Ministry of Transport and Infrastructure
Republic of Kenya

DRAFT

ROAD DESIGN MANUAL PART IV

PAVEMENT REHABILITATION & OVERLAY DESIGN

2012

1 INTRODUCTION....2
1.1 Scope of the manual....2
1.2 Planning period....2
1.3 Priorities for consideration....2
1.4 Maintenance and upgrading....3
1.5 Rehabilitation, strengthening or reconstruction....3
1.5.1 Rehabilitation....3
1.5.2 Strengthening....3
1.5.3 Reconstruction....3

1 INTRODUCTION

1.1 Scope of the manual

The purpose of this manual is to provide guidance on the principles and procedures of rational management of sealed roads in the national network.
The manual sets out a framework within which established assessment and design techniques and engineering judgment are to be applied.

The framework aims at assessing the elements of the road network regularly and on the basis of objectives measurements, determines maintenance and rehabilitation of strengthening requirements. However, within a planning period the criteria for different actions are chosen according to current knowledge of pavement distress and failure characteristics. The former constitutes part of the planning and different categories of action which the management procedure shows to be required are not within the scope of this manual.

1.2 Planning period

It is necessary to anticipate the need for major inputs to the network far enough in advance to allow for design activities, finance allocation and the assembly of resources to be completed on schedule before a project starts. the following preparatory periods are considered the practical minima.

- years for periodic maintenance
- 4 years for extensive rehabilitation and strengthening

Usually uncertainties exist due to inaccurate prediction of pavement deterioration because of either unexpected increases of traffic loads o adverse weather conditions. Accordingly a "stop-gap" maintenance input should be authorised to enable remedial work to be carried out at short notice.

Section of the network that are due for maintenance within the first year of the planning period should be identified and dealt with urgently. it may be justified to implement short term measures to arrest deterioration.

1.3 Priorities for consideration

Ideally the whole network should be assessed annually for its functional and structural performance, though such extensive coverage may not always be possible it is essential however to assess the important sections of the network thoroughly and the remainder in less detail or less frequently. Alternatively the intensity of the assessment should depend on the section. Traffic volumes and the complexity of the pavement structure. Special consideration should always be given to sections in poor condition regardless of other factors.

1.4 Maintenance and upgrading

The purpose of this fll9.11 agement system is to determine from routine monitoring measurements. The types of maintenance operations required for each individual section of the network.

In the majority of cases no action may be required. On some sections the assessment of the pavement surface condition will indicate the need for periodic maintenance in the form of surface treatment. The surface treatment may be in form of resealing or re-carpeting. which treatment waterproof the underlying pavement layers and thus decelerate the deterioration but without improving the structural strength.

Most aspects of a surface condition survey, when considered together with deflection measurements, will show some structural weakness developing in the pavement and that a substantial action other than simple surface treatment will be appropriate. Consequently depending on the nature and extent of the pavement distress. it may be concluded whether the particular section requires rehabilitation, strengthening or reconstruction

1.5 Rehabilitation, strengthening or reconstruction

At terminal stage, the level of service of a section reduces below tolerable limits, the pavement becomes structurally inadequate to sustain its fuctions and periodic maintenance work becomes frequent and uneconomic. To rejuvenate the pavment, the following courses of action are considered;

1.5.1 Rehabilitation

It involves the following steps;

- Reprocessing one or more layers of pavement,
- Improvement of internal drainage,
- Widening narrow pavements,

1.5.2 Strengthening

It consists of constructing one or more layers on the existing pavment.

1.5.3 Reconstruction

If the existing road is considered inadequate for the expected traffic or has poor geometric standards, it may be justifiable to rebuild or realign it.

2 PLANNING CONSIDERATIONS 2
2.1 General..2
2.1.1 Strategic functions (i.e. classification)..2
2.1.2 Geometric standards 2
2.1.3 Maintenance levels and costs 2
2.1.4 Pavement condition surveys 2
2.1.5 Economic viability...2
2.2 Total transport cost..2
2.2.1 Capital costs..2
2.2.2 Recurrent costs 3
2.2.3 Construction costs...4
2.2.4 Vehicle operating costs 4
2.2.5 Road maintenance costs: 4
2.2.6 Further investment costs...4
2.3 Further investment costs 4

Table 2-1: Possible co-ordination of associated investments for a net benefit 3
Table 2-2: Expected consequences of various investments..5

2 PLANNING CONSIDERATIONS

2.1 General

Ideally there should be a continual reappraisal of the use of each section of the network and how effectively it performs its functions. The situation on heavily used sections may warrant more frequent intensified reappraisal. The following are the recommended aspects for which inputs are considered during the assessment.

2.1.1 Strategic functions (i.e. classification)

- Network improvement needs,
- Traffic flow patterns.

2.1.2 Geometric standards

- Accident/safety surveys

2.1.3 Maintenance levels and costs

- inventory updating,

2.1.4 Pavement condition surveys

- Structural performance
- Axle load distribution

2.1.5 Economic viability

- Resources allocation

Considerations such as route classification will rarely change, whereas traffic flow characteristics will be subject to steady and predictable change unless special influences occur (e.g. revision of traffic legislation or substantial change in fuel prices etc.) The pavement condition and subsequently the structural performance are generally less predictable particularly on roads with heavy traffic. Regular monitoring is absolutely necessary so that the onset of pronounced deterioration can be anticipated.

Essentially the management task is to determine the proper nature, strategies and timing of investments in the road network. This manual is intended to guide the management of the existing network.

2.2 Total transport cost

The principal economic criterion is to optimize investments on the basis of "total cost" which generally is comprised of both the capital and recurrent costs.

2.2.1 Capital costs

These are usually well defined and isolated in nature such as overlay or reconstruction operations.

2.2.2 Recurrent costs

These are continually incurred costs during the usage of the road. Some are less well defined for instance accidents and environmental impact cannot readily be assigned economic values.

There are invariably recurrent costs throughout the usage of the road. In some analyses however the total cost may not always include a capital cost. This is the case in the "do noting" option which must be evaluated as a base for comparison with any prospective investment under consideration.

It may happen that the need for one investment (for instance strengthening) will trigger the justification for other associated investments such as pavement widening etc. Effective cost saving may result from co-coordinating the investments and/or interchanging their sequence of execution. It is important to hold an overall view and to appreciate the significant implications of one investment on other possible associated investments. Table 2-1 presents the likely linkages of investments.

The main consequences expected from different actions for which investment is considered are summarised in Table 2-2.

Investment type under consideration	Associated investments which offer cost saving if coordinated
Any	Realignment (to improve geometric standards)
Drainage/shoulder improvement repair	Pavement widening
Surface treatment (e.g. resealing or re-carpeting)	Strengthening Pavement repairs
Strengthening (e.g. overlays)	Pavement widening Shoulder improvement
Rehabilitation	Strengthening Pavement widening
Reconstruction	Pavement widening Realignment Shoulder improvements
Pavement widening	Surface treatment Rehabilitation Reconstruction

Table 2-1: Possible co-ordination of associated investments for a net benefit

In the implementation of the management system, it is essential to reduce the unit running costs of vehicles. In most cases vehicle running costs per unit distance in terms of fuel consumption, tyre replacement, spare parts and maintenance labour are dependent on the condition of the running surface and the average vehicle operating speed. The latter is directly influenced by road characteristics such as the alignment geometry and carriageway width.

Similarly the occurrence and severity of accident are affected by changes in the alignment, carriageway width and surface condition whilst significant resource costs

In the implementation of the management system, it is essential to reduce the unit running costs of vehicles. In most cases vehicle running costs per unit distance in terms of fuel consumption, tyre replacement, spare parts and maintenance labour are dependent on the condition of the running surface and the average vehicle operating speed. The latter is directly influence by road characteristics such as the alignment geometry and carriageway width.

Similarly the occurrence and severity of accidents are affected by changes in the alignment, carriageway width and surface condition. Whilst significant resource costs are incurred through accidents other very important consequences for instance serious injury or loss of life, can not yet be given financial values.

Major components contributing to the total transport cost are:

2.2.3 Construction costs

- If some improvements are considered

2.2.4 Vehicle operating costs

- Road maintenance costs

2.2.5 Road maintenance costs:

- Expected cost at the end of the current design period for the road to handle the expected traffic demand.

2.2.6 Further investment costs

- Expected cost at the end of the current design period for the road to handle the expected traffic demand.

Net present value of these costs is calculated by discounting them to a chosen year. This is usually considered to be the first year of the appraisal.

2.3 Further investment costs

Further investment components should be estimated for the most probable continued requirement of the road, aiming at restoring the road to the same final state for each of the alternative strategies considered in the appraisal. The cost of achieving this will vary for the different strategies. Thus in one strategy the road might be in a suitable condition to be overlaid so as to handle the expected traffic whereas in another strategy the road might require complete reconstruction for similar traffic

The purpose of further investment cost element is to reflect any differences in the dual value of the road as a result of different strategies. Thus, although relative long range estimates are involved, the differences between them are sensible reflection of the residual value in one strategy as compared with another. In any case, the residual value should be discounted over the full appraisal period.

For an economic appraisal all costs may be calculated excluding taxes and transfer payments. Nevertheless the Chief Engineer (Roads) can advise on the current factors applied to the different types of activity (construction, vehicle operating, road maintenance etc…) in order to estimate economic costs.

Action	Effect	Consequence
Drainage repair or improvement	reduce pavement deterioration reduce probability of washout etc	reduce future vehicle running costs increase route reliability reduce maintenance costs
Shoulder repair or improvement	increase effective width of pavement reduce pavement deterioration	reduce accidents reduce future vehicle running costs reduce maintenance costs
Surface treatment	improve running surface condition reduce pavement deterioration	reduce current vehicle running costs reduce future vehicle running costs reduce routine maintenance costs
Pavement strengthening	renew running surface condition reduce pavement deterioration increase pavement bearing capacity	reduce current vehicle running costs future vehicle running costs reduce routine maintenance costs increase life of pavement
pavement rehabilitation	renew running surface condition reduce pavement deterioration increase pavement bearing capacity	reduce current vehicle running costs future vehicle running costs reduce routine maintenance costs
Pavement widening	increase effective width of pavement improve horizontal alignment	reduce accidents increase route capacity
Reconstruction	any or all of the above improve vertical alignment	any or all of the above
Realignment	any or all of the above change route length improve horizontal and vertical alignment	any or all of the above change vehicle running and unit costs change maintenance costs

Table 2-2: Expected consequences of various investments

3 IDENTIFICATION, CAUSES AND TREATMENT OF VISUAL DISTRESS...... 3-2
3.1 Flexible pavements 3-2
3.1.1 Deformation – Rutting.......... 3-4
3.1.2 Deformation –Shoving, plastic Flow.......... 3-6
3.1.3 Deformation Depression and Heave.......... 3-7
3.1.4 Deformation-Corrugations.......... 3-8
3.1.5 Cracking – Block Cracking.......... 3-9
3.1.6 Cracking – Crocodile Cracking (Alligator Cracking, Crazing) ... 3-10
3.1.7 Cracking - Transverse Cracking 3-11
3.1.8 Cracking - Diagonal Cracking.......... 3-12
3.1.9 Cracking - Meandering Cracking 3-13
3.1.10 Cracking – Crescent Shaped Cracking.......... 3-14
3.1.11 Cracking – Longitudinal Cracking 3-15
3.1.12 Edge Break.......... 3-16
3.1.13 Edge Drop off.......... 3-17
3.1.14 Delamination 3-18
3.1.15 Stripping of Sprayed Seals 3-19
3.1.16 Stripping of Asphalt.......... 3-20
3.1.17 Ravelling (or Fretting) 3-21
3.1.18 Flushing (or Bleeding, Fatty or Slick Surface, Black Spots)...... 3-22
3.1.19 Polishing 3-23
3.1.20 Potholing.......... 3-24
3.1.21 Patches: expedient patch and reconstructed patch.......... 3-25

Figure 3-1: Deformation defects in flexible pavements 3-3
Figure 3-2: Cracking of flexible pavements.......... 3-3
Figure 3-3: Surface distress of flexible pavements 3-4

3 IDENTIFICATION, CAUSES AND TREATMENT OF VISUAL DISTRESS

3.1 Flexible pavements

The principal modes of pavement distress of flexible pavements are as follows:

- **Deformation**
  - Rutting
  - Shoving (plastic flow)
  - Depression and heave
  - Corrugation
- **Cracking**
  - Block cracking
  - Crocodile cracking
  - Transverse cracking
  - Diagonal cracking
  - Meandering cracking
  - Crescent-shaped cracking
  - Longitudinal cracking
- **Edge defects**
- **Delamination**
- **Stripping**
  - Sprayed seal
  - Asphalt
- **Ravelling**
- **Flushing**
- **Polishing**
- **Potholing**
- **Failed patches**

Some of these distress types are shown in Figure 3-1, Figure 3-2 and Figure 3-3.

These defects are described below, together with a photograph and a listing of the likely causes of the particular defect and possible treatments.

The causes of these defects can be categorized into three groupings:

- Structural
- Environmental
- Construction quality

In many cases, there may be more than one apparent cause which may make it difficult to identify the primary cause of the defect.

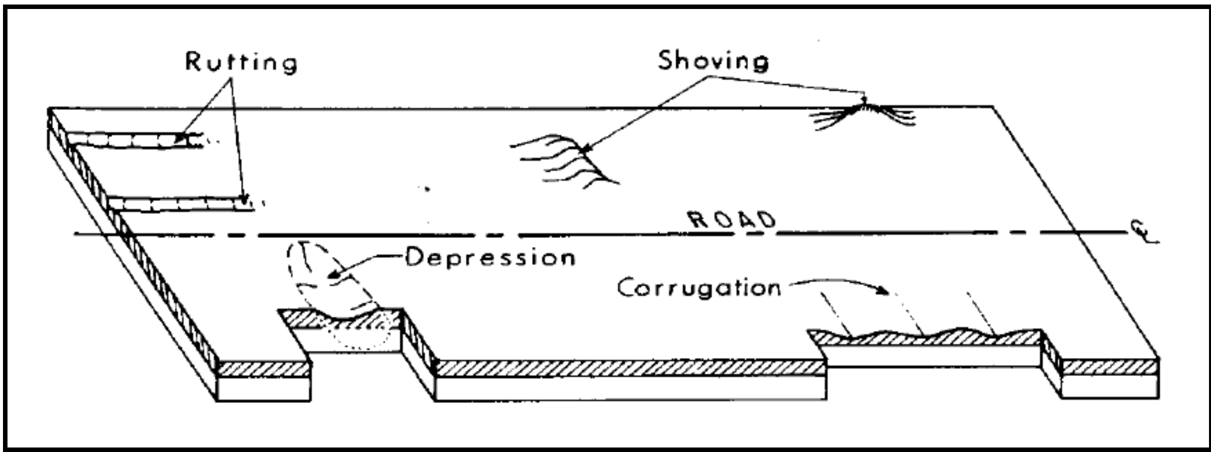


Figure 3-1: Deformation defects in flexible pavements

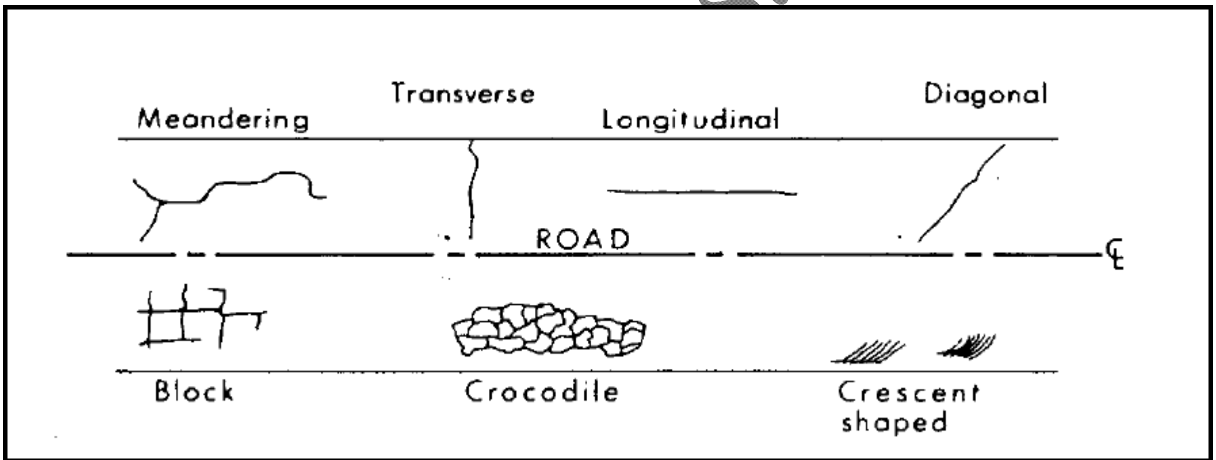


Figure 3-2: Cracking of flexible pavements

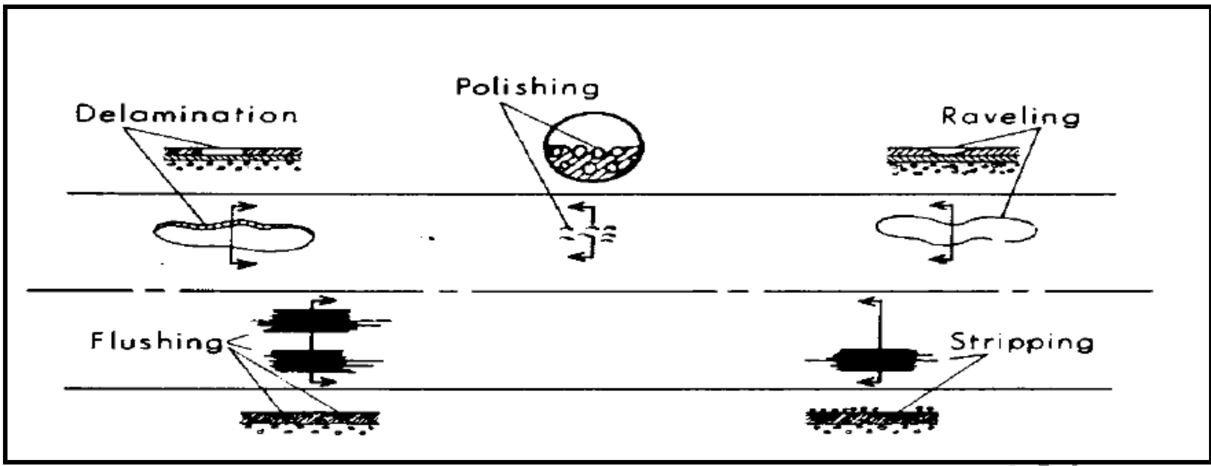


Figure 3-3: Surface distress of flexible pavements

3.1.1 Deformation – Rutting

Description:
Longitudinal deformation in a wheelpath. Result of densification of pavement layers, including subgrade or plastic shear deformation of upper layers. Bound lower layers may not be affected. Length to width ratio determined using a straight edge on the high points normally greater than four to one may occur in one or both wheelpaths of a lane but mostly in the outer wheelpath nearest to the pavement edge.

