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MINISTRY OF ROADS AND PUBLIC WORKS

ROADS DEPARTMENT

ROAD DESIGN MANUAL

PART V
PAVEMENT REHABILITATION
AND
OVERLAY DESIGN

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CHAPTER 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 judgement are to be applied.

The framework aims at assessing the elements of the road network regularly and on the basis of objective measurements, determines maintenance and rehabilitation or 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 process, whereas the latter which involves the identification of priorities and different categories of action which the management procedure shows to be required is not with in the scope of this manual.

The recommended procedure for assessment of the surface condition of the pavement including the nature and extent of each type of distress is included in the appendices to this manual. Procedures for evaluating structural performance of the pavements from the deflection measurements are also included in the appendices.

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: -

- 2 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 or adverse weather conditions. Accordingly a "stop-gap" maintenance input should be authorised to enable remedial work to be carried out at short notice.

Sections 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 function of 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 management 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 recarpeting, which treatments waterproof the under lying 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 functions and periodic maintenance work becomes frequent and uneconomical. To rejuvenate the pavement, the following courses of action are considered: -

(a) Rehabilitation - involving:

(i) Reprocessing one or more layers of pavement.

(ii) Improvement of internal drainage.

(iii) Widening narrow pavements.

(b) Strengthening - consists of constructing one or more layers on the existing pavement.

(c) 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.

CHAPTER 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 or intensified reappraisal. The following are the recommended aspects for which inputs are considered during the assessment: -

(a) - strategic functions (i.e. classification)

- network improvement needs
- traffic flow patterns

(b) - geometric standards

- accident/safety surveys

(c) -maintenance levels and costs

- inventory updating

(d) - pavement condition surveys

- structural performance
- axle load distribution

(e)- 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 optimise investment on the basis of "total cost" which generally is comprised of both capital and recurrent costs.

(a) Capital costs - are usually well defined and isolated in nature such as overlay or reconstruction operations.

(b) Recurrent costs- 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 nothing" 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-ordinating 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

Table 2.1 POSSIBLE CO-ORDINATION OF ASSOCIATED INVESTMENT FOR NET BENEFIT

INVESTMENT TYPE UNDER CONSIDERATION	ASSOCIATED INVETSMENTS WHICH OFFER COST SAVINGS IF COORDINATED
Any	-realignment (to improve geometric standards)
Drainage/shoulder improvement or repair	-pavement widening
Surface treatment (e.g. resealing or recarpeting)	-strengthening -pavement repairs
Strengthening (e.g. overlays)	-shoulder improvement -Pavement widening
Rehabilitation	-Strengthening -Pavement widening
Reconstruction	-Pavement widening -Realignment -Shoulder improvement
Pavement widening	-surface treatment -rehabilitation -reconstruction

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 accidents are affected by changes in the alignment carriageway width and surface condition. As yet however, prediction of accident type and frequency is not well developed for Kenyan

road conditions and only the effect of very substantial changes may be forecast. Moreover, whilst significant resource costs are incurred through accidents, other very important consequences, for instance personal injury or loss of life, cannot yet be given financial values.

The major components contributing to the total transport cost are: -

(a) Construction Costs: - if some improvements are considered.

(b) Vehicle Operating Costs - dependent on route length, volume and type of vehicles utilising the road and their unit costs of operating.

(c) Road Maintenance Costs - expected recurrent costs for routine and periodic maintenance inputs.

(d) Further Investment Costs - expected cost at the end of the current design period for the road to handle the expected traffic demand.

The net present value of these costs is calculated by discounting then to a chosen base year. This is usually considered to be the first year of the appraisal.

2.3 FURTHER INVESTMENT COSTS

The 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 residual value of the road as a result of different strategies. Thus, although speculative long-range estimates are involved, the differences between them are a 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 the taxes and transfer payments. Nevertheless the Chief Engineer (Roads) can advise on current factors applied to (construction, vehicle operating, road maintenance etc.) in order to estimate economic costs.

TABLE 2.2 EXPECTED CONSEQUENCES OF VARIOUS INVESTMENTS

ACTION	EFFECT	CONSEQUENCE
Drainage Repair or Improvement	reduce pavement deterioration reduce probability of wash out 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 maintenance costs
Pavement Strengthening	renew running surface condition reduce pavement deterioration increase pavement bearing capacity	reduce current vehicle running costs reduce 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 reduce 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 above improve vertical alignment	any or all of above
Realignment	any or all of above change route length improve horizontal and vertical alignment	any or all of above change vehicle running and unit costs change maintenance costs

CHAPTER 3 PAVEMENT BEHAVIOUR AND DETERIORATION

Effective corrective action for a defective pavement cannot be designed on surface symptoms alone. The pavement composition must be known and the deterioration should be identified.

3.1 FLEXIBLE AND RIGID PAVEMENTS

It is essential to distinguish between flexible and rigid (or semi-rigid) pavements, the behaviours of which are completely different under similar conditions of load.

3.1 (a) Flexible Pavements

Flexible pavements are defined as pavements comprised of a base of fairly deformable material, such as natural gravel, crushed stone or improved gravel material and a thin bituminous surfacing (surface dressing or not more than 50 mm of asphalt concrete).

The deterioration of flexible pavement always involves deformation, which may originate from any layer for the following reasons: -

-Subgrade	Insufficient bearing strength
	Insufficient cover
	Moisture changes
-Subbase	Insufficient strength
	Inadequate internal drainage
-Base	Insufficient strength or stability
	Attrition
	Lack of edge restraint

3.1 (b) Semi-Rigid and Rigid Pavements

Semi-rigid or rigid pavements are defined as pavements having a base of bound material, the rigidity of which is appreciable, or having a thick asphaltic surfacing.

Semi-rigid pavements are those having bases of cement-stabilised gravel or dense-bitumen macadam whatever the surfacing is and those with asphaltic surfacing thicker than 75mm. Pavements having a lean concrete base are considered to be rigid.

Deterioration of rigid and semi-rigid pavements always involves cracking, which originates either in the base or in the surfacing. There are various possible causes but the main one is excessive tensile strain at the bottom of the bound layers. This may result from insufficient thickness, inadequate support or fatigue.

3.2 MODES OF DETERIORATION

To decide on the technique to use in rehabilitating a pavement, it is first necessary to identify the type of distress affecting the structure. The next step is to determine the cause of distress.

The modes of pavement deterioration may be classified into three rain categories:

- fracture
- distortion
- disintegration

The types of defects and the most likely deterioration mechanisms for each mode of deterioration are shown in Table 3.1. The following points should be noted: -

(i) The actual deterioration in the pavement is often a complex combination of effects in the different layers, e.g.: -

Deformation originating in one layer will cause deformation or cracking of the overlying layers.

Cracking of the surfacing will allow the ingress of water possibly resulting in the deformation of the underlying layers.

(ii) In the absence of remedial measures, deterioration will continue unabated following the "classical" sequence of pavement degradation, e.g.

Deformation of the flexible pavement, cracking of the surfacing, ingress of water, crazing of the surfacing, potholing and finally complete disintegration.

Even the smallest defects may result in major failures if they are not repaired in time.

TABLE 3.1 SURFACE DEFECTS AND POSSIBLE DETERIORATION ECHANISMS

DETERIORATION MODE	SURFACE DEFECTS	POSSIBLE DETERIORATION MECHANISMS
FRACTURE	Cracking	Vertical loading Fatigue and ageing Thermal changes Moisture changes Shrinkage (due to traction 1oads) Slippage Fatigue Loading
	Spalling	Thermal changes Moisture changes
DISTORTION	Permanent deformation	Loading Creep Differential compaction Settlement consolidation Swelling Upward displacement of plastic fines
	Faulting	Loading Pumping Differential compaction Swelling Erosion
DISINTERGRATION	Disruption	Attrition Loss of cohesion Lass of interlock Poor adhesion (bituminous material) Chemical reaction
	Stripping	Poor adhesion of aggregate to binder Chemical reaction
	Ravelling	Abrasion by traffic Degradation of aggregate Poor adhesion of aggregate to binder Insufficient bitumen or aging
	Scaling	Abrasion by traffic Degradation of aggregate Chemical reaction
	Loss of texture	Abrasion by traffic Embedment of aggregate Excess binder

3.3 MOST USUAL DEFECT PATTERNS- POSSIBLE CAUSES

Pavements deterioration generally results in characteristic defect patterns, which can be related to particular causes.

3.3 (a) Definitions

The most common defects are defined as follows: -

- Bleeding (or Fatting-up): - The upward movement of bitumen resulting in loss of texture and the formation of a film of bitumen on the surface.
- Corrugations: - A form of plastic movement typified by ripples across the direction of traffic.
- Cracks: - Approximately vertical cleavage of a pavement layer (fractured surface).
- Crazing: - Interconnected cracks forming series of small blocks, coarse crazing has more than 200mm mesh and fine crazing (or "alligator cracking") has less than 200mm mesh.
- Crescent Cracks (or Slippage Cracks): - Cracks resulting from horizontal movement of the wearing course.
- Deformation: - Any movement of a pavement surface from its original shape.
- Depression: - Localized low area of limited size, which may or may not be accompanied by cracking.
- Disruption: - The breaking up of a pavement layer into small, loose fragments.
- Faults: - Differences in elevation of two slabs at joints or cracks.
- Longitudinal cracks: - cracks that run in a direction approximately parallel to the centre-line.
- Peeling: - The separation of a bituminous wearing course from the underlying layer and its subsequent break-up and loss.
- Potholes: - Bowl-shaped holes of varying sizes in the pavement, resulting from localized disintegration.
- Pumping (or Blowing): - Slab movement under passing loads resulting in the ejection of a mixture of water and fine material along joints, cracks and pavements edges.
- Ravelling: - The progressive separation of aggregate particles in a wearing course from the surface downward or from the edges inward.
- Ruts: - Channelized depressions which develop in the wheel tracks.
- Scaling: - The progressive disintegration and loss of a cement concrete wearing surface.
- Shoving: - A form of horizontal plastic movement resulting in localized bulging of the pavement.
- Spalling: - The breaking or chipping of a pavement layer at joints, cracks or edges.

- Stripping: - The separation and loss of aggregate particles from the bitumen binder.
- Transverse Cracks: - Cracks that follow a course approximately at right angles to the centreline.
- Upheaval: - The localized displacement of a pavement due to swelling of the subgrade.
- Waves: - Transverse undulations at regular intervals (crests 500mm or more apart).

3.3. (b) Typical Defects

Distinction can be made between typical defects and the deterioration mechanisms likely to be associated with them.

(i) Typical defects affecting flexible pavements (Table 3.2)

(ii) Typical defects affecting rigid and semi-rigid pavements (Table 3.3)

(iii) Typical surface detects on all types of pavement (Table 3.4)

Note: - Frequently, different types of defects are associated, e.g. extensive deformation causes cracking of bound materials, or stripping produces bleeding

TABLE 3.2 TYPICAL DEFECTS AFFECTING FLEXIBLE PAVEMENTS

TYPE OF DEFECT	LAYER (S) AFFECTED	DETERIORATION MECHANISMS	POSSIBLE CAUSES
LONGITUDINAL CRACKING	Surfacing (Asphaltic Concrete)	Excessive and repeated loading - fatigue	Insufficient thickness and/or excessive rigidity of AC. Excessive deformation of support
	B (Cement treated) + Surfacing (AC)	Excessive and repeated loading - fatigue	Insufficient thickness and/or strength of the base. Excessive deformation of subgrade, subbase
CRAZING	Surfacing (AC)	Excessive and repeated loading -fatigue	Insufficient thickness and/or excessive rigidity of AC. Advanced deformation of support
	B (Cement treated) + Surfacing (AC)	Excessive and repeated loading - fatigue	Insufficient thickness and/or strength of the base. Excessive deformation of subgrade and subbase
CRESCENT CRACKING	S (AC)	Slippage	Insufficient AC stability – Poor interface bonding
RUTTING	B + S SB + B + S SG + SB + B + S	Densification Densification Densification	Insufficient stability of base Insufficient stability of subbase and/ or base Insufficient base thickness Insufficient pavement thickness and/or base Insufficient subgrade compaction
TRASNVERSE CORRUGATIONS	B + S	Densification	Insufficient base cohesion and compaction Possible failure of bond between surface and base
DEPRESSION	B + S	Densification Disruption	Lack of stability of base (inadequate material and/or compaction, attrition)
	SB + B + S	Densification Disruption	Lack of stability of subbase (ditto)
	SG + SB + B + S	Densification Settlement	Insufficient compaction of subgrade and/ or pavement Insufficient fill compaction – slip- groundwater
EDGE DEFORMATION	Base	Densification Lateral movement	Insufficient edge compaction Lack of edge restraint (crushed stone)
UPHEAVAL	Subgrade	Soil Expansion	Moisture changes (expansive soils)
POTHOLES	S + B	Disruption	Disintegration of surfacing and base (aggravation of some of the above processes)

Note: - AC = Asphaltic Concrete, S = Surfacing, B = Base, SB = Subbase, SG = Subgrade

TABLE 3.3 TYPICAL DEFECTS AFFECTING RIGID AND SEMI-RIGID PAVEMENTS

TYPE OF DEFECT	LAYER (S) FFECTED	DETERIORATION MECHANISM	POSSIBLE CAUSES
LONGITUDINAL CRACKING	B + S	Excessive and repeated loading - Fatigue	Insufficient thickness and/or excessive strength of base Excessive deformation of subgrade + subbase
LONGITUDINAL TRANSVERSE CRACKING	B + S	Thermal changes Shrinkage	Rigidity of the base and/or surfacing; excess cement/ or moisture; Poor cement treated base
TRANSVERSE CRACKING	B + S	Thermal changes Shrinkage	Rigidity of the base and/or surfacing; excess cement/ or moisture; Poor cement treated base; moisture changes
CRAZING	B + S	Excessive and repeated loading - Fatigue	Insufficient thickness and/or strength of the base. Advanced deformation of subgrade + subbase
CRESCENT CRACKING	Asphalt concrete	Slippage	Insufficient premix stability Poor interface bond
RUTTING	Asphalt concrete	Densification Creep	Insufficient AC stability
TRASNVERSE CORRUGATIONS	Asphalt concrete	Densification Creep	Insufficient AC stability
DEPRESSION + CRACKING	SB + B + S SG + SB + B + S	Densification Settlement	Insufficient compaction or strength of SB Insufficient fill compaction; slip or Groundwater
FAULTING	B + S	Loading, Pumping Densification; Erosion	Insufficient strength of subbase and subgrade Lack of drainage and subgrade swelling
POTHOLES	B + S	Disruption	Disintegration of surfacing and base combination of some of the above processes

Note: - AC = Asphaltic Concrete, S = Surfacing, B = Base, SB = Subbase, SG = Subgrade

TABLE 3.4 TYPICAL SURFACE DEFECTS AND THEIR POSSIBLE CAUSES IN VARIOUS PAVEMENT TYPES

TYPE OF DEFECT	LAYER (S) AFFECTED	DETERIORATION MECHANISM	POSSIBLE CAUSES
DISRUPTION	Asphalt concrete	Loss of cohesion	Poor adhesion of aggregate. Permeability, Segregation, Insufficient binder, Aging of bitumen, Chemical reaction
RAVELLING	Asphalt concrete	Abrasion by traffic Lack of adhesion	Soft aggregate, Insufficient bitumen, Aging of bitumen Chemical reaction, nature of aggregate, Insufficient compaction
PEELING	Asphalt concrete Surface dressing	Horizontal forces	Poor bond between base and surfacing defective tack coat: fines on top of base
STRIPPING	Surface dressing	Lack of adhesion	Inadequate binder, lack of rolling, fast early traffic, poor aggregates
EDGE SPALLING	Base	Abrasion Loading	Poor bond between base and surfacing Lack of edge restraint, shoulder erosion
BLEEDING	Surfacing	Pumping of binder	Excess binder Whipped-off chippings Too soft binder

CHAPTER 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: -

(a) assess the effects on the road user,

(b) establish the probable causes of surface distress,

(c) determine the need for, and establish priorities for, maintenance operations and surface rehabilitation,

(d) determine the need for structural evaluation and

(e) assess the rate of pavements 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 and extent of each defect observed.
- Measurements of surface roughness.
- 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. (a) 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, as indicated in Materials Branch Report No.310, Appendix No. 1 entitled "Catalogue of Road Defects".

The basic methods for quantification of the defects are as follows: -

(i) 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 the defects should be recorded.

(ii) 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.

(iii) LONGITUDINAL DEFORMATION (corrugations or undulations)

Evaluate the percentage of surface affected by longitudina1 deformation. Measure the spacing or wavelength. Measure the depth or amplitude of deformation.

(iv) GENERAL DETERIORATION OF SURFACE (ravelling, peeling, stripping, bleeding etc.)

Evaluate the severity of the distress and the percentage of surface affected.

(v) OTHER DEFECTS (depressions, upheaval, potholes)

Identify the type of defect.

Evaluate the percentage of surface affected.

Measure the depth of deformation.

(vi) 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(b) Surface Roughness

There are a number of established techniques for measuring surface roughness. MOR&PW has adopted the towed bump integrator unit developed by the TRRL as a standard; 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 (c) 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).

(i) 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. The procedure for determining the PSR is detailed in Appendix 1.

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.

