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Road Design Manual

Volume 3: Materials and Pavement Design for New Roads

Part 4: Flexible Pavement Design

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Foreword

This manual was developed by the Ministry pursuant to The Fourth Schedule of the Constitution which assigns to the National Government the functions and powers of setting standards for the construction and maintenance of all public roads including those under the County Governments.

It is part of a series of manuals that replace the first generation of road manuals developed in the first and second decades after independence. The second-generation road manuals were developed to cover the entire road project cycle covering planning, appraisal, design, contracts, construction, maintenance, operations and monitoring. The series incorporates best practices, climate change considerations, and recent technologies to enable safe, secure, and efficient road infrastructure.

Under the Kenya Vision 2030, infrastructure expansion and modernisation are one of the foundations for the realisation of Kenya's economic, social and political transformation into a rapidly industrialising middle-income country. The plan envisages an integrated, safe and efficient transport and communication infrastructure network consisting of roads, railways, ports, airports, waterways, and telecommunications infrastructure.

The strategies to be pursued under the Vision 2030 plan to improve infrastructure services and to maximise the economic and social impacts of infrastructure development and management include strengthening the institutional framework for infrastructure development and maintenance; raising efficiency and quality of infrastructure projects; Enhancing local content of identified infrastructure projects to minimise import content; Benchmarking infrastructure facilities and services provision with globally acceptable performance standards; and, Implementing infrastructure projects that will stimulate demand in hitherto marginalised areas.

The first three 5-year Medium Term Plan (MTP) under the Vision 2030 from 2008 to 2022 targeted construction of 1,950 km, 5,500 km and 10,000 km of new paved roads totalling 17,450 km. This was a massive infrastructure development program intended to double the paved road network in 10 years compared to the 8,600 km developed from independence in 1963 to 2008.

Implementing MTP I to III resulted in the construction of 14,000 km of paved roads, which was the phenomenal expansion of the paved road network that extended the paved road coverage to the Arid and Semi-Arid regions previously neglected. However, some key milestones of the Vision 2030 goals have not been realised. This has been due to internal and external challenges. External challenges included: climate change - prolonged droughts and floods; the emergence of the COVID-19 pandemic; global supply chain disruptions; exchange rate volatility; and rising interest rates in the leading economies.

The internal challenges included: inadequate road maintenance equipment; pavement overloading by heavy goods vehicles; huge maintenance backlog of the road network; low contracting and supervision capacity particularly in the Counties; poor quality control and assurance of works; congestion in urban areas; encroachment on road reserves; high cost and delays in payments of land acquisition; lack of harmonisation of cross-border transport regulation and operational procedures; rapid urbanisation; increased traffic volume with the exponential growth of motorcycle traffic; high cost/delays in relocation of utilities and services along and across road reserves; inadequate funding of projects and programs; and, delay or default in payments for goods, services and works.

The inability to address some of the above challenges is largely due to intrinsic systemic challenges which include: inadequate funding of research on roads and road construction materials; poor planning; lack of internalisation of policies and processes; lack of respect for professionals and standard practice; ineffective coordination in the implementation of programs and projects; lack of inclusivity in engagement of manpower and procurement of services and works; and, lack of unity of purpose and synergy in development and delivery of projects.

The infrastructure expansion from 2008 – 2022 did not build the local contracting capacity (Micro, Small and Medium Enterprises) rather it destroyed them due to delays or defaults in payments of invoices at both national and county levels.

The implementation of MTP III came to an end on 30th June 2023, ushering in the implementation of the Fourth Medium Term Plan (MTP IV), which has been aligned with the aspirations of the Kenya Vision 2030 and the Bottom-Up Economic Transformation Agenda (BETA) planning approach and its key priorities.

BETA is the Government's transformation agenda geared towards economic turnaround through a value chain approach. BETA has targeted sectors with the highest impact to drive economic recovery and growth. This will be achieved by bringing down the cost of living; eradicating hunger; creating jobs; expanding the tax base; improving foreign exchange balances; and inclusive growth. BETA ensures rational resource allocation by eliminating wastage of resources occasioned by duplication, overlaps, fragmentation and ineffective coordination in the implementation of programmes and projects.

The Fourth Medium Term Plan key priorities are clustered under five key sectors, namely: Finance and Production; Infrastructure; Social; Environment and Natural Resources; and Governance and Public Administration. The infrastructure sector seeks to: enhance transport connectivity by constructing 6,000km of new roads, maintaining rural and urban roads, rail, air and seaport facilities and services; expanding communication and broadcasting systems; and promoting the development of energy generation and distribution by increasing investments in green energy (geothermal, wind, solar and hydro). The infrastructure gap is expected to be bridged by promoting economic participation of the private sector through public-private partnerships in the financing, construction, development, operation and maintenance of infrastructure.

BETA entails a shift of focus to fundamentals in project planning and implementation which include: respect for technical input, regulations and standard practices; adherence to project life cycle i.e., planning, feasibility studies and design before procurement of works; public and stakeholder consultation; procurement within budgetary ceilings; shifting focus during project implementation from the finished product ‘black top’ to the construction of the foundation; building local capacity particularly MSMEs by ensuring prompt payments; and capacity building at all levels to enable internalisation of policies and processes.

The first generation of the road manuals were used for 35 to 45 years. It is my sincere hope that the second generation of the road standards which have been developed in alignment to the BETA approach will guide in solving most of the above challenges and those expected to emerge in the next 50 years. Implementation of the manuals will enable achievement of the BETA aspirations which include inclusive growth; creation of sustainable employment; building of MSMEs; climate change adaptation and realisation of the UN SDGs; enhanced efficiency in management of infrastructure and transport system; and, laying the foundation for the next national long-term plan at the end of the Vision 2030.

The second generation of the road manuals and specifications was prepared through an extensive consultative process involving review of existing standards and consultation with stakeholders, Ministerial Departments and Agencies, the Technical Task Force, public consultation and stakeholders’ workshops at review and drafting phases, and the National Steering Committee.

On behalf of the Government of Kenya, I would like to thank the African Development Bank for its support in the process of preparing this Manual. I would also like to thank the National Steering Committee, the Technical Task Force, the Technical Administrators, and the KeNHA Project Coordination Team for the sterling work done. I also thank the Consultant, TRL Limited for their role in providing technical expertise that was essential for the success of the Road manuals updating exercise.

Hon. Davis K. Chirchir, E.G.H
Cabinet Secretary, Ministry of Roads and Transport

Preface

This Part covers the structural design of flexible pavement for new roads in Kenya. The definition of a flexible pavement is simply a pavement that does not include a layer of high-strength concrete. Thus, flexible pavements include pavements with unbound granular aggregate layers and pavements with aggregate layers that are bound together with bitumen. It also includes pavements that may contain layers of aggregate that are bound together (or stabilised) with hydraulic binders such as cement and lime, but with relatively low levels of binder. Therefore, this part includes the design of roads with bituminous surfacings and seals, the design of low-volume sealed roads, and the design of unpaved roads.

It makes particular reference to the climatic conditions and materials in Kenya. It adopts an integrated approach in that full details of possible materials for the pavement layers are given as well as the details as to how these may be combined, and in what thicknesses to form a satisfactory pavement for a given design traffic.

Adjustments to the choice of materials for the purposes of enhancing climate resilience have been included. At the highest traffic class, the designer is free to propose unique alternatives for the structural design and materials choices. This enhances the cost-effectiveness and the suitability of the pavement for the local site conditions.

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Document Management

Document Status

This document has the status of a Manual. Users shall apply the contents there-in to fully satisfy the requirements set out. The content of the manual is based on current practice in Kenya and the latest practices in the road sector, both regionally and internationally.

Sources of the Document

Copies of the document can be obtained from:
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Acronyms

AADT	Annual Average Daily Traffic
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphaltic Concrete
ACV	Aggregate Crushing Value
ADT	Average Daily Traffic
ALD	Average Least Dimension
AmSL	Above mean Sea Level
B	Bus
BSM	Bitumen Stabilised Materials
BiSAR	Bitumen Stress Analysis in Roads
BS	British Standards
BSI	British Standards Institution
C	Car
CBR	California Bearing Ratio
CESA	Cumulative Equivalent Standard Axles
CIM	Cement Improved Material
CP	Concrete Pavement
CPB	Concrete Paving Block
CR	Crushing Ratio
CSIR	Council for Scientific and Industrial Research
CUSUM	Cumulatively Summed
CV	Commercial Vehicles
DCP	Dynamic Cone Penetrometer
DESA	Daily Equivalent Standard Axles
DR	Dump Rock
DSD	Double Surface Dressing
EF	Equivalency Factor
EME-2	Enrobé à Module Élevé (EME2 - High modulus asphalt)
EML	Equilibrium Moisture Levels
ESA	Equivalent Standard Axles
ESM	Emulsion Stabilised Materials
ESP	Exchangeable Sodium Percentage
ETB	Emulsion Treated Base
FACT	Fines Aggregate Crushing Test
FI	Flakiness Index
GCS	Graded Crushed Stone
GDP	Gross Domestic Product

Acronyms

GM	Grading Modulus
GPS	Global Positioning System
H	Heavy Duty
HBM	Hydraulically Bound Material
HBS	Hydraulically Bound Stone
HCV	Heavy Commercial Vehicles
HCV/d	Heavy Commercial Vehicles per Day
HFS	Hubbard Field Stabilometer
HGV	Heavy Goods Vehicle
HIG	Hydraulically Improved Granular Material
HPS	Hand Packed Stone
HRB	Hydraulic Road Binders
HSM	Hydraulically Stabilised Material
ICC	Initial Consumption of Cement
ICL	Initial Consumption of Lime
ICS	Interlocking Cobble Stone
ISO	International Standards Organisation
ITS	Indirect Tensile Strength
KS	Kenyan Standard
L	Light Duty
LAA	Los Angeles Abrasion
LGV	Light Goods Vehicle
LL	Liquid Limit
LS	Linear Shrinkage
LV	Low Volume
LVR	Low Volume Roads
LVSR	Low Volume Sealed Roads
M	Medium Duty
Mb	Minibus
MC	Medium Curing
Mc	Motorcycle
MCESA	Million Cumulative Equivalent Standard Axles
MDD	Maximum Dry Density
MGV	Medium Goods Vehicle
MLET	Multi-Layer Elastic Theory
MoRT	Ministry of Roads and Transport
MTRD	Materials Testing and Research Division
NMT	Non-Motorised Traffic

Acronyms

NPRA	Norwegian Public Roads Administration
OB	Omnibus
O-D	Origin – Destination
OMC	Optimum Moisture Content
PC	Pedal Cycle
PI	Plasticity Index
PL	Plastic Limit
PM	Plasticity Modulus (Product of PI and % passing 0.425 mm sieve).
RDM	Road Design Manual
SABitA	Southern African Bitumen Association
SADC	Southern African Development Community
SF	Seasonal Factors
SG	Specific Gravity
SMA	Stone Mastic Asphalt
SSD	Single Surface Dressing
SSS	Sodium Sulphate Soundness
TRL	Transport Research Laboratory
UC	Uniformity Coefficient
UCS	Unconfined Compressive Strength
USA	United States of America
VEF	Vehicle Equivalence Factor
VH	Vibrating Hammer
VPD	Vehicles Per Day
WBM	Water Bound Macadam

Abbreviations

cc	Cubic centimetres
h	Hour
kg	Kilogram
km	Kilometres
kN	Kilo Newton
kPa	Kilo Pascal
l	Litre
m	Metres
m^2	Meter Squared
m^3	Meter Cubed
mm	Millimetres
mm^2	Millimetres Squared
MN	Mega Newtons
MPa	Mega Pascal
N	Newton
Pen	Penetration
µm	Micrometre

Definitions and Glossary of Terms

General

Borrow Area/Pit	Is a site from which natural material, other than solid stone, is removed for construction of the works. The term borrow pit is applicable during and after the extraction of materials.
Cobblestone	Cobble or dressed stone surfacing consists of a layer of roughly rectangular to cubical dressed stone laid on a bed of sand or fine aggregate, within mortared stone or concrete edge restraints.
Concrete Paving Blocks	Precast concrete blocks laid on a base of either flexible or rigid pavement. It can be laid in various patterns. They are manufactured in two categories of shapes, i.e., regular (R) or special (S) in accordance with Kenya standard KS 827.
Graded Crushed Stone	Is a base or sub-base material derived through crushing or rock or stone, conforming to the grading, strength, shape and soundness criteria given in materials specification Chart GM11 of this RDM.
Gravel Wearing Course	Is a top surfacing course made from gravel and applied to a road formation where no pavement or bituminous surfacing are to be placed. The term 'gravel' includes one or a combination of the following materials: lateritic gravel, quartzitic gravel, calcareous gravel, some forms of partly decomposed rock, soft stone, coral rag, clayey sands and crushed rock.
Hand Packed Stone	A process in which stones of maximum dimension ranging from 100 to 200 mm are packed by hand with the largest face downwards and the stones wedged with smaller stone; a fairly level surface on which layers of smaller graded stones are placed.
Hydraulically Bound Stone	Is a high-quality, well-graded aggregate, and cement mixture (or other hydraulic binder), mixed in a stationary plant and laid by a paver. It is used as a high-quality base.
Hydraulically Improved Granular Materials	Are natural sands and gravels, crushed stone gravel/aggregates or natural materials blended with crushed stone aggregates which are deficient in desirable properties, and which may be improved by the addition of either lime, cement or hydraulic road binder. Engineering properties such as strength and plasticity are improved but the material still remains flexible. Improved materials may be suitable for either sub-base or base.
Hydraulically Modified Stone	These are granular materials whose properties are enhanced by the use of hydraulic binders such as cement. The enhancement involves some limited binding of the large particles. It excludes material modified using bituminous binders.
Hydraulic Road Binder	Is a factory-produced hydraulic binder, supplied ready for use, having properties specifically suitable for the treatment of materials for bases, sub-bases and improved subgrade as well as earthwork materials (fill, selected material etc.)
Hydraulically Stabilised Materials	Naturally occurring gravel or crushed rock whose strength is enhanced by the addition of either lime, cement or hydraulic road binders.
Quarry	Is an open surface working from which stone is removed by drilling and blasting, for construction of the works.
Rockfill	Is a rock material of such particle size that the material can only be placed in layers of compacted thickness exceeding 300 mm. Boulders with volumes greater than 0.2 m^3 are not normally used

Definitions and Glossary of Terms

Bitumen and Bituminous Materials

Asphalt Concrete Surfacing	Is a group of bitumen-bound materials used as pavement surfacings. They normally consist of a mixture of coarse aggregate, fine aggregate and filler bound with a bituminous binder.
Asphalt Concrete Wearing Course	Is the upper layer when two-course asphalt concrete is used as a surfacing. It usually differs from the lower binder course, in having a slightly higher bitumen content and lower voids.
Asphalt Concrete Binder Course	Is the lower layer when two-course asphalt concrete is used as a surfacing. It usually differs from the upper, wearing course, in having a slightly lower bitumen content, and greater voids.
Bituminous Binders	Are petroleum-derived adhesives used to stick chippings onto a road surface in surface dressings, to bind together a layer of surfacing or base material, or to bind together aggregates in bitumen bound materials. There are four principal types used in road work (straight-run, cut-back, short residue, and emulsion):
Bitumen Emulsion	Is a binder in which petroleum bitumen, in finely divided droplets, is dispersed in water by means of an emulsifying agent to form a stable mixture.
Bitumen Stabilised Materials	Are pavement materials that are treated with either bitumen emulsion or foamed bitumen. The materials commonly treated include granular materials, previously cement or lime treated pavement materials and reclaimed asphalt pavements.
Cut-Back Bitumen	Is a bitumen whose viscosity has been reduced by the addition of a volatile diluent.
Dense Bitumen Macadam	Is a hot-laid, plant mixture of well-graded aggregate, filler and straight-run bitumen, used for base construction. The resulting mix must conform to stability and flow criteria.
Dense Emulsion Macadam	Is a cold-laid, plant mixture of well-graded aggregate, filler and bitumen emulsion, used for base construction. The specifications are very similar to dense bitumen macadam.
EME (Enrobé à Module Élevé): [High Modulus Asphalt]	A mix technology developed in France providing high-performance asphalt material for use in heavy-duty pavements. Offers high-level resistance to permanent deformation combined with a high stiffness level, well in excess of that of standard mixes used in base layers, especially at elevated temperatures.
Emulsion Slurry Seal	Is a surfacing material, used by itself in one or two layers, or on top of a single surface dressing. It consists of fine aggregate, mineral filler and bitumen emulsion.
Foamed Bitumen	Hot bitumen temporarily greatly expanded in volume by the introduction of steam or water. It can be used in stabilisation or spray seal enrichment applications.
Fog Spray	Is a light application of bitumen emulsion or cut-back, on top of a surface dressing. Its purpose is to improve the waterproofness of the surfacing and to assist in holding the chippings.
Gap-Graded Asphalt	Is a hot-laid, plant mixture of gap-graded aggregate, filler and straight-run bitumen, used for pavement surfacing.
Polymer-Modified Bitumen	A binder consisting of polymeric materials dispersed in bitumen with enhanced binder performance for particular applications

Prime Coat Is an application of low-viscosity bituminous binder to an absorbent surface, usually the top of the base. Its purposes are to waterproof the surface being sprayed and bind it to the overlaying bituminous course. The use of prime emulsion is preferred.

Sand Asphalt Is a surfacing material consisting of a hot-mixed, hot-laid, plant mixture of natural sand and, in some cases, mineral filler and crushed fine aggregate, bound with straight-run bitumen. It is not suitable for heavily trafficked roads.

Sand Bitumen Is a base material consisting of a cold, mixed-in-place combination of sand (or clayey sand) and either bitumen emulsion or cut-back. This material is intended for use in areas with little or no gravel deposits.

Short Residue Bitumen is the primary product of the refinery before the air-blowing process and is a bitumen of variable viscosity whose penetration can be measured, approximating to a slow-curing cut-back.

Stone Mastic Asphalt A gap-graded wearing course mix with a high proportion of coarse aggregate, which interlocks to form a skeletal structure to resist permanent deformation. It has a high binder content.

Straight-Run Bitumen Is a bitumen whose viscosity or composition has not been adjusted by blending with solvents or any other substance.

Surface Dressing Is a method of providing a running surface to a pavement and consists of applications of bituminous binder and single-sized stone chippings. The usual form of this method on a new road is a double surface dressing with the second layer of chips being half the nominal size of the first. Single and triple surface dressings are also used.

Tack Coat Is a light application of bituminous binder to a bituminous or concrete surface to provide a bond between the surface and the overlaying bituminous course.

