



Use of Proprietary Chemical Additives

- Wide variety of chemical additives available including:
  - Wetting agents to improve compaction
  - Hygroscopic salts (e.g. calcium, magnesium or sodium chlorides)
  - Natural polymers (e.g. ligno sulphonates)
  - Synthetic polymer emulsions (e.g. acrylates)
  - Modified waxes
  - Sulphonated oils
  - Biological enzymes

Experience with use of Chemical Additives

- 42 products introduced in Ghana in last 10 years
- No large scale application of any product
- Some products may present some advantages but not cost effective
- Claims of most products not real

Pavement design and materials

Output of SADC research work

- **The grading envelopes for natural gravel bases are too narrow.** ***Alternative (wider) envelopes are recommended for relatively lightly trafficked roads***

- **The minimum standard of 80 per cent soaked CBR for natural gravel bases is inappropriately high for many LVSRs.** ***New limits are recommended depending on traffic, materials and climate.***

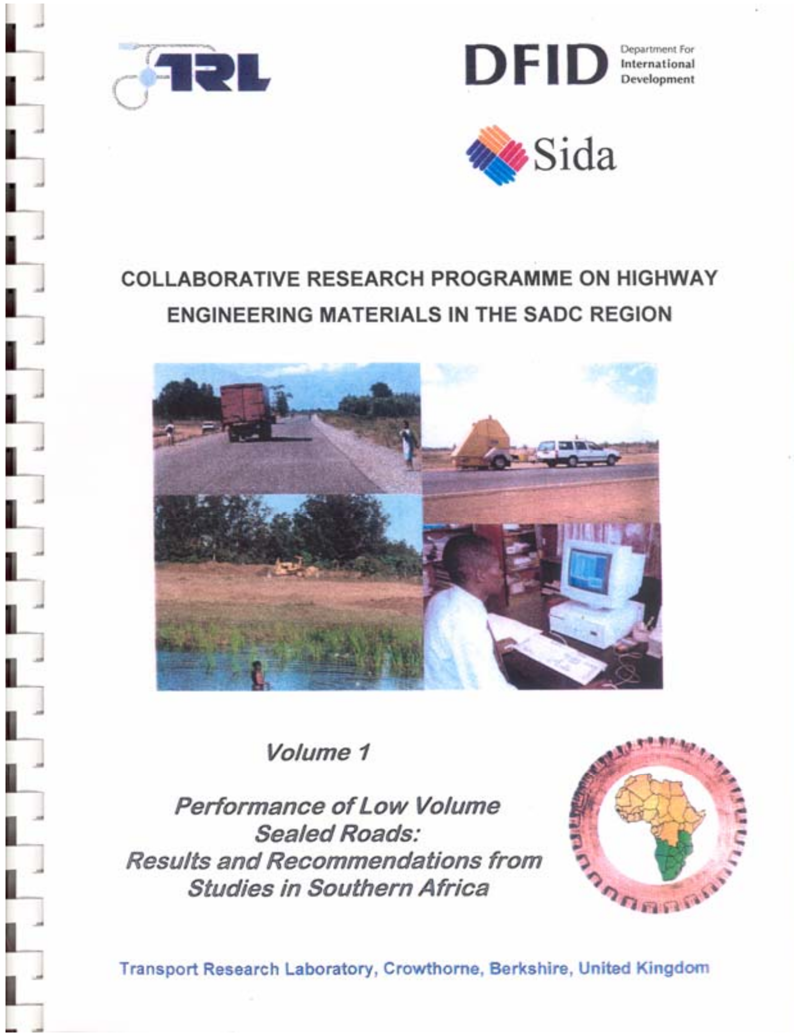
- **Traffic below 300,000 to 500,000 esa was not a significant factor on pavement deterioration. Many road sections performed well even when subjected to a high degree of overloading and with PIs up to 18.** ***New limits for PI are recommended.***

- **Drainage was a significant factor on performance, even in dry areas.** ***A minimum crown height of 0.75 m is recommended***

Extensive research has been undertaken in the SADC region over the past 20 – 30 years. This has enabled local, "non-standard" materials to be successfully incorporated in appropriate pavement designs for LVSRs.