(ii) PRESENT SERVICEABILITY INDEX (PSI)

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: -

$$PSI = AO + A1 \cdot \log[1 + SV] + A2 \cdot RD^2 + B1[C + P]^{1/X}$$

- For Rigid Pavements: -

$$PSI = A'O + A'1 \cdot \log[1 + SV] + B'1[C + P]^{1/X}$$

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 AO, Al, A2, B1, A'O, A'l 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: -

$$PSI = 5.00 - a \cdot R - b \cdot \log R$$

where "R" is roughness and "a" and "b" are coefficients (see note)

Notes: -

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

4.2 STRUCTURAL EVALUATION

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 material 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).

- (1) Measurement of the pavement's bearing capacity (from Benkelman beam deflection, dynaflect, falling weight deflect meter or similar surveys).
- (2) 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, exhibiting considerable scatter of their characteristics.

This justifies the use of a statistical approach, based on the analysis of sufficient numbers 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. (a) The use of the Deflection Measurement

(i) Principal 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 comparisons to be made between the stiffness of different pavements. It will also provide a means of monitoring the structural strength of pavements 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.

(ii) 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 flexible pavements indicates the trend of its adequacy

(iii) Limitations

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

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

(2) Surface deflections depend on the subgrade strength, particularly on 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).

(iii) Variation-Characterisation of Homogeneous Sections

Due to large number of factors affecting the deflection, irrespective of 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 - 250 m. 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 pavements 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. The principle, significance and method of use of moving average are presented in Appendix 4.

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

The characteristic deflection D_{90} is calculated by: -

$$D_{90} = d + 1.3s$$

where "d" is the mean deflection and "s" the standard deviation.

Thus, 10% of the deflections measured are higher than D_{90}, this guarantees the design of the over-lay or strengthening within 90% confidence limits.

(v) Standard Procedures for Measuring For Deflection Measurement

Two standard procedures for measuring deflection are detailed in Appendix 2. 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: -

(a) pavements with thin bituminous surfacing and

(b) 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°C. The surface temperatures shall be measured at a depth of 40 mm. as set out in Appendix 2.

4.2. (b) The Use of Radius of Curvature Measurements

(i) 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 of the deflection basin is largely governed by the rigidity of the upper pavement layers.

Experience has confirmed that pavements 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.

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.

(ii) Advantages

As pointed out in Paragraph 4.2. (a), deflection measurement alone cannot account for a 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.

(iii) Variation-Characterization of Homogenous 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 the advantage of providing a continual evaluation of the pavement structural condition.

Frequency curves for the radii curvature do not fit the symmetrical bell-shaped normal distribution curve. However the distribution of logarithmic values of the radii of curvature approximates to Gaussian distribution. The characteristic the radii of curvature (R10) is then calculated by: -

$$\log R_{10} = m[\log R] - 1.3S[\log R]$$

where m (log R) is the mean of 1ogR and s(log R) is the standard deviation of logR.

(iv) Standard Procedure for Radius of Curvature Measurement

The standard procedure for measuring radii of curvature is detailed in Appendix 4.

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.

A computer programme developed to facilitate both calculation and analysis of the results. This is presented in Material Branch Report No. 347.

4.2. (c) 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.

(i) 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.

(ii) 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. For 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 (to 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 problem occur should be recorded and treated individual.

In the second stage, more accurate results should be obtained by excavating or trenching the pavement at limited locations, within the "sample-sect ions" taken as being representative of longer homogeneous sections of road. Within each samp1e-section, two trenches should be excavated to the subgrade, from the centre line 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: -

- Modulus 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 (d) 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.

(i) 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 be excavated and limited testing carried out, in order to ascertain the thickness, type and state of the various layers.

(ii) 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 (c) (ii). In each hole, the thickness of each pavement layer should be the material forming each layer shall be identified visually and its moisture content measured.

Programme 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 (c) (ii). 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:-

(a) 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 AASHO for other materials)
- CBR (natural material)
- Los Angeles Abrasion test (stone)
- Aggregate Crushing Value test (stone)

(b) 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, and Moisture Content.

On the 3 others: - Density, Tensile Strength (split test), and Moisture Content.

4.1(e) Shoulder Assessment

The type of shoulders should be noted and their condition visually assessed. If it appears that there are problem 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 should 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.

The flow chart given in Figure 1 summarizes this procedure. Computer programmes may be of use in the calculation and analysis of the results.

TABLE 4.1 SUMMARY OF THE PROCEDURE FOR PAVEMENT EVALUATION

A-ROUTINE SURVEY OR FEASIBILITY STUDY OF A REHABILITION 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 REHABILITION PROJECT
FIRST STAGE: DIVISION INTO HOMOGENEOUS SECTONS-CHOICE Of SAMPLE SECTIONS -Visual Assessment: of the 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 500 m. -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 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): - 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 4.2: VERIFICATION OF THE CONSISTENCY OF DEFLECTION WITH SURFACE CONDTION, STRUCTURE DESIGN AND MAINTENANACE RATE

Deflection Level Case No.	Surface Condition	Structure Design	Maintenance Rate	Agreement Between Deflection and Other Criteria? Probable Cause of Disagreement Point to Check	Possible Use of Deflection for Sectioning and Choice of Remedial Measures
(1) High	Poor	Inadequate	Excessive	YES All factors in accordance	Deflection can be used for dividing the road into homogeneous sections and choice of corrective measures
(2) Low	Good	Adequate	Normal	YES All factors in accordance	Deflection can be used as an indicator, for flexible pavement. No corrective measures required
(3) High	Good	Inadequate		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 sections and choice of corrective measures
(4) High	Poor	Adequate	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	Inadequate	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	Poor	Adequate	Excessive	NO The surfacing is defective, the rest of the pavement is sound. Check the surface layer	Deflection is not related to surface deterioration.

CHAPTER 5 CRITERIA FOR MAINTENANCE AND REHABILITION

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, pavement may be classified according to the following index table from the British Transport and Road Research Laboratory (TRRL):

TABLE 5. 1 CLASSIFICATION OF ROAD SURFACE CONDITION

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

The following points should be noted:

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

(i) Roads Requires Local Patching when one of the following conditions arises:

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

(ii) Roads Requires resealing (surface dressing or slurry seal)

when any one of the following conditions arises: -

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

(iii) Roads Requires Minor Overlay or Resurfacing when any of the following conditions arise: -

- 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 nearside traffic lanes reach 15 mm. over more than 20% of the length showing deformation for trunk roads.

(iv) Roads 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

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

(i) Roads 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

(ii)) Roads Requires Overlay or Reconstruction when the surface irregularity exceeds 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 minima 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(a) 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 application 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. It 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 (b) 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: -

(i) Consolidation Phase

During this initial phase, the various pavement layers and the subgrade undergo same 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.

(ii) Elastic Phase

During this phase, a genuine elastic performance occurs. Each wheel load produces 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.

(iii) 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.

(iv) Failure

If the pavement is not strengthened in time, it deteriorates rapidly by 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: -

(1) In 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.

(2) In the case of a rigid pavement, 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.

(3) Some maintenance operations nay influence particular, resealing and drainage improvement deflection. It is therefore, essential to know and the extent of all the principal maintenance operations.

5.4. (c) The Use of Deflection For Performance Prediction and 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 2 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 D1 after carrying N1 standard axles has a residual life equal to (N2-NI) standard axles, N2 corresponding to the critical deflection D2.

Conversely, if it is desired that the pavement considered carried N2 standard axles during its design life, its early life deflection should not exceed Do.

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 subgrade,
- the relationship critical deflection/cumulative traffic,
- the probable variation of the deflection against traffic and
- the cumulative traffic carried until the tine 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. (d) 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 -

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

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

3) Surfacing: Surface dressing
Base: 100- 200 mm. Water-bound macadam
Subbase: 100- 250 mm. Natural gravel

The corresponding curves are shown in Figure 3.

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 moduli of elasticity e1/e2, if the pavement structure is considered as a two-layer 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 2 FLEXIBLE PAVEMENT DEFLECTION HISTORY

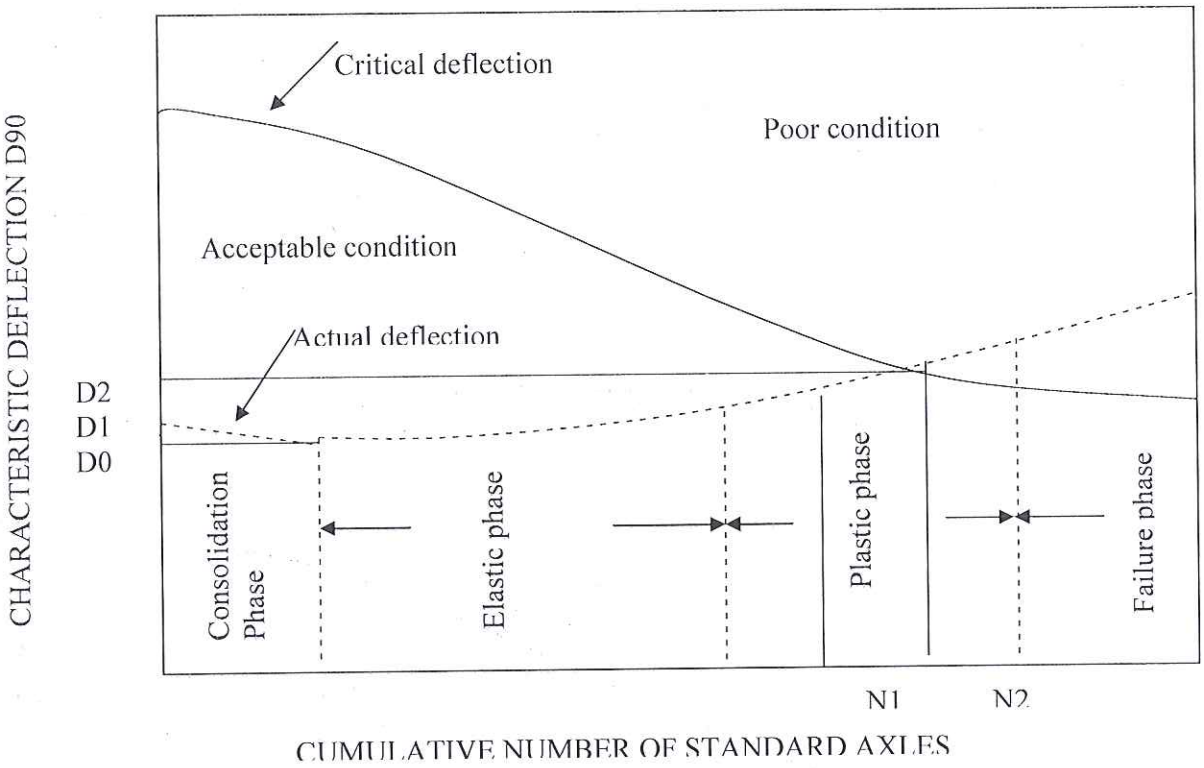
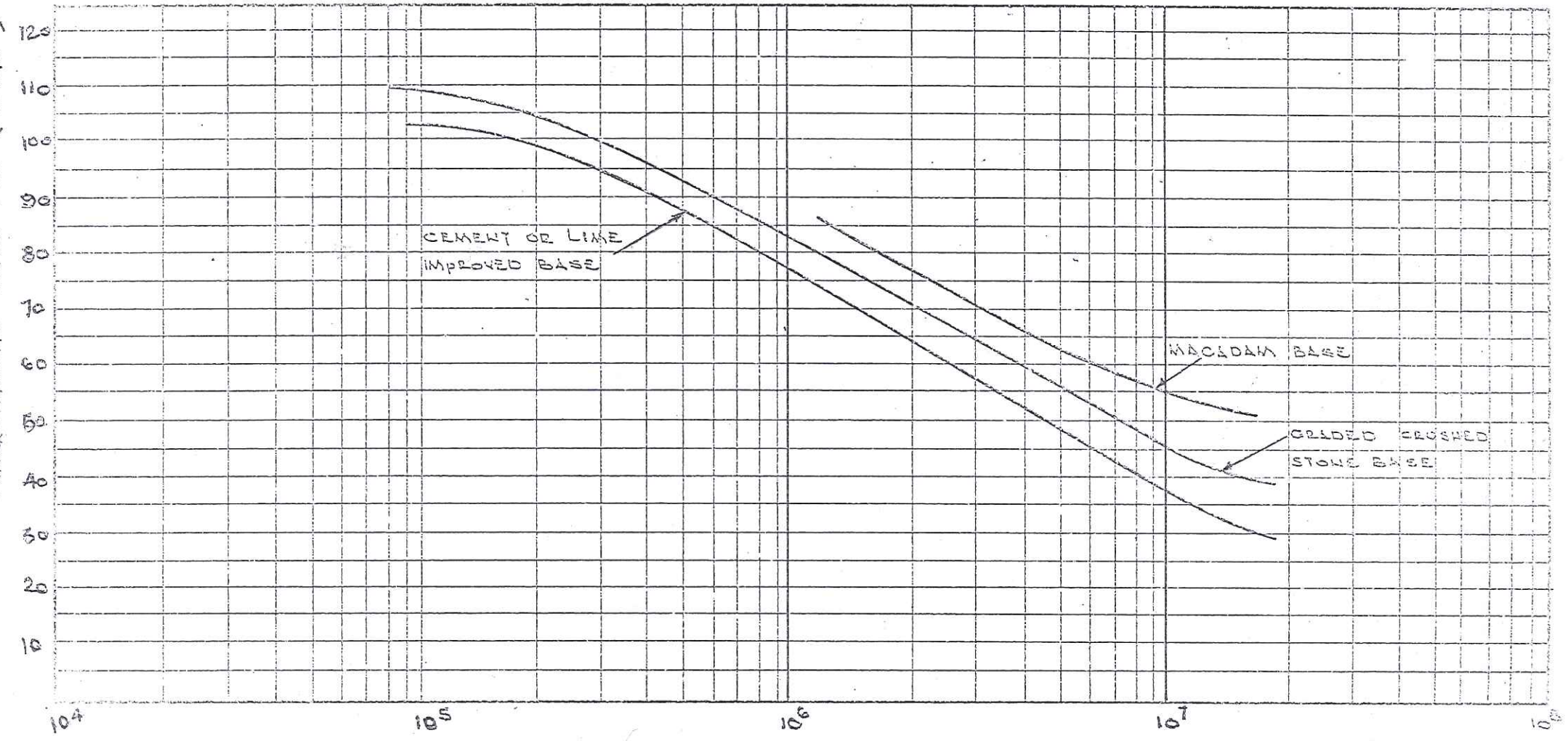


FIGURE 3	DEFLECTION CRITERION CURVES FOR VARIOUS FLEXIBLE PAVEMENTS

SURFACING: SURFACE DRESSING



CHAPTER 6 TECHNIQUES 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, particularly in the run-off conditions. A complete study of the drainage should be made to determine the required corrections.

6.1.(a) External drainage

(i) 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.
- Construct additional catchwater or discharge drains
- Line ditches the sides of which erosion causes to collapse.
- Replace pipes of insufficient section.
- Place additional pipes.

(ii) Groundwater

In cuttings, the road pavement and subgrade may be adversely affected by groundwater (watertable 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-lying 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 reconstruct the pavement. If a longer stretch of the road is affected, alternative routes should be considered if a less costly long term solution cannot be found.

6.1. (b) 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 least 75 mm thick. The use of non-woven textile may also be envisaged.

6.1. (c) Necessity of Carrying Out Drainage Works in Advance of the Overlay. The Need to Re-Evaluate the Structural Conditions After Drainage.

Rectification of any drainage deficiencies should be carried out at least 6 months and 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 local weak spots. If the overlay design was based on the weakest condition in the section it would be over designed 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. (a) 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 may 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 materials resulting from surface deterioration (fine crazing, ravelling, stripping, etc.) should be removed and all open cracks sealed.

6.2. (b) 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.

In this respect, it is essential that a thorough geometric survey of the existing surface be carried out in order to determine the make-up quantities required.

Levelling wedges are patches of material used to fill up sags and depressions or to reduce an excessive crown

The most practical method 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 practice 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 pave-finisher or other appropriate made depending on the areas to be laid and the plant available.

6.2. (c) 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 asphaltic 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 heat bitumen.

6.3. OVERLAYS

6.3. (a) Different Types of Overlay

(i) 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 the existing surfacing, settlement, etc.

Thin smoothing overlays re generally bituminous premixes (asphaltic 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.

(ii) Structural Overlays

Thin structural overlays are always made from asphaltic concrete. However beyond some limiting thickness this solution may become extremely costly so it may be advantageous to employ other strengthening materials on their own or in combination with asphaltic concrete. A distinction should be drawn between flexible and semi-rigid or rigid overlay materials, the behaviours of which are quite dissimilar.

6.3. (b) 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 asphaltic concrete. Two main types of materials suitable for base course are cement or lime improved gravel and graded crushed stone.