Causes:

- Ingress of water through the pavement surfacing or road edges in base,
- Sub-base and subgrade
- Structural overloading of the pavement and/or inadequate pavement
- Thickness (exacerbated, in asphalt pavements, by high pavement temperature)
- Inadequate quality of pavement materials
- poor quality construction control, particularly compaction and drainage
- Pavement at terminal condition.

Non- structural treatments:

- In- place asphalt recycling
- Cold planing to remove high points
- Cold overlays, slurry seals (provided rut depth 15 mm) and micro surfacing
- Thin asphalt surfacing (non- structural)
- Ultra thin overlays-provided rut depth ≤ 2.5 x mix size
- Rip, reshape and reseal - appropriate for granular pavements.

Structural treatments:

- Drainage improvements
- Asphalt overlay or granular resheet
- Deep lift asphalt
- Partial reconstruction and asphalt overlay
- In situ stabilisation
- Heavy patching
- Total reconstruction

3.1.2 Deformation –Shoving, plastic Flow

Description:
Shoving: Building and horizontal deformation of the road surface- generally occurs in areas of high shear stress.
Plastic flow: Deformation in asphalt of asphalt surfaces.

Causes:

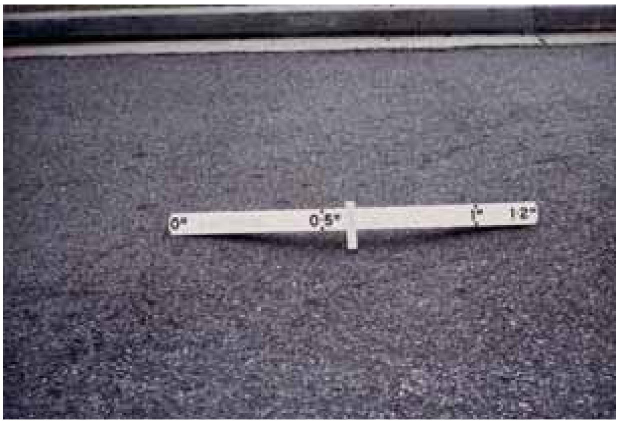
- Lack of containment at pavement edge combined with swelling of moisture- suscepitable pavement material and/or repeated passage of heavy vehicles on relatively narrow sealed formations
- Inadequate pavement thickness
- Inadequate quality of pavement materials e.g asphalt mixes with poor aggregate interlock combined with turning/accelerating traffic; or poor binder/aggregate adhesion (Stripping)
- Inadequate compaction of surfacing or base material
- Localised softening of asphalt binder due to fue/oil spillage, or tempreature-suscepitble binder or excess binder content in asphalt
- Lack of bond between pavement layers
- Moinsture in pavement and/or subgrade.

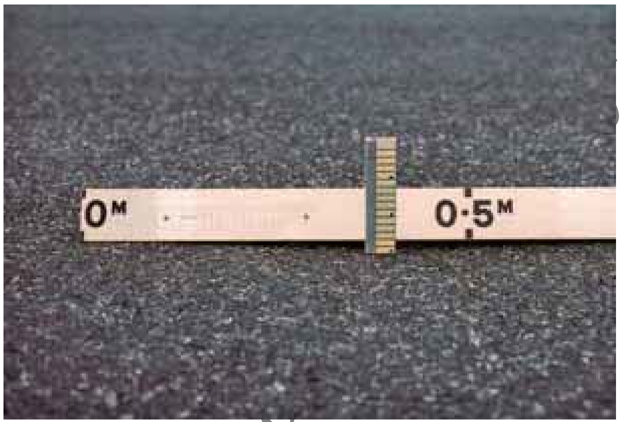
Non-structural treatments:
- In-place asphalt recycling
- Cold planing of unsound material and replacement with adequate material
- Where due to deficiency of unsealed shoulder, resheet shoulder.

Structural treatments:
- Drainage improvements
- Asphalt or granular overlays
- Partial reconstruction and overlay
- In situ stabilisation
- Heavy patching
- Reconstruction.

3.1.3 Deformation Depression and Heave

Description:
Irregular depressions and bulges in the pavement surface





Causes:

- Moisture movement, especially in expansive clay subgrade
- Inadequate drainage
- Inadequate compaction, particularly of base material
- Inadequate quality of pavement materials
- Settlement of trench backfill due to poor compaction or softening caused by leakage from services.

Non- structural treatments:

- Regulate with asphalt or cold overlay
- Reduce moisture ingress by sealing shoulders.

Structural treatments:

- Drainage improvements
- Asphalt or granular overlays
- Partial reconstruct and overlay
- In situ stabilisation
- Heavy patching
- Reconstruction

3.1.4 Deformation-Corrugations

Description:
Transverse undulations in the pavement surface or base, most commonly associated with spray seal or unsealed pavements but can occur in thin asphalt surfacing.
Wavelengths of undulations can range between 0.3 and 2 metres.

Causes:

- Local failure in the pavement
- Inadequate material quality: e.g. inability of asphalt surfacing to resist heavy vehicle loading
- Defective works practice such as irregular compaction energy input
- Poor bonding between thin asphalt surfacing and concrete base.

Treatments:

- Remove and replace base and reseal or overlay
- In situ stabilisation
- Cold plane and overlay asphalt surfaced pavements.

3.1.5 Cracking – Block Cracking

Description:
Interconnected cracks forming a series of blocks approximately rectangular in shape.
Typically distributed over a large area of pavement.

Causes:

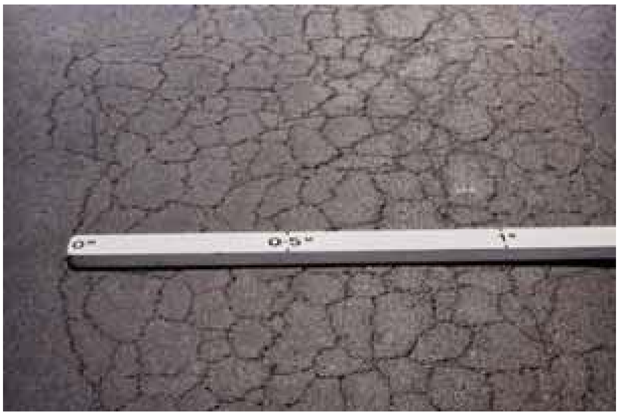
- Reflection from underlying joints
- Shrinkage or fatigue in an underlying bound (cemented) or macadam layer
- Inadequate slab thickness
- Ageing and hardening of bituminous surfacing.

Treatments:

- Crack filing
- Strain Alleviating Membrane (SAM) seals, reinforced seals, ultra thin overlays
- Strain Alleviating Members Interlayers (SAMI) or geotextile seal plus asphalt overlay
- Cold plane and overlay
- In situ asphalt recycling and overlay

3.1.6 Cracking – Crocodile Cracking (Alligator Cracking, Crazing)

Description:
Interconnected or interlaced crakes forming a series of small polygons resembling a crocodile skin. Crocodile cracking is often confined to the wheel paths and may have a noticeable longitudinal grain. The presence of crocodile cracking usually signifies that the surfacing has reached the end of its design life.



Causes:

- Fatigue- induced structural cracking (high pavement curvature value
- Inadequate pavement thickness
- Moisture in formation
- Inadequate quality of pavement or surfacing materials (e.g. brittle or aged bitumen or low-strength aggregates)
- Lack of compaction in asphalt or cementitious layers.

Non- structural treatments:

- Alleviating Membrane (SAM) seals, reinforced seals, ultra thin overlays
- Strain Alleviating Membrane Interlayer (SAMI) or geotextile seal plus thin asphalt overlay
- Cold planing and thin overlay
- In situ asphalt recycling.

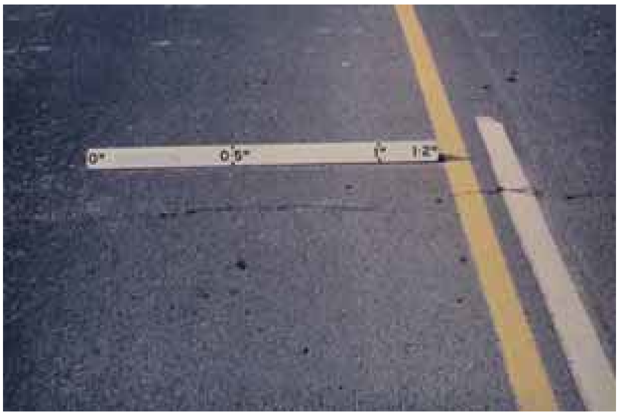
Structural treatments:

- Drainage improvements in combination with another treatment such as an overlay
- Strain alleviating Membrane interlayer (SAMI) plus asphalt overlay
- In situ asphalt recycling plus overlay
- cold planing plus overlay
- In situ stabilisation
- Heavy patching
- Reconstruction

3.1.7 Cracking - Transverse Cracking

Description:

An unconnected crack running across the pavement



Causes:

- Reflection of shrinkage crack or joint from an underlying cemented base
- Construction joint or shrinkage crack in asphalt surfacing (shrinkage cracking in asphalt can be related to low ambient temperatures and/or bitumen hardening)
- Structural failure of cement concrete base
- Shrinkage of slab during curing as a result of sawing joints too late or excess slab length
- Settlement associated with an underground service or a structure (bridge/culvert)
- Intrusion of tree roots into the subgrade or pavement layers.

Treatments:

- Crack seal
- Strain Alleviating Membrane (SAM) seals, reinforced seals, ultra thin overlays
- Strain Alleviating Membrane interlayer (SAMI) or geotextile seal plus asphalt overlay
- Cold planing and overlay
- In situ asphalt recycling.

3.1.8 Cracking - Diagonal Cracking

Description:
An unconnected crack running diagonally across the pavement

Causes:

- Age hardening of bitumen
- Shrinkage of slab during as a result of sawing joints too late or excess slab length
- Reflection of underlying joint
- Settlement associated with an underground service or a structure (bridge/culvert)
- Construction joints
- Instruction of tree roots.

Treatments:

- Crack seal
- Strain Alleviating Membrane (SAM) seals, reinforced seals, ultra thin overlays
- Strain Alleviating Membrane Interlayer (SAMI) or geotextile seal plus asphalt overlay
- Cold planing and overlay
- In situ asphalt recycling and overlay.

3.1.9 Cracking - Meandering Cracking

Description:
Unconnected irregular crack, varying in line and direction: This usually occurs singly.

Causes:

- Moisture in formation
- Reflection of shrinkage cracking from bound base
- In asphalt surfacings on concrete pavements, due to inadequate slab thickness, unstable
- Slabs or slab settlement
- Shrinkage in concrete slabs during curing as a result of delay in sawing joints or excessive
- Slab lengths
- settlement associated with an underground service or a structure (bridge/culvert)
- Intrusion of tree roots into subgrade or pavement layers

Treatments:

- Crack filling
- Strain Alleviating Membrane (SAM) seals, reinforced seals, and ultra thin overlays.
- Strain Alleviating Membrane interlayer (SAMI) or geotextile seal plus asphalt overlay
- Cold planing and overlay
- In situ asphalt recycling and overlay
- Remove trees.

3.1.10 Cracking – Crescent Shaped Cracking

Description:
Unconnected irregular crack, varying in line and direction: which usually occurs singly?

Causes:

- Poor bond between wearing course and underlying layers
- Inadequate thickness of wearing course
- Dragging of asphalt under paver screed during laying, especially at low temperatures
- High horizontal shear forces associated with turning and acceleration movements.
- Inadequate asphalt mix for the traffic conditions
- Low modules base layer.

Non - structural treatments:

- Crack filling
- Cold planing and overlay
- In-situ asphalt recycling and overlay

Structural treatments:

- Overlay
- Heavy patching
- Reconstruction

3.1.11 Cracking – Longitudinal Cracking

Description:

- Cracks which run longitudinally along the pavement.
- Can occur singly or as a series of parallel or echelon cracks
- Some limited branching can occur.
- Longitudinal cracking is often the first type of cracking initiated in a wheel path or rut.

Causes:

when occurring singly:

- Reflection of joints or shrinkage cracks in underlying cemented base
- Poorly constructed joint in asphalt surfacing
- Displacement of joint at pavement widening
- Reflection of joints associated with road widening.

when occurring as a series of near - parallel cracks:

- Volume change of expansive clay subgrade
- Cyclical weakening of the pavement edge
- Differential settlement between cut and fill
- Reflection of cracks in underlying cemented subbase.

Treatments:

- Drainage improvements
- Sealing shoulders
- Crack filling
- Cold planing and overlay
- Heavy patching
- Reconstruction.

3.1.12 Edge Break

Description:
Occurs along the unsupported edges of asphalt or sprayed seal surfaces where the surface of an unsealed shoulder is below the level of the adjacent pavement surface.
Seal/shoulder interface is directly trafficked resulting in abrasion and shear failure of pavement edge (manifest as fretting).
May occur locally or be continuous over a length of road. Frequently occurs on tight curves or where the edge of the pavement is vulnerable to tyre wear and attribution.

Causes:
- An inadequate road alignment or sealed pavement width which causes vehicles to traffic the
- Pavement edge
- Omission of a shoulder resheet following pavement overlay
- Erosion of shoulder by wind and/or water
- Growth of vegetation at the edge of the surface seal.

Treatments:
- Resheet shoulder
- Bitumen stabilised shoulders
- Seal shoulders
- Local pavement widening.

3.1.13 Edge Drop off

Description:
The vertical distance from the surface of the seal at the edge to the surface of the shoulder. Not usually considered a deflect if the drop-off is less than 10 mm to 15 mm.

Causes:

- An inadequate road alignment or sealed pavement width which causes vehicles to traffic the pavement edge.
- Omission of a shoulder resheet following pavement overlay
- Erosion of shoulder by wind and/ or water
- Growth of vegetation at the edge of the seal.

Treatments:

- Resheet shoulder
- Bitumen stabilised shoulders
- Seal shoulders
- Local pavement widening.

3.1.14 Delamination

Description:
Loss of a discrete section of wearing course layer.
A feature of delamination is that there is usually a clear delineation between the wearing course and the lower layer.

Causes:
- Inadequate sweeping of granular base prior to priming
- Inadequate prime or tack coat before placement of upper layers
- Dislodgement of fragments initiated by block cracking or crocodile cracking
- Seepage of water through cracks in asphalt layer. resulting in breaking of bond between surface and lower layers
- Weak loose layer immediately underlying a seal
- Adhesion of surface binder to vehicle tyres
- Inadequate thickness of asphalt layer.