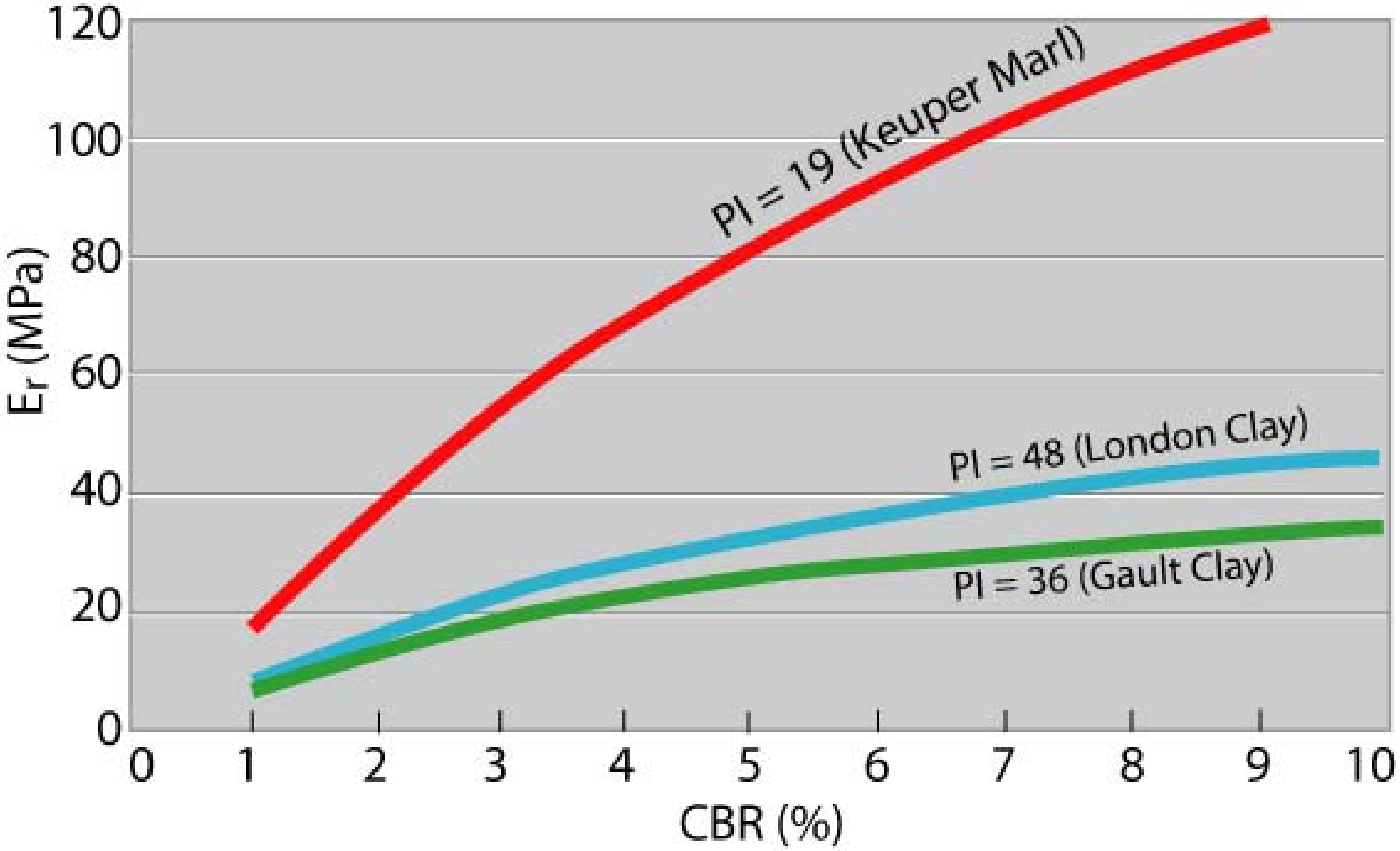
Pavement design and materials

Output of SADC research work

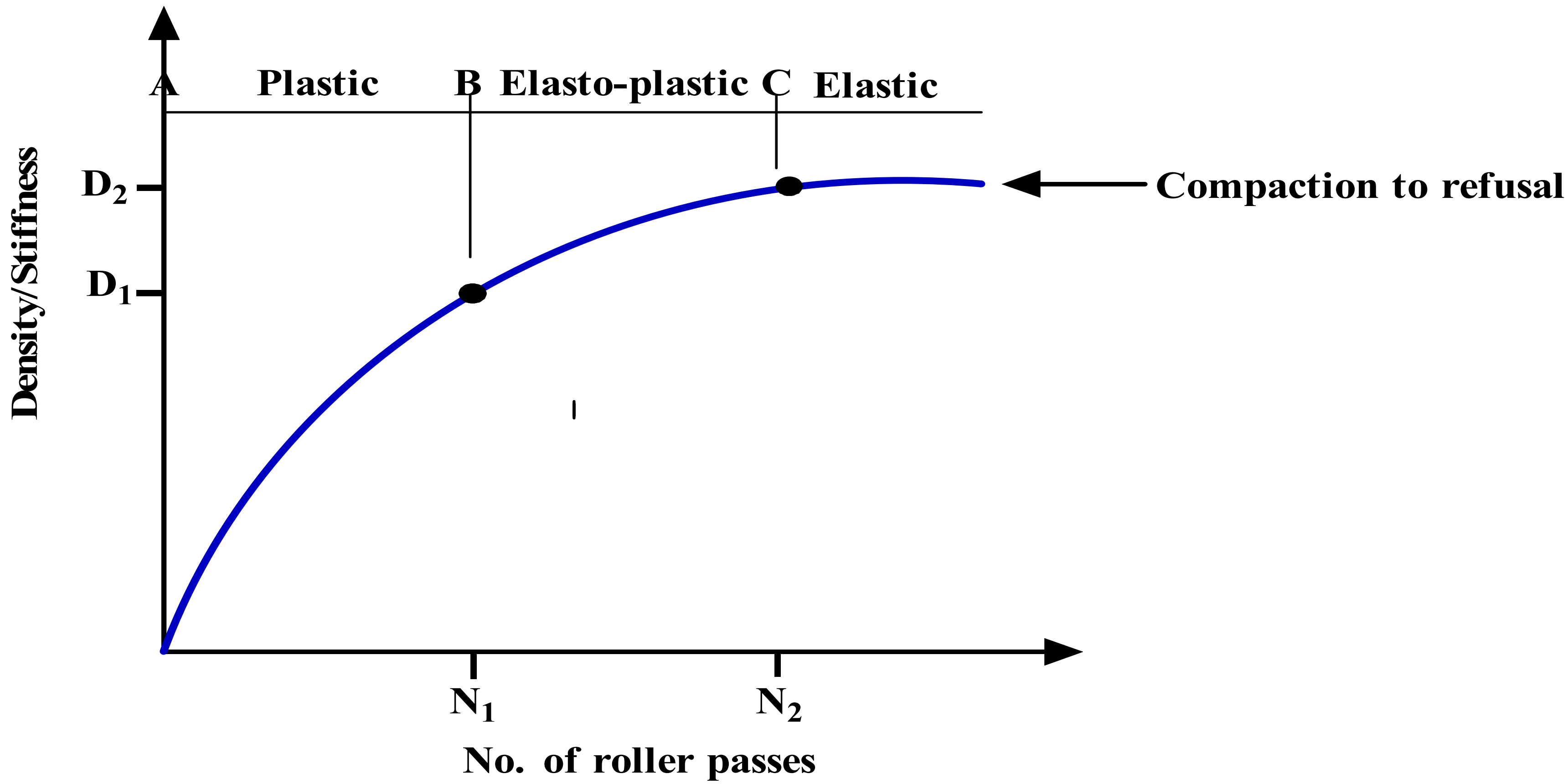


Pavement design and materials

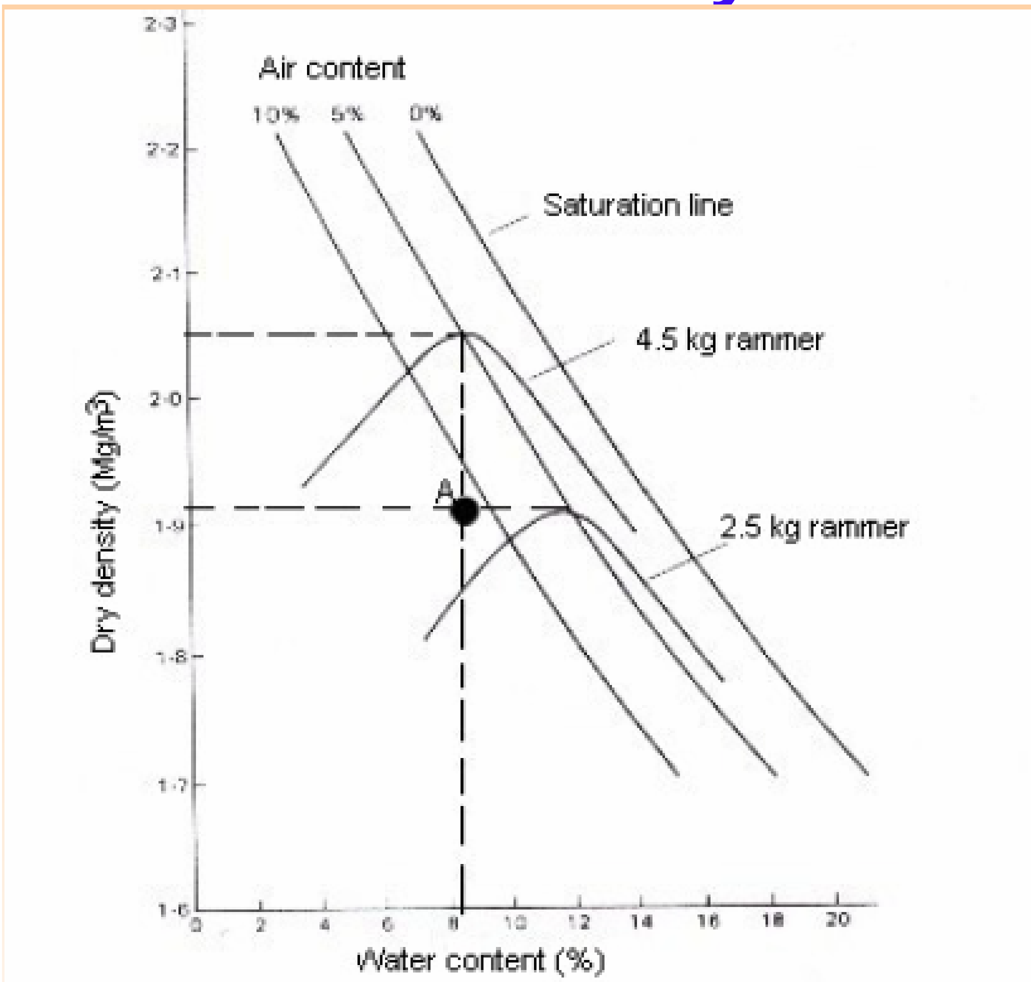
CBR versus stiffness



Compaction/density/permeability

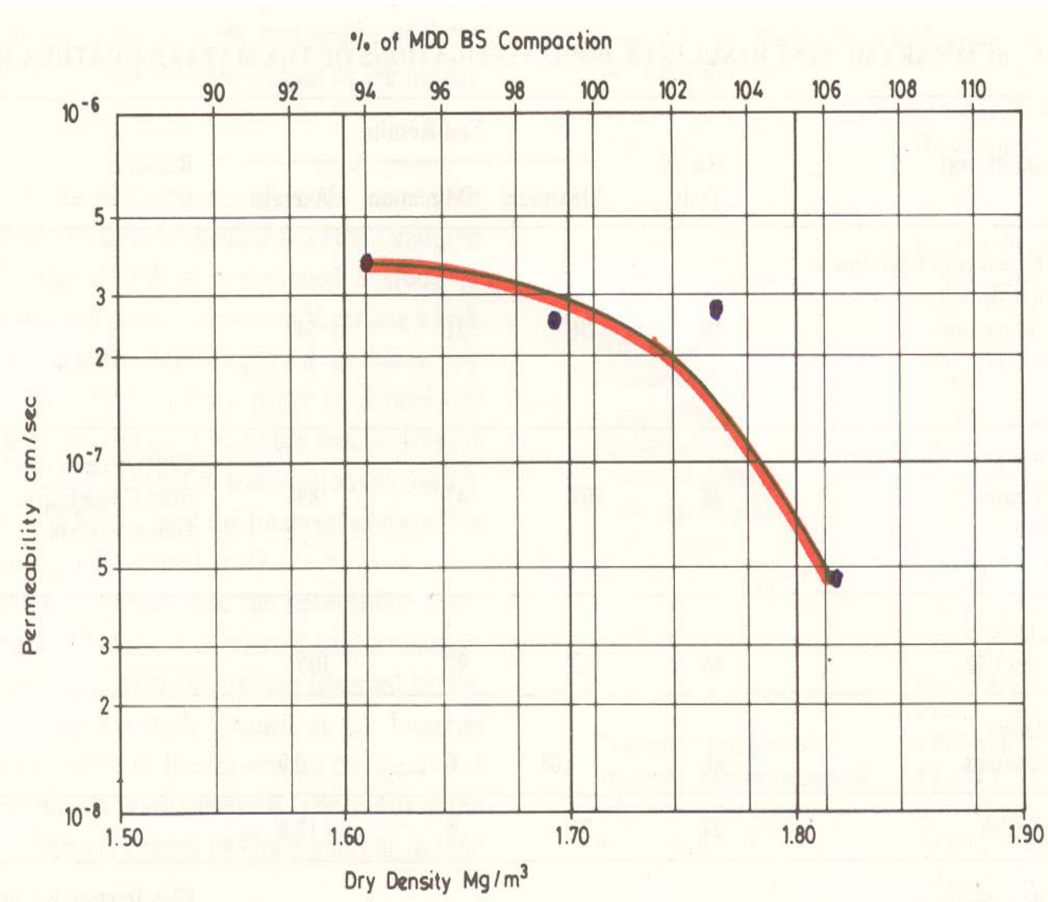