(i) Cement or Lime Improved Materials

The materials shall comply with all the requirements given in Chart B2. 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 asphaltic 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 summarised as follows: -

-Traffic Classes T5 -T4
Surfacing: Double surface dressing

Base :Cement or lime improved material

as per Chart B2 (CBR: min 160)

-Traffic Class T3
- Alternative (A)

Surfacing: 50 mm asphaltic concrete Type II (flexible)

or gap-graded asphalt or sand-asphalt

Base : Cement or line improved material

as per Chart B2 (CBR: min 160)

- Alternative (B)

Surfacing; Triple surface dressing

Base Cement or lime improved material

(LAA: max. 50, ACV: max. 35, UCS: min l200kN/m^2)

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 cement stabilised gravel (see Section 6.3.c—(vi))

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

(ii) Graded Crushed Stone

Graded crushed stone should comply with the requirements given in Chart B4. 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 s.a.) requires:

- either 50 mm flexible asphaltic 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 ax1es early rutting and shear failure has occurred.

The surfacing and basecourse requirements for this type of overlay are summarised as follows: -

- Traffic Classes T4 - T5

Surfacing: Double surface dressing

Base: Graded crushed stone Class C

- Traffic Class T3

Alternative (A)

Surfacing: 50 mm asphaltic 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 availab1e. 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 100 mm, 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.

(iii) 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. (c) Bound Overlay materials

(i) Asphaltic Concrete (Continuously Graded Asphalt)

This is the most common overlay material, usually asphaltic 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 pavement

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

The material specifications, traffic limitations and construction procedures for asphaltic concrete are summarised in Chart S2a and Table S2b.

Notes: -

- Due to the rapid hardening of bitumen in Kenya, the use of bitumen harder than 60/70 grade is not recommended.
- Asphaltic 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 25-30 mm (provided the maximum aggregate size does not exceed 10 mm).

(ii) Gap-Graded ("Hot-Rol1ed") Asphalt

Chart S2c summarises 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.

(iii) 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 Chart S2c.

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

(iii) Dense Bituminous Macadam (DBM)

The materials requirements, traffic limitations and construction procedures are summarized in Chart B6. The following points should be noted:

- Because of the rapid ageing of bitumen observed in this country, the use of 40/50-grade bitumen is not recommended.

- Suitable ranges of compacted thickness to be laid are as follows:

  60 -100 mm for 0/30 mm granularity

  75- 125 mm for 0/40 mm granularity

- Traffic limitations require 0/30 mm DBM for traffic class T1, and 0/40 mm. DBM for traffic classes and T3. However depending on the thickness required 0/30mm 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 asphaltic 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 more dense (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 material

(iv) 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 are summarized in chart B8.

Dense emulsion macadam has severe1 advantages:

- It is economical: cold-mixing equipment is comparatively simple, 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 a grader 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, asphaltic concrete surfacing is required for heavier traffic (TI-T2):

75 mm 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 importance.
- 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).

(v) Cement Stabilized Gravel

The materials' requirements and construction procedures are summarized in chart B3.

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 protect ion 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, asphaltic concrete surfacing is necessary so as to avoid excessive shear stresses and attrition in the stabilized gravel. The required thicknesses of asphaltic concrete (Type I) are: -

  50 mm for traffic Class T3

  75 mm for traffic Class T2

  100 mm for traffic Class TI

- 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 ratio of tensile strength to elastic modulus

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

(vi) Lean concrete

The material requirements and construction procedures are summarized in Chart B7. The following points should be noted:

- Lean concrete as an overlay material has a number of advantages; 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 asphaltic 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 be required not less than 4 hours after completion of compaction.
- No vehicles should be permitted on lean concrete for at least the first 7 days.

6.3. (d) 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. Three methods can be employed to eliminate reflection cracking; these are as follows:

i. Breaking the existing cracked layer(s) into snail pieces and reseating 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.

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

- Bituminous mixes: absolute minimum 120 mm.
- Cement -stabilized gravel: absolute minimum 200 mm.

iii. 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

MINISTRY OF ROADS AND PUBLIC WORKS

ROADS DEPARMENT

ASPHALT CONCRETE TYPE II OVERLAY DESIGN TABLE NO. 0

E = 25000 bars

Equivalent modulus in bars

Traffic x10^6	250	500	750	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000
	Overlay thickness in mm													
.3	133	103	81	66	54	44	37	31	30	30	30	30	30	30
.4	140	110	88	71	59	48	40	34	30	30	30	30	30	30
.5	146	116	93	76	63	52	44	37	30	30	30	30	30	30
.6	151	120	97	80	66	55	47	39	30	30	30	30	30	30
.7	156	125	101	83	69	58	49	42	30	30	30	30	30	30
.8	160	128	105	87	72	61	51	44	32	30	30	30	30	30
.9	163	132	108	89	75	63	53	45	33	30	30	30	30	30
1	166	135	111	92	77	65	55	47	35	30	30	30	30	30
2	0	156	130	110	94	81	69	60	45	34	30	30	30	30
3	0	169	143	122	105	91	79	69	53	40	31	30	30	30
4	0	178	152	131	113	99	86	75	58	45	36	30	30	30
5	0	0	159	138	120	105	92	81	63	49	39	31	30	30
6	0	0	166	144	126	110	97	86	67	53	42	33	30	30
7	0	0	171	149	130	115	101	90	71	56	45	36	30	30
8	0	0	175	153	135	119	105	93	74	59	47	38	30	30
9	0	0	180	157	139	123	109	97	77	62	49	40	32	30
10	0	0	0	161	142	126	112	100	80	64	52	42	34	30
20	0	0	0	0	166	149	134	121	99	81	67	55	46	38
25	0	0	0	0	174	157	142	129	106	88	73	60	50	42
30	0	0	0	0	0	164	148	135	112	93	77	65	54	45
40	0	0	0	0	0	174	159	145	121	102	85	72	61	51
50	0	0	0	0	0	0	167	153	129	109	92	78	66	56
60	0	0	0	0	0	0	174	160	135	115	97	83	71	60

70	0	0	0	0	0	0	180	165	140	120	102	87	75	64
80	0	0	0	0	0	0	0	170	145	124	107	91	79	68
90	0	0	0	0	0	0	0	175	150	128	110	95	82	71
100	0	0	0	0	0	0	0	179	153	132	114	98	85	74

Avoid placing thicknesses > 180 mm and < 30 mm

MINISTRY OF ROADS AND PUBLIC WORKS

ROADS DEPARMENT

ASPHALT CONCRETE TYPE I OVERLAY DESIGN TABLE NO. 1

E = 40000 bars

Equivalent modulus in bars

Traffic x10^6	250	500	750	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000
	Overlay thickness in mm													
.3	106	85	70	58	49	42	36	31	30	30	30	30	30	30
.4	112	91	75	63	55	45	39	34	30	30	30	30	30	30
.5	117	95	79	66	56	48	42	36	30	30	30	30	30	30
.6	121	99	82	70	59	51	44	38	30	30	30	30	30	30
.7	124	102	86	72	62	53	46	40	31	30	30	30	30	30
.8	127	105	88	75	64	55	48	42	32	30	30	30	30	30
.9	130	108	91	77	66	57	50	43	34	30	30	30	30	30
1	132	110	93	79	68	59	51	45	35	30	30	30	30	30
2	150	128	109	94	82	72	63	56	44	35	30	30	30	30
3	161	138	120	104	91	80	71	63	50	40	33	30	30	30
4	169	146	127	112	98	87	77	69	55	45	37	30	30	30
5	179	153	134	118	104	92	82	74	59	48	40	33	30	30
6	-	158	139	123	109	97	87	78	63	52	42	35	30	30
7	-	163	143	127	113	101	90	81	66	54	45	37	31	30
8	-	167	147	131	117	104	94	85	69	57	47	39	33	30
9	-	171	151	132	120	108	97	87	72	59	49	41	34	30
10	-	174	154	137	123	111	100	90	74	61	51	43	36	30
20	-	-	177	159	144	131	119	109	91	77	65	55	47	40
25	-	-	-	167	151	138	126	115	97	82	70	60	51	44
30	-	-	-	173	157	144	132	121	102	87	74	64	55	47
40	-	-	-	-	167	153	141	130	111	95	82	70	61	51
50	-	-	-	-	175	161	148	137	118	101	87	76	66	57

60	-	-	-	-	-	167	155	143	123	107	92	80	70	61
70	-	-	-	-	-	173	160	148	128	111	97	85	74	65
80	-	-	-	-	-	177	166	153	133	115	101	88	77	68
90	-	-	-	-	-	-	169	157	137	119	104	92	80	71
100	-	-	-	-	-	-	173	161	140	123	108	95	83	74

Avoid placing thicknesses > 180 mm and < 30 mm

MINISTRY OF ROADS AND PUBLIC WORKS

ROADS DEPARMENT

DENSE BITUMINOUS MACADAM OVERLAY DESIGN TABLE NO. 2

E = 50,000 bars

Equivalent modulus in bars

Traffic x10^6	250	500	750	100	125	150	175	200	250	300	350	400	450	500
	Overlay thickness in mm													
.3	111	93	78	75	75	75	75	75	75	75	75	75	75	75
.4	118	100	85	75	75	75	75	75	75	75	75	75	75	75
.5	124	106	91	79	75	75	75	75	75	75	75	75	75	75
.6	129	111	95	83	75	75	75	75	75	75	75	75	75	75
.7	134	115	100	87	76	75	75	75	75	75	75	75	75	75
.8	138	119	103	90	80	75	75	75	75	75	75	75	75	75
.9	141	123	107	94	83	75	75	75	75	75	75	75	75	75
1	144	126	110	97	86	76	75	75	75	75	75	75	75	75
2	167	149	132	118	106	95	86	78	75	75	75	75	75	75
3	181	164	147	132	119	108	98	90	75	75	75	75	75	75
4	192	174	157	143	129	118	108	99	83	75	75	75	75	75
5	200	183	166	151	138	126	116	106	90	77	75	75	75	75
6	207	190	173	158	145	133	122	113	96	83	75	75	75	75
7	213	197	180	164	151	139	128	118	101	87	76	75	75	75
8	219	202	185	170	156	144	133	123	106	92	80	75	75	75
9	223	207	190	175	161	149	138	128	110	96	83	75	75	75
10	227	211	194	179	165	153	142	132	114	99	87	76	75	75
20	0	241	224	209	195	183	171	160	141	125	111	99	89	79
25	0	0	234	219	205	193	181	170	151	135	120	108	96	87
30	0	0	243	227	214	201	189	178	159	142	128	115	103	93
40	0	0	0	241	227	214	202	191	172	155	140	126	114	104
50	0	0	0	0	237	224	213	202	182	165	149	136	124	113
60	0	0	0	0	246	233	221	210	191	173	158	144	131	120
70	0	0	0	0	0	240	229	218	198	180	165	151	138	126
80	0	0	0	0	0	247	235	224	204	187	171	157	144	132
90	0	0	0	0	0	0	241	230	210	192	176	162	149	137
100	0	0	0	0	0	0	246	235	215	197	181	167	154	142

50mm AC Surfacing

10	182	166	149	134	120	108	97	87	75	75	75	75	75	75
20	211	196	179	164	150	138	126	115	96	80	75	75	75	75
25	220	206	189	174	160	148	136	125	106	89	75	75	75	75
30	228	214	198	182	169	156	144	133	114	97	83	75	75	75
40	240	226	210	196	182	169	157	146	127	110	95	81	75	75
50	249	236	221	206	192	179	168	157	137	120	104	91	79	75
60	0	244	229	214	202	188	176	165	146	128	113	99	86	75

75mm AC Surfacing

60	231	219	204	189	176	163	151	140	121	103	88	75	75	75
70	238	226	211	196	183	170	159	148	128	110	95	81	75	75
80	243	231	217	202	189	177	165	154	134	117	101	87	75	75
90	248	237	222	208	195	182	171	160	140	122	106	92	79	75
100	0	241	227	213	199	187	176	165	145	127	111	97	84	75

Avoid placing thicknesses > 250 mm and < 75 mm

MINISTRY OF ROADS AND PUBLIC WORKS

ROADS DEPARMENT

DENSE EMULSION MACADAM OVERLAY DESIGN TABLE NO. 3

E = 20,000 bars

Equivalent modulus in bars

Traffic x10^6	400	500	600	800	1000	1250	1500	1750	2000
	Overlay thickness in mm								
.3	125	113	102	84	75	75	75	75	75
.4	132	120	108	90	75	75	75	75	75
.5	138	125	114	95	80	75	75	75	75
.6	142	129	118	99	83	75	75	75	75
.7	146	133	122	102	86	75	75	75	75
.8	150	137	125	105	89	75	75	75	75
.9	153	140	128	108	92	76	75	75	75
1	156	142	131	110	94	78	75	75	75
2	175	161	149	128	110	93	78	75	75
3	187	173	160	139	121	102	87	75	75
4	195	181	169	147	128	109	94	80	75
5	202	188	175	153	134	115	99	85	75
6	207	193	180	158	140	120	103	89	78
7	212	198	188	163	144	124	107	93	81
8	216	202	189	167	148	128	111	96	84
9	219	206	193	170	151	131	114	99	87
10	223	209	196	174	154	134	117	102	89
20	244	230	218	185	175	154	136	120	107
25	0	237	225	202	182	161	143	127	113
30	0	243	231	208	188	167	148	132	118
40	0	0	240	217	197	176	157	141	126
50	0	0	247	224	205	183	164	147	133
60	0	0	0	230	211	189	170	153	138

50mm AC Surfacing

10	178	164	151	129	109	89	75	75	75
20	199	185	173	150	130	109	91	75	75
25	206	192	180	157	137	116	98	82	75

75mm AC Surfacing

25	181	167	155	132	112	91	75	75	75
30	187	173	161	138	118	97	78	75	75
40	196	182	170	147	127	106	87	75	75
50	203	189	177	154	135	113	94	77	75
60	209	195	183	160	141	119	100	83	75

Avoid placing thicknesses > 250 mm and < 75 mm

MINISTRY OF ROADS AND PUBLIC WORKS

ROADS DEPARMENT

LEAN CONCRETE OVERLAY DESIGN TABLE NO. 4

E = 150,000 bars

Equivalent modulus in bars

Traffic x10^6	250	500	750	1000	1250	1500	1750	2000	2500	3000	3500	4000	4500	5000
	Overlay thickness in mm													
.3	228	210	198	190	183	177	172	167	160	153	150	150	150	150
.4	232	213	201	193	186	108	175	170	163	156	150	150	150	150
.5	235	216	204	195	188	182	177	173	165	158	152	150	150	150
.6	237	218	206	198	190	184	179	175	167	160	154	150	150	150
.7	239	220	208	199	192	196	181	176	168	162	156	151	150	150
.8	241	222	210	201	194	198	183	178	170	163	157	152	150	150
.9	243	224	211	203	195	199	184	179	171	164	159	153	150	150
1	245	225	213	204	197	191	185	181	172	166	160	155	150	150
2	256	235	223	214	206	200	194	189	181	174	168	162	158	153
3	263	242	229	220	212	206	200	195	186	179	173	168	163	158
4	268	247	234	224	217	210	204	199	191	183	177	172	167	162
5	273	251	238	228	220	214	208	203	194	187	180	175	170	165
6	277	255	241	231	224	217	211	206	197	190	183	177	172	168
7	280	258	244	234	226	220	214	208	200	192	186	180	175	170
8	283	260	247	237	229	222	216	211	202	194	188	182	177	172
9	285	263	249	239	231	224	218	213	204	196	190	184	179	174
10	288	265	251	241	2333	226	220	215	206	198	191	186	180	176
20	0	281	267	256	248	241	234	229	219	211	204	198	193	188
25	0	287	273	262	253	246	239	234	224	216	209	203	197	193
30	0	292	277	266	258	250	244	238	228	220	213	207	201	196
40	0	0	285	274	265	258	251	245	235	227	220	213	208	203
50	0	0	292	281	271	264	257	251	241	233	225	219	213	208
60	0	0	298	286	277	269	262	256	246	238	230	224	218	213
70	0	0	0	291	282	274	267	261	251	242	234	228	222	217
80	0	0	0	295	286	278	271	264	255	246	238	232	226	220
90	0	0	0	299	290	282	275	269	258	249	242	235	229	224
100	0	0	0	0	294	286	279	272	262	253	245	238	232	227

50mm AC Surfacing

10	243	220	206	196	188	181	175	170	161	153	150	150	150	150
20	260	236	222	211	203	196	189	184	174	166	159	153	150	150
25	266	242	228	217	208	201	194	189	179	171	164	158	152	150

75mm AC Surfacing

25	241	217	203	192	183	176	169	164	154	150	150	150	150	150
30	247	222	207	196	188	180	174	168	158	150	150	150	150	150
40	256	231	215	204	195	188	181	175	165	157	150	150	150	150
50	263	237	222	211	201	194	187	181	171	163	155	150	150	150
60	269	243	228	216	207	199	192	186	176	168	160	154	150	150
70	275	249	233	221	212	204	197	191	181	172	164	158	152	150
80	280	253	237	225	216	208	201	195	185	176	168	162	156	150
90	285	258	241	229	220	212	205	199	188	179	172	165	159	154
100	289	262	245	233	224	216	209	202	192	183	175	168	162	157