Contents

	Foreword	iii
	Preface	v
	Document Management	vi
	Acknowledgements	vii
	Acronyms	viii
	Abbreviations	x
	Definitions and Glossary of Terms	xi
	Contents	xiv
	List of Figures	xvii
	List of Tables	xviii
1	**Introduction**	**1**
	1.1 General	1
	1.2 Objective of this Part	3
	1.3 Scope of this Part	3
	1.4 Organisation of the Manual	3
	1.5 Design Process	4
	1.6 Pavement Layers Terminologies	5
2	**Pavement Design Considerations**	**9**
	2.1 General	9
	2.2 Road Category	9
	2.3 Choice Between Flexible and Rigid Pavements	9
	2.4 Design Period	10
	2.5 Design Traffic and Loading Characteristics	10
	2.6 Foundation Design	11
	2.7 Materials Selection	12
	2.8 Stage Construction	14
	2.9 Pavement Type Selection and Safety Factor	15
	2.10 Minimising Base and Surfacing Thicknesses	15
	2.11 Climate and Geology	15
3	**The Structural Design Method**	**17**
	3.1 General	17
	3.2 Practical and Experimental Considerations	17
	3.2.1 Use of Flexible Pavements	*17*
	3.2.2 Influence of Subgrade	*17*
	3.2.3 The Behaviour of Pavement Materials	*18*
	3.3 Procedure for Mechanistic Pavement Design	20
	3.4 Calculation of Stress, Strain, Deflection and Layer Thickness	21
	3.4.1 Overall Design Approach	*21*
	3.4.2 Design Inputs	*21*
	3.4.3 Calculation of Critical Strains and Stresses	*23*
	3.4.4 Selection of the Appropriate Pavement Structure	*24*
	3.4.5 Determination of Layer Thicknesses	*24*
	3.5 Construction Principles	25
	3.5.1 Minimum Layer Thickness	*25*
	3.5.2 Minimum Significant Thickness Increments	*26*
	3.5.3 Compliance with the Specifications	*26*

4 **Standard Pavement Structures** 27
4.1 General 27
4.2 Key Principles Governing the Use of the Structures 27
4.2.1 Type of Pavement 27
4.2.2 Long-Life Pavements 28
4.2.3 Method of Development of the Standard Pavement Structures 28
4.2.4 Use of Other Types of Pavement 29
4.2.5 Structures for Urban Pavements 29
4.3 Method of Use 29
4.4 Examples of Pavement Design 30
4.4.1 Example 1 30
4.4.2 Example 2 32
4.5 Standard Pavement Structures 35
4.5.1 Standard Pavement Structure Type 1 35
4.5.2 Standard Pavement Structure Type 2 37
4.5.3 Standard Pavement Structure Type 3 39
4.5.4 Standard Pavement Structure Type 4 41
4.5.5 Standard Pavement Structure Type 5 43
4.5.6 Standard Pavement Structure Type 6 45
4.5.7 Standard Pavement Structure Type 7 47
4.5.8 Standard Pavement Structure Type 8 49
4.5.9 Standard Pavement Structure Type 9 51
4.5.10 Standard Pavement Structure Type 10 53
4.5.11 Standard Pavement Structure Type 11 55
4.5.12 Standard Pavement Structure Type 12 57
4.5.13 Standard Pavement Structure Type 13 59
4.5.14 Standard Pavement Structure Type 14 61
4.5.15 Standard Pavement Structure Type 15 63
4.5.16 Standard Pavement Structure Type 16 65
4.6 Pavement Cross-sections 67
4.6.1 Type A 67
4.6.2 Type B 68
4.6.3 Type C 68
4.6.4 Type D 69
4.6.5 Type E 69
4.6.6 Type X 70
4.7 Shoulders 70
4.7.1 Unpaved Roads 70
4.7.2 Paved Roads 70
5 **Low-Volume Sealed Roads and Non-Motorised Traffic Lanes** 73
5.1 General 73
5.2 Standard Pavement Structures for LVSRs 73
5.2.1 Catalogues 73
5.2.2 Non-Motorised Traffic (NMT) Lanes 74
5.2.3 Method of Use 74
5.2.4 Pavement Structure Type LV1 74
5.2.5 Pavement Structure Type LV2 76
5.2.6 Pavement Structure Type LV3 78
5.2.7 Pavement Structure Type LV4 80
5.2.8 Pavement Structure Type LV5 82
5.2.9 Pavement Structure Type LV6 84
5.2.10 Pavement Structure Type LV7 86

	5.2.11	*Pavement Structure Type LV8*	*88*
	5.2.12	*Pavement Structure Type LV9*	*90*
	5.2.13	*Pavement Structure Type LV10*	*92*
	5.2.14	*Pavement Structure Type LV11*	*94*
6	**Design of Unpaved Roads**		**97**
	6.1	General	97
	6.2	Earth Roads	97
	6.2.1	*Suitability*	*97*
	6.2.2	*The Design of Earth Roads*	*98*
	6.2.3	*Spot Improvement*	*98*
	6.3	Gravel Roads	99
	6.4	Gravel Road Pavements	99
	6.5	Materials for Gravel Wearing Course	101
7	**Pavement Drainage**		**103**
	7.1	General	103
	7.2	Drainage of Surface Water	103
	7.3	Sub-Surface Drainage	104
	7.3.1	*General*	*104*
	7.3.2	*Mechanism and Remedies*	*104*
	7.3.3	*Choice of Alignment*	*105*
	7.3.4	*Sub-soil Drains*	*105*
	7.3.5	*Seepage Remedies*	*107*
	7.3.6	*Counterfort Drains*	*108*
	7.3.7	*Sub-horizontal Wells*	*108*
	7.3.8	*Geotextiles*	*108*
8	**Bibliography**		**109**
9	**Appendicies**		**111**
	Appendix A	Mechanistic Pavement Design Example	111

List of Figures

Figure 1.1	The Design Process	4
Figure 1.2	Pavement Layer Terminology	5
Figure 1.3	Pavement Terminology	5
Figure 1.4	Rural Cross-section Terminology	7
Figure 1.5	Urban Cross-section Terminology	8
Figure 3.1	Pavement Model for Dual Tyre Configuration	24
Figure 3.2	Pavement Model for Single Tyre Configuration	24
Figure 4.1	Pavement Cross-section Type A	67
Figure 4.2	Pavement Cross-section Type B	68
Figure 4.3	Pavement Cross-section Type C	68
Figure 4.4	Pavement Cross-section Type D	69
Figure 4.5	Pavement Cross-section Type E	69
Figure 6.1	Formation of an Earth Road	98
Figure 6.2	Pavement Structure of Gravel Roads	100
Figure 6.3	Gravel Material Specification	101
Figure 7.1	Transverse Drains on Super-elevated Curve	105
Figure 7.2	Longitudinal and Transverse Drains	106

List of Tables

Table 1.1	Road Design Manual (RDM) Coding Structure	2
Table 1.2	Subgrade Classes	5
Table 2.1	Selection of Pavement Design Period	10
Table 2.2	Design Traffic Classes	11
Table 2.3	Pavement Foundation Classes and Applicability	11
Table 2.4	Minimum Capping Thicknesses for Improved Subgrade	12
Table 3.1	Subgrade Moduli and Poisson’s Ratio	18
Table 3.2	Capping and Sub-base Materials Moduli and Poisson’s Ratio	19
Table 3.3	Sub-base and Base Materials Moduli and Poisson’s Ratio	19
Table 3.4	Surfacing Materials Moduli and Poisson’s Ratio	19
Table 3.5	Suitable Support Layers	20
Table 3.6	Minimum Pavement Layer Thicknesses	26
Table 4.1	Guide to Pavement Structure Selection	34
Table 4.2	Shoulder Material Requirements	71
Table 5.1	Design Traffic Classification for Low-volume Roads	73
Table 5.2	Guide to Pavement Type Selection	73
Table 6.1	Gravel Pavement Structures (D1)	100
Table 6.2	Foundation for Gravel Road Pavements	100
Table 6.3	Specifications for Gravel Wearing Courses	101
Table 7.1	Recommended Camber for Pavement Types	103
Table 7.2	Particle Size Distribution for Filter Materials	107
Table A.1	Material Characteristics and Strains Using the Standard Axle with Dual Tyres *(Attempt 1)*	112
Table A.2	Material Characteristics and Strains Using the Standard Axle with Dual Tyres *(Attempt 2)*	112
Table A.3	Material Characteristics and Strains Using the Standard Axle with Single Tyres *(check)*	112
Table A.4	Material Fatugue Relationship Coefficients for use With Software	113

1 Introduction

1.1 General

This manual was prepared by the Ministry as part of a series of manuals that cover the entire project cycle. The series incorporate best practices, climate change considerations, and recent technologies to enable the provision of road infrastructure that is safe, secure, and efficient.

The Kenya road manual series is as follows:

Project Cycle Stage	Manual: Volume or Part/Chapter	Code
A. General	**Procedures and Standards Manual**	**PSM**
	1. General	
	2. Policies	
	3. Procedures Guidance	
	4. Codes of Practice	
	5. Guidelines	
	6. Product/Testing Standards	
B. Planning	**Network and Project Planning Manual**	**NPM**
	1. Road Classification	
	2. Route/Corridor Planning	
	3. Route/Corridor Planning	
	4. Highway Capacity	
	5. Project Planning	
C. Appraisal	**Project Appraisal Manual**	**PAM**
	1. Environmental Impact Assessment and Audit	
	2. Social Impact Assessment	
	3. Traffic Impact Assessment	
	4. Road Safety Audits	
	5. Project Appraisal	
	6. Feasibility Studies	
D. Design	**Road Design Manual**	**RDM**
	1. Geometric Design	
	2. Hydrology and Drainage Design	
	3. Materials and Pavement Design for New Roads	
	4. Bridges and Retaining Structures Design	
	5. Pavement Maintenance, Rehabilitation and Overlay Design	
	6. Traffic Control Facilities and Communication Systems Design	
	7. Road Lighting Design	
E. Contracts	**Works and Services Contracts Manual**	**WSCM**
	1. Forms of contracts	
	2. Standard Specification for Road and Bridge Construction	
	3. Bills of Quantities	
	4. Standard/Typical Drawings	
F. Construction	**Road Construction Manual**	**RCM**
	1. Construction Management	
	2. Project Management	
	3. Site Supervision	
	4. Quality Assurance	
	5. Quality Control	

This table continues onto the next page...

Project Cycle Stage	Manual: Volume or Part/Chapter	Code
G. Maintenance	**Road Asset Management Manual**	**RAAM**
	1. Maintenance Management	
	2. General Maintenance	
	3. Pavement Maintenance	
	4. Bridges and Structures Maintenance	
H. Operations	**Road Operation Manual**	**ROM**
	1. Traffic Management	
	2. Vehicle Load Control	
	3. Emergency Services	
	4. Tolling	
I. Monitoring & Evaluation	**Road Design Manual**	**MEM**
	1. Performance Monitoring Manual	
	2. Technical Audits	
	3. Poverty, Gender Equality and Social Inclusion Monitoring	

This Volume 3, Part 4 – Flexible Pavement Design is part of the Roads Design Manual made up of a series of volumes and shown below:

Table 1.1 Road Design Manual (RDM) Coding Structure

Vol.	Manual Title	Part Name	Code
1	**Road Design Manual: Vol. 1** Geometric Design	**Part 1** - Topographic Survey	RDM 1.1
		Part 2 – Traffic Surveys	RDM 1.2
		Part 3 – Geometric Design of Highways, Rural and Urban Roads	RDM 1.3
2	**Road Design Manual: Vol. 2** Hydrology & Drainage Design	**Part 1** – Hydrological Surveys	RDM 2.1
		Part 2 – Drainage Design	RDM 2.2
3	**Road Design Manual: Vol. 3** Materials & Pavement Design for New Roads	**Part 1** – Ground Investigations and Material Prospecting	RDM 3.1
		Part 2 – Materials Field and Laboratory Testing	RDM 3.2
		Part 3 – Pavement Foundation and Materials Design	RDM 3.3
		Part 4 – Flexible Pavement Design	RDM 3.4
		Part 5 – Rigid Pavement Design	RDM 3.5
4	**Road Design Manual: Vol. 4** Bridges & Retaining Structures Design	**Part 1** – Geotechnical Investigation and Design	RDM 4.1
		Part 2 – Bridge & Culvert Design	RDM 4.2
		Part 3 – Retaining Structures Design	RDM 4.3
		Part 4 – Reinforced Fill Structures	RDM 4.4
		Part 5 – Bridges and Structures Condition Survey	RDM 4.5
		Part 6 – Bridge Maintenance Design	RDM 4.6
5	**Road Design Manual: Vol. 5** Pavement Maintenance, Rehabilitation & Overlay Design	**Part 1** – Pavement Condition Survey	RDM 5.1
		Part 2 – Pavement Maintenance, Rehabilitation and Overlay Design	RDM 5.2
6	**Road Design Manual: Vol. 6** Traffic Control Facilities & Communication Systems Design	**Part 1** – Road Marking	RDM 6.1
		Part 2 – Traffic Signs	RDM 6.2
		Part 3 – Traffic Signals and Communication System	RDM 6.3
		Part 4 – Other Traffic Control Devices	RDM 6.4
7	**Road Design Manual: Vol. 7** Road Lighting Design	**Part 1** – Grid-connected Road Lighting	RDM 7.1
		Part 2 – Solar Road Lighting	RDM 7.2

This Manual must be applied sensibly and flexibly in conjunction with the skill and judgement of the Design Engineer. Compliance with the guidance given in the Manual does not relieve the Design Engineer of the responsibility for establishing that their design is suitable, appropriate, safe and adequate for the purpose stated in the project requirements.

1.2 Objective of this Part

The main objective of this Part of Volume 3 is to provide technically suitable and economically justifiable options for the structural design of flexible pavements. The options selected must be suitable for the local conditions considering the availability of materials, technology, employment creation, health and safety, and efficiency of construction.

The options provided in this part may be adjusted by the designer followed by seeking the necessary approvals from the Chief Engineer (Materials).

1.3 Scope of this Part

This Part of Volume 3 provides recommendations for the structural design of flexible pavements in Kenya. The definition of a flexible pavement is simply a pavement that does not include a layer of high-strength concrete (unconfined compressive strength greater than 15 MPa). Thus, flexible pavements include pavements with unbound granular aggregate layers and pavements with aggregate layers that are bound together with bitumen. It also includes pavements that may contain layers of aggregate that are bound together (or stabilised) with hydraulic binders such as cement.

Gravel or unpaved roads are also a form of flexible construction. Their design is similar to that of other flexible structures but the gravel itself wears away, depending on traffic, rainfall and terrain, hence additional material is required to make sure that the gravel is always thick enough to limit the compressive strain in the subgrade to prevent excessive permanent deformation at the surface of the road. The design of gravel roads is also covered in this manual.

A chapter on the design of low-volume sealed roads is also included in this Part. A selection of these structures may also be used for the construction of non-motorised traffic lanes.

1.4 Organisation of this Part

The design of a road requires decisions concerning several engineering factors; the most important of which are the design traffic, the climatic factors expected throughout the design period, and the materials available. This manual starts off from the point where traffic and axle load surveys have already been undertaken (see RDM Volume 1 Part 2), the road alignment already surveyed, and materials prospected (RDM Volume 3 Part 1), materials options understood (see RDM Volume 3 Part 2 and Part 3), and the foundation options determined (see RDM Volume 3 Part 3).

- Chapter 2 summarises the key design considerations that a designer should take into account.
- Chapter 3 discusses the principles of the pavement design method used in this manual.
- Chapter 4 presents a selection of common pavement structure combinations suitable for different design traffic levels.
- Chapter 5 presents key principles and catalogues suitable for low-volume roads and non-motorised traffic lanes in urban areas.
- Chapter 6 presents the design of unpaved roads.
- Chapter 7 presents a very important aspect of pavement performance – that is how to enhance pavement drainage at the design stage.

Pavement surface drainage is addressed in RDM Volume 2.

1.5 Design Process

Road pavements are designed to limit the vertical strain imposed at the subgrade level as a result of traffic that is travelling on the pavement surface thus preventing significant deformations of the subgrade. The pavement spreads the concentrated loads of the vehicle wheels over a sufficiently large area at the subgrade level. At the same time, the pavement materials themselves should not deteriorate to any serious extent within a specified period.

However, road pavements will inevitably deteriorate with time and traffic, therefore, the goal of pavement design is to limit, during the period considered, the deterioration which affects the riding quality of the road, such as rutting, cracking, potholes. and other such surface distresses, to acceptable levels.

At the end of the design period, a strengthening overlay would normally be required but other remedial treatments, such as major rehabilitation or reconstruction, may be needed (please refer to RDM Volume 5 - Pavement Rehabilitation and Overlay Design). The design method aims at producing a pavement which will reach a relatively low level of deterioration at the end of the design period, assuming that routine and periodic maintenance are performed during that period.

An acceptable ride quality depends on a match between what the users expect and what the highway authority (and hence the government) is prepared to provide.

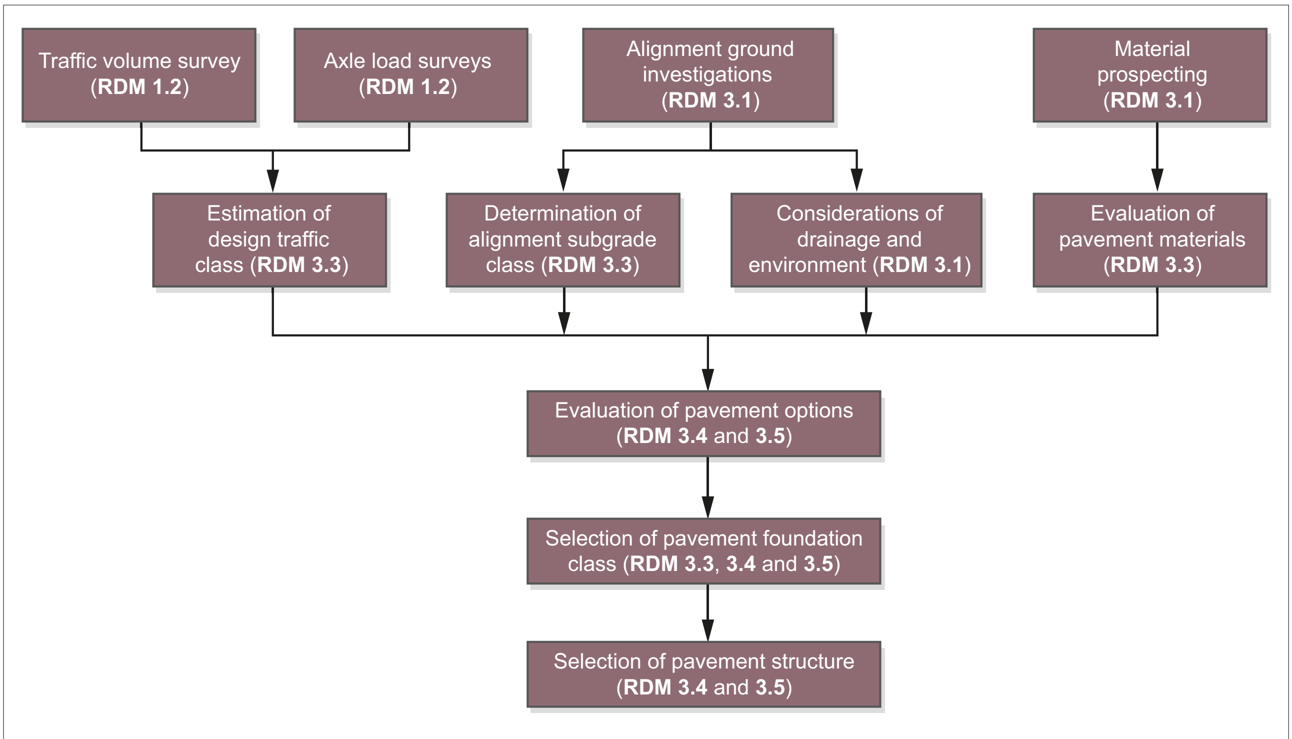
For roads with high traffic levels designed with high geometric standards (and consequently higher vehicle speeds), the pavement design standards are set higher than that of secondary and tertiary roads to limit the extent, severity, and frequency of distress. These differences are implicitly considered in the design, although in broad terms rather than in precise, measurable economic terms.

The designer may undertake the pavement design using the chapters in any combination suitable to achieve a robust design. It is expected that the designer should present several design options and discuss them with the relevant roads authority before a final choice is made.

Pavement for traffic greater than 150 MCESA should be considered for performance design from the foundation up to the surfacing.

The pavement design process discussed in this manual is presented in Figure 1.1.

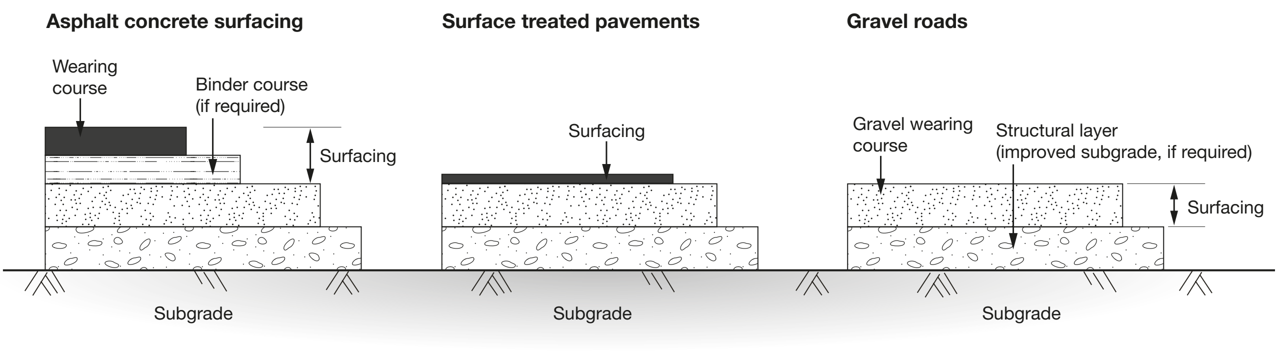
Figure 1.1 The Design Process



1.6 Pavement Layers Terminologies

Figure 1.2 and Figure 1.3 illustrate the terms used in describing the pavement and cross-section components. Figure 1.4 and Figure 1.5 present rural and urban cross-section terminology related to pavement design.

Figure 1.2 Pavement Layer Terminology

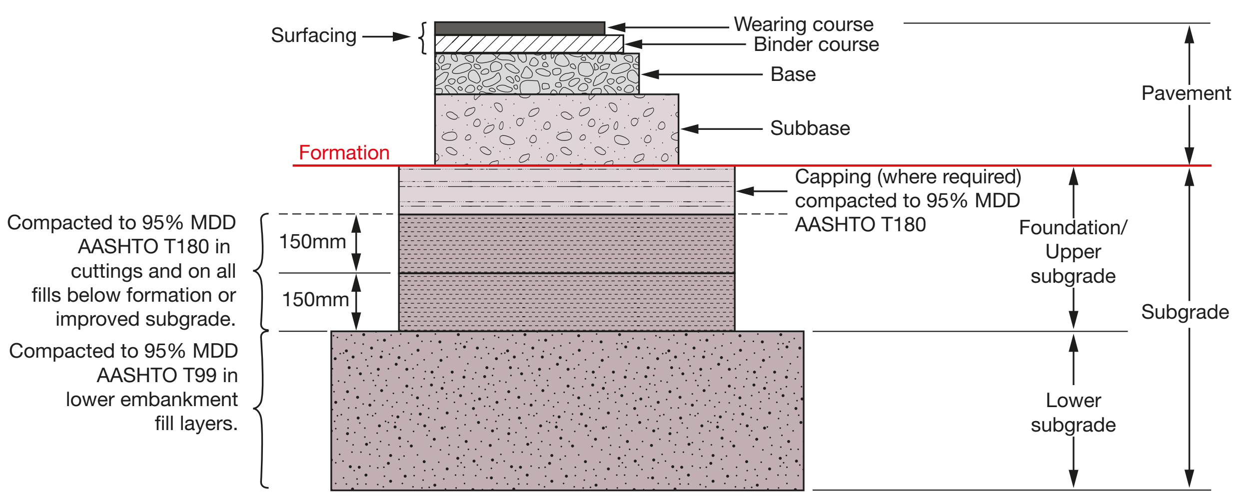


Subgrade is all the material below the pavement and may include in-situ material, fill and capping (improved subgrade). For assessing any section of subgrade, the average should be at least equal to the median for the category selected, and no CBR value should fall below the lowest value in the range. For design purposes, the following subgrade classes (Table 1.1) are recognised:

Table 1.2 Subgrade Classes

Subgrade Class	CBR at 100% MDD (AASHTO T99) and 4 days soak (%)		Surface Modulus (MPa)
	Range (%)	Median (%)	
S1	2 – 5	3.5	40
S2	5 – 10	7.5	65
S3	7 – 13	10	75
S4	10 – 18	14	95
S5	15 – 30	22.5	130
S6	30 – 60	45	200

Figure 1.3 Pavement Terminology



Formation is the surface of the ground, in its final shape, upon which the pavement structure, consisting of sub-base, base and surfacing is constructed.