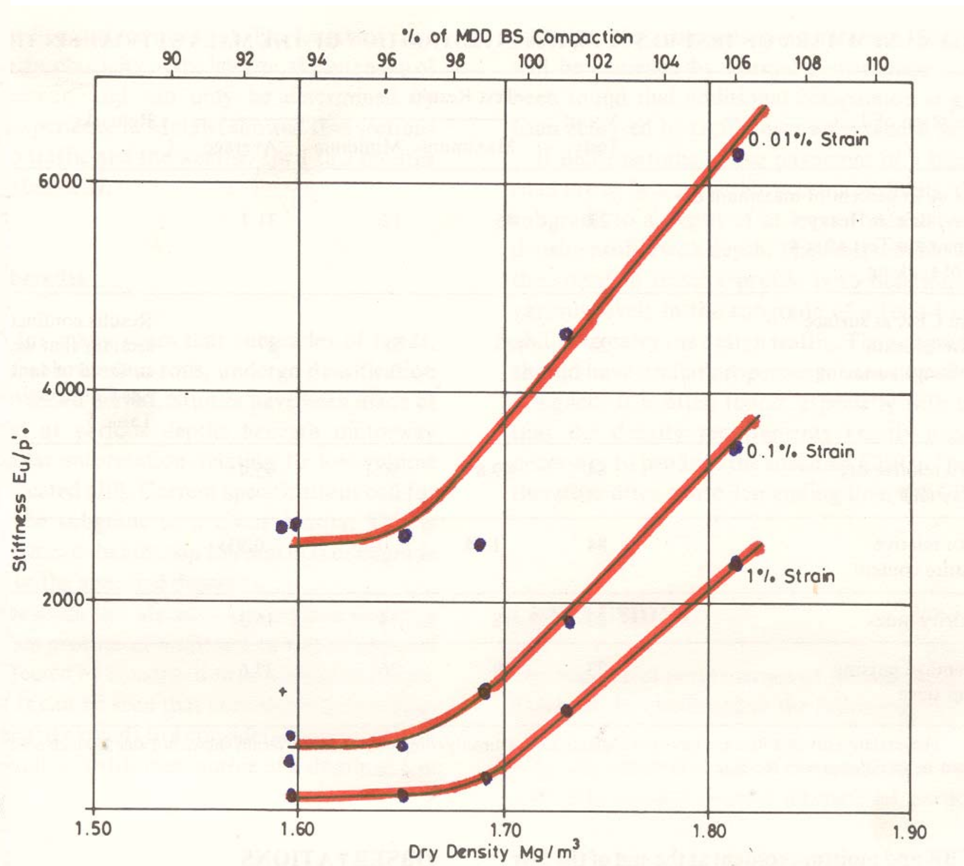
Stiffness versus density



Dry density-water content curves for different compactive efforts

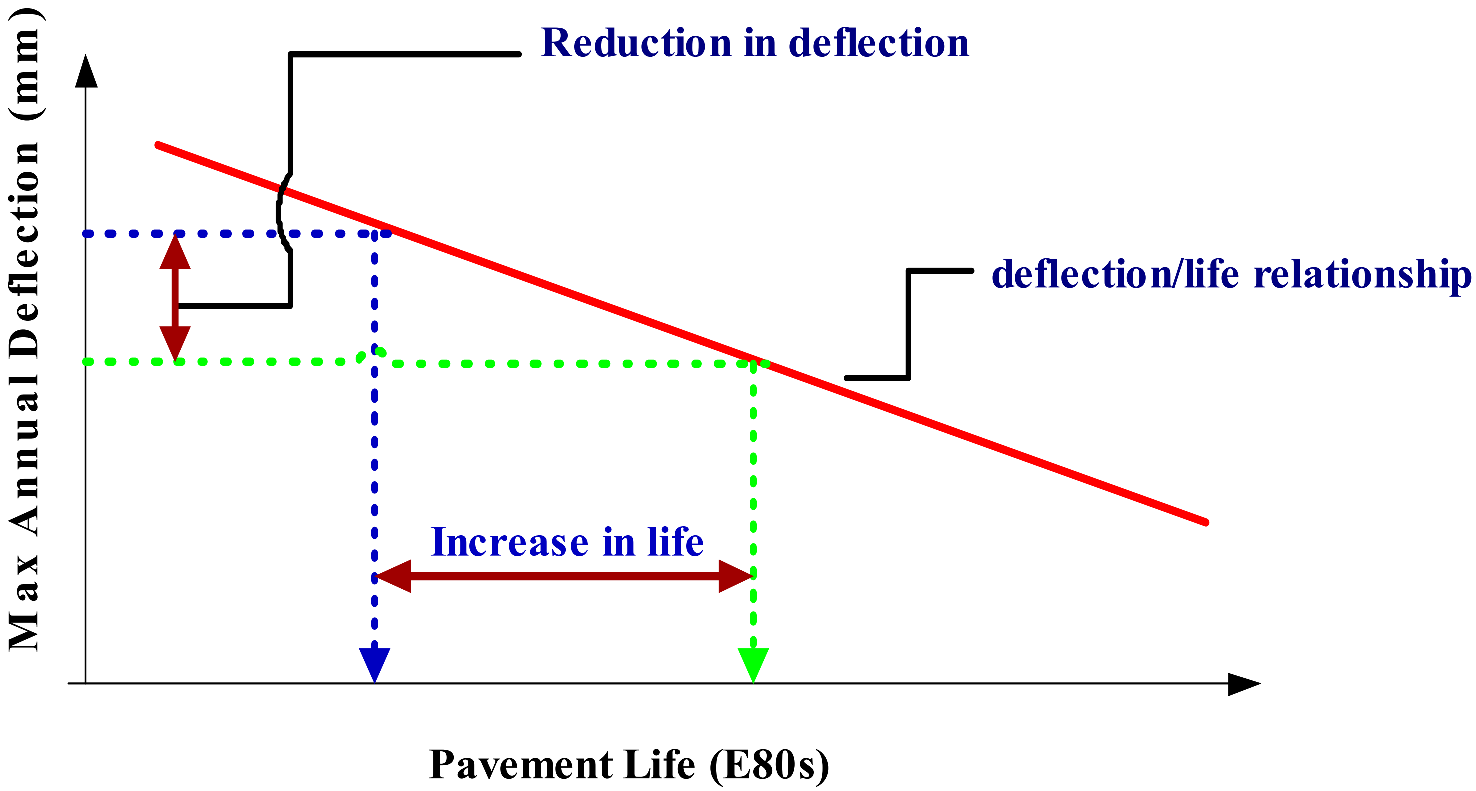
Dry density vs Permeability & Stiffness





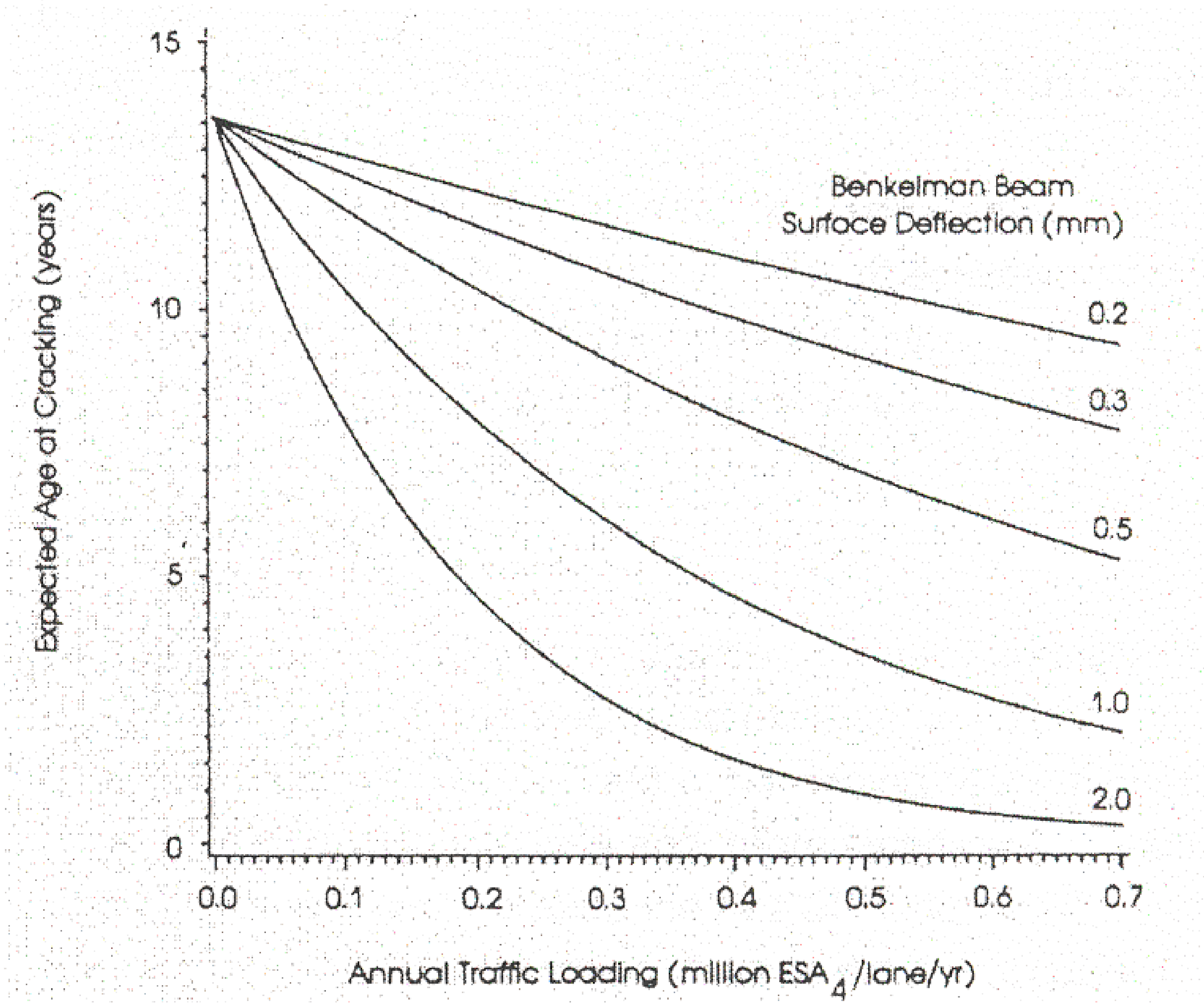
Pavement design and materials

Benefits of "Compaction to Refusal"