Avoid placing thicknesses > 300 mm and <150 mm

MINISTRY OF ROADS AND PUBLIC WORKS

ROADS DEPARMENT

CEMENT STABILISED GRAVEL OVERLAY DESIGN TABLE NO. 5

E = 50,000 bars

Equivalent modulus in bars

Traffic x10^	25	50	75	100	125	150	175	200	250	300	350	400	450	500
	Overlay thickness in mm													
50mm AC Surfacing														
2	31	28	26	249	237	227	218	210	198	188	180	172	166	161
3	32	29	27	256	244	234	225	217	205	194	186	179	173	167
4	33	29	27	262	249	239	230	222	210	199	191	183	177	172
5	33	30	28	266	254	243	234	226	214	203	195	187	181	175
6	34	30	28	270	257	247	238	230	217	207	198	190	184	179
7	34	31	28	273	260	250	241	233	220	209	201	193	187	181
8	34	31	29	276	263	253	244	236	223	212	203	196	189	184
9	35	31	29	279	266	255	246	238	225	214	205	198	192	186
10	35	31	29	281	268	257	248	240	227	216	208	200	194	188
75mm AC Surfacing														
10	329	294	272	256	243	232	223	215	202	191	183	175	169	163
20	348	312	289	273	259	248	239	231	217	206	197	190	183	177
25	355	318	295	279	265	254	245	236	223	212	202	195	188	182
100mm AC Surfacing														
25	330	293	270	254	240	220	220	211	198	187	177	170	163	157
30	335	298	275	258	245	224	224	216	202	191	182	174	167	161
40	345	307	284	267	253	232	232	224	210	199	189	181	174	168
50	352	314	291	273	260	239	239	230	216	205	195	187	180	174
60	359	320	297	279	265	244	244	236	221	210	200	192	185	179

Avoid placing thicknesses > 400 mm and <125 mm

MINISTRY OF ROADS AND PUBLIC WORKS

ROADS DEPARMENT

CEMENT/LIME IMPROVED MATERIAL OVERLAY DESIGN TABLE NO. 6

E = 10,000 bars

	Equivalent modulus in bars									
Traffic x10^6	400	500	600	800	1000	1250	1500	2000	2500	3000
	Overlay thickness in mm									
.3	252	220	193	149	114	100	100	100	100	100
.4	266	234	207	163	128	100	100	100	100	100
.5	277	245	218	175	139	103	100	100	100	100
.6	286	254	228	184	148	112	100	100	100	100
.7	294	262	235	192	156	120	100	100	100	100
.8	301	269	242	198	163	127	100	100	100	100
.9	307	275	248	204	169	133	102	100	100	100
1	312	280	254	210	175	138	107	100	100	100
2	349	317	290	246	211	174	144	100	100	100
3	0	339	312	268	233	196	165	115	100	100
4	0	0	327	284	248	212	181	131	100	100
5	0	0	340	296	261	224	193	143	103	100
6	0	0	350	306	271	234	203	153	113	100
7	0	0	0	315	279	243	212	162	121	100
8	0	0	0	322	287	250	220	169	129	100
9	0	0	0	329	293	257	226	176	135	101
10	0	0	0	335	299	263	232	182	141	107

50mm AC Surfacing

3	325	294	267	223	188	151	120	100	100	100
4	341	309	282	239	203	167	136	100	100	100
5	0	321	295	251	216	179	148	100	100	100
6	0	332	305	261	226	189	158	108	100	100
7	0	340	313	270	234	198	167	117	100	100
8	0	348	321	277	242	205	175	124	100	100
9	0	0	328	284	248	212	181	131	100	100
10	0	0	333	290	254	218	187	137	100	100

Avoid placing thicknesses > 350 mm and <100 mm

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ROADS DEPARMENT

GRADED CRUSHED STONE OVERLAY DESIGN TABLE NO. 7

E = 7,000 bars

	Equivalent modulus in bars										
Traffic	250	500	750	1000	1250	1500	1750	2000	2500	3000	3500
x10^6	Overlay thickness in mm										
.3	272	241	218	165	150	128	114	101	100	100	100
.4	288	255	231	175	159	136	120	107	100	100	100
.5	301	267	242	184	166	142	126	112	101	100	100
.6	313	277	251	191	173	148	131	116	105	100	100
.7	323	286	259	197	178	152	135	120	108	100	100
.8	332	294	266	202	183	157	139	123	111	100	100
.9	347	301	273	207	188	161	142	126	114	100	100
1	400	308	279	212	192	164	145	129	117	100	100
2	0	355	321	244	221	189	168	148	134	115	100
3	0	385	308	265	240	205	182	161	146	125	100
4	0	0	349	281	254	218	193	171	155	133	106
5	0	0	370	294	266	228	202	179	162	139	111
6	0	0	388	305	276	237	210	186	168	144	116
7	0	0	0	315	285	244	216	192	174	149	119
8	0	0	0	324	293	251	222	197	179	153	123
9	0	0	0	331	300	257	228	202	183	157	126
10	0	0	0	339	307	263	233	206	187	160	128

Avoid placing thicknesses > 400 mm and <100 mm

CHAPTER 7 STRUCTURAL DESIGN OF OVERLAY FOR FLEXIBLE PAVEMENTS

7.1 DESIGN PRINCIPLES

7.1. (a) 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 by the load response of the existing pavement, but also by the stress/strain characteristics of the overlay itself. Consequently, this Manual embodies one design chart for each type of overlay material

7.1. (b) Design Period

An overlay is designed to carry a certain number of standard axles. To this estimate the cumulative traffic to be considered in the design, it is necessary to decide on a "design period"
It is known "design period" does not mean that at he end of the period, the overlaid pavement will be worn out to the point that reconstruction is required. "Design period" indicate that towards the end of the period the overlaid pavement will need to be strengthened again so that it can continue to carry traffic satisfactory for further period.
Design periods for the 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, 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. (c) 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 minimise the quantity of high cost bituminous materials.

7.2 PRACTICAL AND EXPERIMENTAL BASES

7.2 (a) 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 l0 million standard axles (both directions).

However, long-term considerations may in some cases lead to the rejection of use of flexible overlays for medium traffic (T3). Indeed, considerable thicknesses are sometimes necessary and this may cause problems with levels, junctions and shoulders.

Furthermore, graded 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 asphaltic concrete, dense bituminous macadam, cement stabilized gravel or lean concrete.

7.2. (b) The behaviour of Overlay Materials

(i) Unbound Materials

The effective modulus of cohesionless materials depends to some extent, on the layer thickness and the modulus of the support (non-linear elasticicity). This applies mainly to grade crushed stone. Cement or lime improved materials generally have a higher cohesion.

Therefore the use G.C.S 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 (see Chart 19).

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.

(ii) 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 have been estimated on the basis of measured characteristics, field observations and theoretical considerations.

The corresponding fatigue diagrams (permissible tensile strain against number of load applications) are shown on Figures 11 and 12.

(iii) Bituminous Mixes

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

The moduli chosen here correspond to the following conditions:

- Loading time: 0.02 seconds (corresponding to a vehicle speed of 60 km/h approximately)
- Weighted mean annual air temperature: 20°C (corresponding to the regions between 1,000 and 2,500 meters altitude)

(iv) Overlay Materials' Moduli

The following moduli have been adopted for the various overlay materials envisaged: -

Material	Modulus	kN/m^2
-Graded Crushed Stone	4,000 kg/cm^2	(4.10^5 kN/m^2)
-Cement or Lime Improved Material	10,000 kg/cm^2	(1.10^6 kN/m^2
Cement Stabilized Gravel	40,000 kg/cm^2	(4.10^6 kN/m^2)
-Dense Bituminous Macadam	50,000 kg/cm^2	(5.10^6 kN/m^2)
-Dense Emulsion Macadam	20,000 kg/cm^2	(2.10^6 kN/m^2)
-Lean Concrete	100,000 kg/cm^2	(1.10^7 kN/m^2)
-Asphaltic Concrete Type I	40,000 kg/cm^2	(4.10^6 kN/m^2)
-Asphaltic Concrete Type II	25,000 kg/cm^2	(25.10^5 kN/m^2)

7.2 (c) Construction Principles

(i) Minimum Layer Thickness

For each material, there is a minimum layer thickness below which proper laying and compaction are not practical. These are as follows: -

-Materials	Minimum thickness
-Graded Crushed Stone 0/40mm	125mm
-Graded Crushed Stone 0/30mm	100mm
- Treated gravel	125mm
- Treated (clayey) sand	100mm
-Dense Bituminous Macadam 0/40mm	75mm
-Dense Bituminous Macadam 0/30mm	60mm
-Dense Emulsion Macadam 0/40mm	100mm
-Dense Emulsion Macadam 0/30mm	75mm
-Asphaltic Concrete 0/20mm	50mm
-Asphaltic Concrete 0/10mm	25 – 30mm
- Sand asphalt	25 – 30 mm

(ii) Compliance with Specifications

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

7.3. THE STRUCTURAL APPROACH

As shown in Chapters 4,5 and 6, the empirical approach; based on the concept of allowable deflection, cannot account for the performance of rigid and semi-rigid pavements. Moreover, there is, as yet, insufficient experience concerning the behaviour of overlays made from bound materials to enable empirical design rules to be derived.

The structural approach is therefore the only means of predicting the performance of such overlays. This approach has the further advantage of providing a good understanding of the behaviour of all types of pavement. Nevertheless, it is clear that the empirical approach remains extremely useful and that all local experience must be taken into account to validate the whole design method. All factual data and information obtained from overlay evaluation will have to be used, as soon as available, to check or improve the structural method proposed here.

7.3 (a) Schematisation of Existing Pavement

(i) Multi-Layer System

The existing pavement is considered as an elastic multi-layer system in which the materials are characterized by Young Modulus of Elasticity and Poisson's Ratio.

1. Two-Layer System

Most of the existing pavements in Kenya have thin bituminous wearing courses (surface dressing or not more than 50 mm of asphaltic concrete weaning course) and therefore approximate reasonably to two-layer system.

The upper layer characterised by its modulus El, it Poisson's' ratio "v_1" and its thickness "h". It includes the thin wearing course, the base and, in some cases, the subbase. The subbase is to be included when its stiffness is of same order as or greater than that of the base.

The lower layer, taken as semi-infinite, is characterized by its modulus E2 and its Poisson's ratio" "v_2". It represents the subgrade including any improved subgrade and the subbase, when the stiffness of the latter is significantly smaller than that of the base.

2.Three-Layer system

Pavements with thick bitumen surfacings (more than 50 mm) have to be considered as three-layer systems.

(ii) Characterization of the Pavement Layers

1. Two Layer Systems

For a standard load (geometry, dimensions and pressure) and for a given value of the thickness "h" theory indicates and experience has confirmed that the product DE2 depends only on the ratio EI/E2.

It has also been established that for a given value of h, the ratio R/E2 depends only on the ratio EI/E2.

Consequently, knowledge of the deflection "D", the radius of curvature "R" and the thickness "h" enables the moduli EI and E2 to be determined. (In addition, the subgrade moduli can be measured directly by plate bearing test).

The relationship between DE2, R/E2 and EI/E2 are plotted on Figures 4 and 5. These relationships have been obtained from the "Alize 3" suite of programmes of the Laboratoire Central des Ponts et Chaussees which is based on Burmiester theory. In this method, the following assumptions are made:

- The standard load represents the dual wheel assembly of a 13 tonnes axle .It is assumed to be equivalent to a vertical pressure "q" uniformly distributed over two equal circular areas of radius "a", the centres of which are at a distance "I" apart where: -

  $q = 6.62$ kg/ cm^2

  $a = 125$ mm

  $I = 3a = 375$ mm

- The Poisson's ratio of all materials is equal to 0.25.

The theory indicates that in addition, that all layers have complete friction between them.

It appears that, for thicknesses "h" greater than 100 mm and ratios E1/E2 smaller than 50 (virtually all Kenyan roads due for strengthening satisfy these conditions), the curves of the above mentioned charts can be represented, with sufficient accuracy, by the following equations: -

$$D \cdot E2 = 11600/[E1/E2]^{y} \qquad (1)$$

$$[R/E2] = 0.028/[E1/E2]^{x} \qquad (2)$$

in which the exponents x and y are expressed as follows:-

$$x = 0.860 \ \log h - 0.474 \qquad (3)$$

$$y = 0.493 \ \log h - 0.410 \qquad (4)$$

By combining equations (1) and (2) the following relationships, giving El and (E1/E2) as functions of "D", "R" and "h" are obtained: -

$$[E1]^{B} = [R/0.028] \cdot [D/11600]^{A} \qquad (5)$$

in which:-

$$A = [1 - x]/[1 - y] \text{ and } B = 1 - A$$

$$[E1/E2]^{X-Y} = R \cdot D/\ 3248 \qquad (6)$$

Alize 3 charts correspond to a 13 tonnes axle, whereas deflection tests in Kenya are carried out using a 6.3 tonne axle. Equation (5) is therefore modified accordingly and becomes:-

$$[E1]B = [R/0.056] \cdot [D/58000]^{A} \qquad (5a)$$

Equation (6) remains unchanged.

Values of El and E1/E2 can be obtained from these two equations, by using a programmable pocket calculator. Charts may also he prepared.

2. Three-Layer System

Determination of the 3 moduli from deflection and radius of curvature is not possible. Moduli must therefore be measured individually either in-situ by plate-bearing tests or dynamic methods or, in laboratory tests on Core samples.

Note:
It is necessary verify that the theoretical model of the existing pavement derived from the elastic method gives a valid representation of the actual structure. This is why a number of different tests desirable on each layer, e.g. field density and moisture content, grading and plasticity, U.C.S etc as indicated in Chapter 4.

7.3. (b) Pavement's Equivalent Modulus

In practice and for the purpose of overlay design, the existing is characterized by an "Equivalent Modulus". This equivalent modulus is defined as the modulus of a hypothetical one layer system such that an overlay placed on it would be subjected to same stress and strain as it is when placed on the existing pavement and submitted to the same load this equivalent modulus is an abstract notion, and should not be confused with any of the physical moduli which can be attributed to a material.

Using the elastic method described above it has been established the equivalent modulus Eq. of a homogeneous section of a pavement can be expressed by:-

$$Eq. = 10^{a-1} \cdot E1 \cdot [R/D]^{a/2}$$

Where "E1" is the modulus of the upper layer of the existing pavement.
"D" and "R" are the characteristics values of the homogeneous section considered (i.e. D_{90} and R_{10}) and
"a" is a coefficient calculated from the formula

$$"a" = 1/[1 + \log_{10}[E1/1018]]$$

By combing equations (5a) and (7), he equivalent modulus Eq can be expressed as a function of the parameters "h", "D" and "R".

7.3. (c) Calculation of stress and strain

The overlaid pavement is considered as an elastic two-layer system, in which the material are characterized by their moduli and Poisson's ratio the exiting pavement being typified by its "equivalent modulus".

The calculation of stress and strain is based on the Alize of the L.C.P.C. with the following assumptions:

- The design load is assumed to be uniformly distributed over two equal circular areas
- The pavement and overlay materials have a Poisson's ratio equal to 0.25
- All layers are considered to have complete friction between them

The method allows the following calculations o be made:

- The horizontal tensile stress and strain at the bottom of overlays made from bound material
- The vertical compressive stress and strain in the surface of the existing pavement

7.3 (d) Determination Of The Overlay Thickness Required

(i) Flexible overlays

In case of flexible overlay materials, deciding criterion is the compressive vertical strain in the surface of the existing pavement or in the surface of the subgrade. The thickness of flexible overlay required has consequently been determined by the comparison of the calculated compressive stain with the maximum permissible strain, as deduced from experience and comparison with the standard structures of the Design Manual for New roads

(ii) Bound overlays

In case of bound overlay materials the deciding criterion is the tensile strain at the bottom of the overlay. The thickness of the overlay required has therefore been determined by comparison of the calculated tensile strain with the maximum permissible strain as deduced from the strain – life relationship of the material considered.

The strain-life relationship of the main bound overlay materials considered (asphaltic concrete type I, dense bituminous macadam, dense emulsion macadam, lean concrete and cement stabilized gravel) have been derived from measured characteristics, monitoring of the performance of overlay trial sections and theoretical considerations. The corresponding fatigue diagrams are given in figure 11 and 12

In this respect it is pointed that the maximum tolerable strains chosen do not correspond to initiation of fatigue cracking at the bottom of the layer, but to the appearance of the first cracks at the surface. In other words the time of propagation of fatigue cracking through the layer has been included in the design life

7.4 Overlay design charts

For each main type of the overlay material envisaged, the thickness required has been calculated by the structural method presented in section 7.3, as a function of the cumulative traffic and the equivalent modulus of the existing pavement. The results are plotted in 7 Overlay Design Charts namely: -

Chart no	Figure	Overlay
1	13	Asphaltic Concrete Type I
2	14	Dense Bituminous Macadam + Surfacing
3	15	Dense Emulsion Macadam+ Surfacing
4	16	Lean Concrete + Surfacing
5	17	Cement Stabilized Gravel + Surfacing
6	18	Cement or Lime Improved Material + Flexible Surfacing
7	19	Graded Crushed Stone + Surfacing

The Choice of the Cheapest Solution

The selection of one type of overlay is mainly a matter of cost and availability of materials. In this respect the following points are emphasized:

(i) Asphaltic concrete is suitable for all traffic, but its exclusive use is generally uneconomical when the thickness exceeds 120mm

(ii) Dense bituminous macadam and lean concrete are unlikely to prove economical for traffic lighter than 10 million standard axles

(iii) Dense emulsion macadam. As an overlay material has a number of advantages and should often prove a viable and economical alternative to dense bituminous macadam and lean concrete.