Foundation is the upper subgrade below the formation. Where no capping (improved subgrade) is provided, it is the upper 300 mm of the subgrade below the formation. Where a capping layer is provided, the foundation shall be defined as the combination of the top 300 mm of fill or cutting and all the capping layers provided.

Improved Subgrade or Capping is a layer of selected fill material, the top of which is at formation level, placed where the natural in-situ or fill material is unsuitable for the direct support of the pavement.

Sub-base is the layer constructed on the subgrade below the base either for the purpose of providing support to the base, and additionally protecting the subgrade. It may be composed of natural gravel, graded crushed stone, macadam, hand-packed stone, hydraulically improved granular materials, hydraulically modified stone, hydraulically bound stone, and bitumen stabilised material.

Base is a layer of material usually constituting the uppermost structural element of a pavement and on which the surfacing may be placed. It may be composed of natural gravel, graded crushed stone, macadam, hand-packed stone, hydraulically improved granular materials, hydraulically modified stone, hydraulically bound stone, bitumen stabilised material, or various forms of asphalt.

Surfacing is the uppermost pavement layer which provides the riding surface for vehicles. It will normally consist of one of the following: surface dressing, sand asphalt or asphalt concrete.

Figure 1.4 Rural Cross-section Terminology

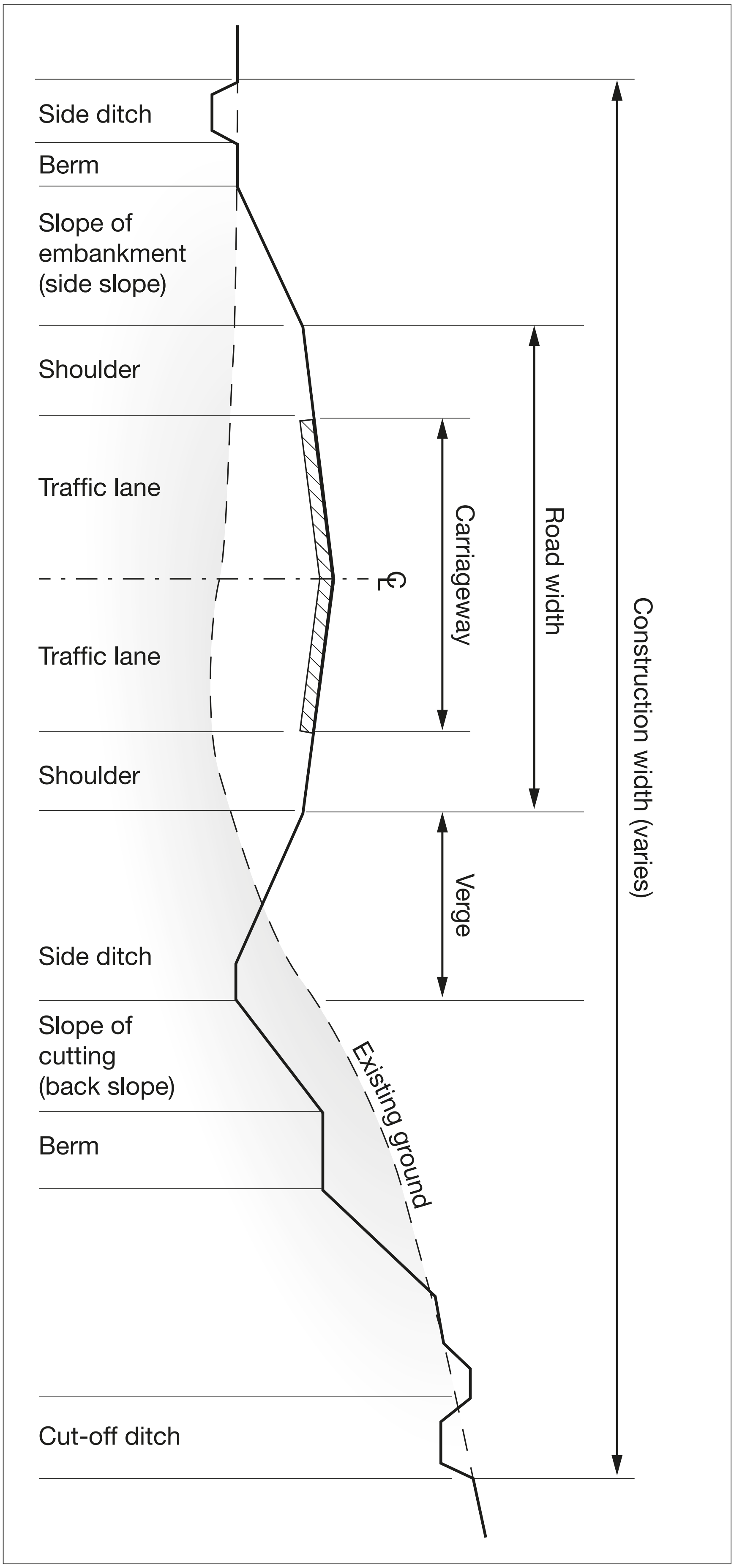
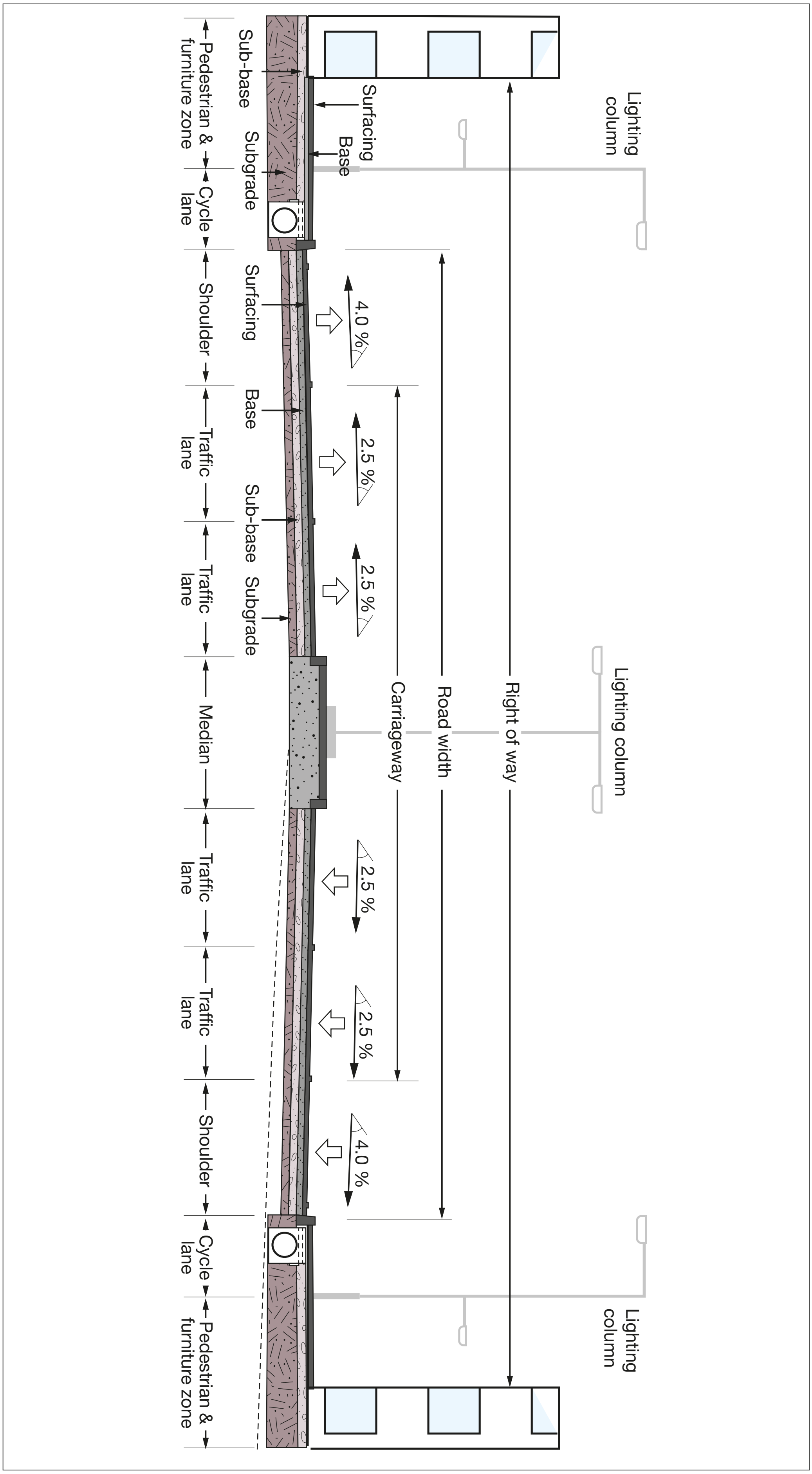


Figure 1.5 Urban Cross-section Terminology



2 Pavement Design Considerations

2.1 General

There are many aspects to consider in the design process before the actual pavement design can be performed. The following key aspects should be considered:

1. Road category.
2. Design period.
3. Design traffic and loading characteristics.
4. The minimum foundation class.
5. Materials characteristics.
6. Stage Construction and lifecycle considerations.
7. Pavement type selection.
8. Minimising base and surfacing thickness.
9. Climate and geology.
10. Practical and experimental considerations.

The following sections discuss these considerations.

2.2 Road Category

Depending on the road category and the level of importance, the level of reliability used in the development of the catalogues for Kenya differs. For high-volume roads, the subgrade failure criteria used is the Shell 50% whereas for low-volume roads, the criterion used is the Kenya Subgrade failure criterion which is essentially a shift factor of about 4.8 applied to the Shell 50% criterion. Therefore, the same level of reliability is given to all roads designed to carry traffic of greater than 1 MCESA. Additionally, trunk and primary roads should be designed with superior materials such as DBM and other hydraulically bound materials that may not be economically justified for low-volume roads. Conversely, weathered, and unbound materials may not be technically suitable for use in heavily trafficked roads. The selection of suitable pavement structures is discussed and presented in Chapter 4.

2.3 Choice Between Flexible and Rigid Pavements

In pavement design, it is prudent to produce design options for both before a final evaluation and selection are made. In some cases, for the same project, it is suitable to have sections that are constructed with flexible pavements and others with rigid pavements, for example steep gradients. Flexible pavements are generally applicable in most circumstances, but rigid pavements are better suited in the following circumstances:

1. On roads carrying heavy and overloaded vehicles travelling at slow speed (e.g. climbing lanes), and with many turning movements such as hairpin bends (curve radius less than 30 m) and junctions, and on steep gradients (greater than 12%).
2. Where there are comparatively less-experienced personnel in the construction of flexible pavements. Rigid pavements can also be constructed with simpler equipment and plant. This is particularly useful for low-volume rural roads.
3. Availability of materials will largely dictate choice. Where cement is more readily available than bitumen, rigid pavements are preferred, and vice versa.
4. Where it is unlikely that maintenance funds will be available in the foreseeable future, such as for low-volume roads.

2.4 Design Period

As previously mentioned, the concept of design period should not be confused with that of pavement life.

Each of the pavement structures proposed has been designed to carry a certain cumulative traffic. When the pavement has carried the expected traffic, it will need to be strengthened so that it can continue to carry traffic for a further period. The need for, and design of, strengthening will be determined as indicated in Volume 5. In this respect, it is necessary that paved roads be continuously surveyed, so that strengthening can be planned and constructed in time, which is to say before extensive deterioration has occurred.

Suitable design periods are presented in Table 2.1. It is assumed that, during the design period, only ordinary maintenance will be carried out; this will comprise shoulder and drainage system maintenance, erosion and vegetation control, localised patching, and periodic resealing. This maintenance is, however, essential, and its neglect will seriously affect the pavement performance. It should be noted that using Table 2.1 is an iterative process in which a design period is selected and used to compute the design traffic. The design traffic is then checked as to which design traffic category it belongs to. The DESA in Table 2.2 provides a good starting point for estimating the design traffic category. In each iteration, the design period is varied until the design period and the design traffic both correspond to the same design traffic category.

The values in Table 2.1 do not take into account designs for long-life (perpetual life) pavements. The design of these pavements is not based on design period, but rather on limiting strains at the bottom of bound layers (bituminous or hydraulic) and on top of the subgrade. The maximum permissible strain at the bottom of the bituminous layer is 70 microstrain, and at the top of the subgrade is 200 microstrain. Bus-rapid-transit (BRT) lanes should be designed for a period of 40 years or until the pavement analysis shows that a long-life pavement has been achieved. Low and high levels of service refer to the perceived importance of the roads in question. This is determined by the relevant authority for the project road. For example, Class S, A, B, and C roads (see RDM 1.3) would require a high level of service whereas other roads would fall into a low level of service.

Table 2.1 Selection of Pavement Design Period

Design Traffic	Level of Service	
	Low	High
Low	10 – 15 years	15 years
Medium and Heavy Traffic	10 – 20 years	15 – 20 years
Very Heavy Traffic	20 years	30 years
Urban Pavements	15 - 20 years	40 years or long-life pavement
Rigid Pavements	–	40 years

2.5 Design Traffic and Loading Characteristics

Traffic flow and axle-load surveys have shown that traffic classes given in Table 2.2 satisfactorily account for all traffic categories likely to be carried by the various classes of roads in Kenya.

During axle load surveys, axles heavier than the legal limit (see RDM Volume 1 Part 2) or 13 tonnes may be recorded. In this case, a sensitivity analysis must be conducted in the computation of the load equivalency factor as discussed in RDM 3.3.

Traffic loading characteristics should also be considered in the design and selection of appropriate pavement types.

Table 2.2 Design Traffic Classes

Design Traffic Class	Cumulative Equivalent Standard Axles	Design Traffic Loading (Million CESA)	Traffic Load Category	ESA/day (DESA): in Year one[2]	
				Min.	Max.
TC0.025	< 25,000	0.025	Low	0.0	0.2
TC0.10	25,000 - 100,000	0.10		0.2	8
TC0.25	100,000 – 250,000	0.25		8	21
TC0.50	250,000 – 500,000	0.50		21	41
TC1	500,000 – 1 million	1		41	83
TC3	1 million – 3 million	3	Medium	83	249
TC10	3 million – 10 million	10		249	829
TC17	10 million – 17 million	17	Heavy	829	1409
TC30	17 million – 30 million	30		1409	2486
TC50	30 million – 50 million	50		2486	4143
TC80	50 million – 80 million	80	Very Heavy	4143	6629
TC150	80 million – 150 million	150		6629	12428
TC150+[1]	> 150 million	Based on specific value		>12428	

Notes:
1. *The "150+" in TC150+ class requires specific considerations and performance design based on the actual value of design traffic determined. In preparing their reports, the designer should then refer to the class based on the specific design traffic determined. For example, if the traffic determined is 160 MCESA, the design class will be TC160.*

2. *The DESA in the First year after opening to traffic (Year one) computed from the design traffic loading taking into account a constant growth rate of 5% over a design period of 20 years.*

2.6 Foundation Design

Pavement foundation design is comprehensively covered in RDM Volume 3 Part 3. The foundation classes selected for design and the applicable design traffic classes are presented in Table 2.3.

Table 2.3 Pavement Foundation Classes and Applicability

Foundation Class	Minimum Foundation Requirement		Equivalent Subgrade Class	Applicable Design Traffic	
	Surface Modulus (MPa)	Equivalent Minimum CBR (%)		Traffic Load Category	Traffic Class
F1	75	10	S3	Low	TC0.025 – TC1
F1	75	10	S3	Medium	TC3 – TC10
F2	95	14	S4	Heavy	TC17 – TC30
F3	130	23	S5	Heavy	TC50
F4	200	45	S6	Very Heavy	TC80 and TC150+
F5	400	140	N/A		

Capping materials may be required on top of the subgrade to achieve the design foundation classes. The minimum thickness of each type of capping material required to improve the subgrade to a higher class is shown in Table 2.4. The minimum thicknesses have been calculated considering the respective elastic modulus of each class of soil. It should be noted that the foundation layers are additive. For example, to improve and S2 subgrade to a S6 (F4) equivalent, it can first be improved to a S4 (F2) by adding 175 mm of G14, followed by 150 mm of G45 into a S6 (F4).

In special circumstances, such as due to scarcity of natural materials, higher quality materials such as crushed rock and hydraulically modified or bound materials may be used as capping. Due to the high cost this would present, their use must be fully justified by the designer.

Table 2.4 Minimum Capping Thicknesses for Improved Subgrade

Native Subgrade Class	Improved Subgrade/Capping		New Subgrade Class	Foundation Class
	Material	Minimum Thickness (mm)		
S1	G8	375	S2	N/A
	G10	300	S2	N/A
	G10	400	S3	F1
	G14	250	S2	N/A
	G14	350	S3	F1
	G14	425	S4	F2
S2	G10	150	S3	F1
	G14	150	S3	F1
	G14	175	S4	F2
S3	G14	150	S4	F2
	G23	150	S4	F2
	G45	150	S5	F3
	G45	250	S6	F4
	HIG100	250	S6	F4
	BSM50	275	S6	F4
S4	G23	150	S5	F3
	G45	200	S6	F4
	HIG100	200	S6	F4
	BSM50	225	S6	F4
S5	G45	150	S6	F4
	GCS/BSM50	275	S6	F4
	HIG160/HMS1	125	S6	F4
	HIG160	250	N/A	F5
	HMS1	225	N/A	F5
S6	GCS	250	N/A	F5
	HIG160	200	N/A	F5
	HMS1	175	N/A	F5
	BSM100	150	N/A	F5

***Notes:** For concrete pavements, only F4 and F5 foundations should be used, and the top-most capping layer must be HIG160, HMS1, BSM100 or higher quality BOUND material. To achieve this for S1 and S2 subgrades, they must first be improved to S3 (F1) or S5 (F3) subgrade class before final improvement to F4 and F5.*

2.7 Materials Selection

No pavement structure can be designed independently of the characteristics of the pavement materials. Indeed, every material has a different behaviour which is largely influenced by the characteristics of the other pavement layers. The selection of pavement materials is a critical element in the design, construction, and maintenance of pavements if performance is to be optimised and whole-of-life costs minimised. As a general rule, the use of locally available materials should be the first choice. If these materials do not meet the specification requirements, then stabilisation or modification with hydraulic or bituminous binders should be considered. As a final resort, the importation of superior material is then considered.

The materials can be obtained from within the road reserve, from material borrow sites and quarries, bound by bituminous or hydraulic binders, and produced using either stationary or moving production plants. These include:

1. Granular materials (clayey and silty sands and gravels).
2. Crushed stone materials and screened rock.
3. Hydraulically and Lime improved materials.
4. Hydraulically bound materials.
5. Bitumen stabilised materials (BSMs).
6. Bitumen bound materials.
7. Primes, tack coats and precoating cut-back bitumen, emulsions, and oils fluids.
8. Bituminous seals.

Special attention should be paid to the use of recycled asphalt pavements (RAP) which at this time should be confined to improved subgrades only.

For base and surfacing materials, the selection of materials is largely governed by pavement structure combinations that have been proven to work together. These have been discussed in Chapter 2.9. High modulus asphalt (EME) and stone mastic asphalt (SMA) are relatively expensive options and should be considered only under special circumstances.

The choice of the pavement materials and, hence, of the pavement structure, will largely depend on the types and the respective costs of the natural materials locally available.

Details on materials characteristics are discussed in detail in RDM Volume 3 Part 3.

Life-cycle Analysis

The purpose of pavement design is to produce several design options that are then evaluated before a final selection. Options using materials within the project area and surroundings are evaluated for their life-cycle costs, long-term performance, and environmental impacts. A suitable tool for this evaluation is the HDM-4 software and other similar tools. In line with this, the carbon footprint in relation to the extraction, construction, and rehabilitation of the materials should be considered. The World Bank offer estimates of greenhouse gas emissions associated with the use of various materials. These estimates are updated from time to time and therefore the latest values should be used. For vulnerable sections, the use of climate-resilient options as discussed in Chapter 2.11 should be undertaken. After undertaking these evaluations, the most economical option that emits the lowest greenhouse gas emissions is recommended.