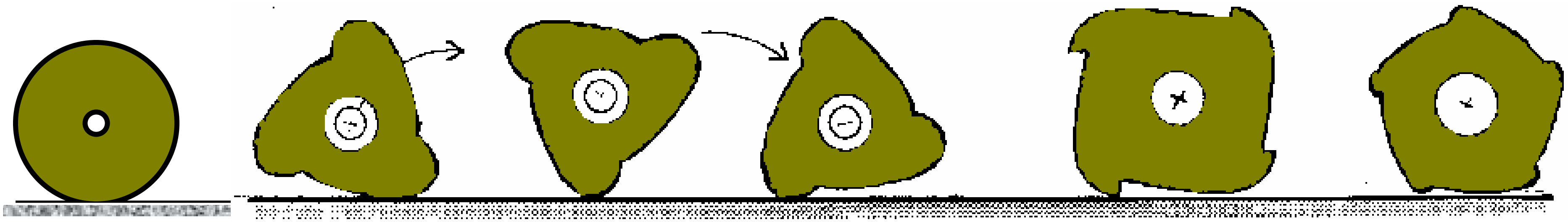


Pavement design and materials

Effect of Surface Deflection on Seal Life



Compaction Options Open to Contractor



Circular
Static/vibratory

3-sided impact

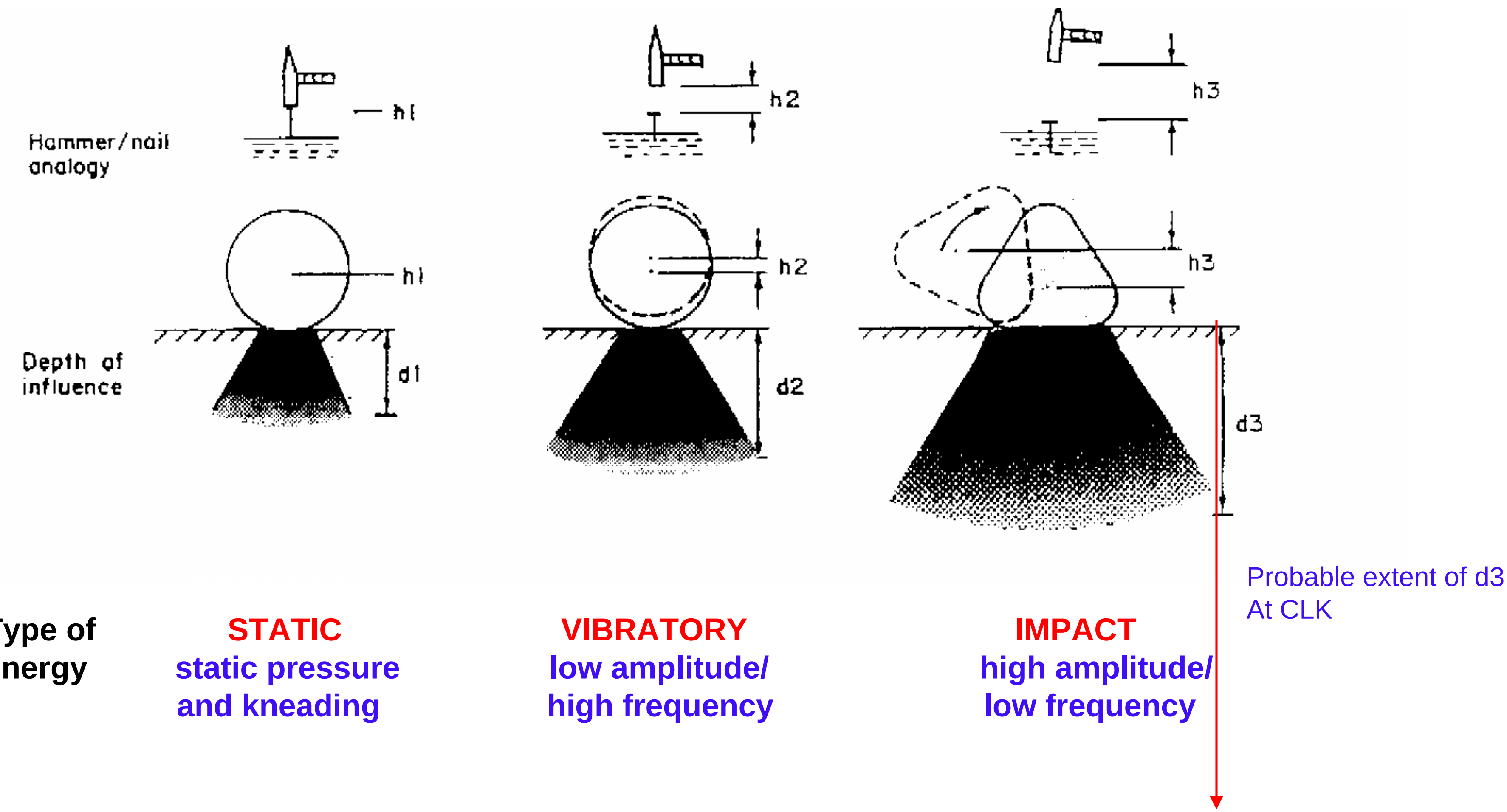
4-sided impact

5-sided
impact

(Not to scale)

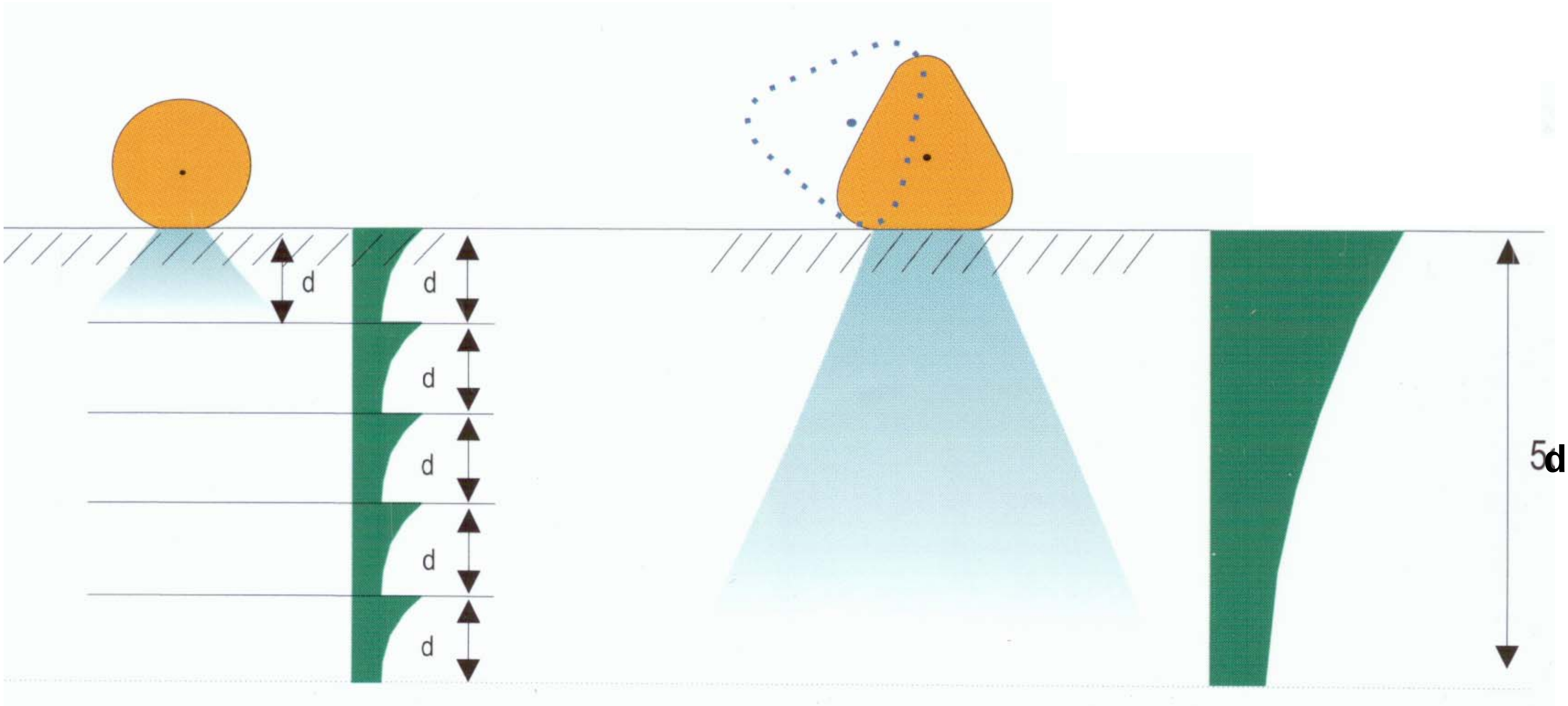
- Wide array of compaction plant offers opportunities for dealing with a wide range of soil types and conditions, including thickness of layer
- Necessary to make appropriate choice of plant as regards *energy rating* and *shape* in relation to prevailing soil conditions and layer thickness

Characteristics of Compaction Plant



Type of energy	**STATIC** static pressure and kneading	**VIBRATORY** low amplitude/ high frequency	**IMPACT** high amplitude/ low frequency