(iv) Cement stabilised gravel shouldcompare favourably with other material for the strengthening of very deformable pavements.

(v) The use flexible overlays (GCS or cement-improved materials) is limited to traffic of less than 10 million standard axles. Moreover long-term considerations may sometimes lead to elimination of flexible overlays for medium traffic (T3) as explained in Paragraph 7.2(a).

(2) – Other Types of Overlays

It is clear that the choice of an overlay is not restricted to one of 7 main types considered above.

Consideration may well be given to other overlay materials, as suggested in Section 6.3.

On the other hand, the design of an overlay may be influenced by factors other than permissible strains, e.g. prevention reflection cracking.

7.5. METHOD OF USE

7.5. (a) First Step: Determination of the Design Parameters

Evaluation of the pavement will enable homogeneous sections to be defined, as explained in Chapter 4.

For each homogeneous section the design parameters, i.e. the characteristic deflection D_{90} and the characteristic radius curvature R_{10} should be determined. The thickness of the upper layer of existing pavement shouldbe measured and, if necessary, averaged.

7.5. (b) Second Step: Schematisation of Existing Pavement

For each homogeneous section, the moduli El/ E2 and Eq. of the existing pavement are determined by calculations or by graphical means.

For the former, the moduli and overlay thicknesses are derived by the following relationships: (Figures Nos. 4,5, 4B and 5B)

$$et \cdot E2 = [2.39 - 1.35 \log h] / 1.58 [E1/E2]^b \qquad (7.1)$$

with $b = 0.27[1 - e^{-\log h}] \log [E1/E2]$

$$\log dt = [1.66 - 10^f][1.84[E1/E2]^{0.0194} - \log h] / 1.58 \qquad (7.2)$$

$$f = -0.856 \log [[E1/E2] + 15] + 0.803$$

where "et" and "dt" are permissible stress and strain for the particular design traffic.

Fatigue laws for the overlay material considered are: -

Material	Moduli (bars)	Fatigue Laws
Asphaltic Concrete (Type II)	25,000	Log et = - o.20log T-2.286
Asphaltic Concrete (Type I)	40,000	Log et = - 0.20logT-2.337
Dense Bitumen Macadam	50,000	Log et = -0.25log T-2.160
Dense Emulsion Macadam	20,000	Log et = -0.17log T-2.430
Lean Concrete	150,000	dt = -2.0logT+ 20.6
Cement Stabilised Gravel	50,000	dt = -0.75log T+ 8.14

7.6. (c) Third Step: Estimation of Cumulative Traffic

As detailed in Chapter 6 of the Pavement Design Manual for New Roads, this Step involves the following operations:

- Study of the initial traffic flows
- Study of the axle-load distribution
- Choice of the design period
- Estimation of the traffic growth rate
- Calculation of the cumulative number of standard axles

7.5. (d) Fourth Step: Inventory and Study of the Available Overlay Materials and Selection of the Possible Types of Overlay

Knowledge of the types and characteristics of the possible overlay materials, traffic and the peculiarities of the existing pavement will permit the selection of one or more types of overlay.

7.5. (e) Fifth Step: Determination of the Overlay Thickness Required.

The thickness required for each type of overlay should be obtained from cumulative traffic and equivalent modulus, by using the appropriate overlay design chart.

7.5 (f) Sixth Step : Economic Comparison of the Possible Overlays and Final Choice of One Overlay Structure

The total cost of each possible overlay should be estimated taking into account all ancillary works, such as levelling course, shoulders upgrading, deviations etc.

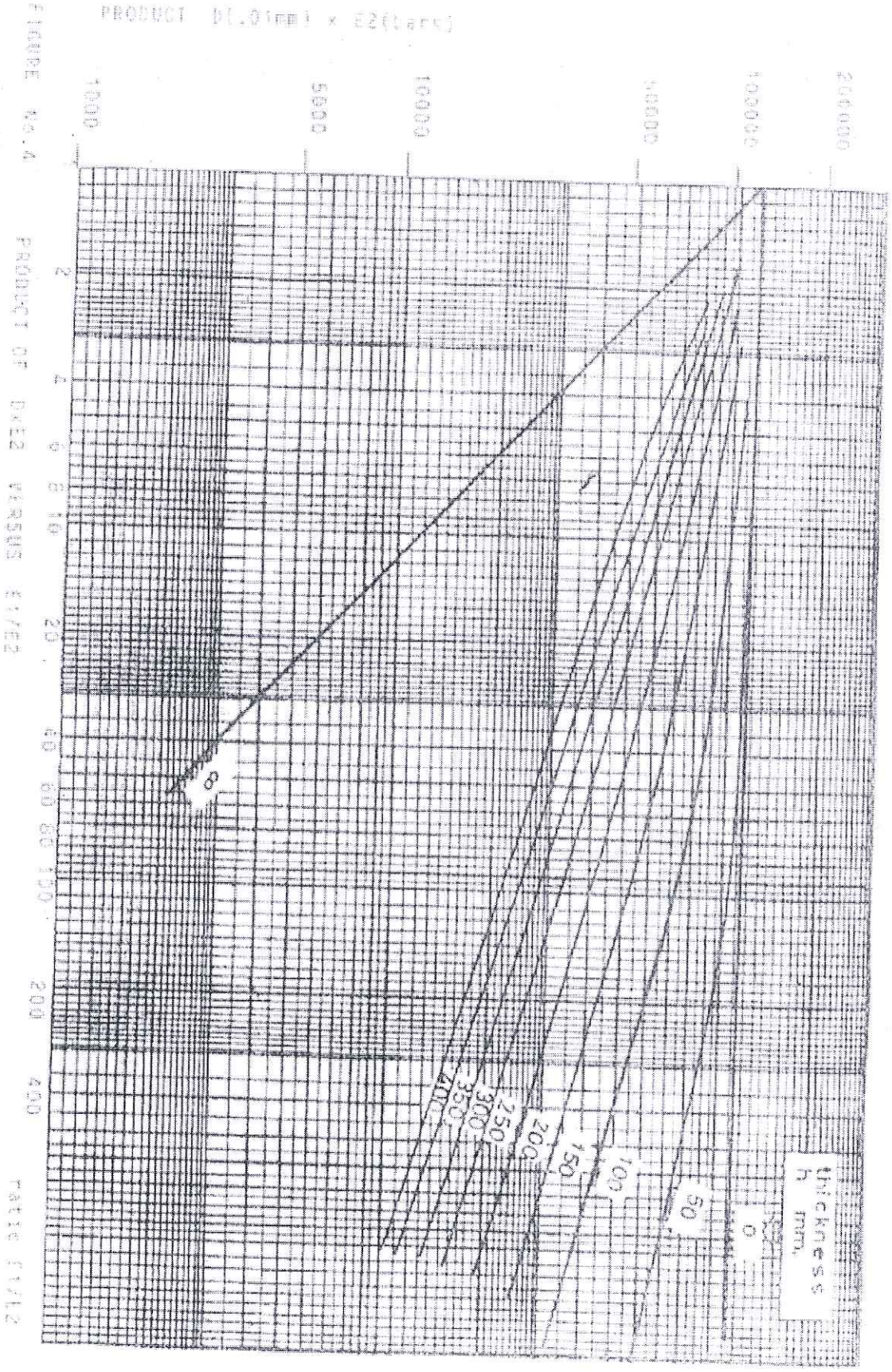
In this respect, the importance of the problem of handling traffic during construction is stressed, particularly as the construction and maintenance of deviations may be very costly.

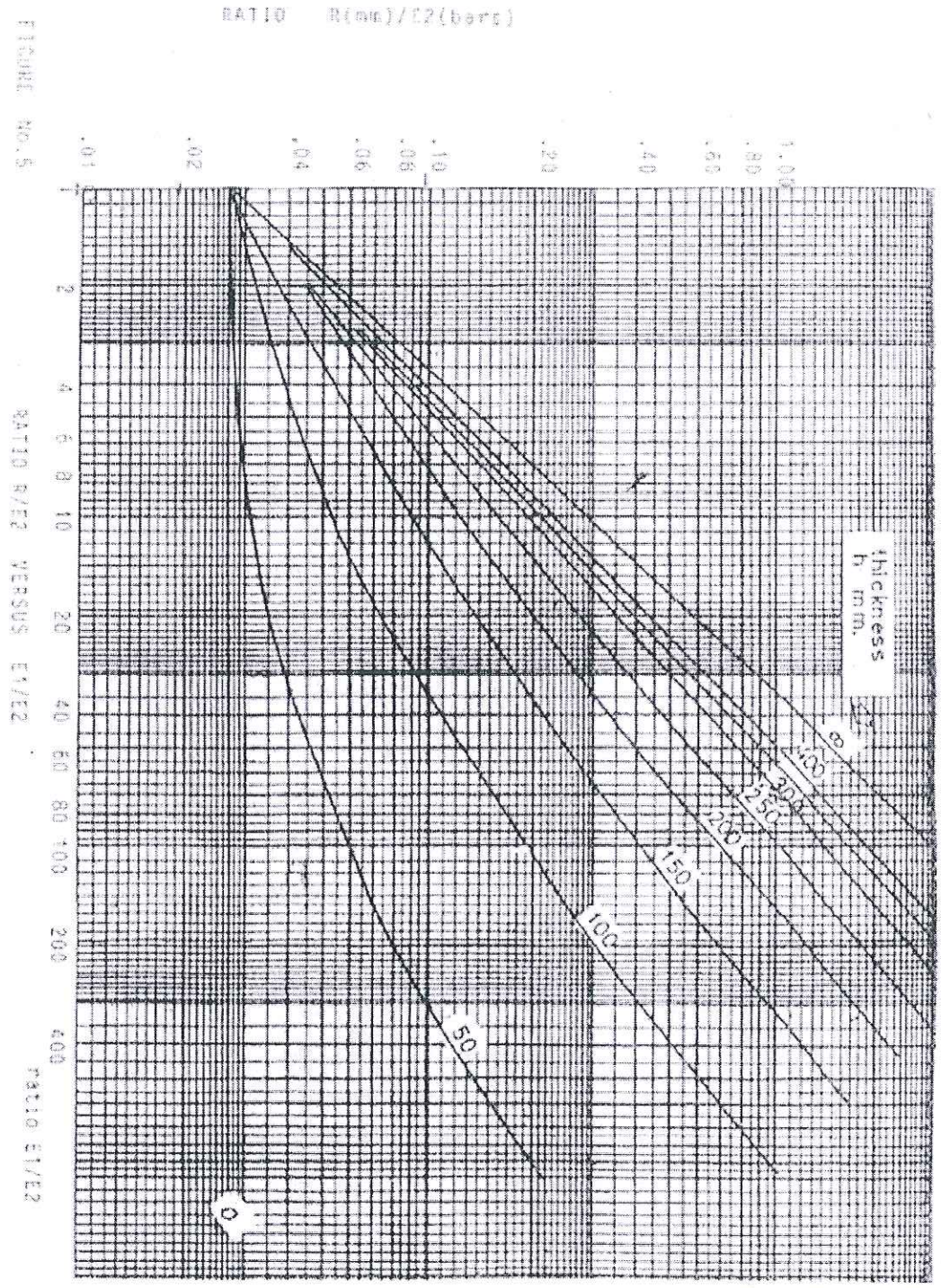
7.5. (g) Finalizing the Overlay Design and Preparation of Special Specifications

Finally, this economic comparison should enable the design engineer to select the optimum solution.

7.5 (g) Seventh Step: Finalizing the overlay Design and Preparation of Special Specifications

For the final refinements to the overlay design, consideration should be given to every peculiarity of the project (materials, climate, drainage, road safety, etc.) and special specifications shall be prepared.


PRODUCT D(.01mm) x E2(kpa)
FIGURE No. 4
PRODUCT OF DEFLECTION AND STRESS RATIO
Radius ratio
thickness h mm
0
50
100
150
200
250
300
350
400
0


RATIO R(mm)/C2(bars)
FIGURE NO.5
.01
.02
.04
.06
.08
.10
.20
.40
.60
.80
1.00
1
2
4
6
8
10
20
40
60
80
100
200
400
RATIO R/E2 VERSUS E1/E2
RATIO E1/E2
thickness h mm.
0
50
100
150
200
250
300
400
600

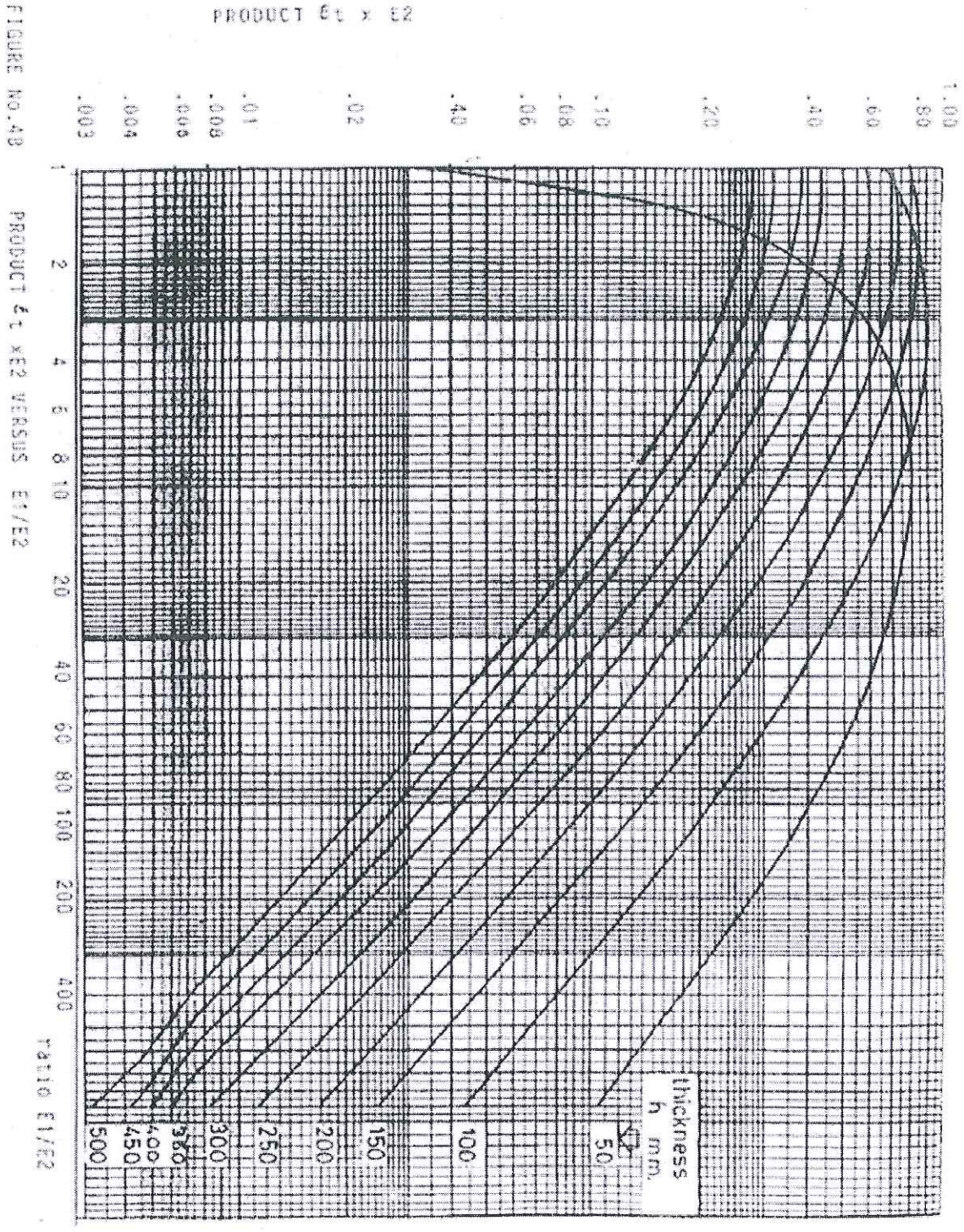
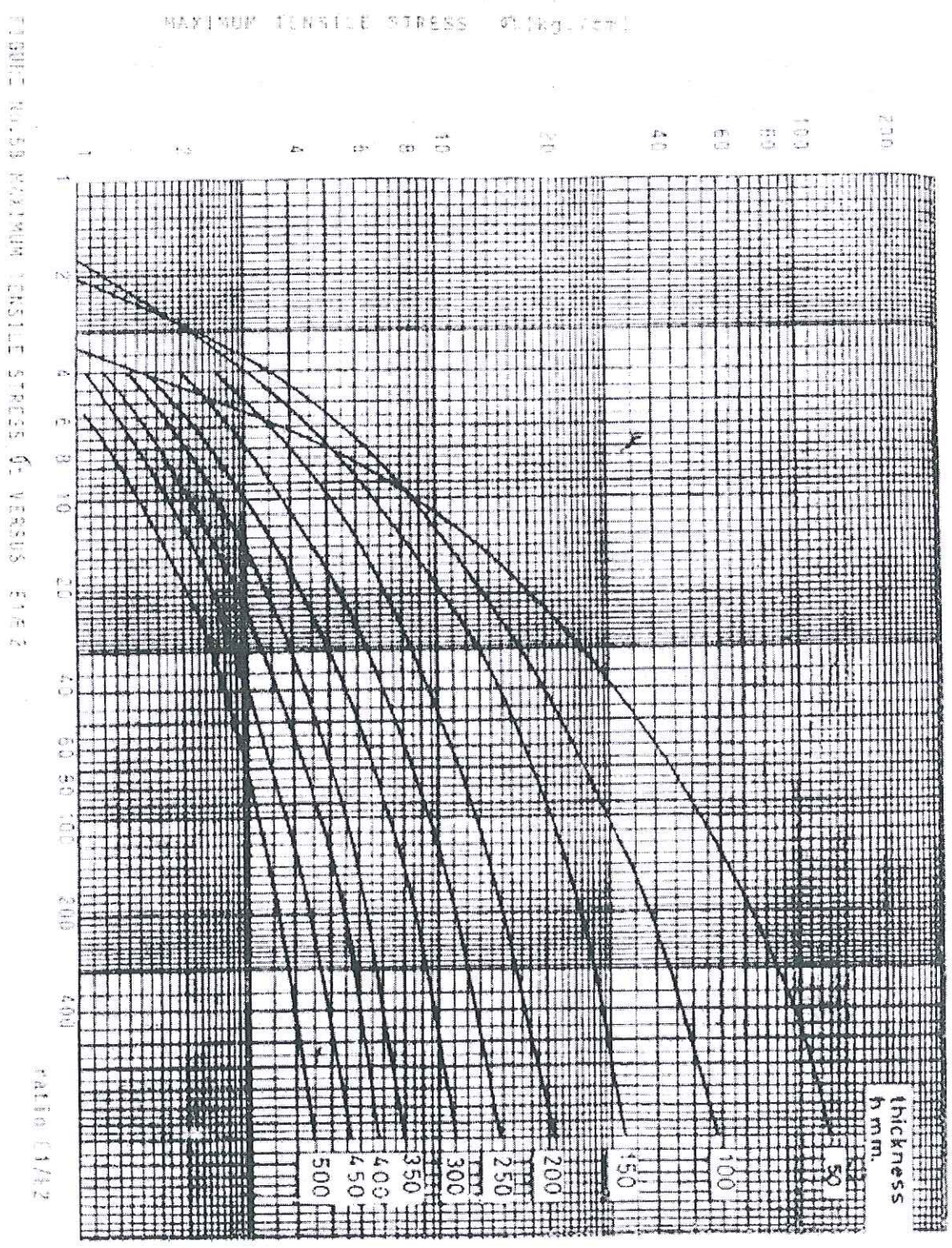