Treatments:
- Cold planing and overlay
- Reseal.

3.1.15 Stripping of Sprayed Seals

Description:
The loss of aggregate from a sprayed seal leaving the binder exposed to direct tyre contact.

Causes:

- Low binder application rate
- Poor binder to stone adhesion due to dirty, dusty or wet aggregate exacerbated by lack of
- Pre-coat on the aggregate
- age hardening (oxidation) or adsorption of binder
- Incorrect blending of binder (cutter or flux oil content too high)
- Stone deterioration
- Inadequate rolling before opening of seal to traffic, particularly on curves and bends
- Inappropriate stone size in reseal
- Temperature susceptible bitumen.

Treatments:

- Enrichment or rejuvenation of binder – only where aggregate loss is limited to a few stones
- Reseal.

3.1.16 Stripping of Asphalt

Description:

The loss of bitumen and/or mineral aggregate or filler from an asphalt layer. The stripping could occur on the surface or within the layer.

Stripping within the layer may lead to the development of potholes.

Photographs show white fines that have been pumped to surface, an early indicator of stripping.

Causes:

- Moisture entry through excessive voids or segregated or cracked surface
- Low binder content
- Age hardening(oxidation) or adsorption of binder
- Incorrect mix design.

Treatments:

- Depending on the extent of the stripping the treatments may range from isolated repairs to complete removal and replacement of the affected asphalt layer.

3.1.17 Ravelling (or Fretting)

Description:
Progressive disintegration of pavement surface by loss of both binder and aggregate.

Cause:

- Binder hardening and oxidation or damage by fuel
- Inappropriate asphalt mix or poor mix design
- Inadequate compaction and/or construction defects due to wet or cold weather, or the use of
- Dirty, dusty or wet aggregate
- Oil and fuel spillages.

Treatments:

- Sprayed enrichment or rejuvenation
- Cold overlay, slurry surfacing and microsurfacings
- Asphalt overlay.

3.1.18 Flushing (or Bleeding, Fatty or Slick Surface, Black Spots)

Description:
An excess of binder on the surface of a pavement, which is liable to pick-up on tyres during hot weather. A potential safety concern because of loss of skid resistance.
Manifest as low texture depth and inadequate tyre to stone contact.

Cause:

- Flushing in the underlying layer - i.e. a previous surfacing
- Inappropriate asphalt type of inadequate mix design
- Excessive rate of application of binder with respect to stone size in sprayed seals
- Excessive prime or poor prime penetration into granular base causing excess binder in the surfacing
- In a seal or asphalt laid over a primer seal before volatiles in primer binder have evaporated
- Penetration or punching of aggregate into an underlying layer e.g. low strength base
- Oil and fuel spillages.

Treatments:

- Reseal
- Solvent treatment plus additional aggregate- for flushed sprayed seals
- Cold planing, scabbing and grooving - for fatty asphalt
- Asphalt overlay.

3.1.19 Polishing

Description

Smoothing and rounding of the upper surface of a sealing aggregate usually occurs in the wheel tracks. Identified by relative appearance and feel of trafficked and untrafficked areas.

Polished areas will feel relatively smooth and will sometimes be noticeably shiny.

The degree of polishing cannot be quantified by observation.

Causes:

- Inadequate resistance to polishing of surface aggregates, particularly by heavy traffic
- Use of naturally smooth aggregates (e.g. water worn gravel).

Treatments:

- Reseal
- Cold overlay, slurry seal, micro surfacing
- Ultra thin overlay
- Asphalt overlay.

3.1.20 Potholing

Description

A step - sided or bowl-shaped cavity extending into layers below the wearing course.

Causes:

- Loss of surface material due to ravelling, stripping, cracking and/or delamination
- Load - associated disintegration of the base
- 'Pick - up' of bitumen wearing surface caused by binder adhesion to tyres
- Moisture entry into a granular base through cracked surface courses resulting in localised softening
- Poor quality base material.

Treatments:

- Normally repaired by routine maintenance techniques
- Reseal
- Asphalt overlays.

3.1.21 Patches: expedient patch and reconstructed patch

Description:

A repaired section of pavement ranging in size from less than 1 m 12 to many linear meters of a half or even full pavement width.

It may or may not be associated with either a loss of serviceability (apart from a loss of appearance) or structural capacity.

Expedient patches will not normally be straight sided and are often a temporary measure. They may contribute to increased road roughness and subsequent further distress.	
Reconstructed patches are generally more permanent and will usually be straight sided.	

Causes:

- Expedient patch: the repair of surfacing deficiencies (deformation or rutting, cracking,
- Stripping, edge break etc.) without prior removal of the affected material
- Reconstruction patch: ranges from correction of a pavement deficiency to the reinstatement of a service trench
- Inadequate compaction may lead to further deformation and distress.

Treatments:

A patch does not indicate the need for any further action but many patches, particularly within a short time period, indicate that there may be a systemic problem in the pavement that requires a more considered treatment. Consideration should be given to the reasons for the patching and a resurfacing appropriate to that type of defect.

4 PAVEMENT EVALUATION....2
4.1 Surface Condition....2
4.1.1 Recording and Quantifying the Defects....2
4.1.2 Surface Roughness....3
4.1.3 Present serviceability concept....3
4.2 Structural evolution....5
4.2.1 The use of the deflection measurements....5
4.2.2 The use of radius of curvature measurements....8
4.2.3 Subgrade and drainage analysis....9
4.2.4 Existing pavement structure analysis....10
4.2.5 Shoulder assessment....11
4.3 Summary of the procedure for pavement evaluation....12

Table 4-1: Summary of the procedure for pavement evaluation....13
Table 4-2: Verification of the consistency of the deflection with surface condition, sructure design and maintenance rate....14

4 PAVEMENT EVALUATION

An evaluation of the existing pavement is necessary to determine its adequacy and to decide on the maintenance or rehabilitation measures which may be needed to meet future demands. Pavement evaluation includes both surface condition ratings and structural adequacy ratings.

4.1 Surface Condition

Surface condition ratings give an indication of how well the road is serving the travelling public. The surface condition surveys provide valuable and necessary information but are not sufficient to judge the structural adequacy of the pavement.

The results of the pavement condition surveys are mainly used to:

- assess the effects on the road user,
- establish the probable causes of surface distress,
- determine the need for, and establish priorities for, maintenance operations and surface rehabilitation,
- determine the need for structural evaluation and
- assess the rate of pavement deterioration, so the approximate time for planning future work or for carrying out another condition survey can be predicted.

A condition assessment can be based on one, or a combination of the following:

- Measurements of surface distress, showing locations extent of each defect observed.
- Measurements of surface roughness, showing location and
- Subjective rating of the pavement riding quality and surface condition.

A pavement assessment should always be related to the history of the pavement. In particular, it is essential to record the maintenance operations carried out, since they may have modified the surface condition by temporarily concealing defects. In addition, the assessment should take into account the function of the road concerned and the traffic which uses it.

4.1.1 Recording and Quantifying the Defects

In the first stage, the defects should be visually identified and their extent estimated, so that the road can be divided into sections which exhibit similar defects and to a similar extent.

In the second stage, at regular intervals (100m, 250m or 500m) all defects should be systematically recorded, located and quantified.

The basic methods for quantification of the defects are as follows.

Rutting

Measure the percentage of rutted road length on each lane. Measure the rut depth under a 3m straight edge and calculate the average rut depth. At a given interval (100m, 250m or 500m) all defects should be recorded.

Cracking and crazing
Evaluate the percentage of surface affected
Evaluate the average crack per unit area (m/m^2)
Evaluate the average interval between cracks,

Class 1: Individual cracks, longitudinal or transverse.
Class 2: Interconnected cracks (crazing).
Class 3: Crazing in which the bituminous surfacing fragments are loose.

Longitudinal deformation (corrugations or undulations)
Evaluate the percentage of surface affected by longitudinal deformation. Measure the spacing or wave length. Measure the depth or amplitude of deformation.

General deterioration of surface (ravelling, peeling, bleeding etc.......)
Evaluate the severity of the distress and the percentage of surface affected.

Other defects (depressions, upheaval, potholes)
Identify the type of defect.
Evaluate the percentage of surface affected.
Measure the depth of deformation.

Patching
Patching shall also be recorded, since it indicates earlier deterioration. It shall be quantified as the percentage of the surface area affected.

NOTE: On a recently resealed road, patching and surface defects such as cracks and crazing are concealed (sometimes temporarily). In such instances, information about the surface condition prior to resealing should be obtained from the maintenance unit.

4.1.2 Surface Roughness

There are a number of established techniques for measuring surface roughness. The towed bump integrator unit developed by the TRRL is one example. This equipment is simple to use, robust and easily transported.

The bump integrator aggregates the total vertical downward movement of a wheel relative to its mounting frame as the wheel is towed at a standard speed along the road. The surface roughness is expressed as the aggregate measurement per unit length of road travelled.
.

4.1.3 Present serviceability concept

This concept, which was developed in connection with the AASHO Road Test, presents serviceability as the ability of a specific section of road to provide a smooth, safe and comfortable ride at that particular time. A present day serviceability value may be obtained by either subjectively rating the pavement through visual observations (present serviceability rating) or by quantitative measurement of surface characteristics (present serviceability index)

4.1.3.1 Present serviceability rating (PSR)

This involves the use of a group of raters who ride the pavement section, observe its riding quality, assess its condition and record their impressions on a standard form....

Ratings vary from "0" (very poor) to "5" (very good). Low ratings indicate poor surface condition and suggest a more detailed examination of the pavement is required. The PSR may be used as a first step in evaluating the adequacy of a pavement.

4.1.3.2 Present serviceability index (PSR)

The present Serviceability index is an equation that, when equated with a panel's serviceability rating, can be used together with results of measured surface defects and roughness, to quantify a road section's rideability. The PSI may be computed from the following equations.

For Flexible Pavements:

$$PSI = A_0 + A_1.\log(1+SV) + A_2.RD^2 + B1(C+P)^{1/2}$$

For Rigid Pavements:

$$PSI = A'_0 + A'_1 \log(1+SV) + B'_1 (C+P)^{1/2}$$

where:

SV= the mean of the slope variance in the two wheel paths
RD= the mean wheel path rut depth
C= the percentage of pavement surface with Class 2 or 3 cracking and crazing.
P= percentage of pavement surface patched and pot-holed
A_0, A_1, A_2, B_1, A'_0, A'_1 and B'_1 are coefficients depending on the equipment used for measuring slope variance.

The PSI is mainly dependent upon the roughness of the pavement surface and consequently a simplified PSI may be determined from the following equation:
PSI= 5.00 - a.R - b.logR

Where, "R" is roughness and "a" and "b" are coefficients (see notes)

Notes

- The above coefficients depend on the county, types of pavements analysed and the equipment used for measuring longitudinal profile variations or roughness.
- A single PSI value is not in itself a measure of absolute pavement performance but its representative of the trend of serviceability that gives indications about the performance of the pavement.

4.2 Structural evolution

The structural adequacy of a pavement may be defined as its ability to carry traffic without developing appreciable structural deterioration. It is dependent upon proper construction with suitable materials and of sufficient thickness to prevent traffic from overstressing the subgrade or any other pavement layer.

Structural evaluation is aimed at determining the current adequacy of the pavement and forecasting its future behaviour under the predicted traffic load. When a pavement is found to be inadequate, its structural evaluation provides a basis for designing the strengthening required (for a given design period).
Complete structural evaluation includes the following:

- Measurements of the pavements bearing capacity (from Benkelman beam deflection, dynaflect, falling weight deflectometer or similar surveys).
- Analyses of the characteristics of all pavement layers and subgrade through sampling and laboratory tests.
-

For any pavement, the strength and subsequently, the structural condition is variable from point to point due to the variable nature of the subgrade and pavement materials properties and also the lack of uniformity inherent in the construction operations.

Therefore, the more damaged a pavement the more variable its strength characteristics since deterioration is never uniform. It is therefore almost impossible to define sections, not exhibiting considerable scatter of their characteristics.

This justifies the use of statistical approach, based on the analysis of sufficient number of results. In this respect, it is considered that the performance of a section is associated with the weaker areas of that section. In Kenya, it is not economically viable to design the strengthening on the basis of the weakest 10% of the pavement area; statistical analyses will enable suitable indicators to be selected appropriate to this design principle.

4.2.1 The use of the deflection measurements

4.2.1.1 Principle and significance

The passage of a wheel load over a pavement produces a small transient depression on the surface. The magnitude of the surface depression or ”deflection" depends on the wheel load, area of contact, wheel speed and the stress- strain characteristics and thicknesses of the various pavement layers including the subgrade.

Therefore, if a standard wheel load, tyre size and pressure, and test procedure are applied, measurement of the surface deflection will enable comparison to be made between the stiffnesses of different pavements. It will also provide a means of monitoring the structural strength of a pavement over a period of time.

For flexible pavements, the deflection can generally be correlated with the subsequent performance of the pavement under traffic, indeed, when a transient strain, induced by a wheel load, exceeds a certain critical value in one or more of the pavement layers or the subgrade, it is assumed that a small non-recoverable strain remains. The accumulation of such permanent strains results in the permanent deformation and subsequent cracking of the road surfacing.

High deflections always indicate structural deficiency. However, low deflections do not necessarily denote a satisfactory structural condition.

4.2.1.2 Advantages

- Deflection measurement is a simple, quick and non-destructive test
- A deflection survey is therefore a practical means of identifying the various homogeneous sections of flexible pavement.
- Analysis of the deflection history of a flexible pavement indicates the trend of its adequacy.

4.2.1.3 Limitations

- Deflections do not account for the behaviour of rigid and semi-rigid pavements. Very low deflections can be measured on inadequate rigid or semi-rigid or semi- rigid pavements (already fractured or about to break)
- Surface deflections do not necessarily measure absolute properties of the pavement structure; the deflection is a function of the strains in the pavement layers and the sub grade. It has value only when the characteristics of each pavement layer and the sub grade are known.
- In this respect, it is stressed that deflections measured on thin pavements largely depend on the deformability of the sub grade. It therefore follows that:

Low deflections may be measured on an inadequate or deteriorated pavement lying on a strong subgrade.

Surface deflections depend on the subgrade strength, particularly on its moisture content. Seasonal variations of subgrade moisture are reflected by seasonal variations in the deflections. It is then necessary to correlate deflection with the actual subgrade moisture content. It is also essential to measure the maximum deflection corresponding to the subgrade at its wettest (i.e. at the end of a rainy season).

4.2.1.4 Variation- Characterization of homogeneous sections

Due to large number of factors affecting the deflection, irrespective the length of the road, variations in deflections from point to point must be expected. Considerable scatter is normal for thin pavements, constructed with natural and therefore heterogeneous materials, the more so when the pavement condition is poorer. It is then necessary to obtain a sufficient number of readings to enable a meaningful statistical analysis to be made. In this respect, the following test patterns are recommended:

Feasibility study or routine survey: Testing at 100 – 250m intervals in each of the four wheel paths

Final design of a strengthening project: Testing at 50 m. Intervals in each of the four wheel-paths

The road shall then be divided into homogeneous sections showing similar levels and statistical distribution of deflection, similar pavement structure, subgrade type, surface condition and traffic loading.

It is essential to study the locations of all anomalous results and also all apparent sections of uniform condition to identify if there are any obvious reasons and common factors.

The selection of homogeneous sections may be achieved by using the "moving average" concept or other approved methods which lead to a linear plot of variation in deflection.

Experience has shown that the distribution of deflections in a homogeneous section approximates to a Normal of Gaussian distribution. Such a distribution will confirm the homogeneity of the chosen section.

$D_{90} = D + 1.3$ Where "d" is the mean deflection and "s" the standard deviation.

Thus, 10% of the deflections measured are higher than D90; this guarantees the design of the overlay or strengthening within 90% confidence limits.

4.2.1.5 Standard procedure for deflection measurements

The standard deflection procedures are measured with a Benkelman Beam, which is placed between the twin wheels of a rear axle; the axle load being is 6.5 tonnes and the tyre pressure 5.25 kg/cm^2.

Generally the "rebound" method can be used on:-

- pavements with thin bituminous surfacing and
- pavements with thick bituminous surfacing, provided that squeezing of the bituminous material does not occur between the wheels.

If squeezing of the bituminous surfacing is apparent (especially with high road temperatures), the "transient" method must be employed. This transient method has the further advantage of providing measurements of residual deflection.

The effect of temperature is extensively significant and temperature correction is necessary when the deflection is measured on thick bituminous surfacing with road temperatures in excess of 35^0C. The surfacing temperatures shall be measured at a depth of 40mm.