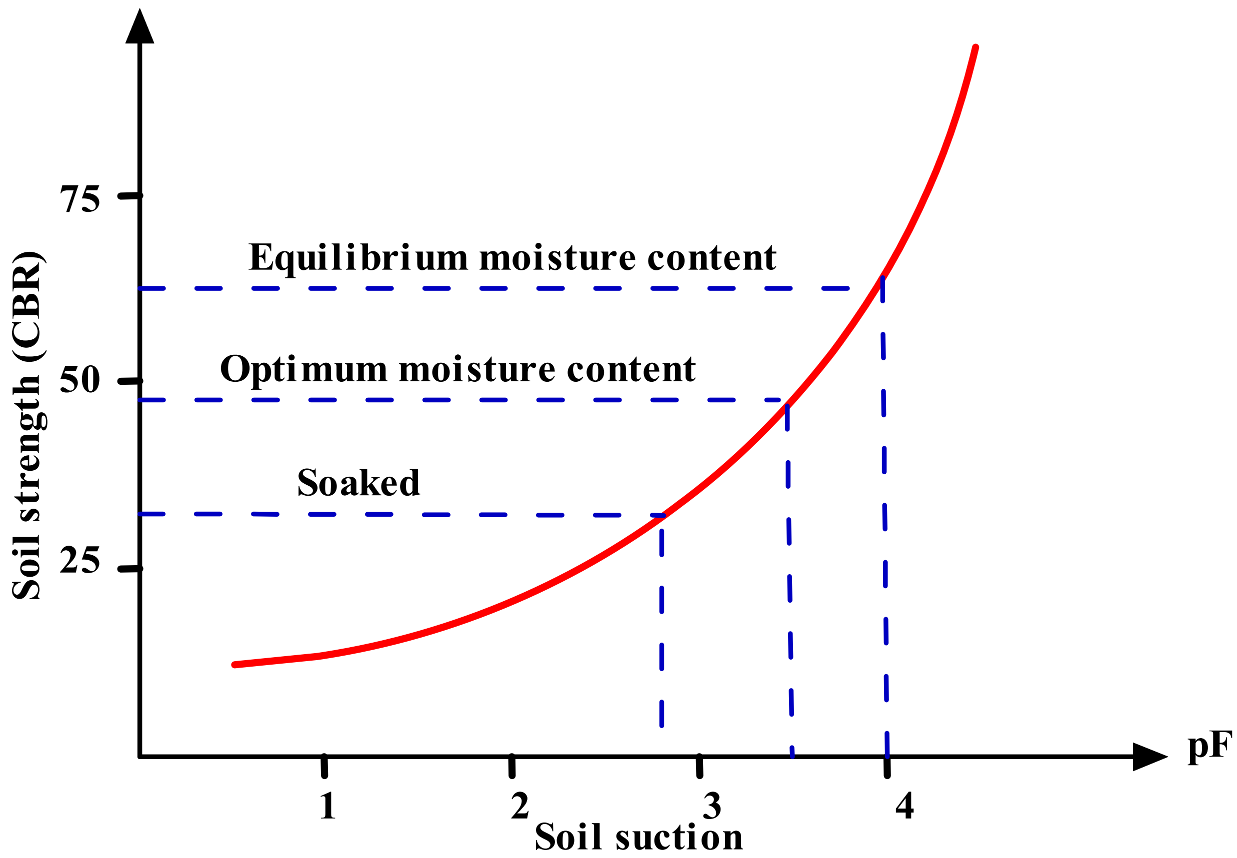
3-sided, 25 kJ impact compactor



Thin-lift, multi-layered compaction **Thick-lift, single-layer compaction**

25 kJ, 3-Sided Impact Compactor

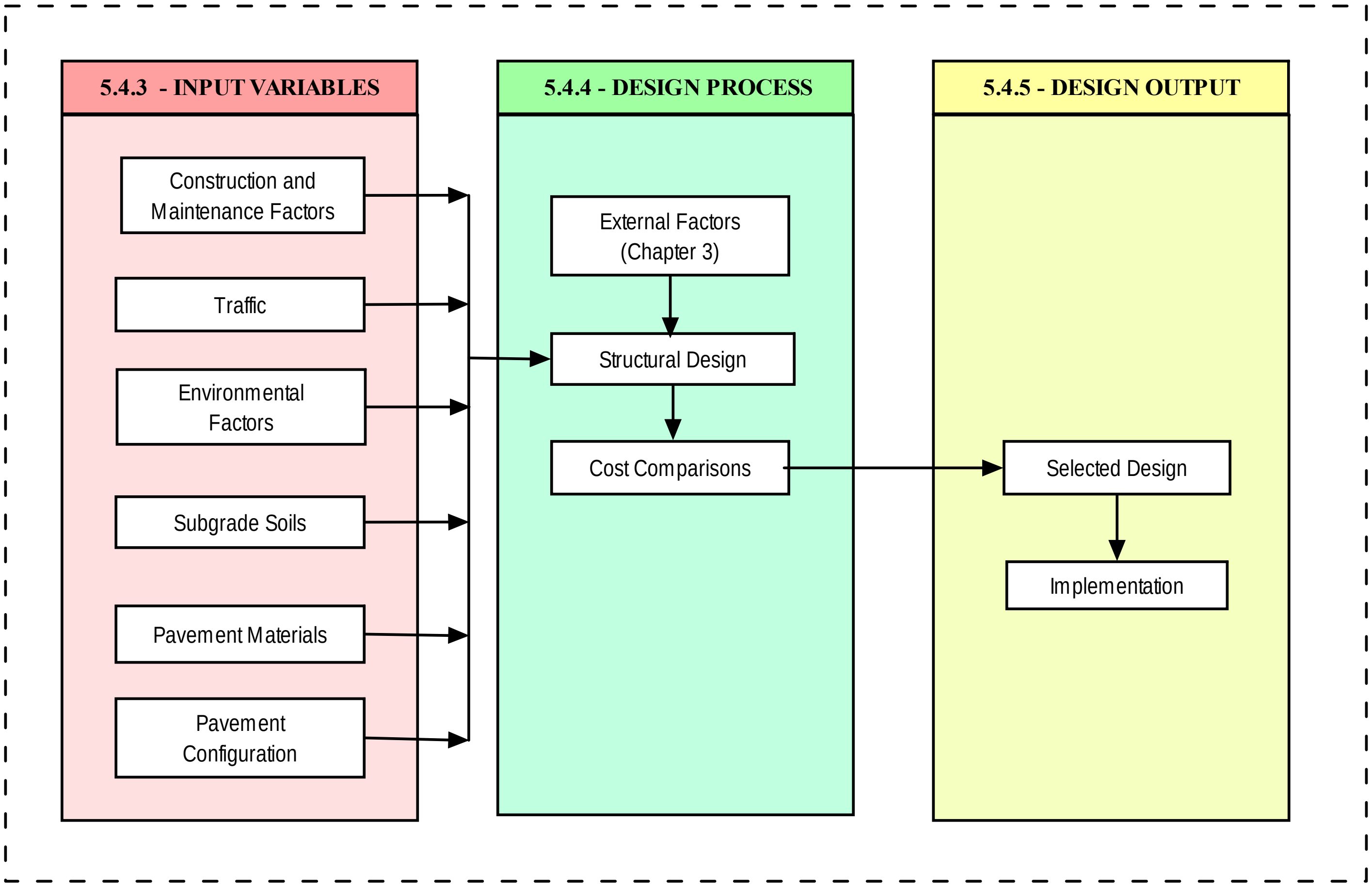
Shear strength versus soil suction



Pavement design methods

- Should be based on experience, theory, structural and material behaviour
- Should take account of local conditions of climate, traffic, available local materials, other environmental factors
- sub-grade classes: wide enough to take advantage of range od strong subgrades
- Design traffic class: wide enough to cater incrementally for traffic loadings up to 0.5 m esa
- Material classes: wide enough to cater for full range and differing properties of natural gravels
- Materials specs should be based on proven field performance in relation to traffic, subgrade design class, geo-climatic zone, etc

Pavement design system



Pavement design system

Pavement design methods

Mechanistic-Empirical Methods

- S-N Method (1993)
- TRH4 (1996)

Empirical Methods

- DCP Method
- SATCC Pavement Design Guide (1997)
- TRL/SADC Pavement Design Guide (1999)

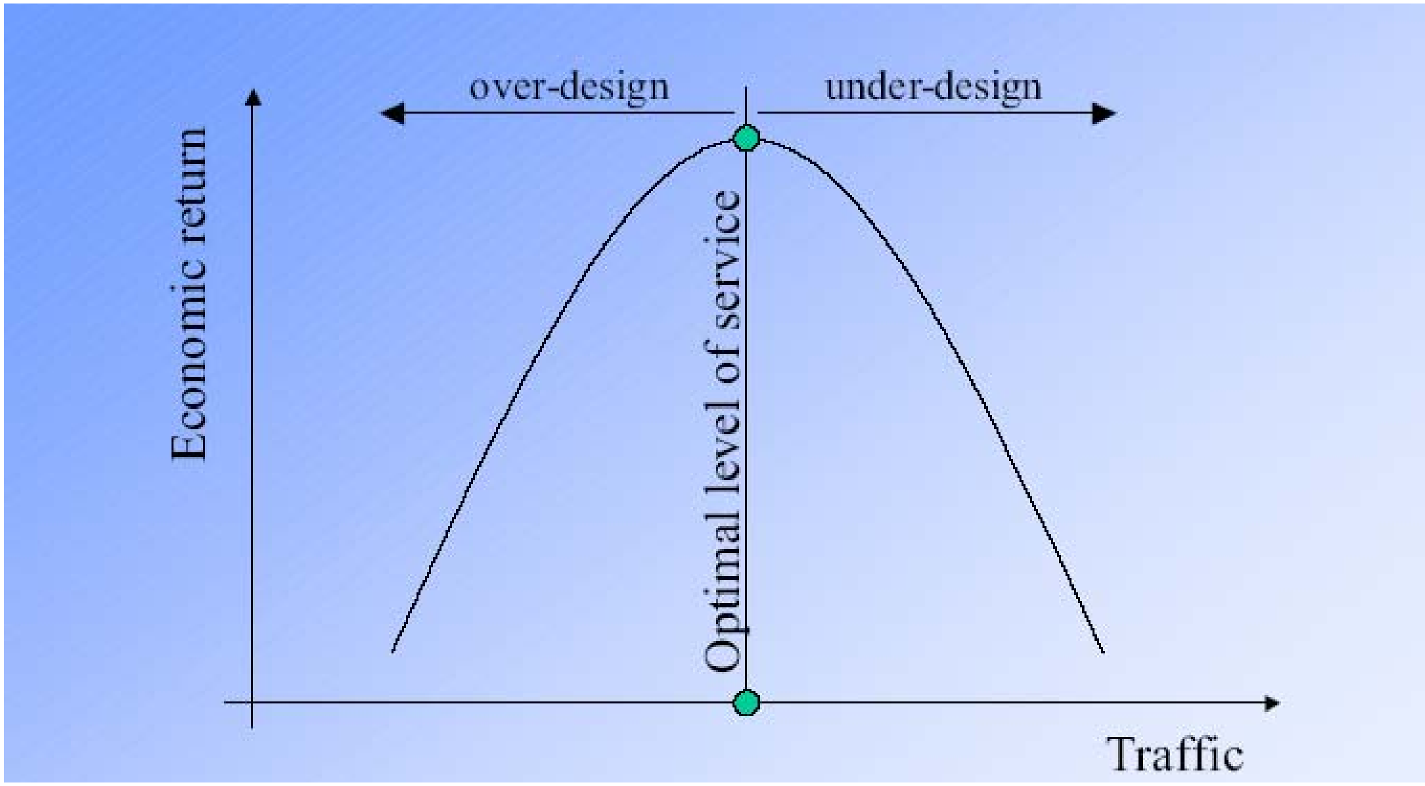
Country-specific: Zimbabwe Pavement Design Guide (1975)

Botswana Roads Design Manual(1982)

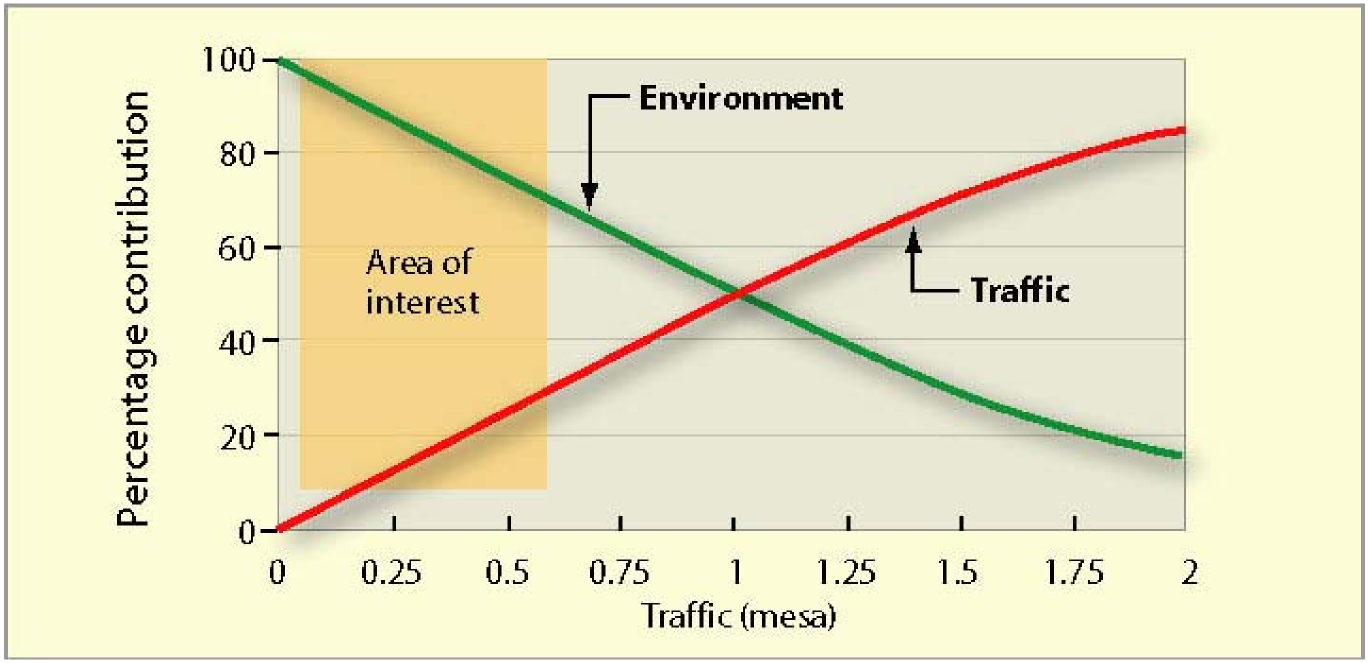
Tanzania Pavement and Materials Design Manual (1999)