Pavements for Urban Roads

The key principles in the selection of materials options for urban pavements are minimising disruption to road users in case of construction, maintenance, and rehabilitation; and minimising damage to the pavement due to maintaining or replacing utility lines. In this regard options that involve the use of surface dressing or hydraulically bound stone are not encouraged due to the lengthy curing periods. Surface dressing is inconvenient due to damage caused by several turning movements, long-duration road closures or restricted vehicle speeds to enable stone embedment, and the risk of flying stones displaced by traffic. The use of bitumen stabilised, and bitumen-bound materials are preferred over hydraulic binders. Asphalt concrete or stone mastic asphalt are preferred surfacing materials.

Low-volume Roads

In the selection of materials for low-volume roads, five major considerations must be borne in mind:

1. Concrete pavements may be preferable (if it has been shown to be economically viable) given that concrete pavements do not require frequent maintenance, require comparatively less-skilled personnel and equipment to construct, and are generally climate resilient.
2. The use of locally available materials so as to minimise materials haulage costs. In cases where stabilisation or improvement of the properties of locally available materials is required, lime should be considered as a first choice.
3. The creation of employment through labour-based approaches such as the use of hand-packed stone in the pavement structure. The use of cobblestone surfacing, particularly in urban areas falls in line with this principle.
4. The occasional passage of very heavily loaded axles that could cause instantaneous deformation of the pavement. When such axles are presumed likely to occur, the base should be of graded crushed stone, crushed stone gravel or crusher-run, or hand-packed stone.
5. The surfacing should be any of the surface treatments discussed in section RDM 3.3 or, if asphalt concrete is to be used, then it should be AC Type I, followed by a surface dressing protection. This minimises rutting caused by the occasional passage of very heavily loaded axles.

2.8 Stage Construction

The challenge is whether it is best to initially design a strong pavement, which will last throughout the design period without the need for strengthening, or to design a weaker, and therefore more economical, pavement with the aim of strengthening it at some intermediate stage to enable it to last the remainder of the design period.

Stage construction offers economic advantages and initial design periods should not exceed 15 years, even if much longer overall lives are anticipated. Stage construction provides an opportunity to choose the structural characteristics of the second stage in light of actual conditions, which may differ substantially from those originally foreseen. Lifecycle costing and economic analysis of the alternatives should be undertaken using software such as HDM-4 of similar.

Stage construction is not recommended for very heavy traffic (TC80 or higher), as the risks of premature deterioration are unacceptable for such important roads. Moreover, it is difficult and costly to manage traffic during strengthening operations.

Stage construction may be considered for medium and light traffic. However, the pavements proposed for light traffic (Classes TC3 and TC1) are generally minimum or near-minimum pavements and it is therefore impracticable to reduce them further. Therefore, stage construction may be considered almost exclusively confined to pavements carrying medium traffic (TC10 to TC50) when normal construction includes 50 mm of premix as surfacing (see Standard Pavement Structures).

If selected, stage construction should then consist of:

1. Construction of the full road base thickness, and application of double surface dressing.
2. An overlay of 30 – 50 mm of premix after about 5 years or a suitable value determined by design. It is important that this overlay is allowed for in the design.

2.9 Pavement Type Selection and Safety Factor

It is apparent that the heavier the traffic, the more costly the pavement and hence the higher the safeguard against failure should be.

For example, under heavy traffic (TC80 or higher), it is unwise to place sophisticated (and expensive) materials, such as hydraulically bound stone or dense bitumen macadam, directly on heterogeneous and deformable natural materials. The selection of suitable pavement structures is discussed and presented in Chapter 4.

Pavement types incorporating asphalt concrete surfacing laid on hydraulically bound or modified materials road base require careful consideration before their use. The site should have access to sufficient water for curing the base, special attention is required to ensure that the specifications of the granular material before treatment are complied with, and the curing procedure must be strictly adhered to. This is especially important in hot and windy conditions. This minimises the development of shrinkage cracking and hence reflection cracking. Further to that pre-treatment of the granular material with lime may be required to bring the plasticity index to within specification limits before further cement stabilisation. In the absence of this, other standard pavement types should be considered.

2.10 Minimising Base and Surfacing Thicknesses

The thicknesses of base and surfacing, which are made of the most expensive materials, should be kept constant and as low as possible, for each class of traffic. However, they should not be less than the pavement layer thicknesses presented in Table 3.6.

2.11 Climate and Geology

Climate affects the choice of materials for use in the pavement layers, particularly the choice of bitumen grades and for granular materials, the allowable plasticity.

Likewise, the geology at the project site and vicinity dictates the type of rocks available and their level of weathering. Consequently, the level of weathering influences the choice between using materials neat or with modifications, and which pavement layers the materials can be used in.

In light of climate change events, it is important that the designer should identify sections of the road that are vulnerable and select materials appropriately. The measures could include:

1. Provision of a bituminous surface dressing on asphalt pavements to mitigate increased oxidation rates.
2. Use of polymer modified asphalts.
3. Use of mechanically stabilised natural granular materials using crushed stone aggregates to reduce plasticity and hence susceptibility to moisture variations.
4. Use of hydraulically improved granular materials that are less susceptible to moisture.
5. Use of low plasticity materials to minimise the loss in strength when wet.
6. Use of geo-grids to enhance the strength of granular materials, and geo-membranes to cut off capillary rise.

Climate and geological considerations are discussed in detail in RDM Volume 3 Part 3.

3 The Structural Design Method

3.1 General

This Chapter discusses the principles to be considered in the structural design of pavements in accordance with this manual. It is the same principles that were used in the development of the standard pavement structure catalogues presented in Chapter 4. A designer may use these principles to undertake the structural design of flexible pavements to accommodate new materials or other combinations of existing materials.

3.2 Practical and Experimental Considerations

3.2.1 Use of Flexible Pavements

Flexible pavements are defined as pavements composed of a case made of fairly deformable material, such as natural gravel, graded crushed stone or hydraulically improved material with a thin bituminous surfacing (surface dressing or not more than 50 mm of premix).

Experience has shown that such flexible pavements are perfectly suitable for light and medium traffic with up to 10 million standard axles, provided that this does not include a substantial proportion of overloaded axles.

For heavy traffic, it is necessary to construct a semi-rigid pavement with a base of bound material, such as dense bitumen macadam, hydraulically bound stone, hydraulically modified stone, and/or a thick bituminous surfacing (high stability asphalt concrete – AC Type I).

3.2.2 Influence of Subgrade

Compressive Strain Criterion

It has been confirmed that the compressive strain on the surface of the subgrade is the criterion that governs the total cover required in the case of a flexible pavement. If the compressive strain is excessive, permanent deformation will occur in the subgrade and this will cause deformation at the pavement surface.

The relationships between the maximum permissible compressive strain and the cumulative number of standard axles are provided in Chapter 3.4.2

In the case of rigid and semi-rigid pavements, the deciding criterion is generally not the compressive strain in the subgrade, but the horizontal tensile strain in the upper layers.

Temporary Minimum Bearing Strength

It has been assumed that, in wet areas, the subgrade may be soaked locally for very short periods.

It has been determined that, for the pavement structures proposed in this Manual, one application of the maximum probable load will not cause any permanent deformation even if the subgrade becomes saturated. The maximum probable axle loads (at the probability of 95%) considered are 130 KN for Traffic Classes TC50 or higher and 100 KN for lower classes.

(It may be noted that much higher actual axle loads have been measured on roads designed for these traffic classes).

This justifies the use of CBRs measured after 4 days' soak, as the various classes of soil can be accurately differentiated based on their soaked CBR.

Subgrade Modulus

The design system incorporates the dynamic elastic modulus of the subgrade as one of the principal design parameters.

The modulus used should correspond to the moisture content that the subgrade soil will generally be subjected to under the pavement. Conversely, the worst-case moisture condition should be considered to account for climate change effects (extended soaking or saturation of the subgrade).

The subgrade moduli and Poisson's ratio of the most common types of soils at their equilibrium moisture contents have been determined by direct measurements (plate bearing tests) and the values adopted are tabulated below (Table 3.1):

Table 3.1 Subgrade Moduli and Poisson's Ratio

Soil Class	Modulus (MPa)	Poisson's Ratio
S1	40	0.45
S2	50	0.45
S3	75	0.45
S4	95	0.45
S5	130	0.45
S6	200	0.35

3.2.3 The Behaviour of Pavement Materials

Unbound Materials

The effective dynamic modulus of unbound base and sub-base layers depends to some extent on their thickness and the modulus of their support. The unbound pavement materials moduli and Poisson's ratio are provided in Table 3.2 and Table 3.3.

In addition, the resistance to attrition of each material has been evaluated and the consequent traffic limitations are given in the Pavement Materials Charts in Chapter 4.

Bound Materials

When bound materials are used, the deciding criterion is usually the horizontal tensile strain at the bottom of the base or premix surfacing. If this strain is excessive, the layer will crack.

The fatigue characteristics of bound materials have been estimated based on the measured characteristics of the material and from theoretical considerations. The bound pavement materials moduli and Poisson's ratio are provided in Table 3.3. The permissible tensile strain design equation is provided in Chapter 3.3 for each type of bound material considered.

This has permitted the determination of the minimum thickness required for each type of bound material under each traffic class.

Bituminous Mixes

Bituminous mixes are visco-elastic materials, and their dynamic moduli therefore depend on the rate of application of the load and on the temperature, the adopted values of which are as follows:

- Loading time: 0.02 seconds.

This loading time is representative of the range of loading times occurring in practice equivalent to a vehicle speed of about 60 km/h.

- Weighted mean annual air temperature using the Shell Design Method at 18 °C.

This temperature is that calculated for the Nairobi area.

In addition, for structural design, bituminous surfacing is considered as a single layer, even if it is actually made up of several layers. The surfacing pavement materials moduli and Poisson's ratio are provided in Table 3.4.

Table 3.2 Capping and Sub-base Materials Moduli and Poisson's Ratio

Material	Elastic Modulus (MPa)	Poisson's Ratio
Natural material (G25)	130	0.45
Natural material (G30)	150	0.45
Natural material (G45)	200	0.35
Hydraulically improved granular material (HIG 50)	225	0.35
Hydraulically improved granular material (HIG60)	300	0.35
Graded crushed stone on subgrade class S3 and S4	300	0.35
Graded crushed stone on subgrade class S5: 400 MPa	400	0.35
Graded crushed stone on subgrade class S6 and above	500	0.35
Bitumen Stabilised Material (BSM50)	400	0.35
Bitumen Stabilised Material (BSM100)	1500	0.35

Table 3.3 Sub-base and Base Materials Moduli and Poisson's Ratio

Material	Elastic Modulus (MPa)	Poisson's Ratio
Natural gravel (G45)	200	0.35
Natural gravel (G80)	300	0.35
Hydraulically improved granular material (HIG50)	225	0.35
Hydraulically improved granular material (HIG60)	300	0.35
Hydraulically improved granular material (HIG100)	450	0.30
Hydraulically improved granular material (HIG160)	1000	0.25
Hydraulically modified stone (HMS1)	1300	0.25
Hydraulically bound stone (HBS3)	4000	0.25
Hydraulically bound stone (HBS6)	7000	0.25
Hydraulically bound stone (HBS9)	10000	0.20
Graded crushed stone	400	0.35
Dry Bound or Wet-bound Macadam	600	0.35
Hand Packed-Stone	350	0.35
Bitumen Stabilised Material (BSM50)	400	0.35
Bitumen Stabilised Material (BSM100)	1500	0.35
Bitumen Stabilised Material (BSM175)	2000	0.35
Sand bitumen mix	1000	0.35
Dense bitumen macadam (DBM)	5000	0.35
Superpave DBM	5000	0.35
EME	8000	0.30

Table 3.4 Surfacing Materials Moduli and Poisson's Ratio

Material	Elastic Modulus (MPa)	Poisson's Ratio
Asphalt Concrete Type I (High Stability)	4000	0.35
Superpave Asphalt Concrete	4000	0.35
Stone Mastic Asphalt	5000	0.35
Asphalt Concrete Type II (Flexible), Sand Asphalt and Gap Graded Asphalt	2500	0.35

It is known that rigid and semi-rigid pavement layers need adequate support. From empirical studies, materials whose moduli are less than 10% of the succeeding rigid or semi-rigid layer are unlikely to give that support. From consideration of the moduli tabulated earlier suitable support layers are tabulated below (Table 3.5).

Table 3.5 Suitable Support Layers

Rigid or Semi-rigid Layer	Suitable Support Layers
Hydraulically improved granular materials (HG100)	S5 Subgrade
	S6 Subgrade
	Gravel (G30 or higher)
	Hydraulically improved granular material (HIG50, HIG60)
Hydraulically improved granular materials (HIG160)	S5 Subgrade or natural gravel (G23)
	S6 Subgrade or natural gravel (G45)
	Gravel (G30 or higher)
	Hydraulically improved granular material (HIG50, HIG60, HIG100)
Hydraulically modified stone (HMS1)	S5 Subgrade
	S6 Subgrade
	Natural gravel (G30 or higher)
	Hydraulically improved granular material (HIG50, HIG60, HIG100, HIG160)
Hydraulically bound stone (HBS3)	Graded crushed stone (GCS-A to GCS-C)
	Hydraulically improved granular material (HIG100, HIG160) Hydraulically Modified Stone (HMS1)
Hydraulically Bound Stone (HBS6)	Hydraulically improved granular material (HIG160), Hydraulically modified stone (HMS1), Hydraulically bound stone (HBS3), Bitumen Stabilised materials (BSM100, BSM175)
Hydraulically Bound Stone (HBS9)	Hydraulically modified stone (HMS1), Hydraulically bound stone (HBS3, HBS6), Bitumen Stabilised materials (BSM100, BSM175)
Dense Bituminous Macadam	Hydraulically improved granular material (HIG160), Hydraulically modified stone (HMS1), Hydraulically bound stone (HBS3), Bitumen Stabilised materials (BSM100, BSM175), Graded crushed stone (GCS-A).
High modulus asphalt (Enrobé à module élevé [EME])	Hydraulically bound stone (HBS6, HBS9)
Asphalt Type I	Dense Bituminous Macadam
	Hydraulically bound stone (HBS3, HBS6, HBS9)
	Hydraulically modified stone (HMS1)
	Hydraulically improved granular material (HIG160)
	Graded crushed stone (GCS-A and GCS-B)
	Bitumen Stabilised Material
Asphalt Type II	Hydraulically improved granular material (HIG100, HIG160) Hydraulically Modified Stone (HMS1)
	Graded crushed stone (GCS-A and GCS-B)
	Bitumen Stabilised Material (BSM100, BSM175)
Sand Asphalt & Gap Graded Asphalt	Graded crushed stone (GCS-A)
	Bitumen Stabilised Material (BSM100, BSM175)
Stone Mastic Asphalt	Hydraulically bound stone (HBS6 or HBS9)
	Dense Bituminous Macadam
	Dry bound or Wet-bound Macadam
	Bitumen Stabilised Material (BSM100, BSM175)
	Sand bitumen mix
	Enrobé à module élevé (EME)

3.3 Procedure for Mechanistic Pavement Design

Mechanistic pavement design provides the designer with the capability of designing a broad range of pavement types, for a broad range of loading types and configurations.

The procedure for undertaking mechanistic design consists of:

1. Determination of design inputs (materials characteristics such as modulus and Poisson's ratio – see Chapter 3.1) and the design traffic value (see RDM Volume 1 Part 2).
2. Adjust materials characteristics for climatic factors if necessary (requires evidence of performance from previous studies).
3. Selecting a trial pavement with predetermined materials characteristics and layer thicknesses. A starting point can be the standard pavement structures in Chapter 4.
4. Analysing the trial pavement to determine the stresses and strains caused by the standard axles (single axle with dual tyres, and single axle with supersingle tyres). This is discussed in Chapter 3.4.3. Software such as ALIZE, KENPAVE, or Rubicon or other similar may be used for this purpose.
5. Application of the computed stresses and strains into the empirical performance equations (failure criteria for the subgrade and **each** material layer). The applicable equations for Kenya are presented in Chapter 3.4.2. This is undertaken to determine the maximum allowable repetitions of traffic that the trial pavement can carry to the point of failure. The maximum allowable traffic repetitions for the trial pavement are taken as lowest value obtained for any of the layers or subgrade of the trial pavement.
6. Comparing the computed maximum allowable traffic repetitions to failure (Step 5) with the design traffic (Step 1).
7. If the traffic in Step 5 is less than the design traffic (Step 1), then the trial pavement is not adequate to carry the design traffic loading. In this case, a new trial pavement is selected by either adjusting the pavement layer thicknesses or by substituting some or all of the pavement materials.
8. Steps 1 to 7 are repeated until a technically suitable pavement where the design traffic is just less than the maximum allowable traffic repetitions determined in Step 5.
9. Several technically suitable pavement options should be developed by the designer for further comparison and evaluation, and final selection.

3.4 Calculation of Stress, Strain, Deflection and Layer Thickness

3.4.1 Overall Design Approach

Mechanistic empirical design is undertaken using software due to the complexity of the calculations. The process involves the following main steps:

1. Decision of design inputs.
2. Calculation of critical strains and stresses.
3. Selection of the design pavement structure.

The computer software KENPAVE and Rubicon have been used to calculate the stresses, and strains deflections at the bottom of each bound layer, the vertical compressive stress, and strains in the surface of each layer including the subgrade, and the deflection at the surface of the pavement. They were used to design the thickness requirements presented in the standard pavement structures in Chapter 4 and Chapter 5. Both KENPAVE and Rubicon produce identical response values as the software ALIZE. Any of these three software and other similar software may be used in the design of pavements. The pavement models are as shown in Chapter 3.4.2.

3.4.2 Design Inputs

The following design inputs are required.

1. Determine available pavement materials.
2. Select a trial pavement structure with layer thicknesses and materials characteristics (moduli, and Poisson's ratio).
3. Select the asphalt failure criterion. The applicable ones for Kenya are as follows:
   a. For ACI (High stability asphalt/Superpave 4000 MPa) $\varepsilon_t = 4710(N)^{-0.202}$
   b. For ACII (Flexible asphalt 2500 MPa), $\varepsilon_t = 5855(N)^{-0.207}$
   c. For DBM (DBM/Superpave DBM 5000 MPa) or SMA, $\varepsilon_t = 6958(N)^{-0.250}$
   d. For Bitumen Sand Asphalt (1000 MPa), $\varepsilon_t = 5835(N)^{-0.193}$

   Where,
   N = The design traffic in equivalent standard axles.
   ε_t = The horizontal microstrain at the bottom of the bituminous layer.

   e. EME asphalt mixtures (8000 MPa)

$$N = F * \left(\frac{57500}{\mu\varepsilon \times S_{mix}^{0.36}} \right)^{5.5}$$

   Where,
   N = Allowable number of repetitions of the load-induced tensile strain.
   S_{mix} = Elastic modulus of mixture in MPa.
   με = Horizontal microstrain in the asphalt.
   N = Number of strain repetitions to failure.
   F = Calibration factor (1-4).

   f. Other bituminous mixtures,

$$N = F * \left(\frac{6918 \times (0.856 \times V_b + 1.08)}{\mu\varepsilon \times S_{mix}^{0.36}} \right)^{5}$$

   Where,
   V_b = Proportion of bitumen by volume in the mixture, as a %.
   S_{mix} = Elastic modulus of mixture in MPa.
   $\mu\varepsilon$ = Horizontal microstrain in the asphalt.
   N = Allowable number of repetitions of the load-induced tensile strain.
   F = Calibration factor (1-4).

4. Select the failure criterion for hydraulically bound or stabilised materials. The applicable ones for Kenya are as follows:
   a. For Hydraulically Bound Stone (HBS9) (10000 MPa), $\sigma_t = 4350(N)^{-0.117}$
   b. For Hydraulically Bound Stone (HBS3) (4000 MPa), $\sigma_t = 1700(N)^{-0.111}$

   Where,
   N = The design traffic in equivalent standard axles.
   σ_t = The horizontal stress at the bottom of the bound layer (measured in kPa).

   c. Other hydraulically modified or bound stone (e.g., HMS1 and HBS6), $N = (2^{10})*(e^{-0.011\sigma t})$

   Where:
   N = The design traffic in equivalent standard axles.
   σt = The horizontal stress at the bottom of the bound layer (measured in MPa).
   e = The natural constant whose value is 2.71828.

5. Select the subgrade failure criterion. The applicable ones for Kenya are as follows:
   a. For Low-Volume Sealed Roads, $\varepsilon_c = 41445(N)^{(-1/4)}$
   b. For all pavements designed to carry more than 1 MCESA, $\varepsilon_c = 28000(N)^{(-1/4)}$

   Where,
   N = the design traffic in equivalent standard axles.
   ε_c = the vertical microstrain at the top of the subgrade.
6. Using the design traffic determined in RDM Volume 3 Part 3, the values of critical strains and stresses are computed for each failure criterion.