4.2.2 The use of radius of curvature measurements

4.2.2.1 Principle and Significance

The zone of influence or radius of curvature of the deflected road surface is a better indicator of the strains imposed on the pavement. Indeed the radius of curvature pf the deflection basin is largely governed by the rigidity of the upper pavement layers.

Experience has confirmed that pavement performance and condition are more closely related to severity of bending than to deflection. On rigid and semi-rigid pavements, the magnitude of surface deflection has little significance and the main structural indicator is the radius of curvature (RDC).

It is mandatory that RDC measurements are incorporated in all deflection survey work to provide a complete assessment and enhance the deductions as to the pavement condition and the strengthening required.

High radii of curvature always indicate rigid base and surfacing whereas low radii of curvature correspond to an unbound pavement. An "unbound" layer consists of either flexible material or broken rigid material.

4.2.2.2 Advantages

As pointed out in paragraph 4.2.1 deflection measurements alone cannot account for pavement’s structural behaviour. Measurements of radii of curvature are meaningful and reliable means of supplementing deflection measurements, and enabling a more rational evaluation of the structural condition of a pavement to be made.

4.2.2.3 Variation- characterization of homogeneous sections

Radius of curvature measurements always exhibit appreciable scatter, especially on a deteriorated pavements. It is therefore necessary to obtain a sufficient number of values to allow for a meaningful statistical analysis. It is recommended that radii of curvature be measured simultaneously with the deflections. This has advantage of providing a continual evaluation of the pavement structural condition.

Frequency curves for the radii of curvature do not fit the symmetrical bell- shaped normal distribution curve. However the distribution of logarithmic values of the radii of curvature be measured simultaneously with the deflections. This has the advantage of providing a continual evaluation of the pavement structural condition.

Frequency curves for the radii of curvature do not fit the symmetrical bell-shaped normal distribution curve. However the distribution of logarithmic values of the radii of curvature approximates to this Gaussian distribution. The characteristic radius of curvature (R_{10}) is then calculated by:-

$$Log_{10} = m(logR) - i.3s(log R)$$

Where m (logR) is the mean of log R and s (log R) is the standard deviation of log R.

4.2.2.4 Standard procedure for radius of curvature measurement

The radius of curvature when measured with a Benkelman Beam although generally satisfactory is not very accurate. The accuracy and reproducibility of the measurement can be greatly improved by the use of an X/Y recorder, which can be connected to the deflection beam. This electronic device automatically records the deflection bowl.

4.2.3 Subgrade and drainage analysis

To properly evaluate the structural condition of an existing pavement, it is necessary to know the strength properties of the subgrade and their possible seasonal variations. In this respect, it is equally important to assess the condition of the drainage system.

- For a routine survey or feasibility study, use of the design and construction records, combined with a visual assessment of the nature of in-situ soils and of the adequacy of drainage, should be sufficient to define homogeneous sections in terms of subgrade strength.
- For the final design of a strengthening project, it is recommended that the following procedure be adopted:

In the first stage, one hole should be dug to subgrade level at a spacing of not more than 500 m, in each outer wheel path alternating the lanes. From each hole one sample of subgrade should be taken visually identified and its moisture content measured. It is essential that this subgrade survey be carried out at the same time as the deflection survey, to permit correlations to be established. Ideally, both deflection and subgrade surveys should be carried out at the end of a rainy season.

In this first stage, the adequacy and the condition of the drainage system should be thoroughly assessed (obviously, during a rainy period). This should cover both internal drainage of the pavement (crossfalls, surface impermeability, shoulders, drainage layers etc…) and external drainage (topography, ditches, drains, pipes, culverts etc.)

The possible influence of groundwater should also be evaluated. If a water-table exists near the formation, its characteristics (level, flow, seasonal variations etc.) should be thoroughly studied. If springs are noticed in cuts, their possible effects on subgrade (and pavement) strength should be assessed.

This first stage will facilitate the division of the road into sections having homogeneous subgrade and drainage conditions. Localized spots where peculiar drainage problems occur should be recorded and treated individually.

In the second stage, more accurate result should be obtained by excavating or trenching the pavement at limited locations, within the "sample- sections" taken as being representative of longer homogeneous sections of road. Within each sample section, two trenches should be excavated to the subgrade from the centreline to the outer edge of the pavement, at profiles where radii of curvature were measured. In each trench, samples shall be taken and tests carried out in both the inner and outer wheel paths.

At each point, the following in-situ characteristics of the subgrade should be measured:

- Modules of elasticity (by plate bearing test, DCP or CBR methods)
- Density
- Moisture content

At each point, a subgrade sample should be taken and subjected to the following tests:

- Particle size analysis
- Atterberg limits
- Standard compaction
- CBR at field density and moisture content

4.2.4 Existing pavement structure analysis

It is essential that all pavement layers are accurately identified and their condition appraised, so that the residual strength of the existing pavement can be evaluated and the causes of structural deficiency and surface distress determined.

- For routine survey or feasibility study, use of the design and construction records, combined with the visual assessment of the surface condition, should be sufficient to define homogeneous sections of pavement structure. If construction records are not available, or not accurate enough, sufficient holes shall excavated and limited testing carried out, in order to ascertain the thickness, type and state of the various layers.

- For the final design of a strengthening project, the following procedure is recommended:

In the first stage, one hole should be excavated through the pavement every 500 m. as indicated in Paragraph 4.2.3. In each hole, the thickness of each pavement layer should be measured, the material forming each layer shall be identified visually and its moisture content measured. Programmed and timing permitting it is preferable if the hole locations also verify the pavement at sections having similar "R" and "D" results. It is essential that all exploratory holes are properly backfilled, compacted and resurfaced upon completion and that they do not create points of future failure in the pavement.

This will permit division of the road into sections having a similar pavement structure (same thickness of the same materials).

In the second stage, more accurate results may be obtained by excavating or trenching the pavement at selected locations within the "sample-sections".

Within each sample- section, two trenches should be dug (as indicated in paragraph 4.2.3. In each trench, the layer thicknesses shall be accurately measured, so that the pavement cross- section can be drawn.

At 2 points in each trench (one in the inner wheelpath, the other in the outer wheelpath), sampling and testing should be carried out for each layer as follows:

Untreated or improved material
Measurements of field density and moisture content.

One sample shall be taken and shall be subjected to the following tests:

- Particle size analysis
- Atterberg limits
- Compaction (vibrating hammer for graded crushed stone, Modified AASHTO for other materials)
- CBR (natural material)
- Los Angeles abrasion test(stone)
- Los Angeles Abrasion test (stone)
- Aggregate Crushing Value test (stone)

Stabilized (Bound) material
At each point, 6 undisturbed samples should be obtained by core- drilling. This applies to all treated layers having a sufficient cohesion (whether treated with cement, lime or bitumen). The following measurements should be made:

On 3 core-samples: Density, Unconfined Compressive Strength, Moisture Content.
On the 3 others: Density, Tensile Strength (split test), Moisture Content.

4.2.5 Shoulder assessment

The type of shoulders should be noted and their condition visually assessed. If it appears that there are problems involving the shoulders (drainage of pavement layers, edge restraint, etc…), specific investigations will be required.

In particular, where substantial works affecting the shoulders are planned, e.g. pavement widening, shoulder upgrading, placing of a drainage layer, the characteristics of the existing shoulder material shoulder be determined, with special regard to their possible re-use or re-cycling. The thickness and the volume of existing shoulders should also be measured. It may be necessary to dig holes through the shoulders, to measure thicknesses and to obtain samples.

4.3 Summary of the procedure for pavement evaluation

The recommended procedure for assessment of the surface condition, determination of homogeneous sections selection of typical sample sections and evaluation of the structural condition of the pavement are summarized in Table 4-1.

The sample sections should be located so as to avoid any peculiarity of the road alignment, such as sharp bends, steep slopes, structures, localized drainage problems etc.

Table 4-2 shows how to check the consistency of the deflection with other factors (surface condition, structure design and maintenance rate), giving the main possible causes of disagreement and indicating whether the deflection results are significant or not.

For each homogeneous section, the design parameters (i.e. the characteristic deflection D_{90} and the characteristic radius of curvature R_{10}) should be determined by the procedures described in this chapter.

A- Routine Survey or feasibility study of a rehabilitation project

- Visual Assessment: of the surface condition and drainage system.
- Study: of the design, construction records and maintenance history.
- Deflection Survey: 4 points every 100-250 m. (four wheel paths).
- Radius of Curvature: 4 points every 100-250 m. (four wheel paths).
- Optional: Roughness survey by Bump integrator (outer wheel paths).
- Optional: Core - Cutting for pavement structure and subgrade
-
- Check: if there is agreement between condition, structure and deflection(table.4.2)
- if Yes: Divide road into homogeneous sections.
- if No: Further investigations to explain disagreement (see Table 4.2) and define homogeneous sections.

B - Final design of a rehabilitation project

First Stage: Division into homogeneous section - choice of sample sections

- Visual Assessment: of surface condition and of the drainage system.
- Study: of the design and construction records and maintenance history.
- Radius of Curvature: 4 points every 50 m (four wheel paths)
- Pavement Structure and Subgrade Moisture Content Survey: hole every 500m.
- Optional: Roughness Survey by bump integrator (outer wheel paths).

- Check if there is agreement between condition, structure and deflection (by using Table 4.2).
- If yes: Divide the road into homogeneous sections.
- If No: Further investigations to explain disagreement (see Table 4.2) and define homogeneous sections.

Second stage: Detailed survey of each sample section

- Systematic Recording and Quantification: of the defects.
- Pavement Structure and Subgrade Analysis: two half width trenches.
- In Each Trench: accurate measurements of layers' thicknesses and an assessment of the layers state.
- At 2 points in Each Trench (Both Wheel Paths) :
- Pavement Structure and Subgrade Analysis: two half width trenches.
- In Each Trench: accurate measurements of layers' thicknesses and an assessment of the layers state.
- At 2 points in Each Trench (Both Wheel paths):
- On the Subgrade: one plate bearing test, density-moisture content sampling and laboratory tests.
- On Each pavement layer: density - moisture content sampling and laboratory tests (treated layer: 6 core samples).
- Laboratory Tests particle size analysis Atterberg limits, CBR,UCS, TS, Los Angeles Abrasion test etc.

Table 4-1: Summary of the procedure for pavement evaluation

Deflection Level Case No.	Surface Condition	Structure Design	Maintenance Rate	Agreement between Deflection and Other Criteria Probable Cause of Disagreement points to Check	Possible Use of Deflection for Sectioning and Choice of Remedial Measures
(1) High	Poor	Excessive	Excessive	Yes All factors in accordance	Deflection can be used for dividing the road into homogeneous section and choice of corrective measures
(2) Low	Good	Normal	Normal	Yes All factors in accordance	Deflection can be used as an indicator, for flexible pavement. No corrective measures required
(3) High	Good			No A) Recent resealing has concealed surface distress Check resealing date. B) New inadequate Pavement, which carried light traffic	Deflection can be used for dividing the road into homogeneous section and choice of corrective measures

(4) High	Poor	Excessive	Excessive	NO Probably one pavement layer is defective, not all layers Check layer by layer	Deflection can be used to define affected sections. Correction of deficiency may be independent of deflection
(5) Low	Poor	Excessive	Excessive	NO Deflection not representative either dry season measurement repeat survey in rainy season or pavement is not flexible	a) Representative deflection can be used as in case No. 1 b) Deflection is not an indicator of structural condition
(6) Low	Adequate	Excessive	Excessive	NO The surfacing is defective, the rest of the pavement is sound Check the surface layer	Deflection is not related to surface deterioration

Table 4-2: Verification of the consistency of the deflection with surface condition, sructure design and maintenance rate

5 CRITERIA FOR MAINTENANCE AND REHABILITATION 2
5.1 Surface condition criteria...2
5.2 Surface roughness criteria 3
5.3 Present serviceability criteria 3
5.4 Deflection criteria 4
5.4.1 Relationship between tolerable deflection and cumulative traffic..4
5.4.2 Life Phases of flexible pavement deflection changes 4
5.4.3 The use of Deflection for Performance Prediction Residual Life Estimation of Flexible Pavements 5
5.4.4 Relations of Tolerable Deflection/Cumulative Traffic Obtained in Kenya. 6
5.4.5 Strengthening...6
5.4.6 Reconstruction...6
5.5 Product RD Criteria 6

Table 5-1: Classification of road surface condition 2

Figure 5-1: Flexible Pavement Deflection History...7

5 CRITERIA FOR MAINTENANCE AND REHABILITATION

Continuous and periodic evaluation of the pavement condition is necessary to determine the trend of changes and to plan and design corrective measures.

The definition of unsatisfactory service in a pavement structure is a complex problem, since it depends, among other factors, on the level of service, safety and the rate of maintenance considered normal or acceptable. Therefore, the criteria suggested in this section should be regarded only as indicative.

5.1 Surface condition criteria

Depending on the extent of cracking and transverse deformation, pavements may be classified according to the following index table from the British Transport and Road Research Laboratory (TRRL):

Transverse Deformation under a 3m Straight-Edge		**Degree of cracking (Visible cracks)**	
Index	Deformation or Rut Depth	Index	Crack Length per Unit Area
D1	<10mm	C1	NIL
D2	10-15mm	C2	$<1m/m^2$
D3	15-20mm	C3	$<1m/m^2$
D4	20-25mm	C4	$2 - 5m/m^2$
D5	>25mm	C5	$> 5 m/m^2$

Table 5-1: Classification of road surface condition

The following points should be noted:

- With a normal crossfall of 2.5% ponding will generally occur at rut depths in excess of 12mm
- For flexible pavements, when the rut depth in the wheel path reaches about 20mm, cracking is usual and water will penetrate the pavement which then deteriorates rapidly.
- When the degree of cracking reaches about 5 m/m^2, pot-holing is imminent and immediate maintenance is required.

Consideration should also be given to other types of surface distress, such as ravelling, stripping, peeling etc.... The surface percentage covered by patched areas should also be measured, since patching represents incurred deterioration.

The following criteria, derived mainly from TRRL research on road deterioration, are suggested:-

Road requires local patching
When one of the following conditions arises:

- Rut depth exceeds 20 mm
- Cracking exceeds 5 m/m^2

Road requires resealing (surface dressing or slurry seal)
When any one of the following conditions arises:

- General deterioration of the surface (fine crazing ravelling, stripping, etc.) covers more than 20% of the whole carriageway area over the length showing distress.
- Mean cracking in the wheel path exceeds $1m/m^2$

Road requires minor overlay or resurfacing:
When any one of the following conditions arises:

- Cracking covers more than 30% of the wheel paths over the length showing distress for trunk roads and 50% for other roads.
-
- Rut depths in near-side traffic lanes reach 15mm over more than 20% of the length showing deformation for trunk roads.

Road requires major-overlay or reconstruction
When the mean rut depth in either wheel path exceeds 20 mm, for trunk roads and 25 mm for other roads.

5.2 Surface roughness criteria

Bases upon TRRL findings, the following criteria are suggested:-

Road Requires Resurfacing
When surface irregularity measured by a bump integrator exceeds the following values:

- Trunk roads 2,800 mm/km
- Other roads 3,100 mm/km

Road Requires Overlay or Reconstruction
When surface irregularity exceed the following values:

- Trunk roads 3,400 mm/km
- Other roads 3,750 mm/km

5.3 Present serviceability criteria

Experience suggests that Present Serviceability Values of 2.5 for trunk roads and 2.0 for other roads should be considered as minimal that indicate when rehabilitation is necessary.
Accordingly, to allow the corrective works to be carried out in due time, pavement rehabilitation should be considered and programmed when the present Serviceability Values reach about 3.0 in the case of trunk roads and about 2.5 in the case of other roads. (The

knowledge of the rate of change in pavement condition will give guidance for works planning).
However, further research is required to determine the correlations between serviceability ratings and surface condition and roughness, applicable to Kenyan roads.

5.4 Deflection criteria

5.4.1 Relationship between tolerable deflection and cumulative traffic

Generally, the lower the stress in a material, the more stress repetitions are required for failure to occur. For a given form of flexible pavement, the magnitude of the surface deflection is an indicator of the strains in the pavement layers and in the subgrade. Therefore, a given pavement structure has a limiting deflection which is a function of the number of load applications. As yet the theoretical determination of the relationship between deflection and future traffic-carrying capacity is still uncertain. This relationship must therefore be established empirically. Its graphic representation is called a "deflection criterion curve".

It is emphasized that there is a different relationship between allowable (or "critical") deflection and cumulative traffic for each type of flexible pavement and, each type of subgrade.