South African Provincial Design Guides

Environmentally Optimised Design



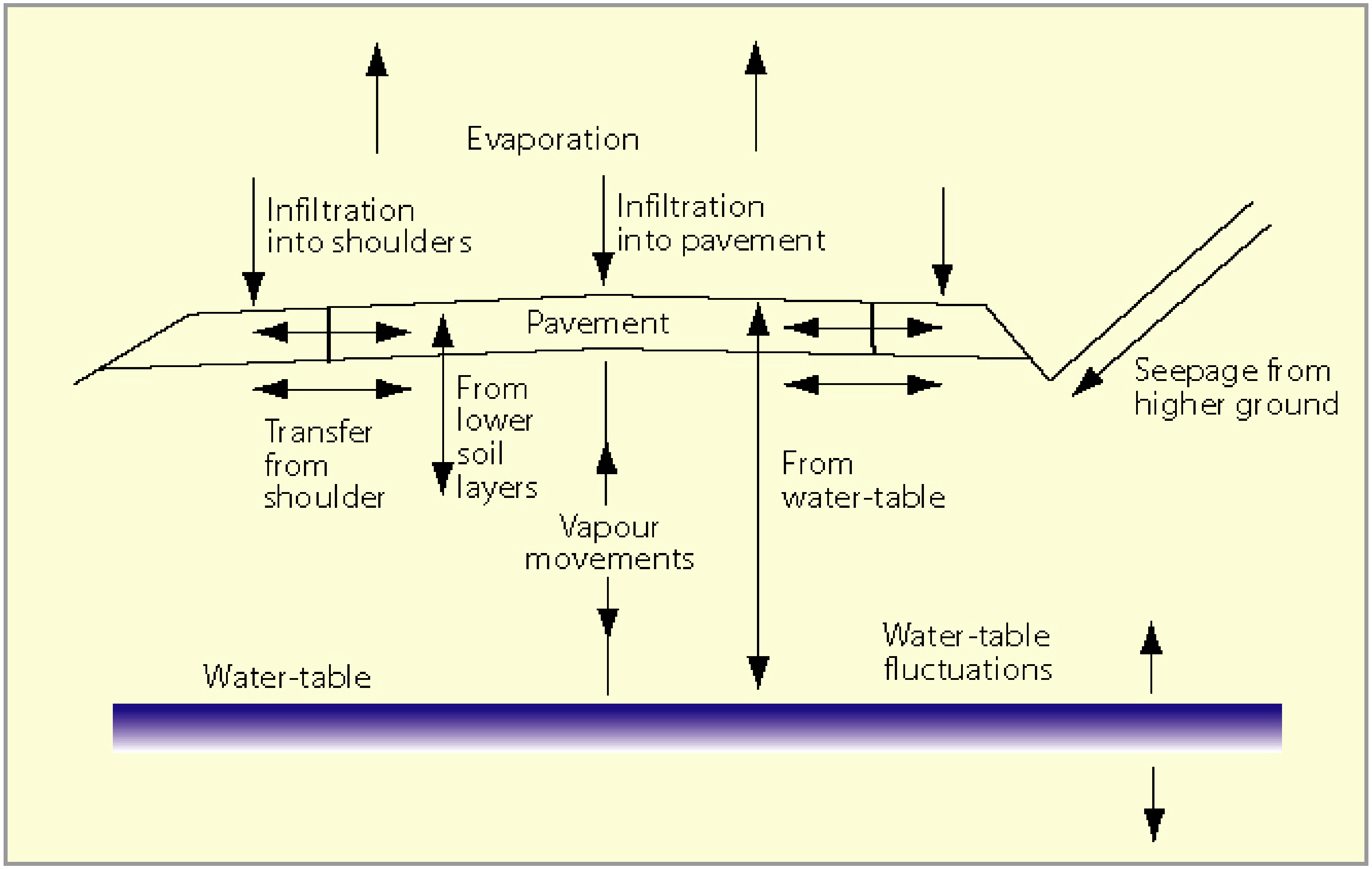
Traffic characteristics



- Most design methods used in SADC region cater for relatively high volumes of traffic, typically in excess of 0.5 million ESAs over a 10–15 year design life with attention focused on load-associated distress.
- For large proportion of LVRs in the region, carrying < 0.30 million ESAs over their design life, priority attention should be focused on ameliorating effects of the environment, particularly rainfall and temperature, on their performance

Pavement design and materials

Moisture movements



Pavement design and materials

Moisture effects

- 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

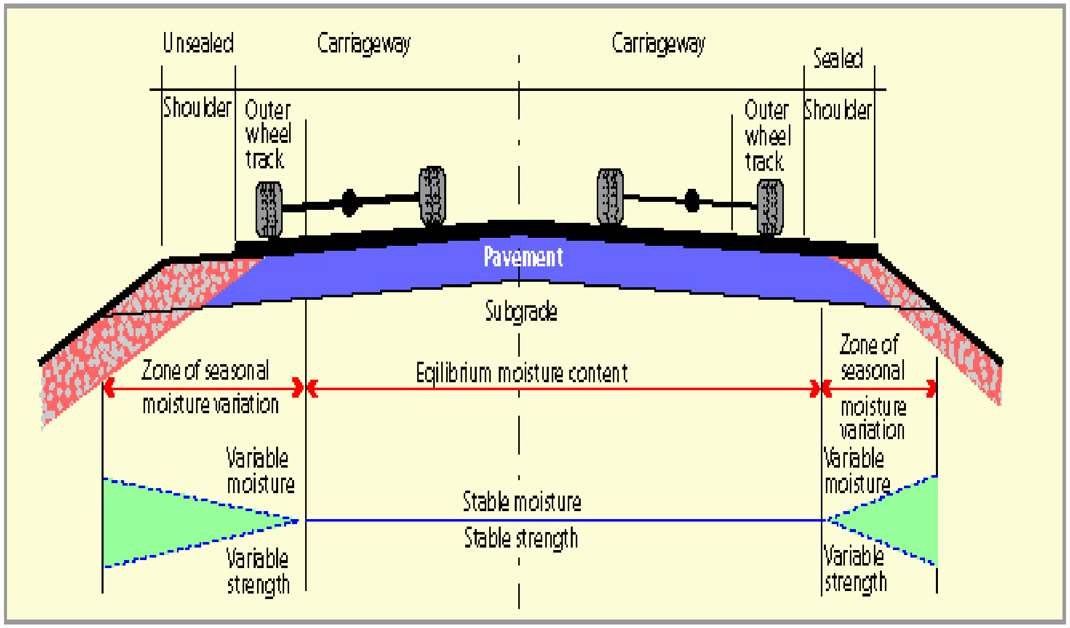


Figure 5.11

Moisture zones in a LVSR

Pavement design and materials

Pavement configuration

- **Pavement configuration influenced by materials properties and influence of water on their properties**
- **Attention to detail in drainage design and construction is essential for optimum performance**
- **Essential to avoid *permeability inversion***