3.4.3 Calculation of Critical Strains and Stresses

The critical strains are computed as follows:

1. Input the pavement models as shown in Figure 3.1 and Figure 3.2.
2. Using software, determine the critical strains at:
   a. Horizontal microstrain at the bottom of the bituminous, at the centre of the wheel load. For dual tyres this should be at the centre of the inner tyre.
   b. Horizontal stress at the at the bottom of the hydraulically bound layer, at either the centre of the wheel load, or at the centre of the dual wheel assembly for dual tyres – whichever is higher. For dual tyres this should be at the centre of the inner tyre.
   c. Vertical microstrain at the top of the in-situ and top of the capping (foundation system), at the centre of the dual wheel assembly for dual tyres. For single tyres this should be at the centre of the tyre.
3. Note that for critical projects, the computation of these stress and strains should be undertaken for a complete axle load group (tandems and tridem systems) of a representative vehicle for each traffic (vehicle) classes.
4. Using the design traffic as shown on 2.5, the maximum permissible values of critical strains and stresses are computed for each failure criterion in Chapter 3.4.2.
5. The computed strains are then compared with those determined through the software model.
6. Iterations of various pavement structures (layer thicknesses and materials) are undertaken until the strains and stresses in step 8 are just less than those determined in step 7. This involves increasing or decreasing the layer thickness or materials qualities.
7. The pavement structure at which step 9 is achieved is an option for the project pavement. Several options should be developed for discussion and final selection.
8. The final choice of structure depends on constructability, availability of materials, climatic factors, carbon footprints, and the economic viability.

Figure 3.1 Pavement Model for Dual Tyre Configuration

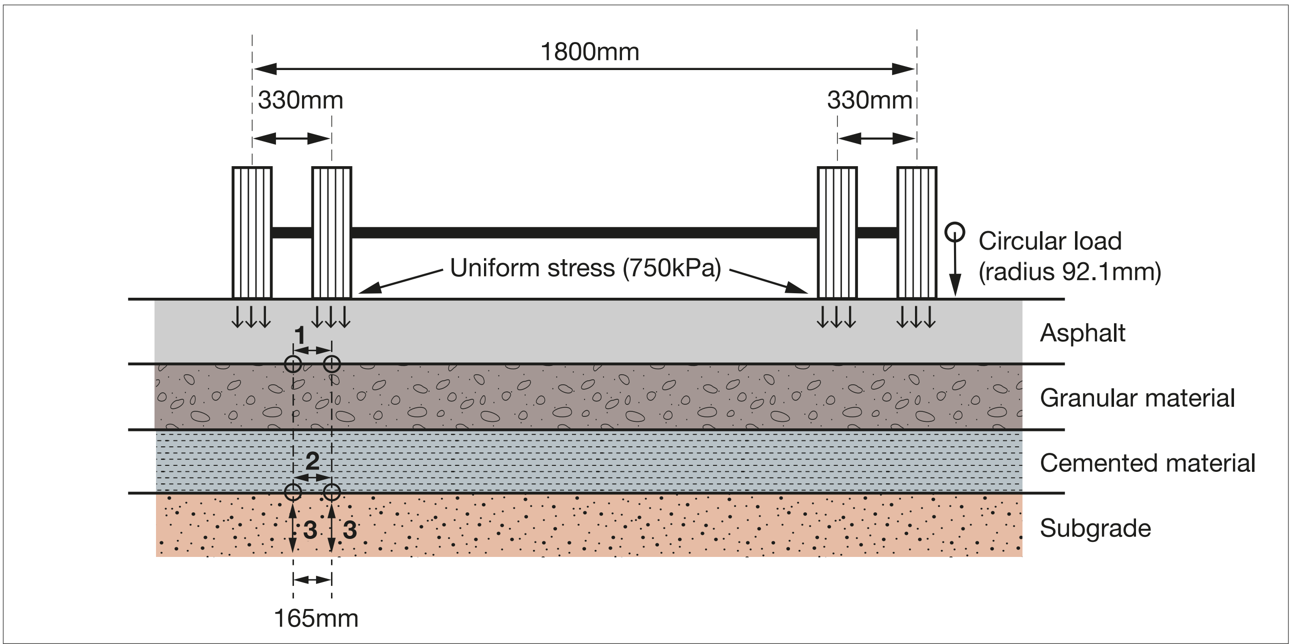
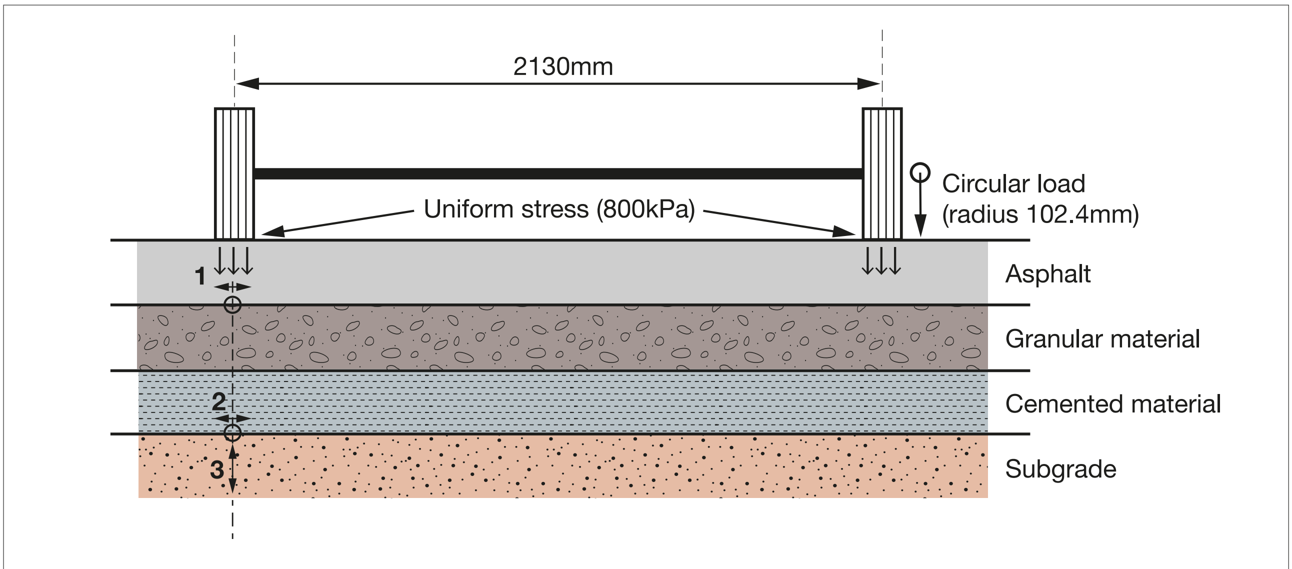


Figure 3.2 Pavement Model for Single Tyre Configuration



3.4.4 Selection of the Appropriate Pavement Structure

The pavement structure is considered as an elastic multi-layer system in which the materials are characterised by Young's modulus of elasticity and Poisson's ratio. The materials are assumed to be homogeneous and isotropic. Traffic is expressed in cumulative numbers of repetitions of a standard load.

In the design procedure., the pavement is regarded as a three- layer system- if it comprises a thin bituminous surfacing (surface dressing or thin premix) or a four-layer system, if it comprises a thick bituminous surfacing (more than 50 mm of premix).

The lowest layer, taken as semi-infinite, represents the subgrade including improved subgrade, if any. The upper layers represent respectively the sub-base, base and, if any, the thick bituminous surfacing.

The calculation of stress, strain and deflection is based on the multi-layer elastic theory (MLET), with the following assumptions:

1. The design load is assumed to be uniformly distributed over one circular area.
2. The layers constitute a semi-infinite half-space.
3. The elastic modulus of any material is constant throughout its depth.
4. All layers are considered to have complete friction between them.

The fatigue criteria of Kenya materials and subgrade have been used with a mechanistic analysis software to determine the appropriate thicknesses of the various pavement structures.

3.4.5 Determination of Layer Thicknesses

In the case of flexible pavements, the total pavement thickness required has been determined by a comparison between the compressive strain applied to the subgrade and the maximum permissible strain which depends on the number of load applications.

In the case of bound materials, the thickness required for each individual layer has been determined by a comparison between the tensile strain at the bottom of the layer and the maximum permissible strain, as deduced from the fatigue law of the material.

In addition, it has been checked that compressive strain on the subgrade does not exceed the permissible value.

3.5 Construction Principles

3.5.1 Minimum Layer Thickness

For each material, there is a minimum layer thickness below which proper laying and compaction are not possible.

For granular materials, if D is the maximum particle size, then the minimum practical thickness is $2.5D$ for surfacing and base and $2D$ for sub-base layers.

In addition, irrespective of the material type, it is impracticable to lay sub-base and bases to compacted thicknesses of less than 100 mm.

For asphalt surfacings of more than 100 mm thickness, at least 75 mm of this should be composed of a binder course (with a nominal size of 25 mm or 37.5 mm).

For both asphalt bases and surfacings, to aid adequate compaction, the nominal maximum aggregate size selected should be two to four times less than the layer thickness.

For the different types of material considered, the minimum practical, thicknesses are as presented in Table 3.6.

Table 3.6 Minimum Pavement Layer Thicknesses

Layer	Material Type	Minimum thickness (mm)
Sub-base	Natural gravel	100
	Clayey sand	100
	Graded crushed stone	100
	Hydraulic improved gravel	125
	Hydraulically modified stone	100
	Hydraulically bound stone	100
Base	Natural gravel	125
	Treated (clayey) sand	100
	Graded crushed stone (GCS-A and GCS-B)	100
	Graded crushed stone (GCS-C)	125
	Water-bound macadam	150
	Hand-packed stone	100
	Dense bitumen macadam (0/25, 0/19, 0/12.5)	125
	Dense bitumen macadam (0/37.5)	150
	Hydraulic-improved or bound	125
	High modulus asphalt Enrobé à module élevé (EME)	60
	Sand-bitumen mix	100
Surfacing	Asphalt Concrete (0/25)	75
	Asphalt Concrete (0/19, 0/14)	50
	Asphalt Concrete (0/12.5, 0/10)	25
	Stone Mastic Asphalt	50
	Gap Graded Asphalt	25
	Cold Mix Asphalt	25
	Sand Asphalt	25
	Cobblestone	100
	Block paving	50

3.5.2 Minimum Significant Thickness Increments

Considering the usual level and thickness tolerances within which the different layers have to be constructed, it is clear that thickness variations of less than 25 mm are meaningless.

Consequently, the layer thicknesses of the structures proposed vary by minimum increments of 25 mm.

3.5.3 Compliance with the Specifications

All the materials are assumed to comply with the requirements given in RDM 3.3 and all the layers to be constructed in accordance with the Standard Specification for Road and Bridge Construction.

4 Standard Pavement Structures

4.1 General

This chapter presents the several standard pavement structures based on experience on the performance of pavements in Kenya. It is not exhaustive by any means, and a designer is empowered to make modifications or even propose the use of completely different structures. If this is the case, then sufficient justification and evidence should be submitted to the Chief Engineer Materials for approval.

4.2 Key Principles Governing the Use of the Structures

4.2.1 Type of Pavement

The selection of the possible types of pavements has been based on the following principles:

- Base materials should not be placed on a more sophisticated sub-base material.
- It is unsafe to place expensive bound base materials on natural materials, which are often deformable and heterogeneous, or on materials whose moduli are less than one tenth of the modulus of the base.

Under graded crushed stone, hydraulically improved granular material, and hydraulically bound stone, it may be technically and economically advantageous to use cement or lime improved material of base quality as sub-base. Indeed, the additional cost is only that of a little more stabiliser and substantial savings on the thicknesses of both base and sub-base may be obtained.

Sand bitumen mix should be used only where no granular material can be found. It will therefore be laid only on a sandy sub-base.

The use of a bituminous binder in the base and cement or lime in the sub-base has been avoided as much as possible, as this complicates the supply problems and generally proves uneconomical.

Under heavy traffic (TC50 or higher), natural gravels and cement (or lime) improved materials cannot be used as base materials as their strength and resistance to attrition are insufficient.

The use of graded crushed stone as base for traffic class TC10, and TC17 with overloaded axles and TC30 is still questionable. Its use as base for class TC30 or higher at any axle loading is still questionable, even under fairly thick surfacing. Its use for Class TC50 traffic is normally excluded due to its excessive deformability, which results in overstressing of the surfacing, and to its insufficient resistance to attrition. However, these difficulties may be overcome by placing graded crushed stone on a sub-base made of cement (or lime) improved material of base quality. (Modulus: at least 10^6 kN/m^2). Indeed, such high-quality sub-base permits the thorough compaction of the base and significantly reduces the deflection and attrition.

Sand bitumen mixes are not suitable for traffic class TC50. The suitability of hot-mixed sand-mix using straight run bitumen for traffic Class TC30 has still to be ascertained.

The materials suitable for base under heavy traffic are then:

1. Dense bitumen macadam (Modulus: 5000 MPa).
2. High modulus asphalt (EME) (Modulus: 8000 MPa).
3. Hydraulically bound stone (HBS6) (Modulus: 7000 MPa).
4. Hydraulically Bound Stone (HBS9) (Modulus: 10000 MPa).

The use of hydraulically bound stone is not justified under light traffic (Classes TC3 and TC1).

1
2
3
4
Standard Pavement Structures

The use of expensive materials such as dense bitumen macadam or hydraulically bound stone is economically unjustified under medium and light traffic (Classes TC10, TC3, and TC1).

The use of asphalt concrete as surfacing is necessary for heavy traffic (Classes TC80 and higher) to adequately protect road bases against attrition and excessive stresses. For asphalt surfacings of more than 100 mm thickness, at least 75 mm of this should be composed of a binder course (with a nominal size of 25 mm or 37.5 mm).

The above considerations have resulted in the selection of 16 different types of pavement structure, the list of which is given in Table 4.1, together with the traffic limitations. A designer is permitted to develop other pavement structures of various combinations consisting of materials in the 16 standard types or other materials provided they are technically and economically justifiable.

***NOTE:* The foundation capping options included in the catalogues are not exhaustive, other options are included in Table 2.4. Performance foundations may also be used.**

4.2.2 Long-Life Pavements

Long-life or perpetual pavements are designed and built to last longer than 50 years, requiring only a periodic mill and inlay of the surface layer. The pavement structure is designed using appropriate materials and layer thicknesses to prevent structural distresses that begin at the bottom of the pavement structure, such as bottom-up fatigue cracking and subgrade rutting.

To eliminate deep structural distresses, horizontal tensile strains at the bottom of the asphalt layer and vertical compressive stresses/strains at the top of the subgrade must be less than critical thresholds at which damage begins to occur. Additional asphalt thickness above what is required to keep stresses/strains below the critical thresholds is unnecessary to ensure long life. Thus, the goal of perpetual pavement design is to optimise layer thicknesses to sustain heavy loads indefinitely without being overly conservative. Asphalt thicknesses for perpetual pavements have typically ranged from 200 mm to 300 mm depending on traffic, materials, and site conditions.

To prevent bottom-up fatigue cracking, perpetual pavements have typically been designed so that the tensile strain at the bottom of the asphalt layer is 70 microstrain. To prevent structural rutting, a vertical strain limit of 200 microstrain at the top of the subgrade is used.

The standard structures given in this Chapter achieve these values at design thicknesses for TC80. Therefore, above this design traffic class, the pavement layer thicknesses have not been increased. However, for TC150+, specific design must be undertaken.

4.2.3 Method of Development of the Standard Pavement Structures

For each, of the 16 types of pavements considered, the thicknesses required have been calculated, for each class of soil and each class of traffic, by the structural method described in Chapter 3.

The design of each type of pavement is presented in one chart, which includes:

1. The Standard Pavement Structure for each foundation class and each design traffic class.
2. Some comments on the peculiarities, advantages, and disadvantages of this type of pavement.
3. The possible alternatives (Including stage construction).
4. The pavement materials required.

4.2.4 Use of Other Types of Pavements

The 16 types of pavements shown in this Manual are considered to cover virtually all the bitumen road designs required in Kenya. Nevertheless, the construction of other types of pavements is not precluded. Indeed, the use of other kinds of pavement materials or substitution of layers included in the standard structures with alternatives may be warranted by local circumstances or economic considerations. ~~This includes the use of proprietary products such as geosynthetics (applications discussed in RDM 3.3).~~ Performance design is advised in such circumstances. This involves the construction of a trial section and conducting deflection tests and rutting trials to establish the pavement layer thicknesses, and materials characteristics.

In such special cases, the design engineer should follow the design and construction principles set out in this Manual and liaise closely with the MTRD for guidance on how the processes required for approval of such materials.

Hand packed stone (HPS) as described in RDM Volume 3 Part 3 is a good material for use as sub-base and bases (for design traffic up to TC10). It can be used as a substitute for granular layers as indicated in Standard Pavement Structure types 1, 2, 6, and 9; and LV5, LV6, LV9, LV10, and LV11. This is especially useful in urban roads and for employment creation. For cases where HPS is used as a base layer, the preferred surfacing is 50 mm asphalt concrete.

4.2.5 Structures for Urban Pavements

For pavements in urban areas, the key principles in selection of options are:

1. Minimising disruption to road users in case of maintenance or rehabilitation, and
2. Minimising damage due to maintaining or replacing of utility lines.
3. In this regard options that involve the use of surface dressing or hydraulically bound stone are not encouraged. The recommended pavement structures are Standard Pavement Types 1, 6, 8, 9, 11, and 14; and LV1, LV2, LV3, LV9, LV10, and LV1115.

Since AC Type I normally requires surface dressing to prevent rapid oxidation, it is not the best option for surfacing. The preferred surfacing is AC Type II, or where the budget permits, stone mastic asphalt.

Additionally, the recommended shoulder types are Type E, X, or other impervious shoulder, with the attendant urban road cross-sections as described in RDM Volume 1 Part 3.

4.3 Method of Use

The design steps are in accordance with steps shown in Figure 1.1.

First Step: Undertake traffic volume surveys.

This is in accordance with the procedures described in RDM 1.2. This provides traffic flow data that is used together with axle load data for determination of the design traffic class.

Second Step: Undertake axle load.

This is in accordance with the procedures described in RDM 1.2. This provides axle load data for determination of the design traffic class.

Third Step: Determining the traffic class.

The study of the initial traffic flows and axle load distributions, the choice of the design period and the estimation of the traffic growth rate will permit the calculation of the cumulative number of standard axles to be carried by the road, taking into account overloaded axles and the possible future effort of axle load legislation.

1
2
3
4
Standard Pavement Structures

The traffic class shall then be determined as indicated in RDM Volume 3 Part 3. For roads carrying overloaded axles, at this stage two traffic classes may be determined. One for all traffic within the legal limits, the other taking into account the over loaded axles.

Fourth Step: Undertake ground investigations.

This is in accordance with the procedures described in RDM 3.1. The main purpose is to identify uniform subgrade sections.

Fifth step: Determine subgrade design classes.

This should be done in accordance with the procedures provided in RDM 3.3 to facilitate foundation design.

Sixth step: Drainage and environmental considerations.

This provides information for drainage and environmental considerations for enhancement of pavement design options as described in section 2.7 and 2.11.

Seventh step: Inventory and study of the available road construction-making materials and selecting the possible type(s) of pavement.

The knowledge of the types and characteristics of the available pavement materials, as well as of the climate, will allow selection of one or more types of pavement - . See RDM 3.1.

Eighth step: Economic and technical comparison of the possible pavement structures. Final choice of one Standard Pavement Structure

The knowledge of the subgrade strength class and of the traffic class will allow the selection of the appropriate Standard Pavement Structure, for each pavement type.

The cost of each possible Standard Pavement Structure shall then be estimated. The specific technical advantages and disadvantages of each type of pavement shall also be considered.

This economic and technical comparison will finally allow the design engineer to choose the most suitable Standard Pavement Structures for (a) legally loaded traffic, or (b) existing traffic for roads with overloaded axles.

The materials used in the catalogues are minimum quality and thickness requirements for the design traffic and the subgrade. It is acceptable to substitute the materials included in the catalogues for higher quality materials if it shown to be economically justifiable and modular ratio requirements are fulfilled.

Ninth step: Determining the foundation class.

See RDM Volume 3 Part 3. NOTE: The foundation capping options included in the catalogues are not exhaustive, other options are included in Table 2.4. Performance foundations may also be used.

Tenth step: Finalising the pavement design and preparation of Special Specifications.

For the final refinements to the pavement design, consideration shall be given to local conditions (e.g. climate resilience, drainage, pavement materials, maintenance requirements, road safety.

4.4 Examples of Pavement Design

4.4.1 Example 1

Consider a pavement to be designed for the following conditions:

- *Climate:* Equatorial with two rainy seasons. The mean annual rainfall is 1,500 mm.
- *Subgrade:* The subgrade soil is a red coffee soil. Its CBR at 100% MDD (Standard Compaction) and after 4 days' soak varies between 7 and 12. with average of 10. The subgrade strength class is then S3 (see Table 1.1).

- *Traffic:* Traffic count and axle load surveys have shown that the initial daily number of commercial vehicles and equivalence factors will be as follows:

  Buses: 30 **Equivalence factor:** 1

  Medium Goods: 160 **Equivalence factor:** 1

  Heavy Goods: 15 **Equivalence factor:** 4

The initial daily number of standard axles is then 250. The economic study of the project has led the design engineer to choose a design period of 15 years and to forecast a constant annual growth rate of 7.5%. The corresponding cumulative number of standard axles is 2.4 million.

Therefore, the traffic class is TC3.

Road Construction Materials

Field investigations and laboratory tests have shown that lateritic gravel of G20 quality occurs in sufficient quantity near the alignment. A stone source suitable for both graded crushed stone and surface dressing chippings exists close to the alignment.