5.4.2 Life Phases of flexible pavement deflection changes

The deflection of a flexible pavement does not remain constant with time. The deflection life of a well designed flexible pavement can be divided into the following four distinctive phases:

Consolidation phase

During this initial phase, the various pavement layers and the subgrade undergo some consolidation due to the action of the wheel loads. This causes a slight decrease of the surface deflection. This phase is relatively short and the magnitude of consolidation depends on the compaction received by the various layers during construction. Stabilising of the subgrade moisture content may also produce consolidation. Ruts may appear in the wheel paths.

This phase will be almost unnoticeable if the various layers have received sufficient compaction during construction.

Elastic phase

During this phase, a genuine elastic performance occurs. Each wheel load procedures a deflection which recovers completely after the passage. The deflection does not change during the elastic phase and is termed "early life deflection". This constant "early life deflection" constitutes an important characteristic. It should be measured after the initial changes (consolidation) have taken place, generally about 6 months after the opening of the road.

Plastic phase (fatigue)

Under the effect of traffic and climate, the pavement deteriorates gradually by attrition in the upper layers. Compression in the subgrade, loss of cohesion in the treated materials and ageing of the bitumen. Each wheel load produces a small, non-recoverable deformation ("residual deflection").During this plastic phase, the deflection increases slowly. Ideally, the pavement should be strengthened towards the end of this phase before extensive deterioration occurs.

Failure
If the pavement is not strengthened in time, it deteriorates rapidly be deformation and disruption. In the absence of heavy repairs and under adverse climatic conditions, holes form which spread and destroy large areas of pavement. There is a sharp increase of deflection during this [phase.

Notes:

- In the case of a poorly designed flexible pavement, there can be no elastic phase. If so plastic deterioration and fatigue will affect the pavement immediately after it is opened to traffic.
- In the case of a rigid pavement, therefore, there is no plastic phase. The pavement may break up suddenly by fracture without showing previous signs of deterioration. In particular, there is no gradual increase of the deflection prior to failure. Consequently the deflection cannot be used as an indicator of the structural adequacy of rigid pavements.
- Some maintenance operations nay influence the deflection. In particular resealing and drainage improvement frequently decrease deflection. It is therefore, essential to know and record the dates and the extent of all the principal maintenance operations.

5.4.3 The use of Deflection for Performance Prediction Residual Life Estimation of Flexible Pavements

For a given type of flexible pavement, it is necessary to know both the relationship between allowable (critical) deflection and cumulative traffic and the variation of the actual deflection against cumulative traffic to be able to predict the future performance of a road.

Figure 5-1 illustrates a notional deflection criterion curve, which is obtained by drawing a line between the plots of the deflections of pavements in poor and acceptable conditions. On the same figure is shown a typical curve representing the variation of the actual deflection against cumulative traffic

A knowledge of both critical deflection and deflection history enables the pavement life expectancy to be estimated. As indicated, a pavement having a deflection D_1after carrying N_1 standard axles has a residual life equal to (N_2-N_1) standard axles, N_2 corresponding to the critical deflection D_2.

Conversely, if it is desired that the pavement considered carried N_2 standard axles during its design life, its early life deflection should not exceed D_0.
This may be used to check, shortly after construction, if the pavement is adequate.

Thus, to be able to plan strengthening for a given flexible pavement it is necessary to know:

- The characteristics of the pavement structure,
- The characteristics of the subgade,
- The relationship critical deflection/cumulative traffic,
- The provable variation of the deflection against traffic and
- The cumulative traffic carried until the time of deflection measurement.

It is therefore clear that one deflection survey alone is absolutely insufficient to evaluate structural adequacy or to make predictions about future performance or residual life.

5.4.4 Relations of Tolerable Deflection / Cumulative Traffic Obtained in Kenya.

It has been possible to establish the relationship between allowable deflection and cumulative traffic for 3 types of flexible pavements, namely:

- Surfacing: Surface dressing or Thin asphalt concrete (25-30mm.-cracked)
  Base: 125-175 mm Graded crushed stone
  Subbase: 100-200mm Flexible material

- Surfacing: Surface dressing
  Base: 125-175 mm Cement or lime improved material
  Subbase: 75-150 mm Flexible material

- Surfacing: Surface dressing
  Base: 100-200mm Waterbound macadam
  Subbase: 100-250 mm Natural gravel

5.4.5 Strengthening

It consists of constructing one or more layers on the existing pavement.

5.4.6 Reconstruction

If the existing road is considered inadequate for the expected traffic or has poor geometric standards, it may be justifiable to rebuild or realign it.

5.5 Product RD Criteria

Theory indicates that, for an ideally uniform section of pavement, the product "RD" ("R" radius of curvature, "D" deflection) depends only on the thickness "h" of the pavement upper layers and the ratio of the modulus of elasticity E_1/E_2, if the pavement/subgrade structure is considered as a two-layers system.

Actually since no section of pavement is perfectly uniform considerable scatter of the product RD is often observed. Nevertheless it is thought that for a given type of pavement and subgrade, there is a critical value of the product RD below which the structural condition is inadequate.

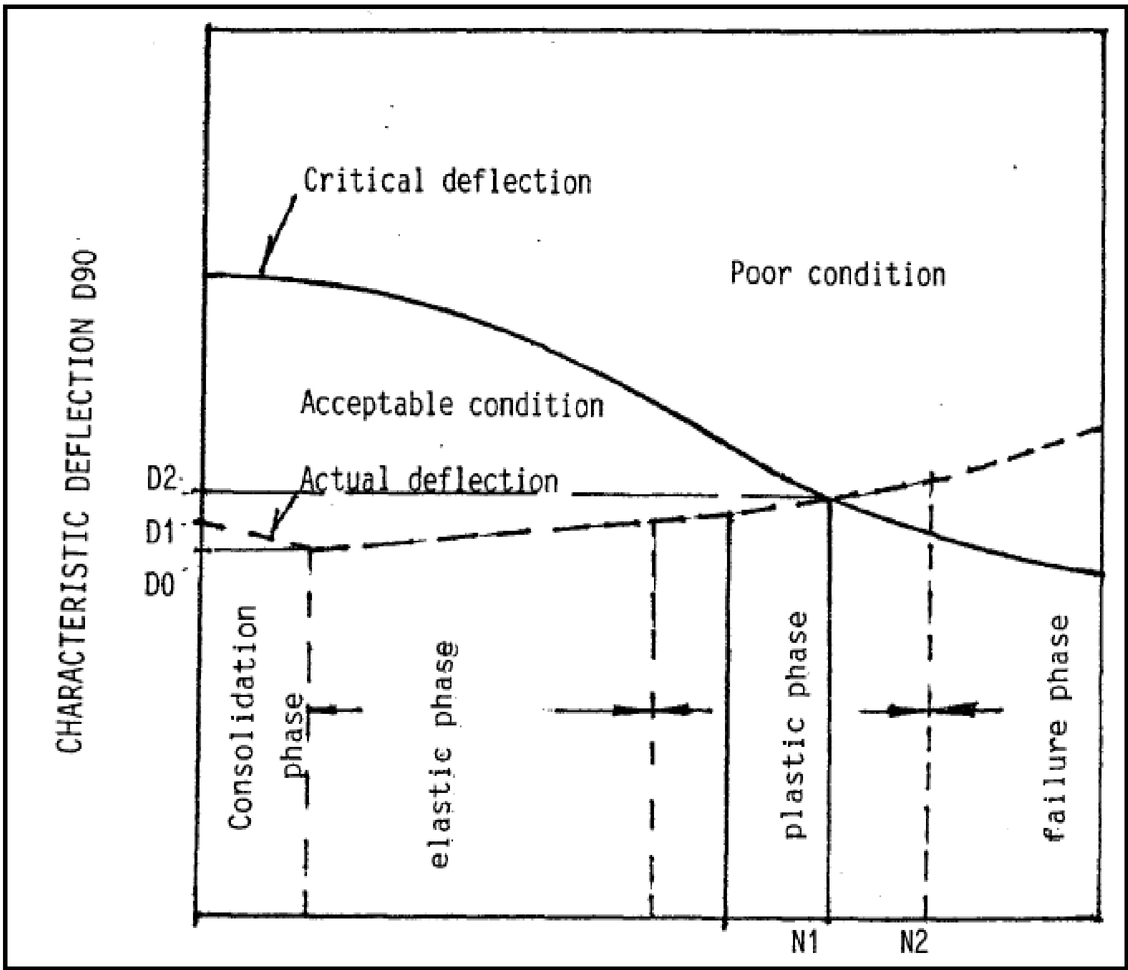


Figure 5-1: Flexible Pavement Deflection History

6 TECHINIQUES AND MATERIALS FOR ROAD STRENGTHENING 2
6.1 Restoration and Improvement of the Drainage System 2
6.1.1 External Drainage 2
6.2 Preparation of the Existing Pavement for overlay 3
6.2.1 Local Repairs 4
6.2.2 Levelling...4
6.2.3 Cleaning and Tack-Coat 4
6.3 Overlays...5
6.3.1 Different types of overlay 5
6.3.2 Flexible overlay materials 6
6.3.3 Bound Overlay Materials...8
6.3.4 Preventing Reflection Cracking...12

6 TECHINIQUES AND MATERIALS FOR ROAD STRENGTHENING

Overlaying a pavement is the most often adopted method of increasing its traffic-carrying capacity; however it is not the only one. Due consideration should always be given to other means of strengthening and in particular to the restoration and improvement of the road drainage system.

6.1 Restoration and Improvement of the Drainage System

If pavement deterioration can be attributed to poor drainage, then the first strengthening operation to undertake is to correct any faults in the drainage system.

Drainage deficiencies may result from poor design of the system or from changes in the road environment, particular in the run-off conditions.
A complete study of the drainage should be made to determine the required corrections.

6.1.1 External Drainage

6.1.1.1 Surface Water

An assessment of the adequacy and the state of the surface drainage system (topography, ditches, drains, pipes, culverts etc will enable the necessary corrective measures to be decided.

Drainage problems are often caused by lack of maintenance. In such a case it is often sufficient to clear the ditches and drains of the vegetation, debris and sediment and to repair any erosion damage.

In some cases, it may be found necessary to carry out the following improvements:

- Widen and deepen the side ditches and outfalls.
- Construction addition catch water or discharge drains
- Line ditches, the sides of which erosion causes to collapse.
- Replace pipes of insufficient section
- Place additional pipes.

6.1.1.2 Ground Water

In cuttings, the road pavement and subgrade may be adversely affected by groundwater (water table or springs); usually, this problem affects only short lengths of road, Subsurface or blanket drains should then be placed to cut off seepage lines or to lower the water-table.

A more difficult situation may exist in low-laying or poorly drained flat areas, where a water-table near formation saturates the subgrade by capillary flow. In such areas, it may be impractical to permanently lower the water-table. If a short length of road is involved the best solution is to raise the formation level and to construct the pavement. If a longer stretch of the road is affected, alternative routes should be considered if a less costly long term solution can not be found.

6.1.1.3 Internal Drainage

The most frequent and serious drainage fault concerns pavements with a permeable base (generally of stone) and having impermeable shoulders and subbase ("trench" type of cross-section)

Water entering such a pavement, through cracks on the surface or defective edge seals, cannot be drained away and accumulates in the base and/or subbase causing the rapid failure of the whole structure.

Regarding drainage of the pavement layers, drainage grips through the shoulders have proven largely ineffective. It is therefore recommended that a continuous drainage layer be provided. Such works should consist of the following:

- Removing the existing impervious shoulders,
- Placing a continuous drainage layer at the level of the underside of the stone base,
- Reinstating the upper shoulder with cohesive and impermeable gravel,
- Resealing the surface, including edge seals.

The drainage layer shall be made of approved filter material (graded crushed stone, sand, etc.) and be at leas 75 mm thick. The use of non-woven textile material may also be envisaged.

6.1.1.4 Necessity of Carrying Out Drainage Works in Advance of the Overlay. The Need to Re-Evaluate the Structural Condition after Drainage.

Rectification of any drainage deficiencies should be carried out at lease 6 months preferably 12 months ahead of the strengthening works so that the saturated layers can dry out and consolidate. In that way at least one rainy season will have put the improved drainage works to the test.

It is necessary to re-evaluate the structural condition of the pavement after drying out and consolidation. Indeed, drainage improvements may increase the pavement strength and enable a reduction to be achieved in the proposed overlay thickness.

6.2 Preparation of the Existing Pavement for overlay

The overlay thickness is designed to provide the additional strength required for most of the existing pavement (normally about 90%), but not for localized weak spots, if the overlay design was based on the weakest condition in the section it would be overdesigned for the rest of the section and therefore unjustifiably expensive. In practice these weaker areas must be identified and rectified prior to overlaying.

6.2.1 Local Repairs

All extensively deteriorated areas, i.e. potholes, depressions and areas exhibiting cracking class 3 (crazing with loose fragments) should be properly patched.

The use of patching material whose stiffness is comparable to that of the existing pavement is recommended otherwise differential settlements and cracks nay occur at the joints.

If the edges of the pavement are damaged, special care must be taken to repair them with strong material, so as to ensure an adequate edge restraint.

The most usual patching materials are cold-asphalt and cement-improved gravel.

All loose material resulting from surface deterioration (fine crazing, ravelling, stripping, etc....) should be removed and all open cracks sealed.

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6.2.2 Levelling

When the existing surface is extensively deformed, it may be necessary to place regulating courses or levelling wedges to restore proper line and cross-section, thus enabling smooth laying and uniform compaction of the subsequent overlay.
Levelling wedges are patches of material used to fill up sags and depressions or to reduce an excessive crown.

The most practical method of levelling will depend on the type, amplitude and distribution of surface irregularities and on the nature and thickness of the overlay.

When the overlay thickness required is large, it is current practical to place the overlay in several layers, the first one acting as a regulating course.

Where only a small overlay thickness is required the pavement is generally still in a fairly good condition and therefore little deformed, However, in cases in which the pavement's structural condition warrants only a comparatively thin overlay whilst the existing surface exhibits pronounced irregularities, it will be necessary to carry out specific levelling operations in order to correct the existing surface and permit proper placing of the thin overlay.
The most suitable material for such levelling wedges is cold asphalt. The binder may be either a bitumen emulsion or a medium-curing cut back. A tack coat is required. The mixture should have a maximum particle size that permits feathering at high spots in the pavement. The most appropriate way of placing such levelling wedges is by motor - grader or paver - finisher or other appropriate means depending on the areas to be laid and the plant available.

6.2.3 Cleaning and Tack-Coat

Immediately before the overlay application, the surface must be thoroughly swept and all loose and foreign material shall be removed.

If an asphalt concrete or gap-graded asphalt or sand asphalt overlay is to be placed, it is generally necessary to spray a tack-coat to assure uniform and complete adherence of the overlay. The ideal material for tack coat is hot neat bitumen.

6.3 Overlays

6.3.1 Different types of overlay

6.3.1.1 Resurfacing, or smoothing overlays

The condition of the pavement surface may require a thin overlay, even though the pavement is structurally sound. The principal reasons for overlaying otherwise adequate pavements are as follows:

- Excessive surface roughness, due to ravelling, peeling, scaling, spalling or patching.
- Surface deformation, resulting from rutting, shoving or corrugating of existing surfacing, settlement, etc........

Thin smoothing overlays are generally bituminous premixes (asphalt concrete, gap graded asphalt or sand-asphalt.) The maximum particle size will depend on the thickness required.

Apart from their specific purpose of restoring the riding quality they also waterproof the surface.

6.3.1.2 Structural overlays

Thin smoothing overlays are generally bituminous premixes (asphalt concrete, gap- graded asphalt or sand-asphalt.) The maximum particle size will depend on the thickness required.

Apart from their specific purpose of restoring the riding quality they also waterproof the surface.

6.3.2 Flexible overlay materials

Experience shows that flexible overlay materials are suitable for light and medium traffic, classes T5 -T4 -T3 and which provides for a cumulative traffic loading of up to 10 million standard axles.

The flexible overlay materials consist of a flexible base course covered with either surface dressing or not more than 50 mm of flexible asphalt concrete. Two main types of materials suitable for base course are cement or lime improved gravel and graded crushed stone.

6.3.2.1 Cement or Lime Improved Materials

The materials shall comply with all the requirements given in Part 3 design manual. Such materials can be employed under double surface dressing for light traffic up to 3 million standard axles, classes T5 -T4 Medium traffic (T3) requires:

- Either 50 mm flexible asphalt concrete as surfacing, or
- A fairly good resistance to attrition if surface dressing is applied.

These materials are unsuitable for traffic over 10 million standard axles, owing to their insufficient strength and resistance to attrition.
The surfacing and base-course requirements for this type of overlay can be summarized as follows:

Traffic Classes T5 -T4
Surfacing: Double surface dressing
Base: Cement or lime improved material (CBR: min160)

Traffic Class T3
Alternative (A)

Surfacing: 50 mm asphalt concrete Type II (flexible) or gap-graded asphalt or sand-asphalt

Base: Cement or lime improved material (Carmen 160)

This type of overlay is relatively cheap, however in some regions particularly the volcanic areas; materials suitable for treatment are scarce.