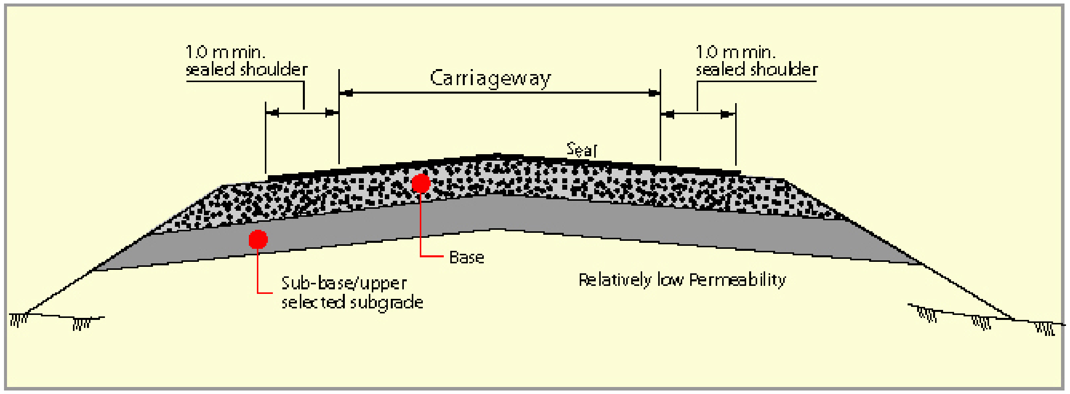


Figure 13b

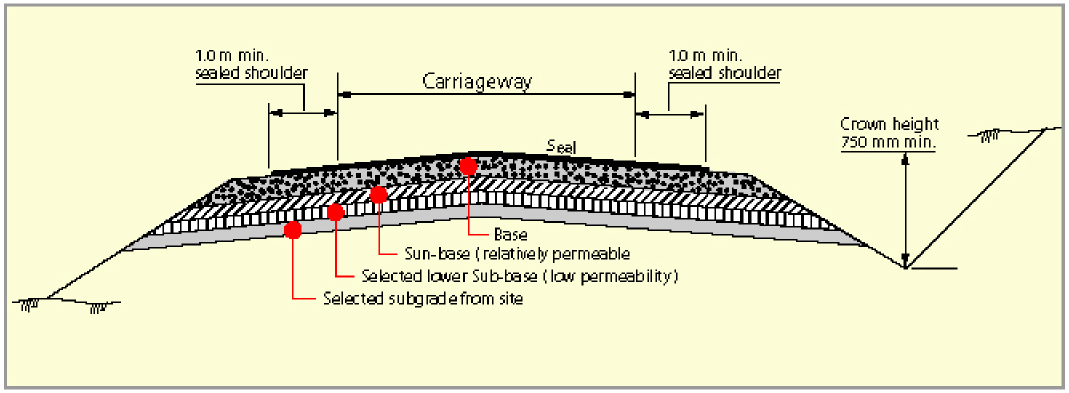
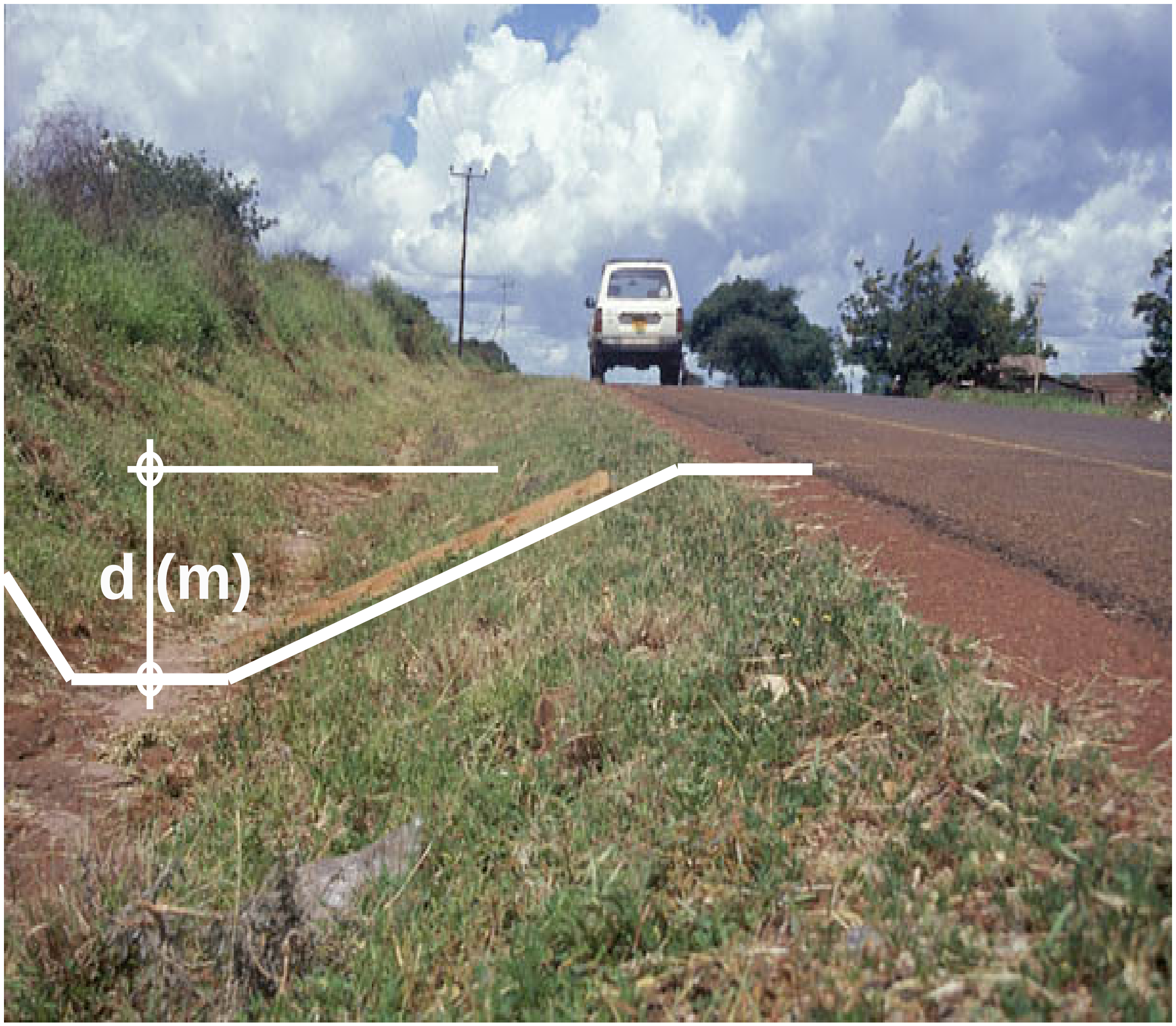


Figure 5.14b

Examples

LVSR Pavements (ideal cross-section)



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

Examples

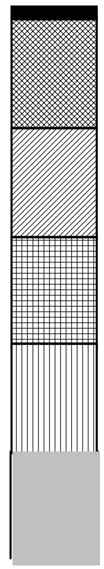
LVSR Pavements (non-ideal cross-section)

Examples

Effects of Moisture Penetration in Shoulder

Pavement design and materials

Typical specifications



<u>**Traditional**</u>	<u>**New**</u>
19/9.5 mm max. size double surface treatment	19 mm max. size Otta seal surfacing with sand/crusher dust cover seal
150 mm crushed stone base compacted to 98% Mod AASHTO	150 mm natural gravel G4 base compacted to refusal (100% Mod. AASHTO)
150 mm natural gravel G5 subbase compacted to 95% Mod AASHTO	150 mm natural gravel G5 subbase compacted to refusal (100% Mod AASHTO?)
150 mm natural gravel G6 USSG compacted to 93% Mod AASHTO	150 mm natural gravel G6 USSG compacted to refusal (100% Mod AASHTO?)
150 mm natural gravel G7 LSSG compacted to 93% Mod AASHTO	150 mm natural gravel G7 LSSG compacted to refusal (100% Mod AASHTO)
Fill, where necessary, at least G10 compacted to 93% Mod AASHTO	Fill, where necessary, at least G10 compacted to refusal (100% Mod AASHTO)

<u>**Life cycle cost ratio**</u>

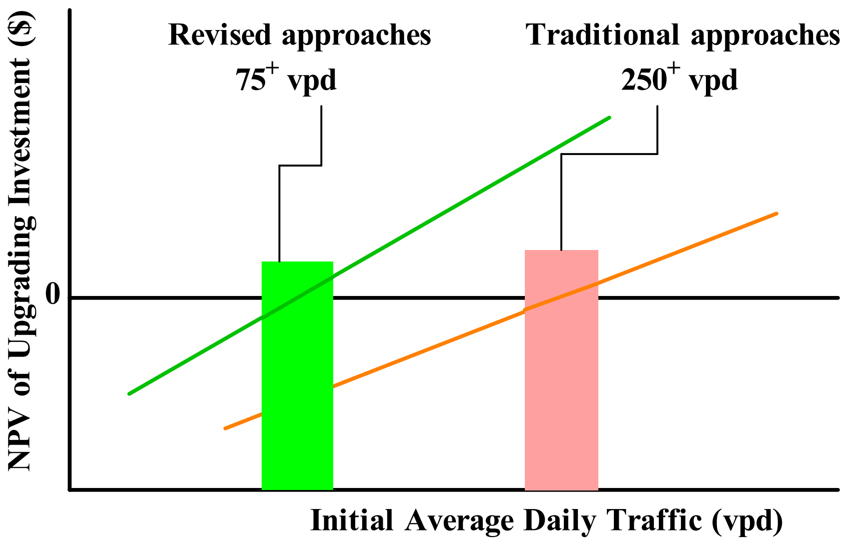
Traditional	New
1.0	**1.3 to 1.5**

Benefits of Adopting Recommendations

Option	Potential Benefits
● Replacing a conventional geometric design process by a "design by eye" approach, where appropriate	● Reduced earth works and environmental damage.
● Use of more appropriate pavement designs and natural gravel rather than crushed stone.	● Reduced pavement costs due to lesser haulage distances and reduced materials processing costs.
● Utilising an existing gravel wearing course e.g. as base or sub-base .	● Reduced haulage distances and materials costs.
● Compacting pavement layers to refusal, where feasible, rather than to arbitrary prescribed levels.	● Increased density, reduced road deterioration and increased maintenance intervals.
● Adopting appropriate surfacing technologies such as sand seals and Otta seals.	● Reduced haulage distances, reduced processing costs.
● Increasing the use of labour and local resources where appropriate.	● Lower economic/financial costs for specific tasks.
● Using seals as a spot improvement measure.	● Reduced surfacing costs whilst maintaining year round access.