Foundation Design

At the design traffic class of TC3, the minimum foundation class required is F2 (see Table 2.3). This can be achieved using a layer of 150 mm of the lateritic gravel as an improved subgrade since it exceeds the requirements of G14 required to improve an S3 subgrade to an F2 foundation (see - Table 2.4). The top 300 mm of fill below the improved subgrade layer (150 mm G14) should be selected such that its minimum CBR is greater than 10 %.

Pavement Structure

Given the materials available, the lateritic gravel is of insufficient strength to provide a suitable sub-base material. It should be improved using 2% - 4% lime or cement to meet the requirements of sub-base (HIG60). It is however unsuitable to meet the requirements to be improved to, for example, HIG160 for base material. The base should therefore consist of crushed stone of GCS quality.

Thus, the Standard Pavement Structure types 7 and 8 may be considered.

Standard Pavement Structure Type 7 consists of:

- *Surfacing:* double surface dressing (14 + 6 mm chippings - cationic emulsion).
- *Base:* 150 mm GCS-A, GCS-B, or GCS-C.
- *Sub-base:* 125 mm lateritic gravel improved with 2%-4% lime (actual quantity determined through laboratory testing).

Standard Pavement Structure Type 8 consists of:

- *Surfacing:* double surface dressing (14 + 6 mm chippings - cationic emulsion).
- *Base:* 150 mm GCS-A, GCS-B, or GCS-C.
- *Sub-base:* 125 mm GCS-B or GCS-C.

Economic Comparison

If it costs:

- KES 55 Million/km to use Structure Type 7+ an overlay of KES 25 Million/km in Year 7
- KES 80 Million/km to use Structure Type 8 + a reseal of KES 10 Million/km in Year 7

Cost estimates show that Standard Pavement Structure Type 7 is the most economic and in case of shortage of funds, it lends itself well to stage construction due to the low initial cost.

Other Considerations

Given the rainfall of 1500 mm/year, climate change effects of increase rainfall/storms could affect the pavement structure severely. Therefore, if the section of road is vulnerable to climate change effects such as flooding, then Standard Pavement Structure Type 8 is more suitable because the crushed stone (GCS) sub-base will be less susceptible to moisture damage than the hydraulically improved laterite (HIG60) sub-base. To further make this climate resilient, the GCS used should be GCS Type A for both sub-base and base.

4.4.2 Example 2

Consider a pavement to be designed for the following conditions:

- *Climate:* Dry sub-humid with two rainy seasons. The mean annual rainfall is 700 mm.
- *Subgrade:* The alignment soils consist of black cotton soils (average thickness 1 m) overlying decomposed rock. The CBR of the black cotton soils vary between 2 and 5 with a mean of 3.5 (Class S1 – see Table 1.1) and that of decomposed rock between 10 and 20 with a mean of 16 (Class S4 – see Table 1.1).
- *Traffic:* Traffic count and axle load surveys have shown that the initial daily number of commercial vehicles and equivalence factors will be as follows:

Buses: 180	**Equivalence factor:** 1
Medium Goods: 360	**Equivalence factor:** 2
Heavy Goods: 320	**Equivalence factor:** 10

The initial daily number of standard axles is then 4,100.

Considering a design period of 15 years and a constant annual growth rate of 5%, the cumulative number of standard axles to be carried by the road is 32 million.

The traffic class is therefore TC50.

Road Construction Materials

Field investigations and laboratory tests have shown that whilst no gravel suitable for base or sub-base is available, stone suitable for asphalt concrete, dense bitumen macadam and hydraulically bound stone is abundant. This stone may also be used as graded crushed stone for sub-base.

Foundation Design

At the design traffic class of TC50, the minimum foundation class required is F3 (see Table 2.3). It is in all respects advantageous to place an improved subgrade. It will consist of a layer of 425 mm of decomposed rock (meeting requirements of G14). This will improve the S1 subgrade to equivalent S4 subgrade. A borrow pit for this material can be opened close to the alignment. The S4 subgrade should further be improved to meet the requirements of an F3 foundation class or higher. This can be achieved using a 200-mm layer of graded crushed stone (GCS-E, equivalent to G45) to provide a F4 foundation (see - Table 2.4). ~~The top 300 mm of fill below the improved subgrade layer (425 mm G14) should be selected such that its minimum CBR is greater than 3 %.~~

In Summary:

- *Improved subgrade 2:* 200 mm graded crushed stone (GCS-E).
- *Improved subgrade 1:* 425 mm decomposed rock (G14).

Note: *350 mm of the decomposed rock (G14) could have been used to attain equivalent S3 subgrade class (F1), but it is usually more economically to make use of locally available materials to achieve as high a foundation class as possible so that thinner pavement layers would be required. Pavement layers are generally more expensive that subgrade materials. Thus, it is better to use 425 mm decomposed rock (G14) to attain equivalent S4 subgrade class (F2).*

Pavement Structure

Given the materials available, the stone can be used to make GCS-A, AC Type I, DBM, and HBS3 for the pavement layers.

Thus, the Standard Pavement Structure types 4 and 11 may be considered.

Standard Pavement Structure Type 4 consists of:

- *Surfacing:* 100 mm Asphalt concrete Type I (AC I) + 14 mm surface dressing.
- *Base:* 175 mm Hydraulically bound stone (HBS3).
- *Sub-base:* 125 mm Graded crushed stone (GCS-A).

Standard Pavement Structure Type 11 consists of:

- *Surfacing:* 50 mm Asphalt concrete Type I (AC I) + 14 mm surface dressing or stone mastic asphalt.
- *Base:* 150 mm Dense bitumen macadam (DBM).
- *Sub-base:* 125 mm Graded crushed stone (GCS-A).

Economic Comparison

If it costs:

- KES 110 Million/km to use Structure Type 4 + an overlay of KES 45 Million/km in Year 7.
- KES 140 Million/km to use Structure Type 11 + a reseal of KES 10 Million/km in Year 7.

Cost estimates show that Standard Pavement Structure Type 11 is the most economic.

Other Considerations

Given the rainfall of 700 mm/year, indications are that availability of water for curing of HBS could be low, hence Standard Pavement Structure Type 11 is again preferred. If that is the case, then the HBS in the improved subgrade could be replaced with 200 mm of GCS-A. Moreover, it is likely to be more climate resilient than Standard Pavement Structure Type 4, because the 150 mm base of DBM would prevent ingress of excessing water to the lower layers or capillary rise compared to HBS that would have shrinkage cracks that could allow ingress of water.

Table 4.1 Guide to Pavement Structure Selection

Type No.	Base	Sub-base	Traffic Class						
			TC3	TC10	TC17	TC30	TC50	TC80	TC150
1	Natural Gravel	Natural Gravel	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable
2	Hydraulically Improved Granular Material	Natural Gravel	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable
3	Hydraulically Improved Granular Material	Hydraulically Improved Granular Material	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable
4	Hydraulically Bound Stone	Graded Crushed Stone	Economically unjustified	Economically unjustified	Appropriate	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable
5	Hydraulically Bound Stone	Hydraulically Improved Granular Material	Economically unjustified	Economically unjustified	Appropriate	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable
6	Graded Crushed Stone	Natural Gravel	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable
7	Graded Crushed Stone	Hydraulically Improved Granular Material	Appropriate	Appropriate	Suitability to be determined	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable
8	Graded Crushed Stone	Graded Crushed Stone	Appropriate	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable
9	Sand Bitumen Mix	Silty/Clayey Sand	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable	Technically unsuitable
10	Dense Bitumen Macadam	Hydraulically Modified Stone	Economically unjustified	Economically unjustified	Appropriate	Appropriate	Appropriate	Appropriate	Appropriate
11	*Dense Bitumen Macadam	Graded Crushed Stone	Economically unjustified	Economically unjustified	Appropriate	Appropriate	Appropriate	Appropriate	Appropriate
12	Hydraulically Bound Stone	Hydraulically Modified Stone	Economically unjustified	Economically unjustified	Appropriate	Appropriate	Appropriate	Appropriate	Appropriate
13	Hydraulically Bound Stone	Bitumen Stabilised Material	Economically unjustified	Economically unjustified	Appropriate	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable
14	Bitumen Stabilised Material	Graded Crushed Stone	Economically unjustified	Appropriate	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable	Technically unsuitable
15	Bitumen Stabilised Material	Hydraulically Modified Stone	Economically unjustified	Economically unjustified	Appropriate	Appropriate	Technically unsuitable	Technically unsuitable	Technically unsuitable
16	High Modulus Asphalt (EME-2)	Hydraulically Modified Stone	Economically unjustified	Economically unjustified	Economically unjustified	Economically unjustified	Appropriate	Appropriate	Appropriate

Key: ** Bitumen-rich with lower stability and voids*

Appropriate | *Technically unsuitable* | *Economically unjustified* | *Suitability to be determined*

4.5 Standard Pavement Structures

4.5.1 Standard Pavement Structure Type 1

General

This pavement structure is economic, but base quality natural gravels are scarce in Kenya. In some cases, mechanical stabilisation may be necessary to achieve a material complying with the specification.

These structures are very flexible. The use of premix as surfacing is therefore not recommended.

This type of pavement is not suitable for traffic class TC17 or higher because of the insufficient strength and poor resistance to attrition of natural gravels.

Materials Required

- *Surfacing*

  TC10 Triple surface dressing

  TC3 Double surface dressing

  If hand packed stone is used for base, then the surfacing must be AC Type I (50 mm) + Single surface dressing.

- *Base*

  Lateritic gravel, quartizitic gravel, calcareous gravel, coral rag, mechanically stabilised gravel, and hand packed stone. If hand packed stone is used as base, then the sub-base can also be hand packed stone, or G30 material..

- *Sub-base*

  Natural gravel (including weathered rock and soft stone) or clayey/silty sand.

Materials Specification and Construction Procedures (see RDM 3.3)

- *Surface dressing:* see Charts SU1 to SU5 applied as a double or triple seal.
- *Natural gravel (G80) or Hand packed stone, Dry-bound/Wet-bound Macadam for base:* see Chart GM10; or GM12, GM13.
- *Natural material (G30):* see Chart GM8 or GM12.

Capping material: see GM2, GM3, GM4, and GM6.

Pavement Cross-Section

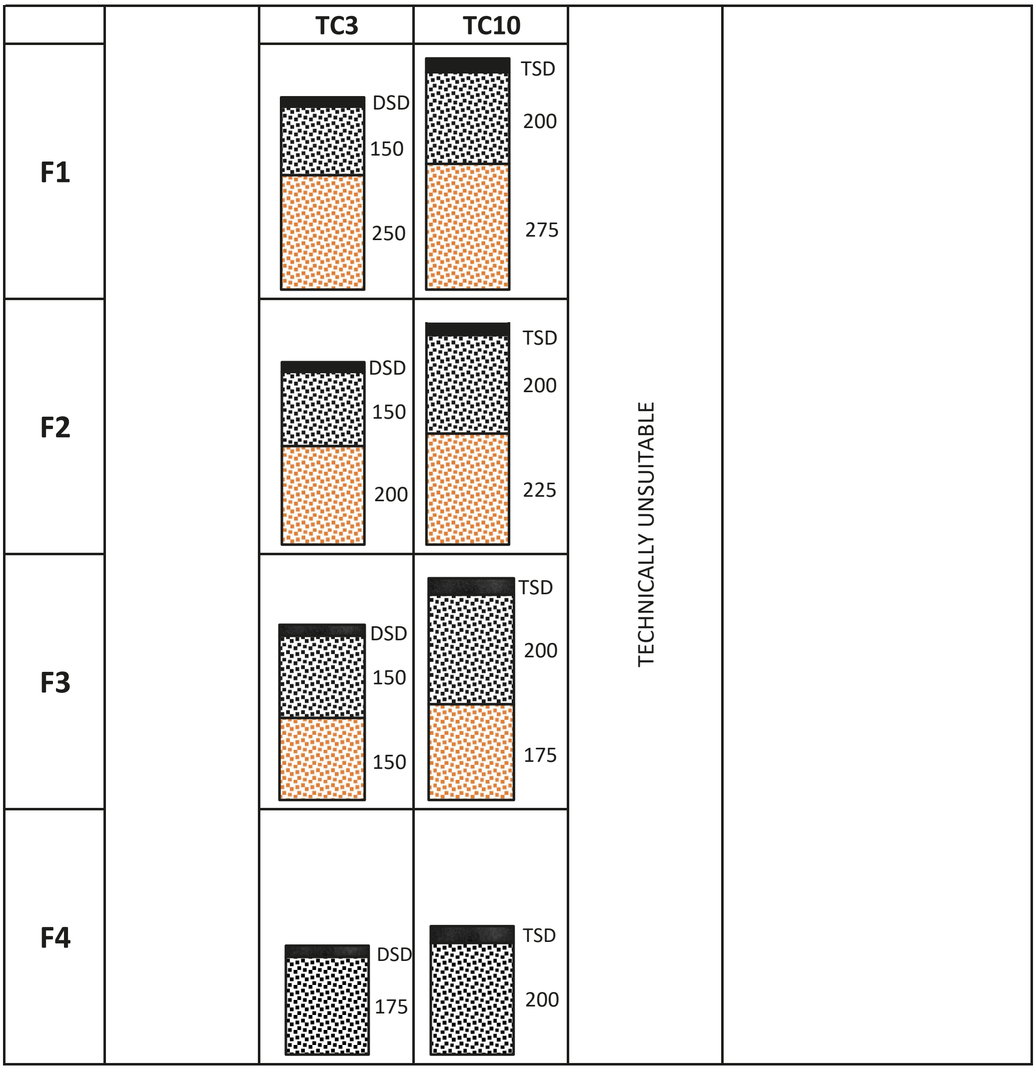
Type A (See Chapter 4.6.1)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 1**

SURFACING:	Double or Triple Surface Dressing
BASE:	Natural Gravel (G80), or Hand Packed Stone*
SUB-BASE:	Natural Gravel (G30)



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	S1			S2			S3			S4	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing, TSD = Triple Surface Dressing. For hand packed stone base, the thickness shall be at least 200 mm for TC10, and 150 mm TC3 AND when used as a base layer, then the surfacing must be 50 mm ACI+ Single surface dressing.

4.5.2 Standard Pavement Structure Type 2

General

This pavement structure is comparatively economical and materials suitable for treatment can be found in most regions of Kenya. However, specific difficulties may arise in arid areas due to lack of water, excessive evaporation, and shrinkage.

These structures are essentially flexible. Care must be taken to ensure that the base material is not too rigid, as this would result in overstressing and cracking of the base. The base modulus should not exceed 3000 MPa.

The type of pavement is not suitable for traffic class TC17 or higher, because of the insufficient strength and poor resistance to attrition of the base materials.

Alternative Structures (B) for TC10 Traffic

They consist of triple surface dressing on a 200 mm base on the same sub-base as (A). The base material shall have sufficient resistance to attrition (L.A.A. less than 50, ACV less than 35, UCS over 1.0 MPa but less than 2.0 MPa.

Materials Required

- *Surfacing*

TC10	Alternative (A)	Asphalt concrete Type I (High Stability) + Single Surface Dressing
	Alternative (B)	Triple surface dressing on 200 mm base.
TC3		Double surface dressing.

  For asphalt surfacing, The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

  Hydraulically improved granular material.

- *Sub-base*

  Natural gravel or clayey/silty sand or hand packed stone.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete:* see Chart SU9.
- *Gap-graded asphalt and Sand-asphalt*: For TC3: see Charts SU6 and SU7.
- *Surface dressing:* see Charts SU1 to SU5 applied as a double or triple seal.
- *Hydraulically improved granular material (HIG160) for base:* see Chart HM4.
- *Natural material (G30) or hand-packed stone for sub-base:* see Chart GM8 or GM12.
- *Capping material:* see GM2, GM3, GM4 and GM6.

Pavement Cross-Section

Type A (See section 4.6.1)

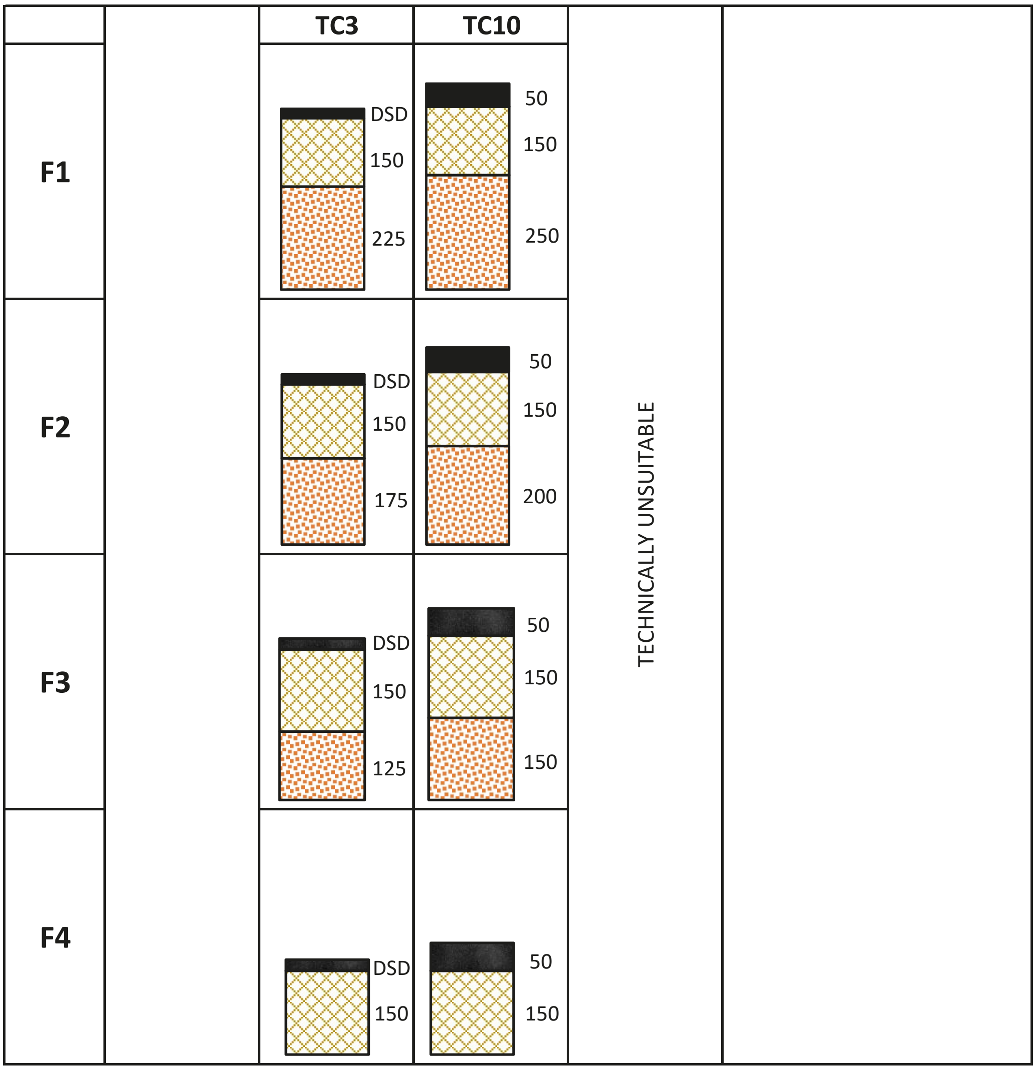
Note: *The base for this type of road is unsuitable for traffic class TC17 or higher. For roads where overloaded axle considerations may push the traffic category higher than TC10, this type of pavement should not be used.*

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 2**

SURFACING:	Double Surfaced Dressing/Asphalt Concrete Type 1+ Single Surface Dressing
BASE:	Hydraulically Improved Granular Material (HIG160)
SUB-BASE:	Natural Gravel (G30), or Hand Packed Stone*



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. Double Surface Dressing for TC3. Triple Surface Dressing is an alternative to AC I in TC10. If no stone suitable for chippings is available, a thin layer (25 mm+) of asphalt concrete Type II dry sand-asphalt may be used instead of surface dressing. For hand packed stone sub-base, the thickness shall be at least 200 mm for F1 and F2; and 150 mm for F3.

4.5.3 Standard Pavement Structure Type 3

General

This type of pavement structure is, in general, fairly economical, and materials suitable for treatment can be found in most regions of Kenya. However, specific difficulties may arise in arid areas due to lack of water, excessive evaporation, and shrinkage.

These structures are flexible. Care shall be taken to ensure that the base material is not too rigid, as this would result in overstressing and cracking of the base. The base modulus shall not exceed 3000 MPa.

This type of pavement is not suitable for traffic class TC17 or higher, because of the insufficient strength and poor resistance to attrition of the base materials.

Alternative Structures (B) for TC10 Traffic

They consist of triple surface dressing on a 200 mm base on the same sub-base as (A). The base material shall have sufficient resistance to attrition (L.A.A. less than 50, ACV less than 35, UCS over 1.0 MPa but less than 2.0 MPa.

Materials Required

- *Surfacing*

TC10	Alternative (A)	Asphalt concrete Type I (High Stability) + single surface dressing,
	Alternative (B)	Triple surface dressing on 200 mm base.
TC3		Double surface dressing.