Care should be taken to ensure that the overlay material is not too stiff so as to avoid it being overstressed and cracking as a result. If the treated material has appreciable rigidity, the overlay thickness required is determined as for a cement stabilized gravel (see section 6.3)

Treated materials should not be laid in layers of compacted thickness less that 125 mm. and treated clayey sand in layers less than 100 mm.

6.3.2.2 Graded crushed stone

Graded crushed stone should comply with the requirements given in party 3 design manual.

Graded crushed stone can be used under double surface dressing for light traffic up to 3 million standard axles (T5-T4). Whilst medium traffic (T3:3 to 10 million axles.) requires:

- either 50 mm flexible asphalt concrete as surfacing, or
- sufficient angularity and hardness of the stone if surface dressing is applied.

Graded crushed stone is not suitable for traffic over 10 million standard axles because attrition is likely to affect it and in instances where such a road has been subjected to a high percentage of over laden axles early rutting and shear failure has occurred.
The surfacing and base course requirements for this type of overlay are summarized as follows.

Traffic Classes T4- T5

Surfacing: Double surface dressing

Base: Graded crushed stone Class C

Traffic Class T3
Alternative (A)

Surfacing: 50 mm asphalt concrete type II (Flexible) or gap-graded asphalt or sand-asphalt

Base: Graded crushed stone Class B

Alternative (B)

Surfacing: Triple surface dressing

Base: Entirely crushed G.C.S. Class B

Graded crushed stone is considered where gravel suitable for the base is not available. Graded crushed stone is effective in preventing cracks from reflecting through to the surface from the overlaid pavement.

The minimum compacted thickness that can be practically placed is 125 mm for 0/40mm granularity and 100mm. for 0/30 mm granularity.

Note: if suitable stone for chippings cannot be found, a thin layer (25 mm+) of asphalt concrete (Type II), gap-graded asphalt or sand-asphalt may be placed instead of surface dressing.

6.3.2.3 Other flexible overlay materials

Consideration can be given to other flexible materials, such as:

- low-plasticity gravel treated in-situ with bitumen, or
- graded crushed stone treated in-situ with a low content (2%) of bitumen emulsion. or
- a mixture of gravel and graded crushed stone possibly treated with lime or a small amount of cement.

However, experience on these composite materials is limited and special studies would be required in each case.

6.3.3 Bound Overlay Materials

6.3.3.1 Asphalt concrete (Continuously Graded Asphalt)

This is the most common overlay material, usually asphalt concrete (Type I) and is used to resist rutting and high stresses. However this material cannot be laid in thin layers on a deformable support because it would be overstressed. Appreciable thicknesses are hence necessary if it is to be used for overlays to flexible pavements.

It may therefore be advantageous to strengthen very deformable pavements with more flexible materials such as asphalt concrete (Type II), gap-graded asphalt or sand-asphalt.

The material specifications, traffic limitations and construction procedures for asphalt concrete are summarized in Part 3 Design Manual.

Notes:

- Asphalt concrete (Type II) is suitable only for light and medium traffic (up to 10 million standard axles).

The minimum practical thickness that can be laid by the current types of finishers is 25-30mm (provided the maximum aggregate size does not exceed 10mm).

6.3.3.2 Gap-graded (Hot- Rolled) asphalt

Part 3 Design manual summarizes the materials' requirements, traffic and construction limitations applicable to gap-graded mixes suitable for thin wearing courses (25-50 mm) and light to medium traffic (T5, T4, T3). Such mixes are expected to be flexible, fatigue- resistant and durable, owing to the good distribution of the voids structure and the rounded shape of most of the fine aggregate.

Gap-graded asphalt may be suitable for heavier traffic or thicker layers, subject to its compliance with severe specifications; in particular a better resistance to rutting is then required. However because of the rapid ageing of bitumen, a durable compromise between resistance to rutting and resistance to fatigue may be difficult to achieve.

6.3.3.3 Sand Asphalt

The use of sand asphalt is a viable solution where suitable stone cannot economically be found. The materials' requirements, traffic and usage limitations are given in part 3 Design Manual.

As its resistance to rutting is low, sand asphalt is only suitable for thin wearing courses<50mm) and light to medium traffic (T5 -T4 -T3).

6.3.3.4 Dense Bituminous Macadam (DBM)

The materials' requirements, traffic limitations and construction procedures are summarized in part 3 Design Manual. The following points should be noted:

- Suitable ranges of compacted thicknesses to be laid are as follows:
  60-100mm for 0/30 mm granularity
  75-125 mm for 0/40 mm granularity
- Traffic limitations required 0/30 mm DBM for traffic class T1, and 0/40 mm. DBM for traffic classes T2 andT3. However, depending on the thicknesses required, 0/30 mm DBM may be used for traffic classes T2 and T3
- To provide for imperviousness and good riding quality it is usual to place a wearing course of 50 mm thick asphalt concrete on top of the dense bituminous macadam. It is also possible to cover the dense bituminous macadam with surface dressing, however it is then absolutely necessary to use a denser (DBM) grading and a slightly higher bitumen content and to pay special attention to the evenness of the DBM surface.
- Dense bituminous macadam is adequate for all traffic, but is only economically viable for heavy traffic (T1-T2).

- Dense bituminous macadam must be protected immediately with a wearing course to prevent percolation of rainwater into it.
- Dense bituminous macadam may be trafficked immediately after compaction: this is an appreciable advantage over the cement treated materials.

6.3.3.5 Dense Emulsion Macadam (DEM)

Dense emulsion macadam is a cold mixed, cold laid, plant-mix of well graded aggregate and bituminous emulsion.

The materials' requirements, traffic limitations and construction procedures and summarized in part 3 Design Manual.

- It is economical: cold-mixing equipment is comparatively simple and cheap and large production outputs can be maintained. No heating is required.

- It is easy to use: no temperature control is necessary. Moreover, the mix can be laid by grater and therefore lends itself remarkably well to regulating and levelling operations.

- Dense emulsion macadam can be placed in comparatively thin layers: 75 mm for 0/30 mm DEM and 100 mm for 0/40 mm DEM.
- When properly formulated and placed, its strength is marginally less than that of dense bitumen macadam. On the other hand, as the binder is used cold, it is not oxidized during mixing and laying and remains tacky and ductile. This gives a good fatigue resistance to dense emulsion macadam.

The following points are also stressed:

- The granularity 0/30 mm is required for traffic classes T1 and T2.
- The 0/40 mm DEM can be employed for T3, if the thickness required exceeds 100 mm.
- To adequately protect the base against excessive stresses and attrition, and to obtain sufficient imperviousness and satisfactory riding quality, asphalt concrete surfacing is required for heavy traffic (T1-T2):

  - 75mm for traffic class T1
  - 50 mm for traffic class T2

- Surface dressing is adequate for medium traffic (T3)
- Dense emulsion macadam is suitable for all traffic, but is economically justified only for heavy and medium traffic (T1-T2-T3).
- Heavy compaction is required for dense emulsion macadam.

- The adjustment of the moisture content is of prime important.
- Dense emulsion macadam must not be placed in layers of compacted thickness exceeding 150 mm, so that water can evaporate. It shall be allowed to "cure" before any covering is applied.

Dense emulsion macadam can be trafficked immediately after compaction (the action of traffic is beneficial as it provides additional compaction).

6.3.3.6 Cement Stabilized Gravel

The materials' requirements and construction procedures are summarized in part 3 Design Manual.

The following points are emphasized:

- To ensure the uniformity of the mix, it is advisable to use a stationary mixing plant. In this respect it should be noted that only low-plasticity materials (plasticity modulus not exceeding 700 can be properly mixed in stationary plant.
- Attention is drawn to the time limitations imposed by the rapid setting of the cement. Compaction must be completed not later than 2 hours after mixing and protection against evaporation must be placed not later than 4 hours after Compaction.
- No vehicle should be permitted on cement stabilized gravel for at least 7 days.
- For heavy and medium traffic, asphalt concrete surfacing is necessary so as to avoid excessive shear stresses and attrition in the stabilized gravel. The required thicknesses of asphalt concrete (Type I) are:

  - 50 mm for traffic Class T3
  - 75 mm for traffic Class T2
  - 100 mm for traffic Class T1
- Surface dressing is adequate for light traffic.
- This type of overlay is comparatively cheap, considering the other structures required for heavy traffic. It compares very advantageously with lean concrete, in particular because of its more favourable ration of tensile strength to elastic modulus.

Unfortunately, suitable gravels are scarce in many parts of the country especially in the volcanic regions.

6.3.3.7 Lean Concrete

The material requirements of construction procedures are summarized in Part 3 Design Manual. The following points should be note:

- Lean concrete as an overlay material has a number of advantage; its characteristics are independent of the temperature and a high modulus of elasticity is obtained.
- Due to its rigidity, lean concrete must be placed in thick layers (minimum 150 mm).
- Widely spaced cracks, due to shrinkage and thermal changes, are almost inevitable; Care must be taken to ensure that the pavement layers are properly drained. A continuous drainage layer through the shoulders is needed.

Eliminating reflection cracking would require considerable bituminous wearing course thickness, which is regarded as economically unreasonable and technically unnecessary. Indeed, in spite of their unpleasant psychological effect, reflection cracks do not affect the riding quality and have no structural effect if the overlay is otherwise adequately designed and constructed.

An asphalt surfacing of 75 and 50 mm has consequently been adopted for traffic classes T1 and T2 respectively, mainly for the sake of imperviousness and good riding quality. Surface dressing has been considered suitable for traffic Class T3.

- Attention is drawn to the time limitations due to the rapid setting of cement. Compaction should be completed not less than two hours after the start of mixing and protection against evaporation is required not less than 4 hours after completion of compaction.
- No vehicle should be permitted on lean concrete for at least the first 7 days

6.3.4 Preventing Reflection Cracking

When overlaying a cracked pavement, special care must be taken to prevent any existing cracks from reflecting through to the overlay surface. This point is of prime importance in the case of an existing rigid or semi-rigid pavement exhibiting large and open cracks. There methods can be employed to eliminate reflection cracking; these are as follows:

- Breaking the existing cracked layer(s) into small pieces and resealing them firmly. Field trials may be required in order to verify the practicality and effectiveness of such a method since each case will require individual study and comparative cost analyses

- Placing a sufficient thickness of overlay. This method is generally costly as the overlay thickness required is considerable:

  - Bituminous mixes: absolute minimum 120mm

- Cement-stabilized gravel: absolute minimum 200mm

Placing an intermediate layer of unbound granular material ("cushion course"). This method is very effective and is therefore recommended. The most suitable "cushion" material is graded crushed stone.

7 STRUCTURAL DESIGN OF OVERLAYS FOR FLEXIBLE PAVEMENTS 2
7.1 Design principles 2
7.1.1 Overlay Thickness and Characteristics 2
7.1.2 Planning period...2
7.1.3 Stage construction 2
7.2 Practical and Experimental Bases 3
7.2.1 Use of Flexible Overlays 3
7.2.2 Behaviour of overlay Materials...3
7.2.3 Construction Principles...5
7.3 Design of Asphalt Overlays of Flexible Pavement 5
7.3.1 General 5
7.3.2 Defection procedure 6
7.3.3 Effective analysis procedure 12

Table 7-1: Minimum Layer Thickness 5
Table 7-2: Suggested layer coefficients for existing AC pavement layer materials ...13
Table 7-3: Suggested layer coefficients for stabilised roadbase materials 14
Table 7-4: Drainage assessment 14
Table 7-5: Recommended mi values for modifying structural layer coefficients of untreated road base and sub base materials...14

Figure 7-1: Tensile strain criteria for various bituminous layers...................................4
Figure 7-2: Temperature Adjustment Factor for Benkelman Beam Deflections.........10
Figure 7-3: Overlay thickness design chart...12

7 STRUCTURAL DESIGN OF OVERLAYS FOR FLEXIBLE PAVEMENTS

7.1 Design principles

7.1.1 Overlay Thickness and Characteristics

No overlay structure can be designed independently of the characteristics of the overlay materials. Indeed, each overlay material has different properties and the thickness required is governed not only be the load response of the exiting pavement buy also by stress/strain characteristics of the overlay itself.

7.1.2 Planning period

An overlay is designed to carry a certain number of standard axles. To estimate the cumulative traffic to be considered in the design, it is necessary to decide on a "design period".

It is known that "design period" does not mean that at the end of the period the overlaid pavement will be worn out to the point that reconstruction is required. "Design Period" indicates that, towards the end of the period, the overlaid pavement will need to be strengthened again, so that it can continue to carry traffic satisfactorily for a further period.

Design periods for overlays will normally range between 7 and 15 years

It is assumed that, during the design period, only routine maintenance will be carried out; i.e. shoulder and drainage system maintenance, erosion and vegetation control localized patching and periodic resealing. This maintenance is however essential and its neglect will seriously affect the pavement performance and shorten its life.

7.1.3 Stage construction

Stage construction of overlays arises when it has been established that inadequate drainage is a main cause of the deterioration and that the pavement strength will be significantly increased by restoration or improvement of the drainage system and subsequent consolidation of the saturated layers.

The first stage should then consist of:

- Drainage restoration or improvement
- Shoulders reinstatement plus either resealing, or flexible overlay (flexible base course covered with surface dressing).

The second stage should consist of the application of a bituminous overlay, the design of which should be based on the pavement structural condition after drainage and consolidation.
Such stage construction will minimize the quantity of high cost bituminous materials.

7.2 Practical and Experimental Bases

7.2.1 Use of Flexible Overlays

Flexible overlays (graded crushed stone or cement improved materials, plus surface dressing or a thin layer of flexible premix) may be used for cumulative traffic up to 10 million standard axles in both directions).

However, long-term crushed stone overlays do not greatly reduce road deflections; this means that, when the next stage of strengthening takes place, a very heavy overlay will be required again. It may therefore be advantageous to accept a higher initial capital investment and to use bound materials in the first stage, so as to facilitate further overlaying and minimize the total cost of the successive strengthening operations.

For heavier traffic (T1-T2), attrition and deformation would be excessive and it is therefore necessary to employ bound (semi-rigid or rigid materials such as asphalt concrete, dense bituminous macadam, cement stabilized gravel or lean concrete).

7.2.2 Behaviour of overlay Materials

7.2.2.1 Unbound Materials

The effective modulus of cohesionless materials depends to some extent on the layer thickness and the modulus of the support (non-linear elasticity).

This applies mainly to graded crushed stone (GCS), cement or lime improved materials generally have a higher cohesion.

Therefore, the use of GCS as an overlay on very low-modulus pavements is of little structural benefit, since such an overlay will also exhibit a low modulus. Consequently the utilization of graded crushed stone is not recommended on very deformable pavements.

It can be assumed that within these reduced ranges of overlay thicknesses and existing pavement moduli, the variations of the overlay materials moduli are limited. An average modulus can therefore be attributed to each type of material for the purpose of structural calculations.

7.2.2.2 Bound Materials-tensile Strain Criterion

When bound materials are used the deciding criterion is generally the horizontal tensile strain at the bottom of the overlay. If this strain is excessive the layer will crack and deteriorate rapidly.

The fatigue performance of bound materials has been estimated on the basis of measured characteristics field observations and theoretical considerations.

The fatigue laws are shown in Figure 7-1.