PRODUCT ε1 x ε2
.003
.004
.006
.008
.01
.02
.04
.06
.08
.10
.20
.40
.60
.80
1.00
PRODUCT ε1 xε2 VERSUS ε1/ε2
1
2
4
6
8
10
20
40
60
80
100
200
400
Ratio ε1/ε2
Thickness h mm.
50
100
150
200
250
300
350
400
450
500

FIGURE NO.4B


MAXIMUM TENSILE STRESS
thickness
h mm.
50
100
150
200
250
300
350
400
450
500

CHAPTER 8 STRUCTURAL DESIGN OF OVERLAY FOR RIGID AND SEMI- RIGID PAVEMENT

The design of overlays for rigid and semi-rigid pavements is governed by a number of factors peculiar to this type of pavement and the design method described in the preceding chapter does not apply. This chapter gives some guidelines for the strengthening of such rigid and semi-rigid pavements.

8.1. PREVENTIVE OVERLAY FOR INTACT RIGID PAVEMENTS

The failure of a rigid pave is usually sudden. Ideally, such pavements should be strengthened before failure occurs. Such preventive strengthening should be considered when the pavement is nearing the end of its design life or when an increase of traffic is expected.

8.1(a) Characteristics of Rigid and semi-Rigid Pavements

Rigid and semi-rigid pavements in good condition exhibit low deflections and high radii of curvature.

Homogeneous sections can be characterized by the characteristic radius of curvature R_{10} given by: -

$$R_{10} = r - 1.3s$$

" r" being the mean and "s" the standard deviation.

8.1 (b) Deciding Criterion

Analysis of the structural behaviour of rigid and semi-rigid pavements proves that the deciding criterion for overlay design is neither the vertical compressive strain in the subgrade nor the horizontal tensile strain in the overlay, but the horizontal tensile strain in the existing bound layer.

Application of the overlay design charts given in Chapter 7 valid lead to the conclusion that no strengthening is required or result in the selection of inadequate overlays.

8.1 (c) Overlay Design Method

The basic idea is to design the overlay so that it significantly reduces the tensile strain in the existing bound layer.

To this effect, the existing pavement is represented by a two or three-layer elastic system, as explained in Paragraph 7.3 (a) and the existing stresses and strains are calculated.

A knowledge of the strain/life relationship of the bound materials is necessary to determine the maximum permissible strain corresponding to a given number of load applications.

The overlaid pavement is then regarded as a three or four-layer system. The thickness of the overlays required is then determined by successive approximations; so that the tensile strain in the existing bound layers do not exceed permissible values.

These calculations require a computer. (the "ALIZE 3" computer program of the L.C.P.C. or the MILFEUIL of the C.E.B.T.P. can be used). Currently it is not possible to give here a general method. Each case of overlay for rigid pavement should therefore be treated individually.

8.1 STRENGTHENING OF DETERIORATED RIGID PAVEMENTS

The following types of deterioration may be identified:

8.1(a) Deterioration of Loss of Cohesion

(i) General Loss of Cohesion

This kind of degradation of bound layers generally indicate by high deflections and low radii of curvature. Such a pavement can be treated as though it were of a flexible pavement and the overlay designed accordingly.

(ii) Surface Disintegration

This type of defect affects the surface of cement treated layers (chemical reaction, rise of laitance, etc.). It is generally necessary to remove all loose material (and the overlying bituminous surfacing) and then to overlay the remaining pavement.

8.2 (b) Deterioration by Fracture (Without Loss of Cohesion)

(1) Cracking (Without Faulting)

If the rigid pavement is affected only by cracking (no faulting or unstable slabs), the overlay shall be designed so that:

(a) All strains are reduced to the desirable level.

(b) Cracking does not reflect through the overlay.

Usually, the deciding criterion is the prevention of reflection cracking.

(2) Faulting - Unstable and Rocking Slabs

Overlaying is impracticable and pavement reconstruction is required (see Section 9.5

CHAPTER 9 OTHER REHABILITION TECHNIQUES AND RECONSTRUCTION

Besides overlays and drainage improvements, there are a number of other corrective measures which, although not directly related to structural adequacy, contribute to restoring a pavement to a satisfactory condition. This chapter provides general guidance on these techniques and deals also with some aspects of pavement reconstruction.

9.1 SURFACE TREATMENTS

Surface treatments are used for the following reasons:

- To renew and add life to the old bituminous surfacing.
- To stop the disintegration (ravelling and stripping) of defective surfacing.
- To seal small cracks and waterproof the surface

With regard to skid resistance, the most satisfactory method of correcting

a slippery surface is to apply a surface dressing using hard, angular and non-polishing aggregates.

Surface treatments are economical and may be applied to any type of paved road.

9.1 (a) Surface Dressing

Surface dressing has been thoroughly dealt with in materials Branch Report No.339. The materials' requirements, traffic limitations, design method and construction procedures are summarised in charts Sla, S1b and S1c (see Chapter 6).

Classical binders (cut-backs and emulsions) are suitable only for traffic up to about 6,000 vehicles per day on 2 lanes. For heavier traffic, special binders, containing polyvinyl chloride or rubber, are required.

9.1 (b) Emulsion Slurry Seal

Emulsion slurry seal has been dealt with in materials Branch Report No.339. The materials' requirements, usual rates of application and construction procedures are summarised in Chart S3.

- Type I (fine) is employed mainly to seal cracks.
- Type II (normal) is normally used for resealing an existing surfacing.
- Type III (coarse) is reserved for heavy traffic and for areas where a good skid resistance is required.

9.1(c) Fog Seal or Surface Enrichment

Fog seals are very light applications of diluted bitumen emulsion aimed at rejuvenating old surfacings and sealing small cracks and surface voids.

The bitumen emulsion shall be slow-breaking anionic A3 or cationic K3. The emulsion should be diluted at the rate of 1:1 or 2:3 parts emulsion to water. The dilute emulsion should be applied by distributor.

Typical rates of application provide 0.2 to 0.65 litres/m^2 of emulsion (0.12 to 0.4 litres/m^2 of residual bitumen), depending on the texture and porosity of the surface. The optimum rate of application of solution is the maximum, which the surface will absorb without run-off. This can only be determined by field trials.

Traffic can usually be allowed on the treated surface within 2 hours.

Successful surface enrichment will improve the flexibility and imperviousness of old surfacings.

9.2 CRACK SEALING

When cracking is not accompanied by deformation, sealing the cracks to prevent the ingress of water may be an effective remedial measure, at least in the short term.

Various sealing compounds may be employed. The choice depends principally upon the width of the cracks.

(i) Narrow cracks (less than 2 mm in width) are difficult to seal effectively. The use of the following sealers may be envisaged:

- Emulsion slurry seal type I
- A mixture of fluid cut-back bitumen and sand
- A mixture of rubber latex and bitumen emulsion (one part in ten parts)

(ii) –medium cracks (2-5 mm in width) may be sealed with an emulsion slurry seal or rubber-bitumen sealing compound.

The cracks should be thoroughly cleaned with compressed air prior to filling with the sealing compound using a pouring pot and hand squeegee or special extrusion equipment.

(iii) -Large cracks are usually accompanied by distortion and require more extensive treatment (removal and replacement of defective areas or overlay).

9.3 EDGE AND SHOULDER REINSTATEMENT AND UPGRADING

Properly shaped and strong pavement edges and shoulders are essential for road safety, pavement drainage and edge restraint.

Pavement rehabilitation should always include the reinstatement or upgrading of weak, worn or eroded shoulders. If the edges of the pavement layers are

affected by deformation or spalling they should be repaired at the same time. These works may be combined with the placing of a drainage layer.

9.4 WIDENING

The pavement structure for widening shall be constructed in the same manner as for a new pavement at the same location. If the existing pavement is to be overlaid, it is recommended that the widening strip be constructed up to the level of the existing surface. The whole surface is then covered with the overlay, both old pavement and widening, to ensure a neat and uniform final appearance.

Attention is drawn to the difficulty of properly laying and compacting narrow strips of materials. Special compacting equipment will be required.

It is desirable to construct any widening with materials of the same type and stiffness as those forming the existing pavement, in order to prevent longitudinal cracking at the joint.

Care shall always be taken to ensure that, after widening, the existing pavement layers and the widened strip are properly drained.

9.5 PAVEMENT RECONSTRUCTION

Pavement reconstruction may be necessary for the following two main reasons: -

1) The geometric standards of the existing alignment are inadequate.
2) The existing pavement layers are in too poor a state to be economically overlaid.

In the first case, a new alignment is obviously necessary. In the second case, the choice of using the old alignment or a new one will be governed by the geometric standards of the existing road and the respective costs of the different solutions, (such costs should include for passing traffic, drainage and structures).

9.5(a) Reconstruction on the Same Alignment

Reconstruction means that existing surfacing and roadbase have to be broken up and either removed or reprocessed.

The new pavement will then be redesigned as for a new road, taking into account the subgrade bearing strength and the characteristics of all pavement materials, whether old or new.

Depending on how the existing pavement materials are reused, the following cases may be identified: -

(i) Removal and Replacement of the Defective Pavement Layers.

Poor quality materials, polluted crushed stone layers; disrupted bound layers, etc. should be removed and disposed of.

(i) Scarification, Reshaping and recompacting Deformed Layers

Flexible layers affected by extensive deformation and under compacted may, if they are not too degraded or polluted, be reused by scarification, reshaping and recompaction.

(i) Breaking Reseating Damaged Rigid Layers

Certain defects peculiar to rigid pavements, such as faulting or rocking or unstable slabs, render overlaying impractical. It is sometimes possible to eliminate rocking slabs by rolling with heavy rollers. The aim is to break the unstable slabs and reseat them firmly on the underlying layer.

(i) Breaking Damaged Rigid Layers into Small Fragments

Another method of eliminating rocking or unstable slabs is to break them into small fragments, with a drop hammer. Once the rigid layer has been broken, it should be graded, watered and compacted in the same manner as for a crushed stone layer.

(i) Treatment of Defective Layers with Lime or Cement

It is sometimes advantageous to treat inadequate pavement materials, by mixing then in place with lime and cement. The construction procedures are the same as for lime or cement in materials for new roads; they are summarized in Chart B2. This type of treatment is particularly relevant to pavement materials having a high plastic index.

(i) Retread Process

This process is particularly relevant to deteriorated waterbound macadam or graded crushed stone bases covered with surface dressing.It comprises of the following operations:

- Scarification of the old pavement
- Addition and mixing of new aggregate, if necessary
- Reshaping
- Application of bituminous binder and mixing in place
- Compaction
- Application of surface treatment

Suitable binders are as follows:

- anionic emulsion A2 and A3
- cationic emulsion K2
- medium-curing cut-back MC 250 and MC 800

Mixing may be done by grader, but a more uniform mix will be achieved by using a pulvimixer. However, pulvimixers can be used only if there are no stones larger than 50mm

Usually, this treatment involves the upper 100-150 mm (compacted thickness) of the old road.

9.5 (b) Reconstruction on a New Alignment

The pavement shall be designed in accordance with the materials and Pavement Design manual for New Roads.

APPENDDIX 1 PROCEDURE FOR DETERMINING PRESENT SERVICEABILITY RATINGS

1. (a) Selection of the Rating Panel

The rating panel should be composed of 5 persons, who fully understand the purpose of the pavement ratings and rating method

If possible, the panel of five should be compared for rating ability against a larger group of 10 to 15 engineers. The comparisons can be made by means of a small experiment.

In this preliminary experiment, about 10 sections of pavement, each approximately 500 m long and of fairly uniform appearance, should be selected, so located that all sections can be rated during a few hours of driving. The beginning and end of each section should be clearly marked on the road surface. The condition of these sections should range from "very poor" to "very good".

Each member of the larger group and the panel of five should rate each section, using the standard rating form (see page A.3). All ratings should be tabulated and the mean ratings and probabilities of acceptance calculated for both the small panel and the larger group.

The mean ratings of the panel of five should be compared with those of the larger group. If the mean ratings consistently differ by less than about 0.3 and the probability of acceptance curves are reasonably close, then the panel is satisfactory.

The panel ratings should then be examined for consistency. The experiment should be repeated by the five members to check their ability to reproduce results. They should not be permitted to see their original ratings nor any of the results of the first experiment. In the second rating, each member should match his original results within about 0.3. There should be even less difference between the who1e panel's mean values for each section.

If the panel is not consistent or if its mean ratings are not in agreement with those of the larger group, other engineers should be substituted for at least one or two members of the panel.

1. (b). Rating Rules

The following general rules should be observed:—

(i) The rater should consider only the present condition of the surface and consequently may rate a pavement good even if he strongly suspects it will fail in the near future.

(ii) The rating should be based on the fact that the pavement has to carry mix traffic (high-speed cars and low-speed trucks) under all types of weather conditions.

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Each member of the larger group and the panel of five should rate each section, using the standard rating form (see page A.3 below). All ratings should be tabulated and the mean ratings and probabilities of acceptance calculated for both the small panel and the larger group.

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The panel ratings should then be examined for consistency. The experiment should be repeated by the five members to check their ability to reproduce results. They should not be permitted to see their original ratings nor any of the results of the first experiment. In the second rating, each member should match their original results within about 0.3. There should be even less difference between the whole panel's mean values for each section.

If the panel is not consistent or if its mean ratings are not in agreement with those of the larger group, other engineers should be substitute for at least one or two members of the panel.

1(b) Rating Rules

The following general rules should be observed:-

i. The rater should consider only the present condition of the surface and consequently may rate a pavement 'good' even if he strongly suspects it will fail in the near future.

ii. The rating should be based on the fact that the pavement has to carry mixed traffic (high speed cars and low-speed trucks) under all types of weather conditions.

iii. The geometric characteristics (alignment, carriageway and shoulders width) of the section of road being rated should be ignored.

iv. The skid resistance of the surface should not be considered in rating.

v. The rating should be concerned primarily with longitudinal and transverse distortion of the surface, potholes, bumps, cracking and patching. Erosion of shoulders and large sags resulting from fills settlement should be ignored.

vi. The rater should not give consideration to isolated conditions, such as bumps due to settlement at culverts and bridges, rough railway crossings, etc

vii. The rater should keep in mind the class of road on which the section is located when answering the question "is the pavement of acceptable quality"?

viii. In rating a series of pavement sections, the rater should not refer to completed forms to see what value was assigned to the previous section. Each section should be rated independently. The rater should not discuss any of his ratings with another rater nor should he seek advice from anyone on the condition or design of any section.

ix. Each individual rating should be an overall opinion or impression of the pavement's present serviceability, based upon the past experience of the engineer. The rater should not mentally weigh the various defects to determine the rating.

1 (c) Rating Procedure

Ratings from 0 to 5 are assigned to each section, with the higher numbers indicating the more satisfactory condition. The rating form is shown in Fig 12 on page A.3.

One such form is required for each rater for each section. Immediately after driving over the section, the rater should assign a rating to the pavement by marking the vertical linear scale. After marking the rating scale, the question "is the pavement of acceptable quality"? must be answered "Yes" or "No" or "Undecided". The rater should answer this question independently of the rating number assigned. He should also note the main factors influencing his rating, without weighing them.