  For asphalt surfacing, the nominal maximum aggregate size selected should be two to four times less than the layer thickness

- *Base*
  Hydraulically improved granular material or clayey/silty sand or hydraulically modified stone.
- *Sub-base*
  Hydraulically improved granular material or clayey/silty sand.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete:* see Chart SU9.
- *Gap-graded asphalt and Sand-asphalt:* For TC3, see Charts SU6 and SU7.
- *Surface dressing:* see Charts SU1 to SU5 applied as a double or triple seal.
- *Hydraulically improved granular material (HIG160) or hydraulically modified stone (HMS1) for base:* See Chart HM4 or HM5.
- *Hydraulically improved granular material (HIG60) for sub-base:* see Chart HM2.
- *Capping material:* see GM2, GM3, GM4, GM6, and GM9.

Pavement Cross-Section

Type A (See Chapter 4.6.1)

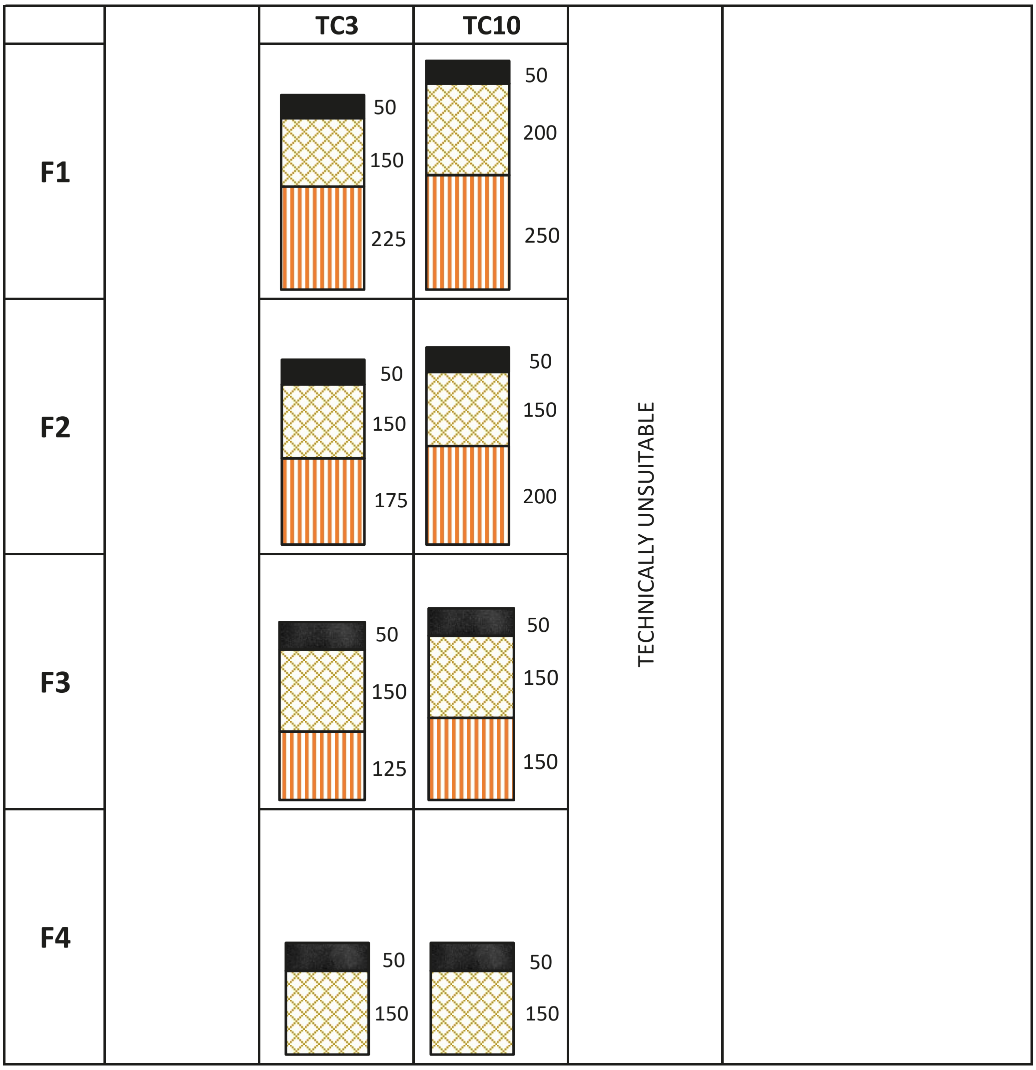
Note: *The base for this type of road is unsuitable for Traffic Category TC30 or higher. For roads where overloaded axle considerations may push the Traffic category higher than TC10, this type of pavement should not be used.*

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 3**

SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing
BASE:	Hydraulically Improved Granular Material (HIG160) or Hydraulically Modified Stone (HMS1)
SUB-BASE:	Hydraulically Improved Granular Material (HIG60)



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. Double Surface Dressing for TC3. Triple Surface Dressing is an alternative to AC I in TC10. If no stone suitable for chippings is available, a thin layer (25 mm+) of asphalt concrete Type II dry sand-asphalt may be used instead of surface dressing. Base thickness may be reduced by 25 mm if HMS1 is used.

4.5.4 Standard Pavement Structure Type 4

General

This type of pavement structure is fairly economical for the TC17 to TC50 traffic level compared to the other structures suitable for heavy traffic. However, gravels suitable for stabilisation are scarce in several areas of Kenya. Moreover, specific difficulties may be encountered in arid areas due to lack of water, excessive evaporation hindering the setting of cement and shrinkage.

These structures are semi-rigid and special care shall be taken to ensure the uniformity of the mix and compliance with the time limitations, due to the rapid setting of cement.

Materials Required

This type of pavement is economically unjustified for traffic class TC10 or lower.

Surfacing

Asphalt concrete Type I (High Stability) + Single Surface Dressing. The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

Base

Hydraulically bound stone (HBS3).

Sub-base

Graded crushed stone (Class A or B), or wet or dry-bound Macadam.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete:* see Chart SU9.
- *Surface dressing:* see Charts SU1.
- *Hydraulically bound stone (HBS3) for base:* see Chart HB1.
- *Graded crushed stone (Class A or B) GCS-B for TC17, and GCS-A for TC30 and TC50; or Wet-bound or dry-bound Macadam for sub-base:* see Chart GM11 or GM13.
- *Capping material:* see GM2, GM3, GM4, GM6, GM9, GM11 and BM1.

Pavement Cross-Section

Type A (See Chapter 4.6.1)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 4**

SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing
BASE:	Hydraulically Bound Stone (HBS3)
SUB-BASE:	Graded Crushed Stone (GCS-A, and GCS-B) or Wet/Dry-bound Macadam

		TC17	TC30	TC50		
F1	ECONOMICALLY UNJUSTIFIED				TECHNICALLY UNSUITABLE	
F2						
F3		50 / 200 / 175	75 / 200 / 175	100 / 200 / 175		
F4		50 / 175 / 125	75 / 175 / 125	100 / 175 / 125		

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. For sub-base, GCS-B for TC17, and GCS-A for TC30 and TC50.

4.5.5 Standard Pavement Structure Type 5

General

This type of pavement structure often compares favourably with Type 4. Indeed, the addition of a little more stabiliser into the sub-base provides significant savings on both base and sub-base thicknesses. However, gravels suitable for stabilisation are scarce in several areas of Kenya. Moreover, specific difficulties may be encountered in arid areas due to lack of water, excessive evaporation hindering the setting of cement and shrinkage.

These structures are semi-rigid and special care shall be taken to ensure the uniformity of the mix and compliance with the time limitations, due to the rapid setting of cement.

This type of pavement is economically unjustified for traffic classes TC10 or lower.

Materials Required

- *Surfacing*

  Asphalt concrete Type I (High Stability) + Single Surface Dressing. The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

  Hydraulically bound stone.

- *Sub-base*

  Hydraulically improved granular material or clayey/silty sand.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete:* see Chart SU9.
- *Surface dressing:* see Charts SU1.
- *Hydraulically bound stone (HBS3) for base:* see Chart HB1.
- *Hydraulically improved gravel:* see Chart HM4.
- *Capping material:* see GM2, GM3, GM4, GM6, GM9, GM11, BM1 and HM4.

Pavement Cross-Section

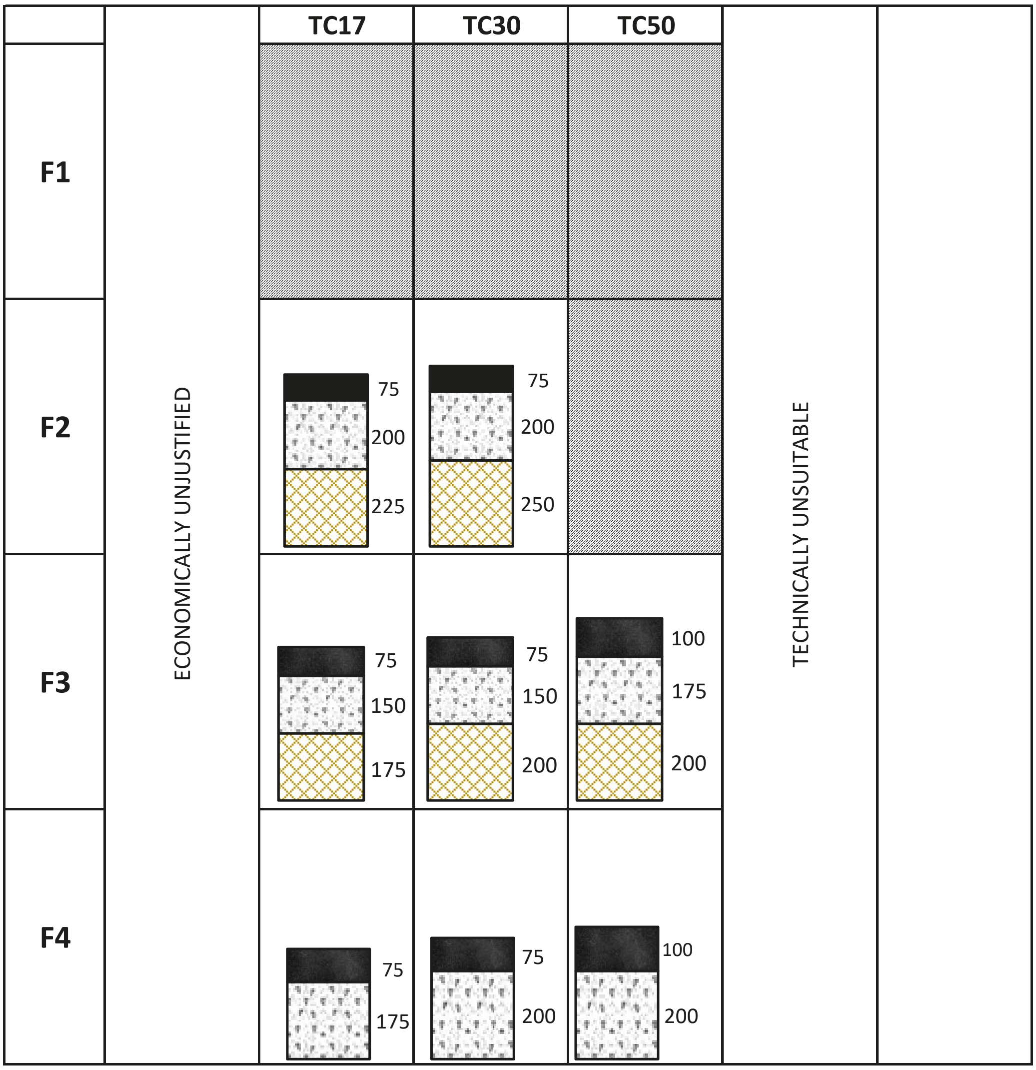
Type A (See Chapter 4.6.1)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 5**

SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing
BASE:	Hydraulically Bound Stone (HBS3)
SUB-BASE:	Hydraulically Improved Granular Material (HIG160)



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. For F2 and F3, sub-base thickness may be reduced by 25 mm if HMS1 is used.

4.5.6 Standard Pavement Structure Type 6

General

This type of pavement should be considered where no gravel suitable for base is available.

These structures are very flexible and the use of premix as surfacing is therefore not recommended.

Special attention must be paid to the drainage of the pavement layers and to the edge restraint of the base.

This type of pavement is not suitable for traffic class TC17 and higher due to the insufficient strength and resistance to attrition of the pavement materials.

Materials Required

- *Surfacing*

  TC10 Triple surface dressing

  TC3 Double surface dressing

- *Base*

  TC10 Graded crushed stone (Class B), or wet or dry-bound Macadam.

  TC3 Graded crushed stone (Class C), or wet or dry-bound Macadam.

- *Sub-base*

  Natural gravel (including weathered rock and soft stone), or clayey/silty sand, or hand packed stone.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surface dressing:* see Charts SU1 to SU5 applied as a double or triple seal.
- *Graded crushed stone (Class B or C); or dry-bound/wet-bound Macadam for base:* see Chart GM11 or GM13.
- *Natural material (G30); or hand packed stone for sub-base:* see Chart GM8 or GM12.
- *Capping material:* see GM2, GM3, GM4 and GM6.

Pavement Cross-Section

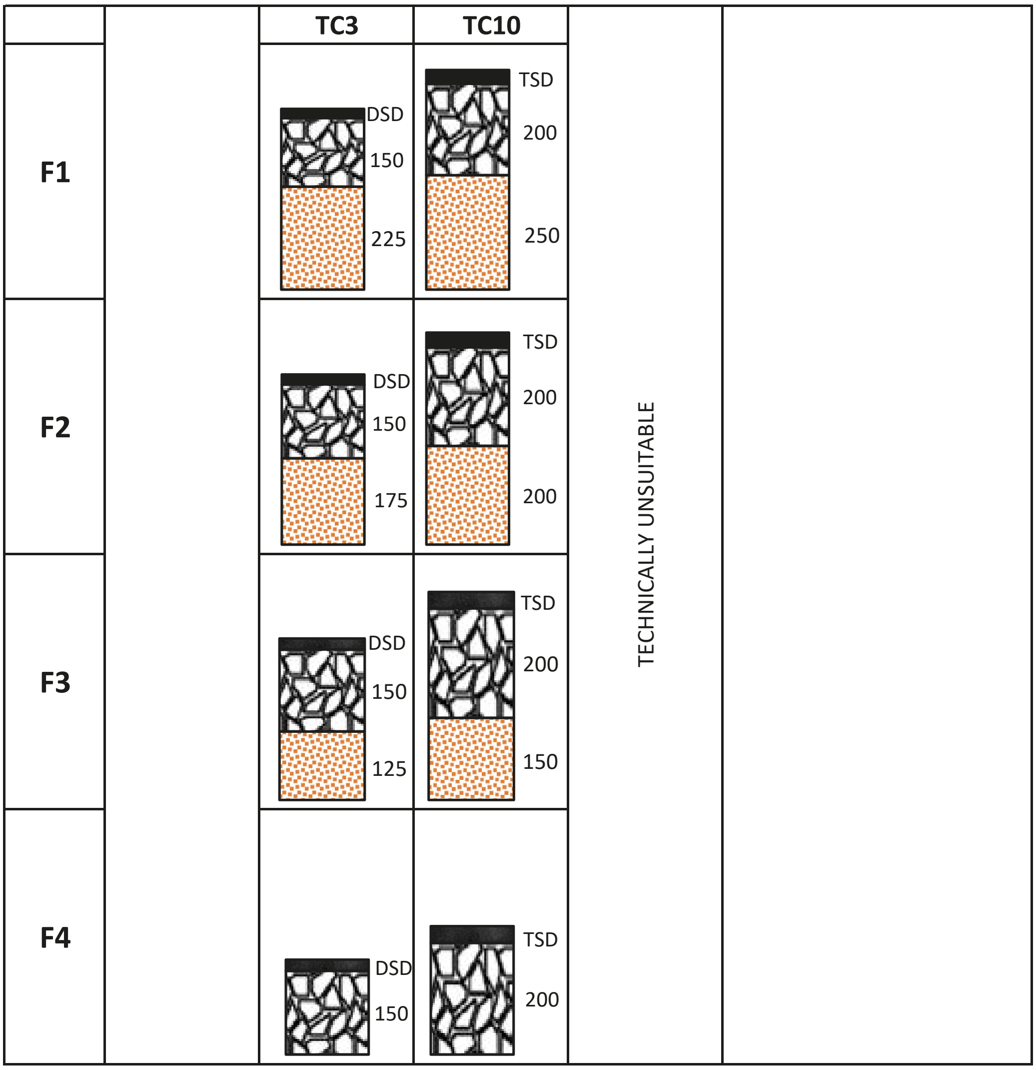
Type B, C or D depending upon sub-base type (see section 4.6).

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 6**

SURFACING:	Double or Triple Surface Dressing
BASE:	Graded Crushed Stone (GCS-B and GCS-C) or Wet/Dry-bound Macadam
SUB-BASE:	Natural Gravel (G30), or Hand Packed Stone*



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. Triple Surface Dressing and GCS-B for TC 10, and Double Surface Dressing and GCS-C for TC3. For hand packed stone sub-base, the thickness shall be at least 200 mm for F1 and F2; and 150 mm for F3.

1 2 3 4 Standard Pavement Structures

4.5.7 Standard Pavement Structure Type 7

General

This type of pavement should be considered where no gravel suitable for base is available.

Special attention must be paid to the drainage of the pavement layers and to the edge restraint of the base.

This type of pavement is not suitable for traffic class TC30 or higher because of attrition of the base.

Alternative Structures (B) for TC10 Traffic

They consist of triple surface dressing on 200 mm base on the same sub-base as (A). The graded crushed stone for base shall be entirely crushed.

Materials Required

- *Surfacing*

TC17		Asphalt concrete type I (high stability) + single surface dressing.
TC10	Alternative (A)	Asphalt concrete Type I (high stability) + single surface dressing.
	Alternative (B)	Triple surface dressing on 200 mm base.
TC3		Double surface dressing

  For asphalt surfacing, the nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

TC17	Graded crushed stone (Class A), or wet or dry-bound Macadam.
TC10 (A)	Graded crushed stone (Class B), or wet or dry-bound Macadam.
TC10 (B)	Graded crushed stone (Class B), or wet or dry-bound Macadam.
TC3	Graded crushed stone (Class C), or wet or dry-bound Macadam.

- *Sub-base*

  Hydraulically improved granular material or clayey/silty sand.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete:* see Chart SU9.
- *Gap-graded asphalt and Sand-asphalt:* see Charts SU6 and SU7.
- *Surface dressing:* see Charts SU1 to SU5 applied as a double or triple seal.
- *Graded crushed stone (Class B or C); or wet-bound or dry-bound Macadam for base:* see Chart GM11 or GM13.
- *Hydraulically improved granular material (HIG60) for sub-base:* see Chart HM2.
- *Capping material:* see GM2, GM3, GM4, GM6 and GM9.

Pavement Cross-Section

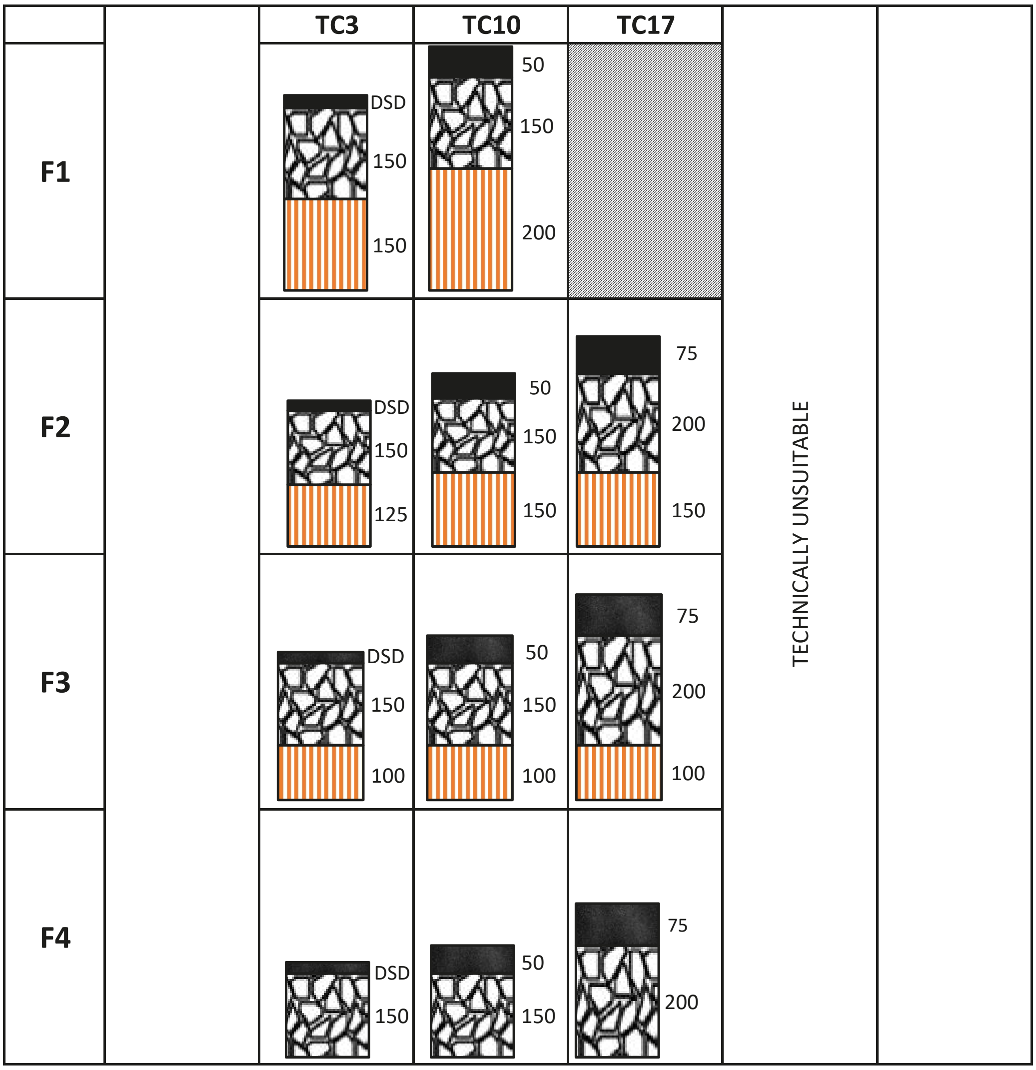
Type B or D (see Chapter 4.6)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 7**

SURFACING:	Double Surfaced Dressing/Asphalt Concrete Type 1+ Single Surface Dressing
BASE:	Graded Crushed Stone (GCS-A, GCS-B, and GCS-C) or Wet/Dry-bound Macadam
SUB-BASE:	Hydraulically Improved Granular Material (HIG60)



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. GCS-A for TC17. GCS-B for TC10. Triple Surface Dressing and GCS-B for TC 10 as an alternative for AC I, and Double Surface Dressing and GCS-C for TC3. If no stone suitable for chippings is available, a thin layer (25 mm+) of asphalt concrete Type II dry sand-asphalt may be used instead of surface dressing

4.5.8 Standard Pavement Structure Type 8

General

This type of pavement is to be used where there is no natural gravel.