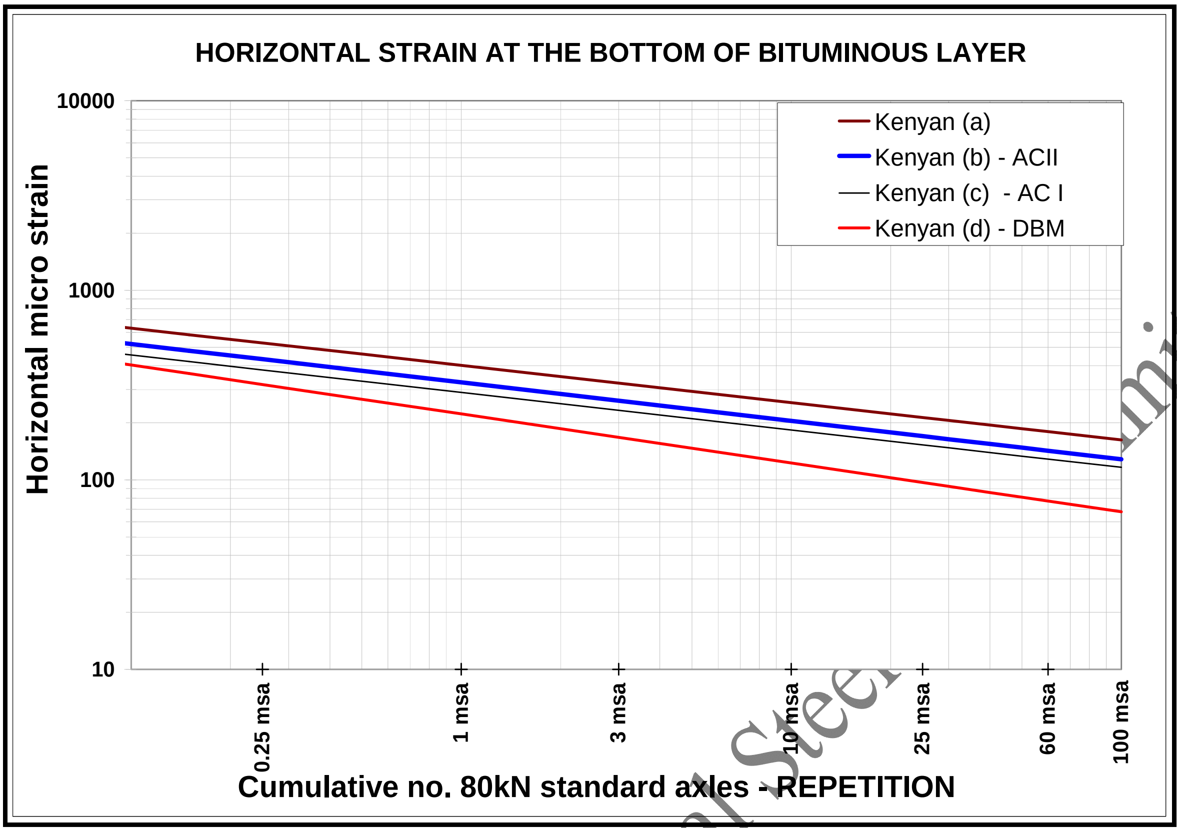

Figure 7-1: Tensile strain criteria for various bituminous layers

7.2.2.3 Bituminous Mixes

Bituminous mixes are visco-elastic materials and their dynamic moduli are therefore functions of the rate of application of the load and the temperature.

The distribution of temperature, both on a daily and a seasonal basis, has an important bearing on pavement performance. The effect of temperature changes in asphalt on pavement performance is a complex matter which must be taken into account at the design stage.

For example, if traffic loading occurs at night when temperatures are low, and the asphalt is relatively brittle, then a considerable reduction in the life of a thin asphalt surfacing may occur due to the onset of flexural cracking. On the other hand, if traffic loading occurs during periods of high temperature, then this may lead to increased strains in the lower layers of the pavement if these layers are composed of cemented material. If the lower layers are unbound materials, however, then the higher stresses induced in the unbound materials will result in higher moduli values being achieved.

7.2.3 Construction Principles

7.2.3.1 Minimum Layer Thickness

For each material, there is a minimum layer thickness below which proper laying and compaction are not practical. These are presented in Table 7-1:

Material	Minimum thickness (mm)
Graded Crushed Stone 0/40mm	125
Graded Crushed Stone 0/30mm	100
Treated Gravel	125
Treated (clayey) Sand	100
Dense Bituminous Macadam (0/40mm)	75
Dense Bituminous Macadam (0/30mm)	60
Dense emulsion Macadam (0/40mm)	100
Dense Emulsion Macadam (0/30mm)	75
Asphalt Concrete (0/20mm)	50
Asphalt concrete (0/10mm)	25-30
Sand asphalt	25-30

Table 7-1: Minimum Layer Thickness

7.2.3.2 Compliance with Specifications

All the materials are assumed to comply with the requirement given in Chapter 6 and all the layers to be constructed in accordance to the current specifications.

7.3 Design of Asphalt Overlays of Flexible Pavement

7.3.1 General

Asphalt overlays may be used to correct both surface deficiencies (ravelling roughness, slipperiness) and structural deficiencies. Surface deficiencies in asphalt pavements usually are corrected by thin resurfacings (functional overlays), but structural deficiencies require overlays designed on factors such as pavement properties and traffic loadings (structural overlays).

There are many instances when a surface treatment will not accomplish what is needed.

Examples are depressions or severe ravelling. In such cases, a thin overlay should be used over any required levelling course. Thin overlays usually range from 2.5cm to 5cm thick using a fine-grained top size dense mix. These are considered maintenance.

The overlay design procedures in the remainder of this section provide an overlay thickness to correct a structural deficiency. If no structural defiance exists, a thin overlay may still be required to correct a functional deficiency.

This section covers the design of structural overlays by means of one or several lifts of asphalt concrete.

It is assumed that this option is feasible, i.e. that the condition of the existing pavement is not such that it dictates substantial removal and replacement of the existing pavement.

Such conditions would include:

- A large amount of very severe alligator cracking.
- Excessive rutting which can be attributed to unstable existing materials
- Seriously deteriorated stabilized roadbase requiring an excessive amount of repairs prior to overlay operations
- Contaminated granular roadbase
- Excessive stripping of the existing AC surface

Two methods of overlay design are recommended, namely a deflection procedure (Asphalt Institute) and an effective thickness (or component analysis) procedure (AASHTO). It is recommended that both methods always be used for comparison purpose. It is unlikely that the methods will agree exactly, and sound engineering judgment is required to estimate the possible reasons for the discrepancies and make a choice or a compromise between the results obtained by both methods.

Preference may be given to the effective thickness procedure when the history of pavement construction is well known and the destructive testing results are such that the quality of the materials is also well-known. When the results and the records indicate the possibility of significant variation and uncertainty in the structure of the existing pavement, or extensive localized repairs, it is probably preferable to rely on statistical deflection result indicative of the overall load carrying capacity of the system comprising the pavement and its supporting subgrade.

7.3.2 Defection procedure

The deflection procedure recommended herein uses the results of a deflection survey conducted with a Falling Weight Deflectometer (FWD) or a Benkelman Beam.

In selecting between deflection devices the following should be noted:

- The Benkelman Beam is used for points testing at user-specified locations and both the outer and inner wheel paths may be tested. It is a manually operated, low-cost, mechanical testing system. For stiff pavements, the bowl measurements are affected by the movement of the reference beam in the deflection bowl.
- FWD provides the most accurate means of measuring the 'true' deflection at any single point as, unlike Benkelman Beam deflection; the measured deflections are not influenced by movement of the reference frame within the deflection bowl. However, it is not as cost-effective as the Benkelman Beam in measuring deflections at closely spaced intervals if this is required to accurately characterise pavements with variable stiffness.

7.3.2.1 Falling Weight Deflectometer

7.3.2.1.1 *General*

The overlay guidelines in this section are applicable to asphalt and granular overlays on all flexible pavements including those containing cemented materials.

Overlays for pavements can be designed using a General Mechanistic procedure (GMP). The GMP for the design of overlays is, in principle, identical to the mechanistic procedure for the design of new pavements, except that there is an initial phase in which the properties of the materials in the existing pavement are determined. Asphalt overlays are designed to limit fatigue cracking of the overlay and permanent deformation of the pavement. Granular overlays with sprayed bituminous surfacings are designed only to limit permanent deformation of the pavement.

Bound materials (asphalt, cemented materials) within the existing pavement might be expected to have little or no remaining fatigue life when a structural overlay is being considered if there is reliable evidence. Hence, the design method might not need to address the overlay requirements that prevent fatigue of the existing bound layers in the pavement. The asphalt and cemented materials in the existing pavement as presented in Chapter 7 of Part 3, Materials and pavement Design for New Roads, and comprise:

- Bituminous layer fatigue is predicted from the tensile strains occurring under a Standard Axle load at the base of he proposed bituminous overlay and existing bituminous layer(s).
- Cemented layer fatigue is predicted from the tensile stress occurring under a Standard Axle load at the base of the existing cemented layer(s).
- Permanent deformation performance is predicted from the vertical compressive strains at the top of subgrade under a Standard Axle load.

The design traffic loading is expressed in terms of standard axle repetitions (mesa) as described in Chapter 2 of Part 3 Materials and Pavement Design for New Roads. Typically, design periods of 10 - 20 years are used for granular and asphalt overlays. With certain combinations of overlay thickness and existing pavement characteristics, the onset of fatigue cracking may occur well before the permanent deformation criterion is exceeded. In such cases, a shorter design period may be employed for fatigue than deformation if this results in lower whole-of life costs. The rationale is that as permanent deformation occurs deeper in the pavement than fatigue cracking, which is limited to the overlay itself, it is more difficult and expensive to rectify.

7.3.2.1.2 *Selection of homogeneous sections*

The structural capacity of a pavement that requires rehabilitation typically varies both longitudinally and transversely over the project alignment. Therefore, to design cost-effective overlays it is usually necessary to divided the project into subsections that have relatively uniform strength, which is indicated by the measured deflections.

7.3.2.1.3 *Back -calculation of layer moduli from measured deflections*

The moduli of the existing pavement layers and subgrade may be determined from the measured Falling Weight Deflectometer (FWD) deflections and layer material properties in a process known as back-calculation. A methodical trial and error approach is used to determine the layer moduli under a predicted deflection bowl that best matches the measured deflection bowl.

The FWD deflection bowls are measured with a plate diameter of 300 mm and an applied load selected according to the stiffness of the pavement.
Numerous back-calculation routines are available for estimating layer moduli. In selecting an analysis routine it should be noted that the overlay design method is based on mechanistic procedures similar to those used for the design of new pavements (Part 3 - Materials and Pavement Design for New Roads). The allowable traffic loadings are determined from the critical strain responses calculated from the linear elastic module (e.g. ELMOD 6, CIRCLY, RUBICON etc ...) The accuracy of the analysis is likely to be the greatest if a linear elastic module is used to both back-calculate the existing pavement moduli and then to determine the new overlay thickness requirements.

7.3.2.1.4 *Estimation of pavement layer and subgrade design moduli*

The GMP requires a reasonable knowledge of the structural composition and condition of the existing pavement, often provided by pavement investigation and/or good historical construction and maintenance records. From this information, the materials type and thickness of each pavement layer is established and the in situ subgrade CBR estimated for each pavement layer is established and the in situ subgrade CBR estimated for each homogeneous subsection. Pavement deflection results combined with the visual condition of the pavement may be used to identify pavement investigation sites. The test data from the weaker areas of pavement in each homogeneous subsection are usually of most relevance. The representative moduli of the subgrade and unbound granular materials need to be estimated using the design procedures for new pavements (Part 3). This occurs after adjusting the measured subgrade CBR for any seasonal effects or proposed remedial treatments (i.e. drainage improvements, provision of sealed shoulders etc.) that will change the moisture regime or the support conditions.

The design moduli for asphalt and cemented materials in the existing pavement are likely to differ significantly from the values used in the design of new pavements mainly due to the effects of past trafficking and a range of environmental effects.
Hence, in the mechanistic overlay design procedures, the design moduli assigned to cemented layers might not exceed that typical of cracked cemented materials, irrespective of the actual strength characteristics at the commencement of the overlay design period.

Backcalculation of layer moduli from measured FWD deflection bowls may also provide useful information about the layer moduli of unbound pavement materials and subgrade.

The subgrade could be sub layered into two or more layers in the back-calculation process to assist the model to match the measured deflections. This differs from the design procedure of new pavements where a single, more conservative, semi-infinite subgrade is commonly adopted. The subsequent overlay design process however, is based on procedures for the design of new pavements, and uses a single, semi-infinite subgrade layer. It is recommended that the backcalculated moduli for the top (200-400 mm) layers of subgrade be adopted for the semi-infinite support condition.

The moisture content of granular materials and the subgrade support at the time of deflection testing may differ from typical in-service moistures in the overlay design period, in selecting the design moduli, it may be necessary to adjust the backcalculated values for any significant expected moisture effects.

The moduli of granular materials and subgrades have been observed to be stress-dependent: the moduli of granular materials increase with increasing stress levels, whereas the moduli of fine-grained subgrade materials decrease with increasing stress levels. The applied load stress during the FWD testing of the existing pavement at the field temperature may differ from the Standard Axle load stress applied to the overlaid pavement at the WMAPT (Weighted Mean Annual Pavement Temperature). In addition, existing bound materials are modelled as if they are fatigue cracked in the overlay design analysis, and this may be a lower modulus than indicated by the deflection testing the difference in stress condition between testing and in-service may also be minimised by the judicious choice of FWD test load. If an adjustment for stress dependency is required, it may be necessary to use a linear elastic model to calculate the difference in applied stress and use laboratory triaxial test data (e.g. Vuong et al 1988) to adjust the backcalculated moduli for the change in applied stress.
These adjustments may have a significant effect on the design moduli of granular base materials.

7.3.2.1.5 *Overlay Design Procedure*

Once the design moduli of the existing pavement layers and subgrade have been determined for each homogeneous section, then the overlay material type (asphalt or granular) with an appropriate overlay design moduli and a trial treatment thickness are all selected.

The trial treatment needs to take into account:

- minimum overlay thickness required to correct pavement roughness, rutting and surface drainage/crossfall
- the proposed milling depth (if any) required to restore pavement shape, remove substandard material or surface cracking.

The allowable traffic loading of the trial treatment is calculated for each relevant pavement distress mode; that is allowable traffic loading in terms of permanent deformation for all overlay types and also the fatigue life of the treatment when an asphalt overlay is proposed. If the allowable traffic loading for each distress mode exceeds the design traffic loading, the trial overlay thickness is acceptable, otherwise a new trial overlay configuration is selected and the process repeated until this a new trial overlay configuration is selected and the process repeated until this occurs.

7.3.2.2 Benkelman Beam

The steps involved in the procedure are as follows:

- Step 1: Determine a representative rebound deflection (RRD)
- Step 2: Determine the design future traffic in terms of cumulated equivalent standard axles (ESAs).
- Step 3: Determine the required overlay thickness.

Step 1

The individual deflection measurements recorded during the deflection survey must be adjusted by a temperature adjustment factor which can be read from Figure 7-2.

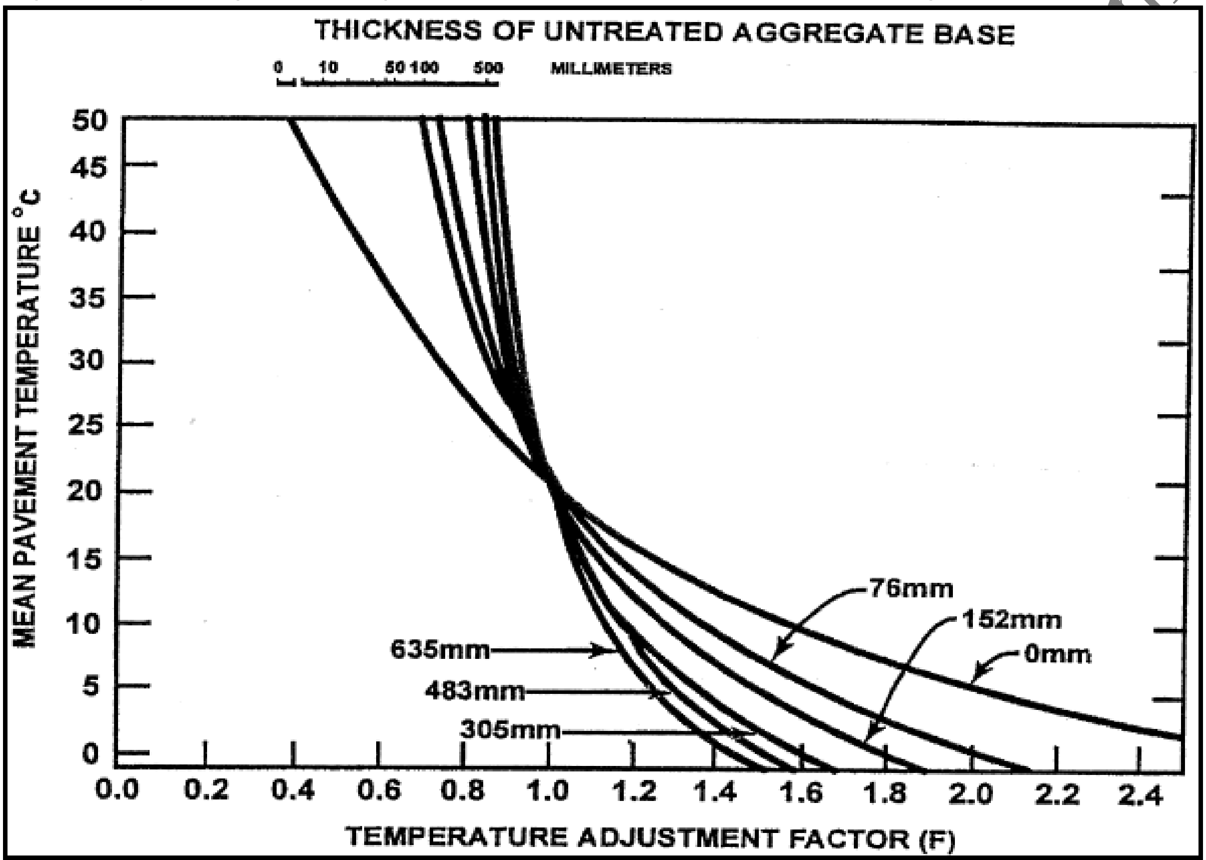

Figure 7-2: Temperature Adjustment Factor for Benkelman Beam Deflections

The mean and standard deviation of the adjusted individual deflection readings are then calculated. The representative rebound deflection RRD is taken as:

RRD=(x+2s) x c

Where:

x is the arithmetic mean of the individual deflection measurements adjusted for temperature,

s is the standard deviation of the adjusted individual measurements,

c is critical period adjustment factor

The critical period is the interval during which the pavement is most likely to be damaged by heavy loads. The Asphalt institute recommends the following methods for determining the critical period adjustment factor:

- Obtain a continuous record of measured rebound values for a similar pavement in a similar environment and on a similar subgrade, and determine the most critical period. Then either:

Make the rebound measurements during the critical period, in which case the adjustment factor, c, equals 1.0. Or:

Make the rebound measurements at any time and adjust to the critical deflection by letting the adjustment factor, c, equal the ratio of the critical period deflection to the deflection for the date of the test.