The PSR for each pavement section rated is the mean of the individual rating values assigned by each of the panel members.

Figure 12: Present Serviceability Rating (PSR) Form

SERVICEABILITY RATING FORM

ROAD:

SECTION: DATE: RATER :

Rating Scale

5	Very good
4	Good
3	Fair
2	Poor
1	Very poor
0	

Is the pavement of acceptable quality?

On the trunk system	YES	
	NO	
	UNDECIDED	
On the secondary system	YES	
	NO	
	UNDECIDED	

Factors affecting your rating	NONE	MINOR	MAJOR
Longitudinal Distortion			
Transverse Distortion			
Rutting			
Cracking			
Patching			
Others			

REMARKS:

APPENDIX 2

BENKELMAN BEAM DEFLECTION

TESTING PROCEDURE

2 (a) Rebound Deflection Procedure

1. Locate the point to be tested and mark it on the road.
2. Centre the twin rear wheels of the truck above the selected point.
3. Insert the probe of the Benkelman beam between the twin wheels and place it on the selected point. If required, insert a second beam in a similar way between the other pair of twin rear wheels.
4. Remove the locking pin from the beam and adjust the front legs as necessary.
5. Start the buzzer on the beam (or tap it gently) and zero the dial gauge.
6. Record the initial dial gauge reading either zero or some small positive or negative reading).
7. Immediately after recording the initial reading, drive the truck forward slowly at a creep speed 10m or more.
8. Record the final dial gauge reading. When the gauge movement stops, stop the buzzer. (the gauge movement may resume after a short pause, but no more readings are necessary).
9. For each beam, calculate the rebound deflection by subtracting the final gauge reading from the initial gauge reading.

2(b) Transient deflection Procedure

1. Locate the point to be tested and mark it on the road.
2. Position the truck such that the rear wheels are 1.25m behind the marked point.
3. Insert the Benkelman beam between the twin rear wheels until the probe toe rests on the marked point. If required, insert a second beam in a similar way between the other pair of twin rear wheels.
4. It is helpful in positioning the truck and aligning the beams parallel to the truck axis if a pointer is fixed to the truck 1.25m in front of each pair of twin wheels.

5. Check the beams pivot arm for free movement, adjust the foot screws as necessary.
6. Start the buzzer on the beam (or tap it gently) and zero the dial gauge.
7. Record the initial dial gauge reading(either zero or some small positive or negative reading).
8. Drive the truck slowly forward at creep speed and, whilst buzzing, note the maximum dial gauge reading and the final gauge reading when the truck wheels have moved 10m or more clear of the tip of the beam.
9. For each beam, calculate the deflection by adding the differences between the first and maximum dial gauge readings to the difference between maximum and final dial gauge reading.

2 (c) Notes

i) Temperature measurements

If the pavement surfacing consists of more than 50mm of bituminous material, the surface temperature shall be measured in the following manner:

- Drive a small hole (Diameter of about 10mm and Depth of about 40mm)
- Fill the hole with oil or water, insert the thermometer and record the temperature
- At the same time, record the air temperature
- Pavement temperature shall be recorded at least every hour.

ii) Axle Load and Tyre pressure

- The current procedure uses a 6350 Kg axle and a tyre pressure of 5.25 Kg/cm^2.
- These axle load and tyre pressure are now thought to be excessively low. The possibility of adopting more realistic axle load and tyre pressure is contemplated.

APPENDIX 4

THE PRINCIPLE OF MOVING AVERAGES

The moving averages for deflection values consist of calculating for a transverse profile 'k', the average of the deflections measured on profiles k, k-1, k-2, k-3,.... and on the 'm-1' preceeding profile. The number of profiles 'm' is chosen by the designer:

For example, if six profiles are chosen, the averages for these profiles would be:

1. K-5, k-4, k-3, k-2, k-1, k
2. K-4, k-3, k-2, k-1, k, k+1
3. K-3, k-2, k-1, k, k+1, k+2
4. K-2, k-1, k, k+1, k+2, k+3

Schematic presentation of the "Moving Average" Method

k-5	k-4	k-3	k-2	k-1	k	k+1	k+2	k+3	.....	
+	+	+	+	+	+	+	+	+	+	wheel-path 1
+	+	+	+	+	+	+	+	+	+	wheel-path 2
+	+	+	+	+	+	+	+	+	+	wheel-path 3
+	+	+	+	+	+	+	+	+	+	wheel-path 4

Simultaneously with the average, the characteristic deflection D90 is calculated and both values may be used in categorizing the homogenous sections.

Chart B2 CEMENT AND LIME - IMPROVED MATERIALS

FOR BASE

MATERIAL REQUIREMENTS

Material before treatment	
- Grading:	
- Natural gravels:	
- Maximum size:	10-50 mm
- Passing 0.075 mm sieve:	Max. 35%
- Silty sands - Clayey sands:	
- Maximum size:	1-10 mm
- Passing 0.075 mm sieve:	Max. 40%
- Uniformity Coefficient:	Min. 5
- Plasticity Index:	Max. 25
- Plasticity Modulus:	Max.2,000
- Organic Matter	Max. 1%
- Extra requirements for lime treatment:	
- Passing 0.425 mm sieve:	Min. 15%
- Plasticity Index:	Min. 10

Cement
Ordinary Portland Cement (KS 02-21) without any addition
Amount usually required:
Plastic gravels: 3-6%
Clayey sands: 3-5%

Lime
Hydrated Calcium Lime (Clause 205 of Standard Specifica.)
Amount usually required: 4 - 6%

Treated material
CBR (Lab. mix - 95% MDD Mod. - 7 days cure + 7 days soak) Min. 160
Plasticity Index : Maximum 15

TRAFFIC LIMITATIONS

Suitable for T3 - T4 - T5 - Unsuitable for T1 - T2

CONSTRUCTION PROCEDURES

Minimum thickness of compacted layer: 125 mm (Gravel) - 100 mm (Cl. sand)

LAYING: by grader

MIXING: in place (Pulvimixer or travel-plant)

COMPACTION:

- Minimum dry density: 95% MDD (Modified)
- Compaction moisture content: between OMC (Mod.) - 2 and OMC (Modified)
- Maximum thickness compacted in one layer: 200 mm
- Time allowed to complete compaction and finishing:
  2 hours (Cement) 12 hours (Lime)

PROTECTION AND CURING:

- Time allowed to place protection: 4 hours (Cement) 24 hours (Lime)
- No traffic permitted for first 7 days

Chart B3

CEMENT - STABILIZED MATERIALS FOR BASE

MATERIAL REQUIREMENTS

Material before treatment	
- Materials: Gravels and coarse(clayey)sands	
- Grading:	
- Maximum size	2-40 mm
- Passing 0.075 mm sieve:	Max. 35%
- Uniformity coefficient:	Min. 10
- Plasticity Index:	Max. 25
- Plasticity Modulus: Mix-in-place	Max. 1,500
Mix-in-plant	Max. 700
- Organic matter:	Max. 0.5%

Cement
Ordinary Portland cement (KS 02-21) without any addition
Amount usually required:
Plastic gravels: 5-8%
Clayey sands: 5-7%

Treated material
UCS (Lab. mix-95% MDD Mod.-7 days cure+7 days soak) Min. 1,800 kN/m^2 Plasticity Index: Maximum 10

TRAFFIC LIMITATIONS NONE

CONSTRUCTION PROCEDURES

Minimum thickness of compacted layer: 125 mm

MIXING AND LAYING:

- Preferably mixing in stationary plant and laying by paver
- Mixing-in-place by powerful pulvi or travel-plant may be allowed

COMPACTION:

- Minimum dry density: 95% MDD (Modified)
- Compaction moisture content : between OMC (Mod.) - 2 and OMC (Mod.)
- Maximum thickness compacted in one layer: 200 mm
- Time allowed to complete compaction and finishing: 2 hours

PROTECTION AND CURING

- Time allowed after mixing to place protection against evaporation: 4 hours
- No traffic permitted for first 7 days.

Chart B4 GRADED CRUSHED STONE FOR BASE

MATERIAL REQUIREMENTS

Grading after compaction		
Sieve (mm)	% by weight passing	
	0/30	0/40
50	-	100
40	100	90-100
28	90-100	75-95
20	65-95	60-90
10	40-70	40-75
6.3	30-55	30-63
2	20-40	20-45
1	15-32	15-35
0.425	10-24	10-26
0.075	4-10	4-12

Stone requirements				
Stone Class		A	B	C
LAA	Max.	30	40	45
ACV	Max.	25	30	32
SSS	Max.	12	12	12
FI	Max.	25	30	30
CR	Min.	100	80	60

Cleanliness and Plasticity:
Stone free of foreign matter
The fines (passing 0.425 mm) shall be NON-PLASTIC

TRAFFIC LIMITATIONS Unsuitable for T1

Traffic Class	T1	T2	T3	T4	T5
Stone Class required	-	A	B	C	C
Granularity required	-	0/30	0/40	0/40	0/40

CONSTRUCTION PROCEDURES

Minimum thickness of compacted layer: 125 mm (0/40) - 100 mm (0/30)

LAYING:

- by paver (T2 - T3) - by paver or by grader (T4 - T5)

COMPACTION:

- Minimum dry density: 96% MDD (Vibrating Hammer)
  or 82% Specific Gravity of stone (Oven-dry value)
- Compaction moisture content: between 80 and 105% OMC (V.H.)
- Maximum thickness compacted in one layer: 200 mm
- Compacting equipment:
  - Pneumatic-tyred rollers (Minimum 3 t/wheel)
  - Vibratory rollers (Minimum 2 kg/mm of roll width)

Chart B6 D E N S E B I T U M E N M A C A D A M

F O R B A S E

MATERIAL REQUIREMENTS

Grading		
Sieve (mm)	% by weight passing	
	0/30	0/40
50	-	100
40	100	90-100
28	90-100	75-95
20	65-95	60-90
14	55-80	50-75
10	45-70	40-65
6.3	35-60	30-55
2	20-40	18-38
1	15-30	12-30
0.300	8-20	6-20
0.150	5-15	4-15
0.075	3-8	2-8

Coarse Aggregate (> 2 mm)	
Crushing Ratio	Min. 60%
Flakiness Index	Max. 25%
Los Angeles	Max. 35
Aggr. Cr. Value	Max. 28
S.S. Soundness	Max. 12%

Fine Aggregate (< 2 mm)	
Sand-Equivalent	Min. 40
S.S. Soundness	Max. 12%

Mineral Filler:	Non-plastic
Passing 0.425 mm	100%
Passing 0.075 mm	Min. 75%

Bitumen: 60/70 or 80/100	
Usual amount:	3.5 - 5%

TRAFFIC LIMITATIONS T1: 0/30 mm required T2-T3: 0/30 or 0/40 mm

CONSTRUCTION PROCEDURES

Minimum thickness of compacted layer: 100 mm (0/30) - 125 mm (0/40)

MIXING:

- in stationary plant
- Temperature: 125 - 165°C (80/100) 130 - 170°C (60/70)

LAYING:

- by paver
- Min. temperature : 125°C (80/100) 130°C (60/70)

COMPACTION

- Voids in total mix: Min. 4% Max. 12%
- Temperature at the end of compaction: Min. 70°C (80/100) 80°C (60/70)
- Maximum thickness compacted in one layer: 200 mm
- Compacting equipment: Pneumatic-tyred rollers (Min. 3 t/wheel)
  Vibratory rollers (Min. 2 kg/mm of roll width)

Chart B7 L E A N C O N C R E T E

F O R B A S E

MATERIAL REQUIREMENTS

Stone grading	
Sieve (mm)	% passing
40	100
28	90-100
20	65-95
10	40-70
6.3	30-55
2	18-40
1	13-32
0.425	9-24
0.075	2-10

Coarse Aggregate (>2 mm) requirements	
Crushing Ratio	Min. 80%
Flakiness Index	Max. 25%
Los Angeles Abrasion	Max. 35
Aggregate Crushing Value	Max. 28

Combined Aggregate requirements	
Fines (passing 0.425 mm)	NON-PLASTIC
Sand-equivalent	Min. 30
Sodium Sulphate Soundness	Max. 12%
Organic matter	Max. 0.3%

Cement : Ordinary Portland - Usual amount : 3 - 4%
or Special slow-setting cement

Lean Concrete	
UCS (7 days cure)	Min. 3,500 kN/m^2
UCS (28 days cure)	Min. 5,000 kN/m^2
Split Tensile Strength (28 days cure)	Min. 500 kN/m^2

TRAFFIC LIMITATIONS NONE

CONSTRUCTION PROCEDURES

Minimum thickness of compacted layer: 150 mm

MIXING : in stationary plant

LAYING : by paver

COMPACTION:

- Minimum dry density: 95% MDD (Modified)
  or 85% Specific Gravity of stone (Oven-dry value)
- Compaction moisture content: between OMC (Mod.) - 2 and OMC (Mod.)
- Maximum thickness compacted in one layer: 250 mm
- Time allowed to complete compaction and finishing: 4 hours

PROTECTION AND CURING:

- Time allowed to place protection: 4 hours
- No traffic permitted for first 7 days

Chart B8 D E N S E E M U L S I O N M A C A D A M
F O R B A S E

MATERIAL REQUIREMENTS

Grading		
Sieve (mm)	% by weight passing	
	0/30	0/40
50	-	100
40	100	90-100
28	90-100	80-95
20	75-95	70-90
14	65-85	55-77
10	52-70	45-65
6.3	40-55	35-52
2	27-40	22-35
1	20-32	16-28
0.425	13-24	10-22
0.300	11-21	8-19
0.150	7-15	5-13
0.075	4-9	3-8

Coarse Aggregate (> 2 mm)	
Crushing Ratio	Min. 40%
Flakiness Index	Max. 25%
Los Angeles	Max. 35
Aggr.Crush. Value	Max. 28
S.S. Soundness	Max. 12%

Fine Aggregate (< 2 mm)	
Sand-Equivalent	Min. 40
S.S. Soundness	Max. 12%

Addition of filler only exceptionally

Bitumen Emulsion
Cationic K3 or Anionic A3 made with 80/100 bitumen Residual bitumen amount: usually 3-5%

TRAFFIC LIMITATIONS

T1 - T2 : Granularity 0/30 mm required - T3: 0/30 or 0/40 mm

CONSTRUCTION PROCEDURES

Minimum thickness of compacted layer: 75 mm (0/30) - 100 mm (0/40)

MIXING

- in cold-mix stationary plant
- aggregate moisture content prior to mixing: 3-5%

LAYING

- by paver or by motor-grader

COMPACTION

- Voids in total mix: T1 - T2 Max. 12% T3: Max. 15%
- Optimum moisture content range: 4-7%
- Maximum thickness compacted in one layer: 150 mm
- Compacting equipment:

  Pneumatic-tyred rollers (Min.3 t/wheel)

  Vibratory rollers (Min. static load: 2 kg/mm of roll width)

MATERIAL REQUIREMENTS

Bituminous Binder
Cationic Emulsion K1-60 or Cut-back MC 3000 or Cut-back 800/1400

Chippings grading				
Sieve (mm)	Nominal size (mm)			
	14/20	10/14	6/10	3/6
28	100	"	"	"
20	85-100	100	"	"
14	0-30	85-100	100	"
10	0-7	0-30	85-100	100
6.3	"	0-7	0-30	85-100
5	"	"	0-10	"
3	"	"	"	0-30
2	0-2	0-2	0-2	0-10
0.5	"	"	"	0-2

Chippings requirements					
Chip. Class		1	2	3	4
LAA	Max.	20	25	30	35
ACV	Max.	16	20	23	26
SSS	Max.	12	12	12	12
FI	Max.	20	20	25	25

Angularity (all classes):

Minimum size of stone crushed: at least 4 times maximum size of chippings

Cleanliness (all classes):

Passing 0.075 mm: Max. 1%

Free of deleterious matter

TRAFFIC LIMITATIONS

Total traffic on 2 lanes (v/day)	> 6,000	2,000-6,000	500-2,000	< 500
Chippings Class required	1	2	3	4

CONSTRUCTION PROCEDURES

SPRAYING:

- by bitumen distributor
- Spraying temperatures:
- K1-60: ambient MC 3000 : 100 - 135°C 800/1400 : 135 - 160°C

SPREADING THE CHIPPINGS:

- by mechanical spreader
- Time allowed (after spraying) to spread chippings : 1 minute

ROLLING:

- preferably by pneumatic-tyred rollers (Min. 1 t/wheel)
- Steel-wheeled rollers of less than 8 tonnes acc pted
- Time allowed (after spraying) to start rolling: 2 minutes

TRAFFIC CONTROL:

- Speed must be restricted to 30 km/h till chippings are held

Chart S1b S U R F A C E D R E S S I N G

D E S I G N

NUMBER OF SEALS

On new roads : generally double surface dressing

Triple seal : under heavy traffic if complete imperviousness required

CHIPPINGS SIZE

- Single seal (or First seal of double S.D.)