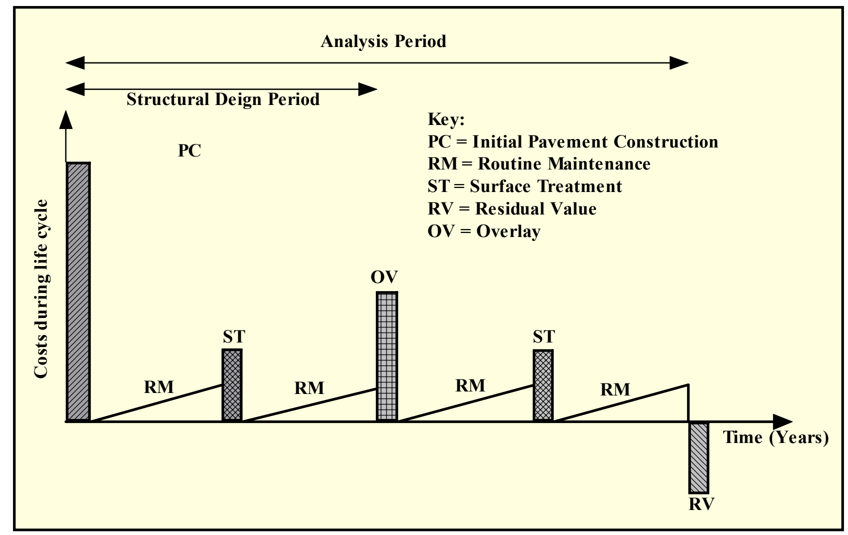
Pavement design and materials

Life cycle cost analysis



Break-even traffic

Traditional vs revised approaches



Components of a Life Cycle Costing

Examples

Overloading

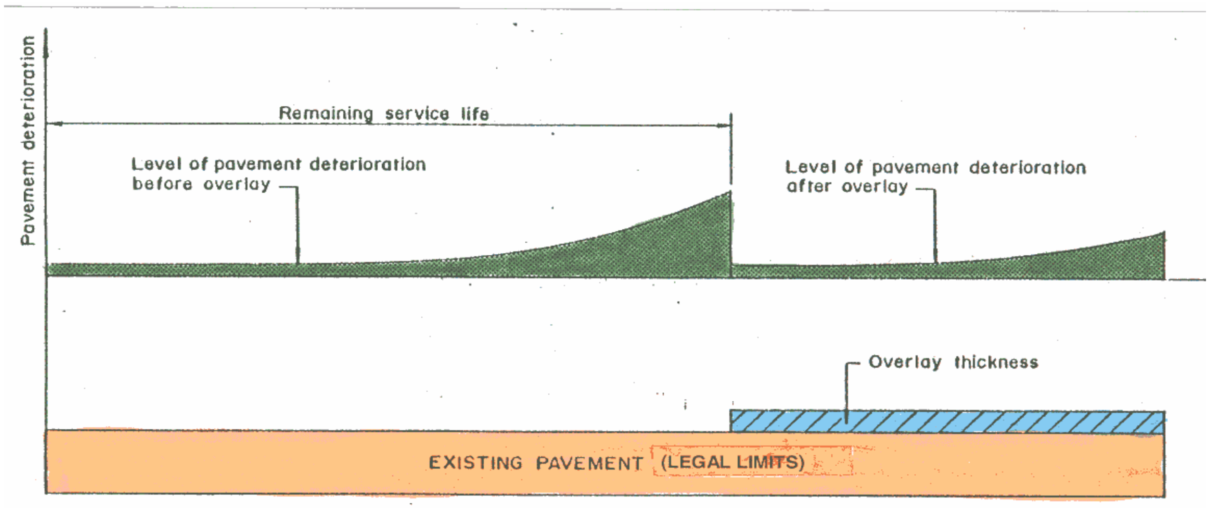
Examples

Impact of Overloading on Pavements

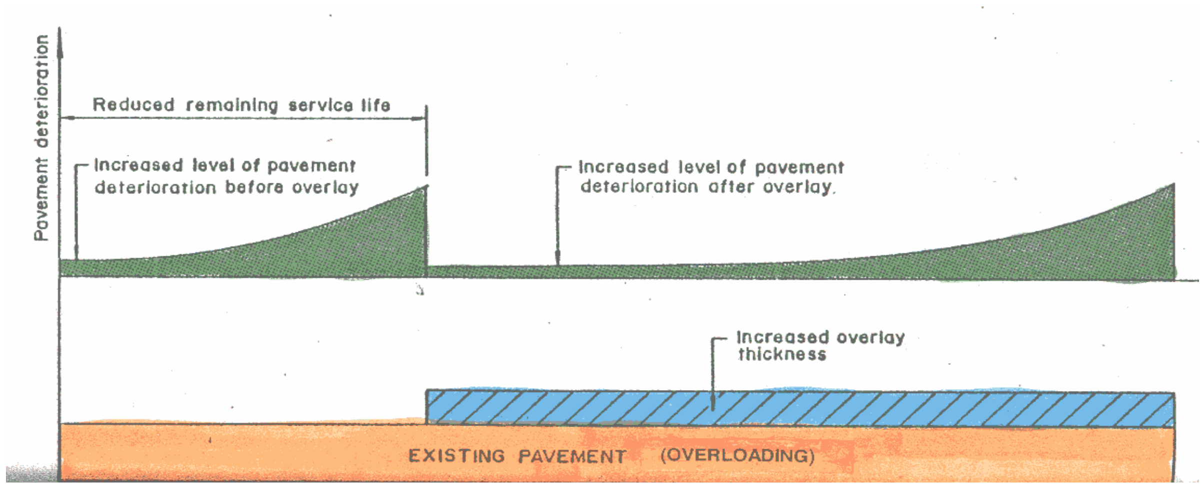
Examples

Impact on Pavements

Pavement performance under legal load limits



Pavement performance under overloading



Examples

Cost of Overloading

- **Botswana – 2004 US $2.6 million**
- **South Africa – 2002: US $100 million**
- **Sub-Saharan Africa – 2004: US $500 million**

Examples

Developments in Overload Control

- Mandatory off-loading of over-loaded vehicles
- Decriminalisation of offenses for overloading by handling them administratively and imposing a requirement on the overloader to pay an overloading fee
- Linking level of imposed fees for overloading with actual cost of road damage, i.e. by imposing economic fees
- Outsourcing weighbridge operations to the private sector on a concession basis, i.e. embarking on a commercialised public/private sector approach to overload control

Examples

Modern Weighbridge Equipment

Examples

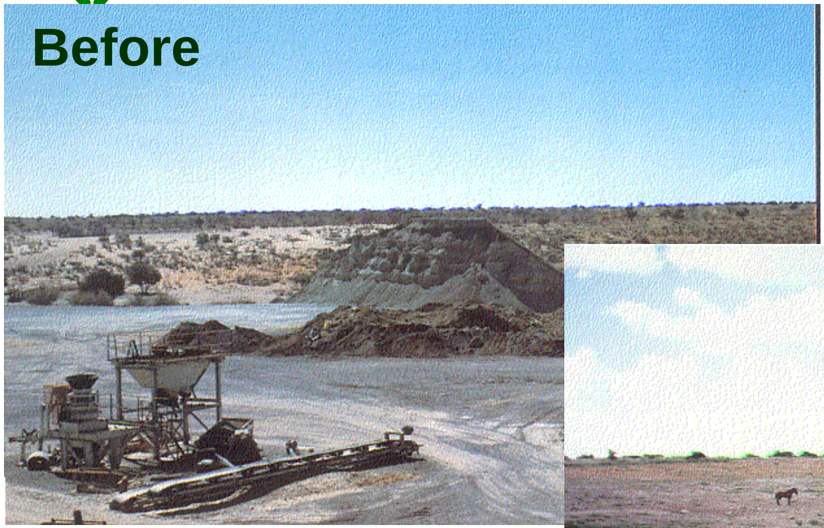
Environmental issues – borrow pits

Typical, un-renovated borrow-pit in the SADC region

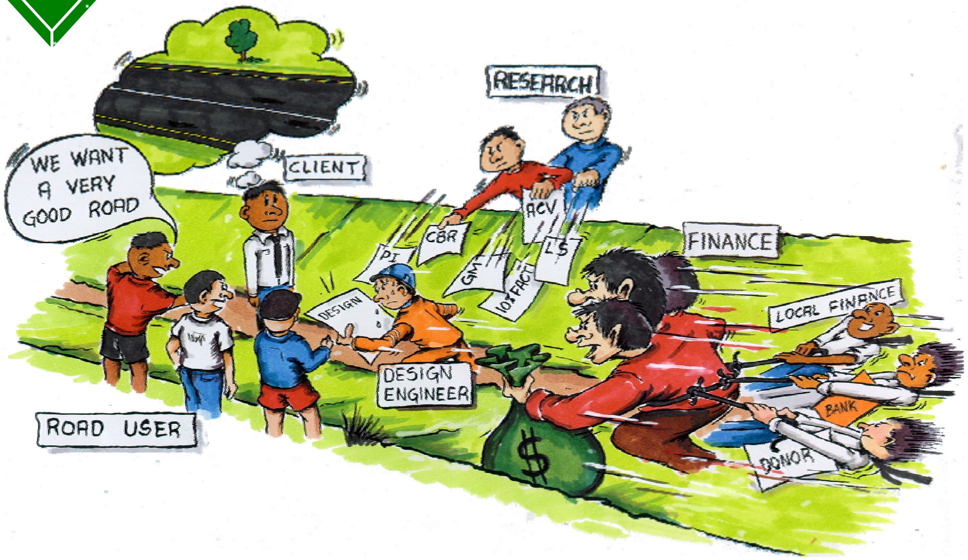
- Children exposed to risk of drowning and poor quality water
- Ponding increases level of mosquito-borne disease

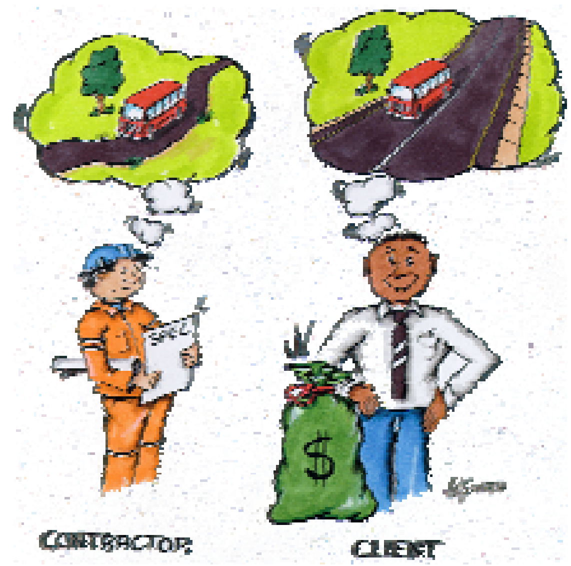
Examples

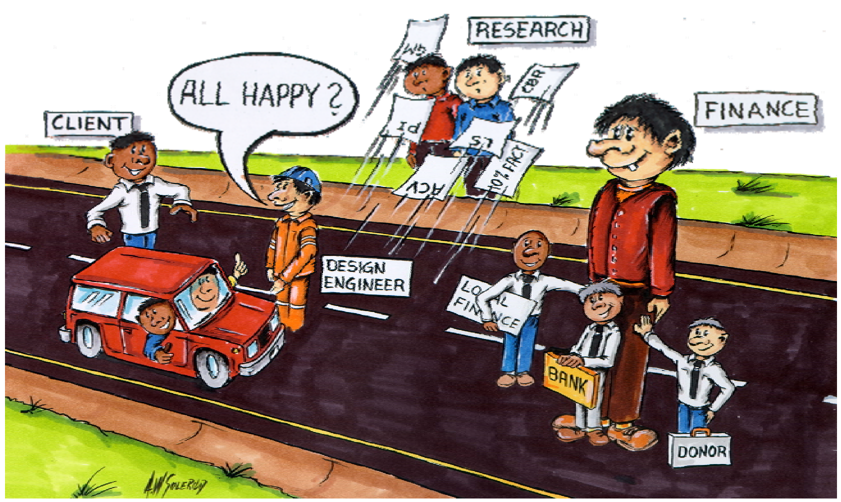
Environmental issues – borrow pit restoration



The Final Result – A Meeting of Minds







The Final Result

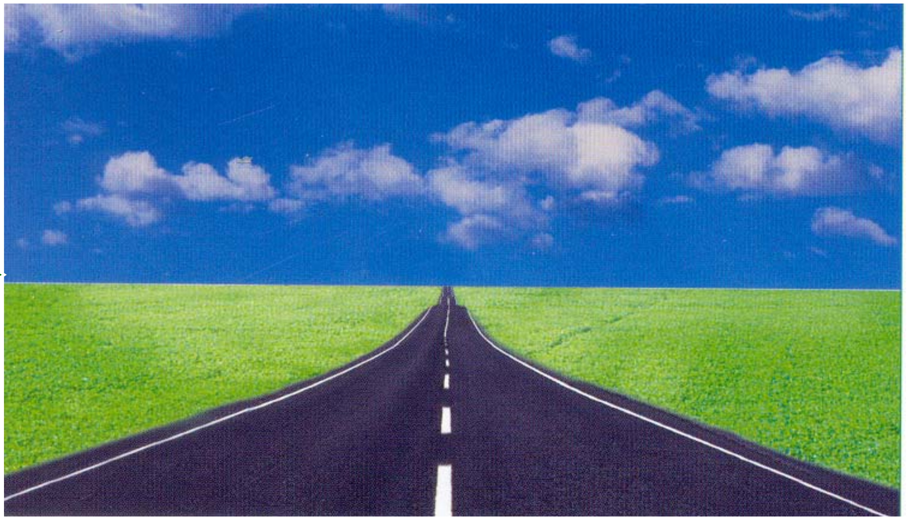
The successful engineering of a low volume sealed road requires ingenuity, imagination and innovation. It entails "working with nature" and using locally available, non-standard materials and other resources in an optimal and environmentally sustainable manner.

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 LVSR will reduce transport costs and facilitate socio-economic growth and development and reduce poverty in the SADC region.

<u>Finally</u> – Our Vision

"It is not wealth which makes good roads possible – but, rather, good roads which make wealth possible
– Adam Smith



Thank you