- If no record of comparable deflection data is available, make the rebound measurement t any time and make any needed adjustment using engineering judgment.

Step2
The design number of equivalent standard axles (ESAs) expected to be carried by the road after overlay should be determined using the guidelines provided in Part 3, Materials and Pavement Design for New Roads. As a reminder, this design number of ESAs is expressed in equivalent 8.2 tonne axles.

Step 3
To find the thickness of asphalt concrete overlay required, enter the overlay thickness design chart, Figure 7-3, with the RRD obtained in Step 1, move vertically to the curve representing the design ESA (from Step 2), and move horizontally to the Overlay Thickness Scale.

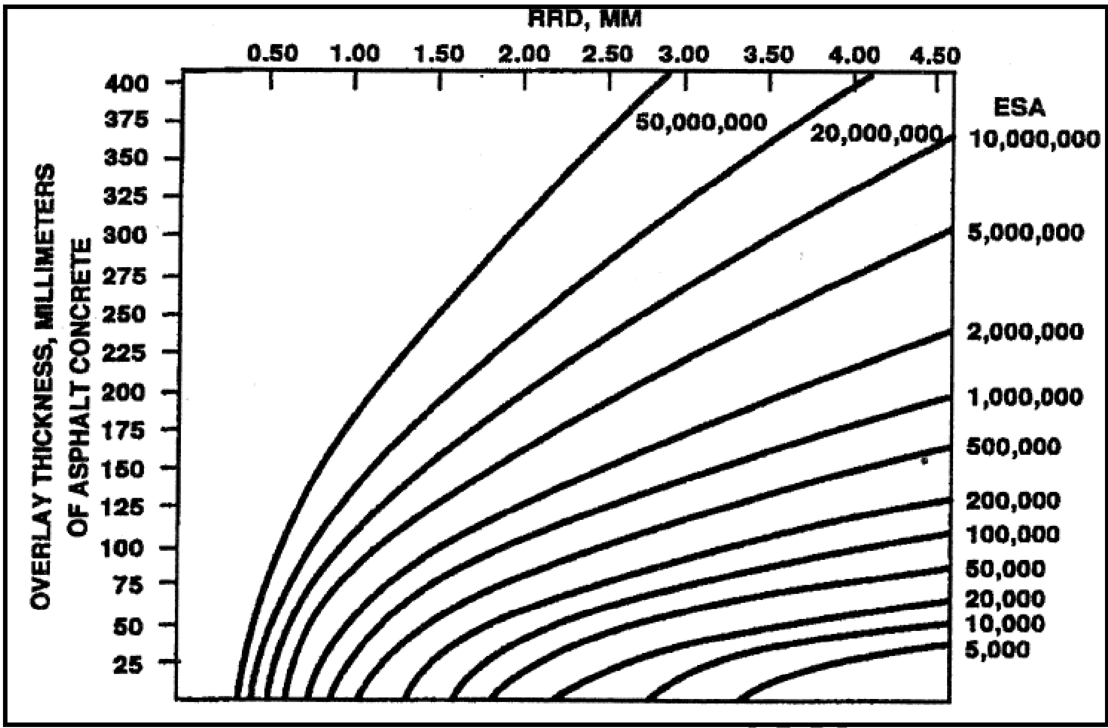

Figure 7-3: Overlay thickness design chart

7.3.3 Effective analysis procedure

The required thickness of AC overlay is computed as:

Where:

T_0 = required overlay thickness in centimetres

SN_{new} = structural number of a new pavement (centimetres) – Refer to Appendix I

SN_{eff} = effective structural number of the existing pavement (centimetres) – Refer to Appendix II

a_0 = structural coefficient of the AC overlay

It may be noted that the structural numbers have the same dimension as the thickness.

SN_{new} is computed as indicated in Appendix I. It requires the determination of the required structure of a new pavement for the specific subgrade strength and traffic applicable to the project, in accordance with the procedure detailed in Chapter 2 of Part 3, Materials and Pavement Design for New Roads. The procedure given in Appendix I lists structural layer coefficients for the conversion of the required structure into SN_{new}.

The same coefficient as given for new AC surface course materials may be used for the structural coefficient a_0 of the AC overlay.

SN_{eff} requires knowing the existing pavement structure and using the equation:

$SN_{eff}=a_1T_1+a_2T_2m_2+a_3T_3m_3$

Where
T_1, T_2, T_3= thicknesses (in centimetres) of existing pavement surface, roadbase and subbase layers

a_1, a_2, a_3= corresponding structural layer coefficients
m_2, m3=drainage coefficients for granular roadbase and subbase

The thicknesses Ti are determined from the previously collected data and field work. The coefficients a_i may be determined from Table 7-2, which lists suggested layer coefficients for commonly used materials. Other suggested coefficients, for stabilized roadbase materials, are given in Table 7-3.

Material	Surface condition	Coefficient
AC Surface	Little or no alligator cracking and/or only low-severity transverse cracking	0.35 to 0.40
	<10 percent low-severity alligator cracking and /or <5 percent medium-and high-severity transverse cracking	0.25 to 0.35
	>10 percent low-severity alligator cracking and/or >10 percent medium-severity alligator cracking and/or >5-5 percent medium-and high-severity transverse cracking	0.20 to 0.30
	>10 percent low-severity alligator cracking and/or <10 percent medium – and high – severity transverse cracking	0.14 to 0.20
	> 10 percent medium –severity alligator cracking and/or <10 percent medium-severity alligator cracking and/or > percent medium-and high –severity transverse cracking	0.08 to 0.15
Granular Roadbase or Subbase	No pumping, degradation, or contamination by fines. Some pumping, degradation, or contamination by fines.	0.10 to 0.14 0.00 to 0.10

Table 7-2: Suggested layer coefficients for existing AC pavement layer materials

Material	Surface Condition	Coefficient

Stabilized Road base	Little or no alligator cracking and/or only low-severity transverse cracking	0.20 to 0.35
	<10 Percent low-severity alligator cracking and or <10 Percent medium-and high –severity transverse cracking	0.15 to 0.25
	>10 Percent low –severity alligator cracking and/or > 10 Percent medium –severity alligator cracking and/or >5-10 percent medium- and high –severity transverse cracking	0.15 to 0.20
	> 10 Percent medium – severity alligator cracking and/or <10 percent high – severity alligator cracking and/or >10 percent medium – and high severity transverse cracking	0.10 to 0.20
	>10 Percent high –severity alligator cracking and/or >10 percent high severity transverse cracking	0.08 to 0.15

Table 7-3: Suggested layer coefficients for stabilised roadbase materials

It must be realized that relatively limited guidance is available for the selection of layer coefficients for in-service pavement materials. Engineers are encouraged to use judgment and to build experience in the selection of the coefficients, particularly with regard to local materials and pavement behaviour.

The drainage coefficients m_2 and m_3 may be determined on the basis of Table 7-4 and Table 7-5 further below.

Quality of drainage	Water removal period
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very poor	Water will not drain

Table 7-4: Drainage assessment

Quality of drainage	Percent of time pavement structure is exposed to moisture levels approaching saturation			
	<1%	1 to 5 %	5 to 25 %	> 25 %
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

Table 7-5: Recommended mi values for modifying structural layer coefficients of untreated road base and sub base materials

7.3.3.1 Surface preparation for overlay

In the design of overlays and the adoption of the overlay as rehabilitation solution the construction feasibility should be verified first (besides the economic constraints) with reference to factors such as:

- Traffic control, traffic disruption
- Materials and equipment availability
- Construction problems such as utilities, bridge clearances, side slope extension

Having determined the feasibility, careful and correct preparation of the existing pavement, prior to construction of overlays, is essential to good construction and to maximum overlay performance. The overlay thickness is designed to correct a below average pavement condition, but not to provide the extra structural strength needed for localized weak areas. If the overlay thickness is based on the weakest condition in the section, it would be over-designed for the rest of the section and thus be needlessly costly. Therefore, the weaker areas must be corrected to provide a uniform foundation for the overlay.
Some of the factors which need consideration in preparation of the existing pavement are as follows:

Pre-Overlay pavement Repairs
If distress in the existing pavement is likely to affect the performance of the overlay, it should be repaired prior to the placement of the overlay. Much of the deterioration that occurs in overlays results from deterioration that was not repaired in the existing pavements. The cost trade offs of pre-overlay repair and overlay type should be also be considered.
Severe alligator cracking and linear cracks, rutting and surface irregularities should be repaired prior to overlay of AC pavements.
The pre-overlay repairs generally fall in the maintenance categories. One particular pre-overlay operation to consider is an effective reflection crack control.

Reflection Crack Control
Reflection cracks are a frequent cause of overlay deterioration. The thickness design procedures described in the preceding sections do not consider reflection cracking. Pre-overlay repairs (patching and crack filling) may help delay the occurrence and deterioration of reflection cracks. Additional reflection crack control measures include:

- Pavement fabrics
- Crack relief layers. These are composed of open-graded coarse aggregate and a small percentage of asphalt cement.
- Increased overlay thickness

Sub-drainage
The existing sub drainage condition of the pavement should be evaluated since it has a great influence on how well the overlay performs. Removal of excess water from the pavement cross-section will increase the strength of the pavement layers and subgrade, and reduce deflections.

Milling – Recycling
Milling with or without the intent of recycling the material, can improve the performance of the overlay, by removing some of the cracked and hardened materials and by minimizing existing rutting or other significant distortions.

Surface Recycling

This process may be considered as analogous to pre-overlay surface preparation or an in place variant of cold milling and recycling. The asphalt pavement surface is heated in place, scarified, remixed, re-laid, and rolled. Asphalts, recycling agents, new asphalt hot mix, aggregates, or a combination of these may be added to obtain a desirable mixture.

When new asphalt hot-mix is added, the finished product may be used as the final surface: otherwise, an asphalt surface course should be used.

Shoulders

Overlaying traffic lanes generally requires that the shoulders be overlaid to match the grade line of the traffic lanes. In selecting an overlay material and thickness for the shoulder, the designer shoulder consider the extent to which the existing shoulder is deteriorated and the amount of traffic that will use the shoulder. For example, if trucks tend to park on the shoulder at certain locations, this should be considered in the shoulder overlay design.

If an existing shoulder is in good condition, any deteriorated areas should be patched. An overlay may then be placed to match the shoulder grade to that of the traffic lanes. If an existing shoulder is in such poor condition that it cannot be patched economically, it should be removed and replaced.

APPENDIX I

DERIVATION OF S_{new}, STRUCTURAL NUMBER OF A NEW PAVEMENT

SN_{new} is required in the component analysis procedure (Chapter 7) to determine required asphalt overlay thickness. SN_{new} is computed in three steps as follows:

- **Step 1:** Select an appropriate required structure of a new pavement for the specific subgrade strength and traffic applicable to the project, in accordance with the procedure detailed in Chapter 2 of Part III, Materials and Pavement Design for New Roads. The structure selected is characterized by the thickness T_i of its component layers, i.e. T1, T2, T3 = thicknesses of required pavement surfacing. Roadbase and subbase layers respectively.
- **Step 2:** To each of the layers determined in Step 1, assign an appropriate structural layer coefficient a_i.

The following structural layer coefficients are recommended:

- Bituminous surface: $a_1 = 0.44$
- Bituminous roadbase: $a_1 = 0.30$ (note: use 0.25 for in-place recycled materials)
- Cement or lime stabilized roadbase: $a_2 = 0.15$ to 0.20
- Granular roadbase: $a_2 = 0.14$
- Cement or lime stabilized subbase: $a_3 = 0.12$
- Granular subbase: $a_3 = 0.11$
- Granular subbase: $a_3 = 0.09$

- **Step 3:** Compute SN_{new} as:
  $SN_{new} = a_1T_1+a_2T_2+a_3T_3$

APPENDIX II

DERIVATION OF S_{EFF}, STRUCTURAL NUMBER OF AN EXISTING PAVEMENT

The Non Destructive Test (NDT) method of SN_{eff} determination follows an assumption that the structural capacity of the pavement is a function of its total thickness and overall stiffness.

The relationship between SN_{eff} and stiffness is:

$SN_{eff} = \frac{6Tt}{100} \times 3\sqrt{Ep}$ Equation 1

Where T_t = total thickness (in centimetres) of all pavement layers above the subgrade
E_p = effective modulus of pavement layers above the subgrade (kPa)
E_p may be back – calculated from deflection data as follows.
The data required for the calculation is:
D_0= deflection measured at the centre of the load plate (and adjusted to a standard temperature of 20^0 c), cm
P= applied load, kg
D=total thickness of pavement layers above the subgrade, cm
D_r=deflection at a distance r from the centre of the load, cm
r= distance from centre of load, cm
a = NDT load plate radius, cm
With the above data, using Figure 1, the ratio of E_P/M_R can be calculated
Where M_R= subgrade resilient modules, kPa

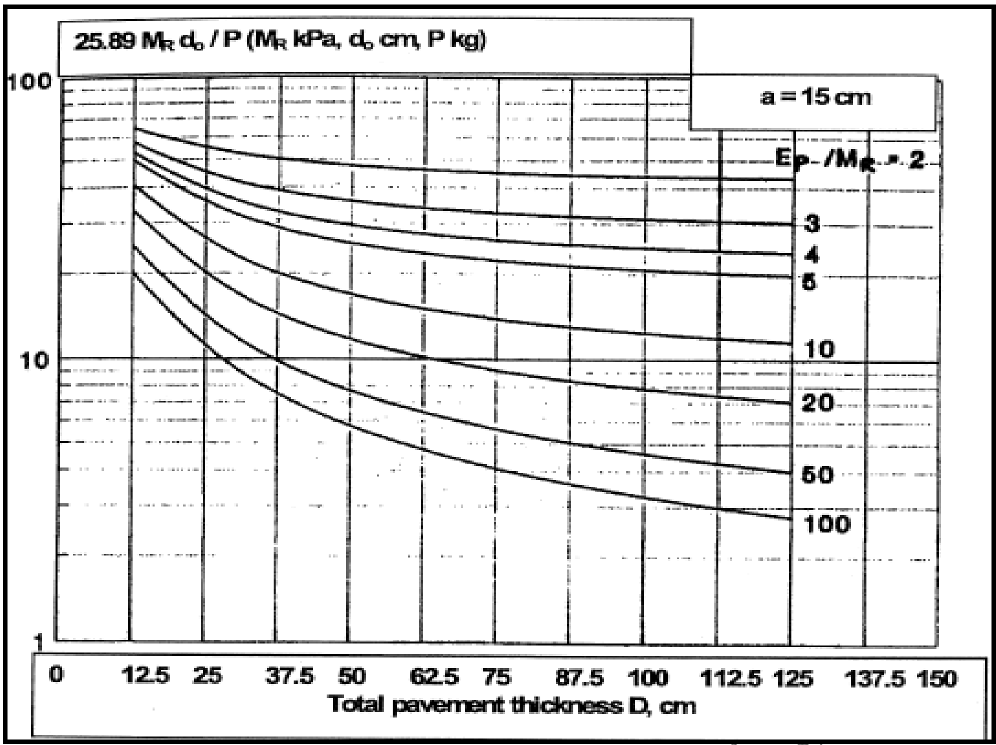

Figure 1: Determination of E_p/M_r