Type of Surface	Average number of commercial vehicles per day in the lane under consideration			
	1,000-2,000	200-1,000	20-200	< 20
Hard	14	10	10	6
Normal	14	14	10	10
Soft	20	14	14	10

- Double seal

Normal combination : 20+14 - 14+10 - 10+6 - 6+6

For better skid resistance : 14+14 - 10+10 - 14+6

CHOICE OF BINDER

Climate area	Road Temp.	Aggregate	Binder preferred	Alternative
Cool and wet	18 - 45°C	Acid	Emulsion K1-60	MC3000+Additive
		Basic	Emulsion K1-60	MC3000+Additive
Hot and dry	35 - 60°C	Acid	CB 800/1400+Ad.	Emulsion K1-60
		Basic	Cut-back800/1400	Emulsion K1-60
Intermediate	25 - 50°C	Acid	Emulsion K1-60	C.B.*+Additive
		Basic	Emulsion K1-60	Cut-back*

* Selection of cut-back : The higher the road temperature, the more viscous the cut-back (See Chart S1d).

APPLICATION RATES (See Design Chart next page)

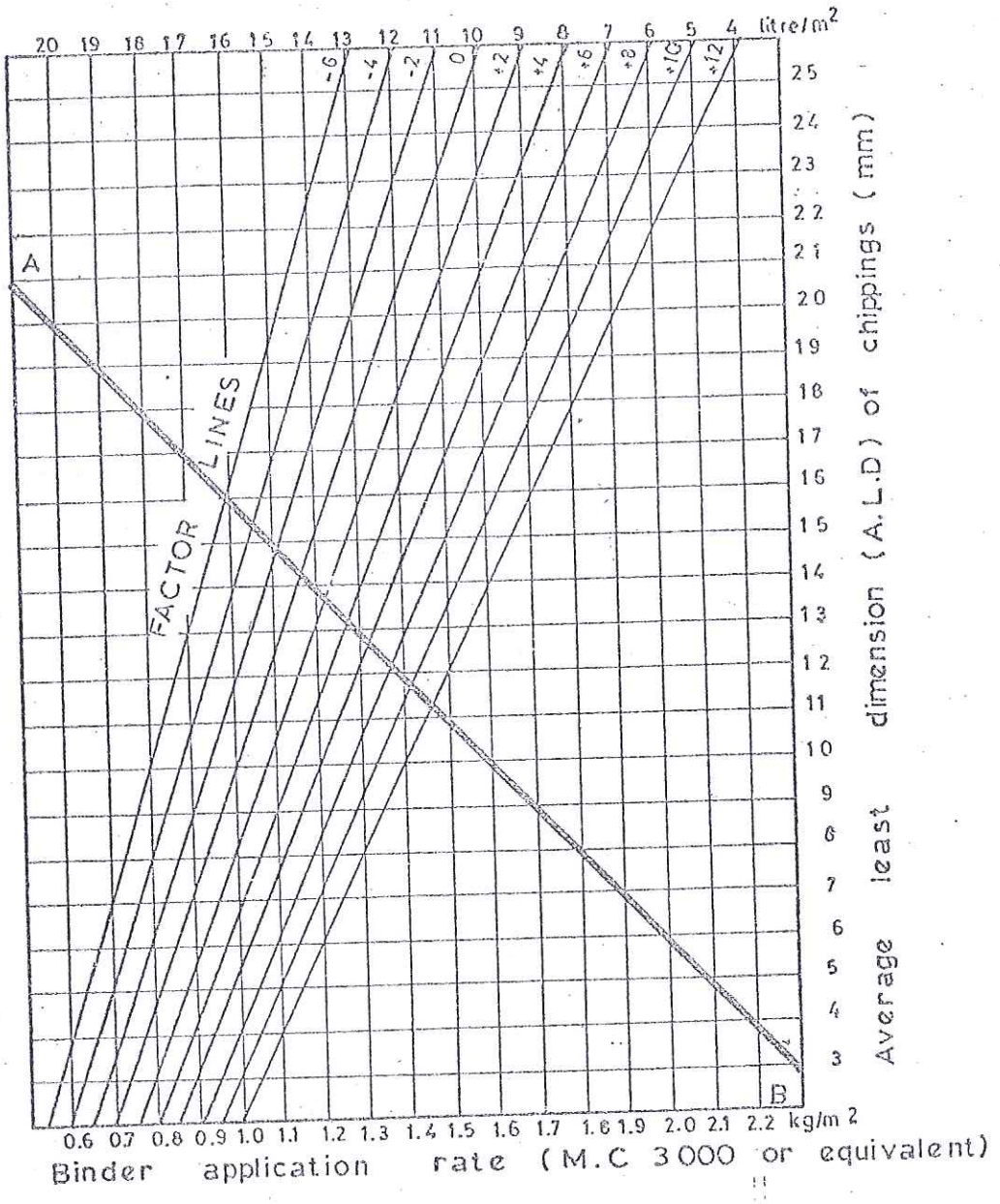
- Chippings spread rate

1-Determine the Average Least Dimension of chippings (preferably by direct measurement).
2-Read the spread rate on the line AB of the Design Chart.

- Binder Spraying rate

1-Determine the Design Factor by summing up the 4 constants, as indicated on the Design Chart.
2-Read the spray rate on the appropriate factor line of the Design Chart.

Chart S1c SURFACE DRESSING DESIGN CHART



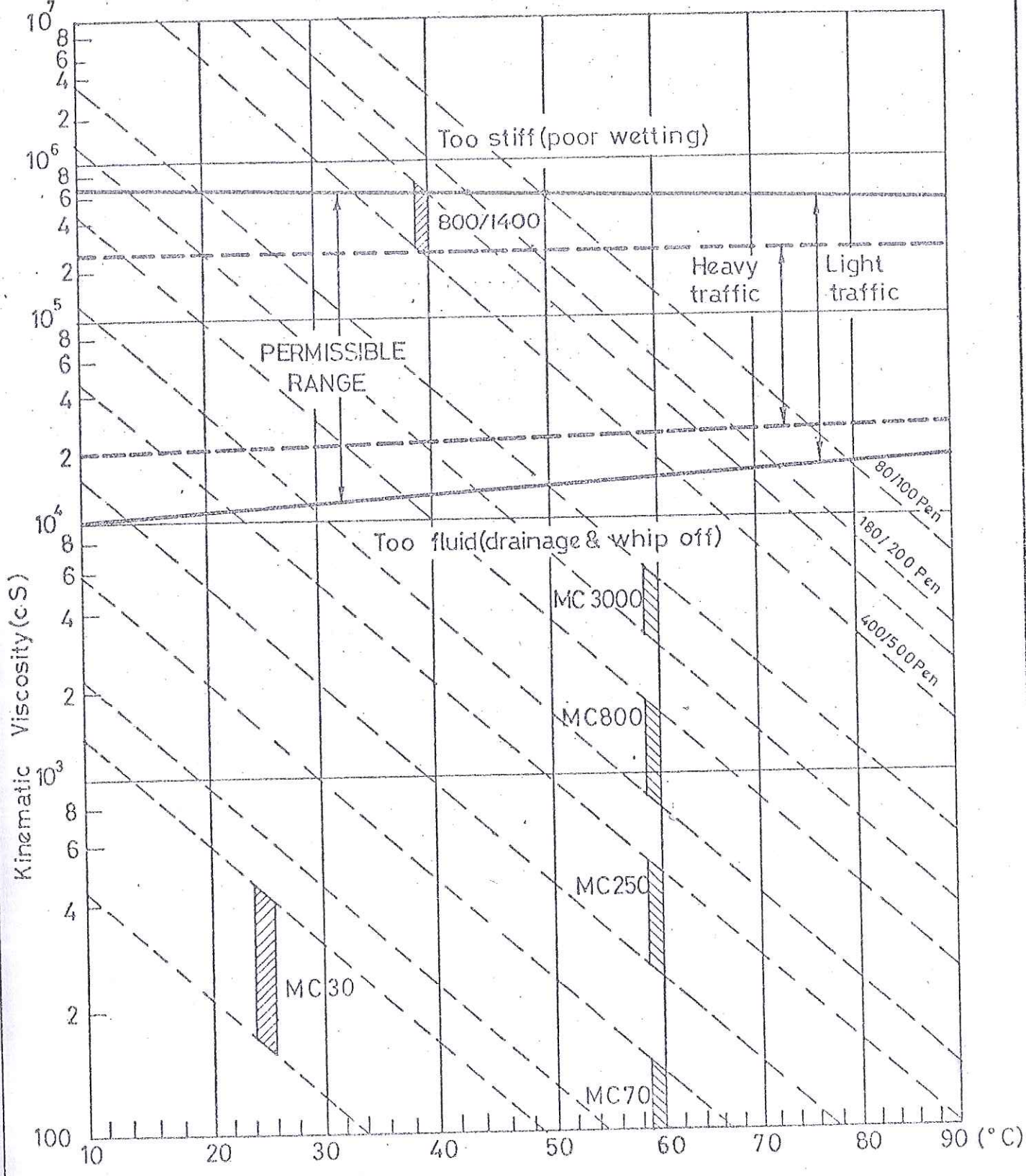
Traffic	Vehicles/day	Constant
Very light	0-100	+3
Light	100-500	+1
Medium	500-1,000	0
Medium heavy	1,000-3,000	-1
Heavy	3,000-6,000	-3
Very heavy	over 6,000	-5

Type of chippings	Constant
Round/Dusty	+2
Cubical	0
Flaky	-2
Precoated	-2

Existing Surface	Constant
Untreated/Primed base	+6
Very lean bituminous	+4
Lean bituminous	0
Average bituminous	-1
Very rich bituminous	-3

Climatic conditions	Constant
Wet and cold	+2
Wet and hot (tropical)	+1
Temperate	0
Dry and hot (semi-arid)	-1
Very dry and very hot (arid)	-2

Chart S1d SURFACE DRESSING



CHOICE OF BINDER FOR SURFACE DRESSING

SURFACE TEMPERATURE VISCOSITY CHART

Chart S2a

A S P H A L T C O N C R E T E

(Continuously-graded Asphalt)

MATERIAL REQUIREMENTS

Coarse Aggregate (>2 mm)				
Aggregate Class		a	b	c
LAA	Max.	30	35	40
ACV	Max.	25	28	30
SSS	Max.	12	12	12
FI	Max.	20	25	25

Mineral Filler	
Cement, Lime, Limestone or other mineral matter. Shall be non-plastic	
Passing 0.425 mm	100%
Passing 0.075 mm	Min. 75%

Fine Aggregate (< 2 mm)	
Sand-Equivalent	Min. 40
S.S. Soundness	Max. 12%

Usual Bitumen Content (%)		
Course	W.C.	B.C.
A.C. Type I (0/6)	6-8	-
A.C. I (0/10-0/14)	5.5-7	5-6.5
A.C. Type I (0/20)	-	4.5-6
A.C. II (0/10-0/14)	5.5-7.5	-

Mix. Grading : See Table S2b

Type of mix	A.C. Type I	A.C. Type I	A.C. Type II
Course	Wearing C.	Binder C.	Wearing C.
Bitumen grade	60/70-80/100	60/70-80/100	80/100
Crushing Ratio (%)	100	100	Min. 60
Marshall Stability (N)	Min. 9,000	Min. 7,000	5,000-9,000
Flow Value (mm)	2 - 4	2 - 4	2 - 5
Voids in total mix (%)	3 - 5	3 - 7	3 - 8

TRAFFIC AND USE LIMITATIONS

Traffic Class	T1	T2	T3	T4	T5
Coarse Aggregate Class required	a	b	b	c	c

Asph. C. Type I: Suitable for all traffic-Thick layer or rigid support
Asph. C. Type II: Suitable for T3 - T4 - T5 - Thin layer

CONSTRUCTION PROCEDURES

Minimum thickness of compacted layer: 25 mm (0/10 and smaller) 50 mm (0/20
MIXING: in stationary plant Temp. bit.: 130-150°C (60/70) 120-140°C (80/100
LAYING: by finisher - Min. temp. 130°C (60/70) 125°C (80/100)
COMPACTION: Min. mix density : 96% Lab. design Marshall density
- Min. temperature at end of compaction: 80°C (60/70) - 70°C (80/100)
- Compacting equipment:
  - Steel-wheel rollers (5-7 kg/mm of roll width)
  - Pneumatic-tyred rollers (Min. 2 t/wheel)

Sieve Size (mm)	TYPE I (HIGH STABILITY)						TYPE II (FLEXIBLE)	
	WEARING COURSE			BINDER COURSE			WEARING COURSE	
	0/14	0/10	0/6	0/20	0/14	0/10	0/14	0/10
28	-	-	-	100	-	-	-	-
20	100	-	-	90-100	100	-	100	-
14	90-100	100	-	75-95	90-100	100	90-100	100
10	70-90	90-100	100	60-82	70-90	90-100	70-95	90-100
6.3	55-75	60-82	90-100	47-68	52-75	60-82	55-85	62-90
4	45-63	47-67	75-95	37-57	40-60	45-65	46-75	50-80
2	33-48	33-50	50-70	25-43	30-45	30-47	35-60	35-65
1	23-38	23-38	33-50	18-32	20-35	20-35	25-45	25-50
0.425	14-25	14-25	20-33	11-22	12-24	12-24	14-32	14-33
0.300	12-22	12-22	16-28	9-17	10-20	10-20	11-27	11-27
0.150	8-16	8-16	10-20	5-12	6-14	6-14	6-17	6-17
0.075	5-10	5-10	6-12	3-7	4-8	4-8	3-8	3-8

TABLE S2b : GRADING REQUIREMENTS FOR ASPHALT CONCRETE

Chart S2c

GAP - GRADED ASPHALT AND SAND - ASPHALT

MATERIAL REQUIREMENTS

Coarse Aggregate (> 2 mm) for Gap-graded Asphalt	
Los Angeles	Max. 40
A.C.V.	Max. 30
S.S. Soundness	Max. 12%

Fine Aggregate(<2 mm) for G.G.Asphalt Combined Aggregate for Sand-Asphalt	
Sand-Equivalent	Min. 40
S.S. Soundness	Max. 12%

Usual Bitumen Content (%)	
Sand-Asphalt	6-10
G.G.A.(15% stone content)	7-9
G.G.A.(30% stone content)	6-8
G.G.A.(50% stone content)	5-7

Mineral Filler	
Cement, Limestone or other mineral. Shall be non-plastic	
Passing 0.425 mm	100%
Passing 0.075 mm	Min. 75%
Bulk density in toluene:	0.5-0.9g/ml

Type of mix		Gap-gr.Asphalt	Sand-Asphalt
Bitumen grade		60/70-(80/100)	60/70-80/100
Marshall Stability (N)	Min.-Max.	3,000-9,000	3,000-9,000
Flow Value (mm)	Min.-Max.	2 - 6	2 - 6
Voids in total mix (%)	Min.-Max.	3 - 10	5 - 10
Filler/Bitumen ratio	Min.-Max.	1.0 - 1.5	
Hubbard-Field Stability -60°C(N)		-	Min. 5,000

Sand-Asphalt Grading	
Sieve(mm)	% passing
10	100
6.3	95-100
2	70-100
1	47-95
0.425	20-75
0.300	15-60
0.150	8-30
0.075	4-12
Uniformity Coefficient: Minimum 5	

Examples of typical gap-graded mixes			
Sieve(mm)	30-40%stone	35-45%stone	45-55%stone
20	100	100	100
14	75-100	75-100	75-100
10	70-90	70-90	65-85
6.3	65-77	62-78	52-65
2	60-70	55-65	45-55
1	60-70	55-65	45-55
0.425	50-68	43-60	30-48
0.300	45-65	35-55	25-45
0.150	20-40	15-35	12-32
0.075	6-12	6-12	5-12

TRAFFIC AND USE LIMITATIONS : The above mixes are designed for thin wearing courses (25-50 mm)-They are suitable for T3 - T4 - T5- Gap-graded Asphalt may be suitable for heavier traffic, subject to its compliance with more severe specifications, to be derived from further research.

CONSTRUCTION PROCEDURES

See chart S2a

Chart S3 EMULSION SLURRY SEAL

MATERIAL REQUIREMENTS

Anionic emulsion A4 (slow-setting or rapid-setting), or
Cationic emulsion K3

Aggregate grading			
Sieve Size (mm)	% by weight passing		
	TYPE I (Fine)	TYPE II (Normal)	TYPE III (Coarse)
10	-	-	100
6.3	-	100	80-95
5	-	90-100	70-90
2	100	60-87	40-65
1	60-85	40-67	25-45
0.425	30-48	22-38	15-28
0.300	25-42	18-30	12-25
0.150	15-30	10-20	7-18
0.075	10-20	5-15	5-15

Aggregate

Shall be free of organic and other deleterious matter

Sand-equivalent: Minimum 40

Percentage of crusher dust:
- Slurry Class A Min. 50%
- Slurry Class B Min. 25%

Mineral filler

Ordinary Portland Cement or Hydrated Lime or other non-plastic mineral matter
Usual amount: 1% (by weight)

Mixture: Emulsion: usually 15-25% (by weight of dry aggregate)
Water : usually 10-25% (by weight of dry aggregate)

Rate of application: 130 - 250 m^2/m^3 (4 - 8 litre/m^2)

CONSTRUCTION PROCEDURES

MIXING: by concrete mixer or, preferably, slurry machine

LAYING: by slurry machine

CURING: no traffic until cured to a firm condition (no pick-up by tyres)

ROLLING: if required, by pneumatic-tyred roller