Special attention must be paid to the drainage of the pavement and to the edge restraint of the base.

This type of pavement is suitable for traffic Classes TC3, TC10, and TC17 but not for higher traffic classes because of the attrition in the base.

Alternative Structures (B) for TC10 Traffic

They consist of triple surface dressing on 200 mm base on the same sub-base as (A). The graded crushed stone for base shall be entirely crushed.

Materials Required

- *Surfacing*

TC17		Asphalt concrete type I (high stability) + single surface dressing.
TC10	Alternative (A)	Asphalt concrete Type I (high stability) + single surface dressing.
	Alternative (B)	Triple surface dressing on 200 mm base.
TC3		Double surface dressing

For asphalt surfacing, the nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

TC17	Graded crushed stone (Class A), or wet or dry-bound Macadam.
TC10 (A)	Graded crushed stone (Class B), or wet or dry-bound Macadam.
TC10 (B)	Graded crushed stone (Class B), or wet or dry-bound Macadam.
TC3	Graded crushed stone (Class C), or wet or dry-bound Macadam.

- *Sub-base*

TC10 - TC17	Graded crushed stone (Class B), or wet or dry-bound Macadam.
TC3	Graded crushed stone (Class C), or wet or dry-bound Macadam.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete:* see Chart SU9.
- *Gap-graded asphalt:* see Chart SU7.
- *Surface dressing:* see Charts SU1 to SU5 applied as a double or triple seal.
- *Graded crushed stone (Class B or C), wet-bound or dry-bound Macadam for base:* see Chart GM11 or GM13.
- *Graded crushed stone (Class B or C), wet-bound or dry-bound Macadam or hand packed stone for sub-base:* see Chart GM11, GM13, or GM12.
- *Capping material:* see GM2, GM3, GM4, GM6, GM8, GM9, GM11 and BM1.

Pavement Cross-Section

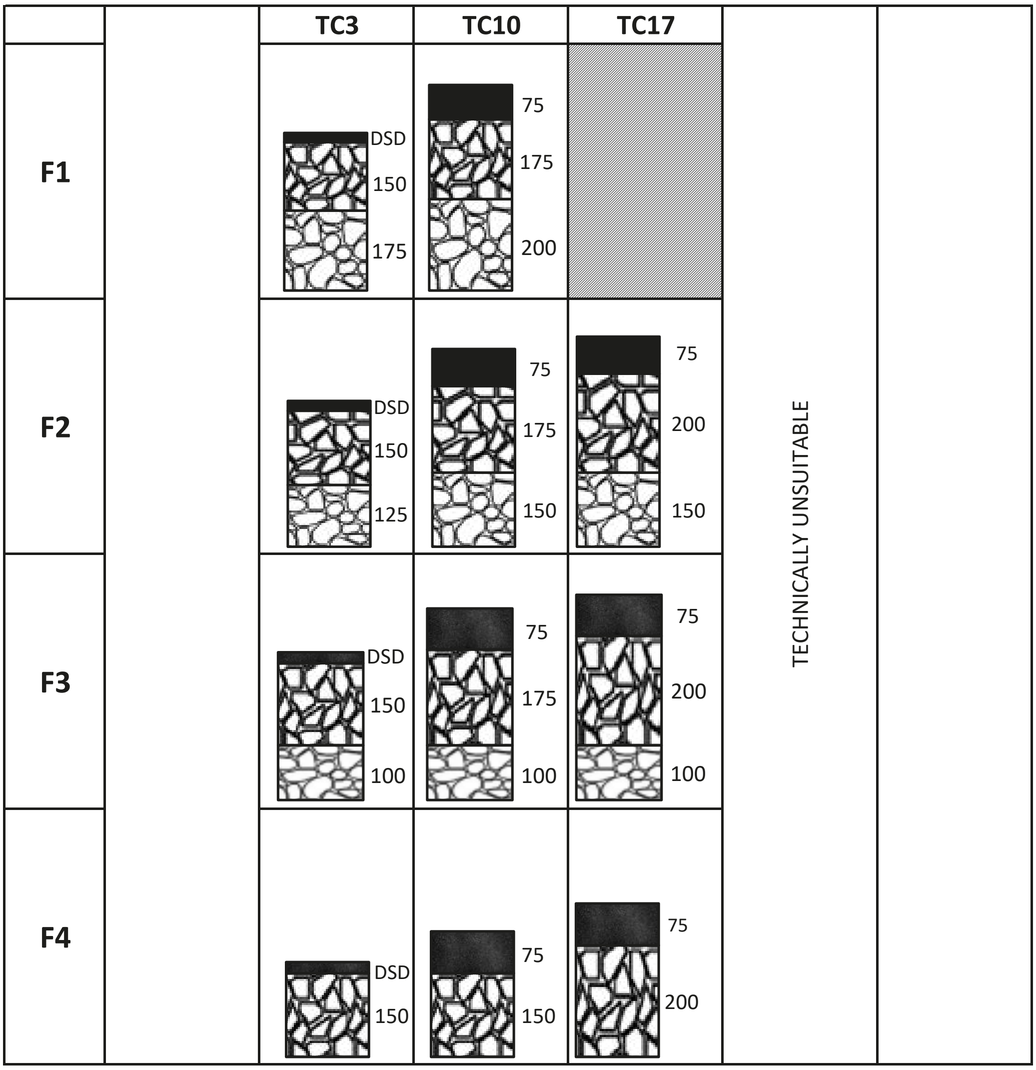
Type C (see section 4.6.3)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 8**

SURFACING:	Double Surfaced Dressing/Asphalt Concrete Type 1+ Single Surface Dressing
BASE:	Graded Crushed Stone (GCS-A, GCS-B, and GCS-C) or Wet/Dry-bound Macadam
SUB-BASE:	Graded Crushed Stone (GCS-B, and GCS-C) or Wet/Dry-bound Macadam



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	**-**	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing. TC3 base is GCS-C, TC10 base is GCS-B, and TC17 base is GCS-A. TC3 and TC10 sub-base is GCS-C, TC17 sub-base is GCS-B. Triple Surface Dressing and GCS-B for TC 10 as an alternative for AC I, and Double Surface Dressing and GCS-C for TC3. If no stone suitable for chippings is available, a thin layer (25 mm+) of asphalt concrete Type II dry sand-asphalt may be used instead of surface dressing

4.5.9 Standard Pavement Structure Type 9

General

This type of pavement is to be used where there is no natural gravel.

Special attention must be paid to the drainage of the pavement and to the edge restraint of the base.

This type of pavement is suitable for traffic Classes TC3, TC10, and TC17 but not for higher traffic classes because of the attrition in the base.

Alternative Structures (B) for TC10 Traffic

They consist of triple surface dressing on 200 mm base on the same sub-base as (A). The graded crushed stone for base shall be entirely crushed.

Materials Required

- *Surfacing*

TC10	Alternative (A)	Asphalt concrete type I (high stability) + single surface dressing, sand asphalt or gap-graded asphalt.
TC10	Alternative (B)	Triple surface dressing on 175mm base.
TC3		Double surface dressing.

  For asphalt surfacing, the nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*
  Sand mix or bitumen stabilised silty/clayey sand (road-mix).

- *Sub-base*
  Silty or clayey sand, or hand packed stone.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete:* see Chart SU9.
- *Gap-graded asphalt and sand asphalt:* see Chart SU6 and SU7.
- *Surface dressing:* see Charts SU1 to SU5 applied as a double or triple seal.
- *Sand-bitument mix for base:* see Charts BB3 and BB4.
- *Silty/Clayey sand (G30) or Hand-packed stone for sub-base:* see Chart GM8 or GM12.
- *Capping material:* see GM2, GM3, GM4 and GM6.

Pavement Cross-Section

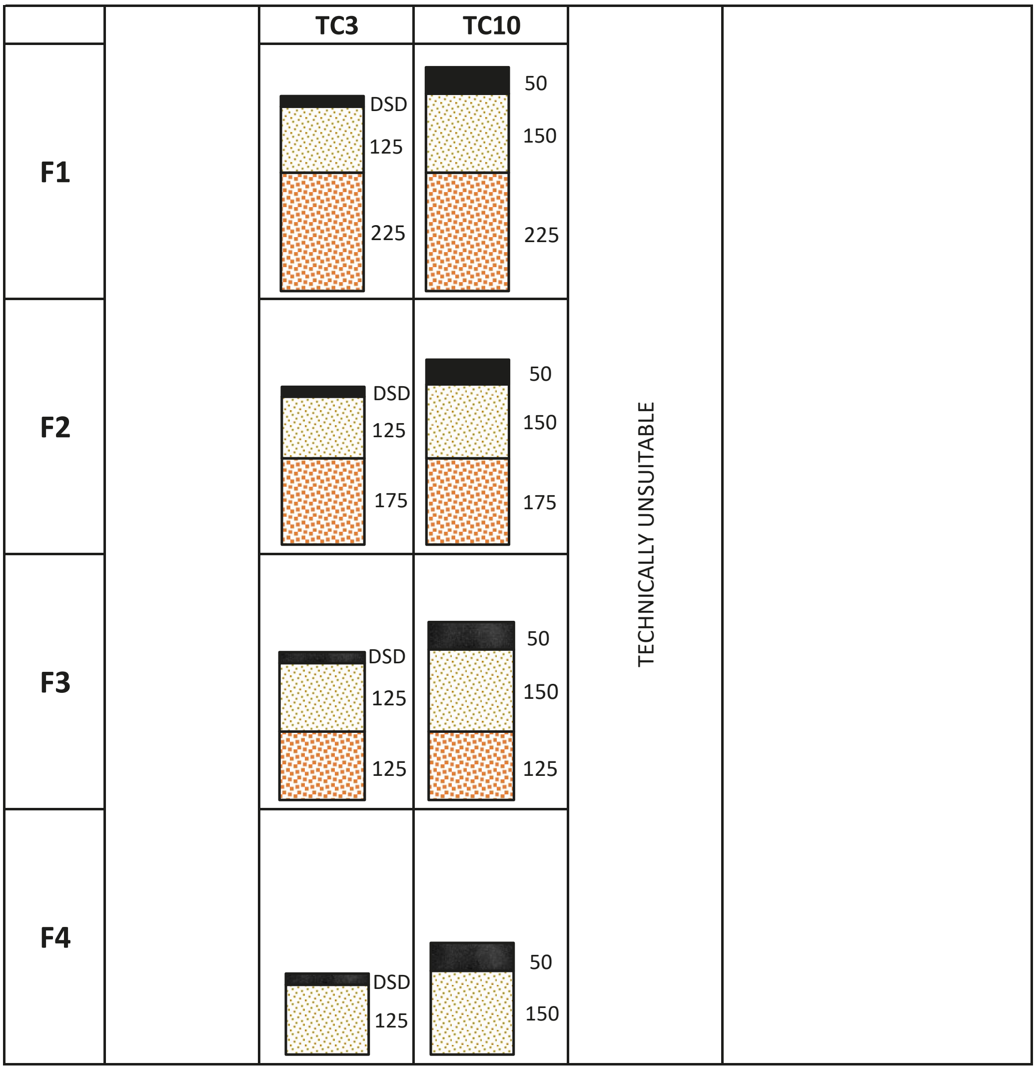
Type A (see Chapter 4.6.1)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 9**

	SURFACING:	Double Surfaced Dressing/Asphalt Concrete Type 1+ Single Surface Dressing
	BASE:	Sand Bitumen Mix (BB3 or BB4)
	SUB-BASE:	Silty/Clayey Sand (G30), or Hand Packed Stone*



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. Double Surface Dressing for TC3. Triple Surface Dressing is an alternative to AC I in TC10. If no stone suitable for chippings is available, a thin layer (25 mm+) of asphalt concrete Type II dry sand-asphalt may be used instead of surface dressing. For hand packed stone sub-base, the thickness shall be at least 200 mm for F1 and F2; and 150 mm for F3.

4.5.10 Standard Pavement Structure Type 10

General

This type of pavement is economically justified only for heavy traffic (Classes TC17 and higher).

Because of the rapid ageing of bitumen observed in Kenya, it is recommended that the DBM. be as dense as possible.

Consequently, comparatively high bitumen contents (4.5 to 5%) may be chosen which would have the further advantage of facilitating compaction of thick layers.

Materials Required

- *Surfacing*

  Asphalt concrete Type I (high stability) + single surface dressing, or stone mastic asphalt. The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

  Dense bitumen macadam (constructed in two layers to aid sufficient compaction). The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Sub-base*

  Hydraulically improved granular material or clayey sand or hydraulically modified stone.

Materials Requirements and Construction Procedures (see RDM 3.3)

- *Asphalt concrete or stone mastic asphalt:* see Charts SU9 or SU11 for TC50 and higher.
- *Surface dressing:* see Chart SU1.
- *Dense bitumen macadam for base:* see Chart BB1.
- *Hydraulically improved granular material (HIG160) or hydraulically modified stone (HMS1) for sub-base:* see Chart HM4 or HM5.
- C*apping material:* see GM2, GM3, GM4, GM6, GM9, GM11, BM1, HM3 and HM4.

Pavement Cross-Section

Type A (see Section 4.6.1)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 10**

SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing: or *Stone Mastic Asphalt
BASE:	Dense Bitumen Macadam (DBM)
SUB-BASE:	Hydraulically Improved Granular Material (HIG160) or Hydraulically Modified Stone (HMS1)

		TC17	TC30	TC50	TC80	TC150
F1	ECONOMICALLY UNJUSTIFIED					
F2		50 / 100 / 175	50 / 125 / 175			
F3		50 / 100 / 150	50 / 125 / 125	50 / 150 / 175		
F4		50 / 100 / 100	50 / 125 / 100	50 / 150 / 125	75 / 150 / 150	100 / 150 / 150

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (M CESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

Other capping options available in RDM 3.3. * Stone Mastic Asphalt is not economically viable for TC30 and lower. For TC80 and TC150, a surfacing alternative is DBM + double surface dressing. The DBM should be of at least nominal aggregate size 25 mm. For F2 and F3, sub-base thickness may be reduced by 25 mm if HMS1 is used.

4.5.11 Standard Pavement Structure Type 11

General

This type of pavement is economically justified only for heavy traffic (Classes TC17 and higher).

Because of the rapid ageing of bitumen observed in Kenya, it is recommended that the DBM. be as dense as possible.

Consequently, comparatively high bitumen contents (4.5 to 5%) may be chosen which would have the further advantage of facilitating compaction of thick layers.

Materials Required

- *Surfacing*

  Asphalt concrete Type I (High stability) + Single Surface Dressing, or Stone mastic asphalt. The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

  Dense bitumen macadam (constructed in two layers to aid sufficient compaction). The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Sub-base*

  Graded crushed stone (Class A), or wet or dry-bound Macadam.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete or stone mastic asphalt:* see Chart SU9 or SU11 for TC50 and higher.
- *Surface dressing:* see Charts SU1.
- *Dense bitumen macadam for base:* see Chart BB1.
- *Graded crushed stone (Class A), or wet-bound or dry-bound Macadam for sub-base:* see Chart GM11 or GM13.
- *Capping material:* see GM2, GM3, GM4, GM6, GM8, GM9, GM11 and BM1.

Pavement Cross-Section

Type A (see Chapter 4.6.1)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE — TYPE 11

SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing: or *Stone Mastic Asphalt
BASE:	Dense Bitumen Macadam (DBM)
SUB-BASE:	Graded Crushed Stone (GCS-A) or Wet/Dry-bound Macadam

		TC17	TC30	TC50	TC80	TC150
F1	ECONOMICALLY UNJUSTIFIED					
F2		50 / 100 / 175	50 / 125 / 175			
F3		50 / 100 / 150	50 / 125 / 125	50 / 150 / 175		
F4		50 / 100 / 100	50 / 125 / 100	50 / 150 / 125	75 / 150 / 150	100 / 150 / 150

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

Other capping options available in RDM 3.3. * Stone Mastic Asphalt is not economically viable for TC30 and lower. For TC80 and TC150, a surfacing alternative is DBM + double surface dressing. The DBM should be of at least nominal aggregate size 25 mm.

4.5.12 Standard Pavement Structure Type 12

General

This type of pavement is economically justified only for heavy traffic (Classes TC17 and higher).

Specific difficulties may be encountered in dry areas due to excessive evaporation hindering the setting of cement and shrinkage. Attention is drawn to the time limitations for compaction and protection, and to the necessity of proper curing of hydraulically bound stone.

These structures are rigid, and widely spaced cracks, due to shrinkage and thermal stresses, are almost inevitable. But such cracks are harmless if the base and sub-base are properly constructed and drained.

Materials Required

- *Surfacing*

  Asphalt concrete Type I (High Stability) + Single Surface Dressing, or Stone mastic asphalt. When the AC Type I layer is thicker than 100 mm, it is recommended that it should consist of a binder course of at least 75 mm (as per Chart SU10) and the rest of the thickness to make up a wearing course (as per Chart SU11). The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

  Hydraulically bound stone.

- *Sub-base*

  Hydraulically improved granular material or clayey/silty sand or hydraulically modified stone.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete or stone mastic asphalt:* see Chart SU9 or SU11 for TC50 and higher.
- *Surface dressing:* see Charts SU1.
- *Hydraulically bound stone (HBS6 or HBS9) for base:* see Chart HB2 and HB3.
- *Hydraulically improved granular material (HIG160) or hydraulically modified stone (HMS1) for sub-base:* see Chart HM4 or HM5.
- *Capping material:* see GM2, GM3, GM4, GM6, GM9, GM11, BM1, HM3 and HM4.

Pavement Cross-Section

Type A (see Chapter 4.6.4)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 12**

SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing: or *Stone Mastic Asphalt
BASE:	Hydraulically Bound Stone (HBS6 and HBS9)
SUB-BASE:	Hydraulically Improved Granular Material (HIG160) or Hydraulically Modified Stone (HMS1)

		TC17	TC30	TC50	TC80	TC150
F1	ECONOMICALLY UNJUSTIFIED					
F2		50 / 150 / 150	50 / 150 / 175			
F3		50 / 150 / 125	50 / 150 / 150	75 / 150 / 150		
F4		50 / 125 / 100	50 / 150 / 100	75 / 150 / 100	100 / 150 / 100	125 / 150 / 100

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (M CESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

Other capping options available in RDM 3.3. * Stone Mastic Asphalt is not economically viable for TC30 and lower. For TC80 and TC150, a surfacing alternative is DBM + double surface dressing. The DBM should be of nominal maximum aggregate size 25 mm. HBS6 for TC17, TC30, and TC50. HBS9 for TC80 and TC150. For F2 and F3, sub-base thickness may be reduced by 25 mm if HMS1 is used.

4.5.13 Standard Pavement Structure Type 13

General

This type of pavement is economically justified only for heavy traffic (Classes TC17 and higher).

Specific difficulties may be encountered in dry areas due to excessive evaporation hindering the setting of cement and shrinkage. Attention is drawn to the time limitations for compaction and protection, and to the necessity of proper curing of hydraulically bound stone.

These structures are rigid, and widely spaced cracks, due to shrinkage and thermal stresses, are almost inevitable. But such cracks are harmless if the base and sub-base are properly constructed and drained.

Materials Required

- *Surfacing*

  Asphalt concrete Type I (High Stability) + Single Surface Dressing, or Stone mastic asphalt. When the AC Type I layer is thicker than 100 mm, it is recommended that it should consist of a binder course of at least 75 mm (as per Chart SU10) and the rest of the thickness to make up a wearing course (as per Chart SU11). For asphalt surfacing, the nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

  Hydraulically bound stone.

- *Sub-base*

  Bitumen stabilised material.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete or stone mastic asphalt:* see Chart SU9 or SU11 for TC50 and higher.
- *Surface dressing:* see Charts SU1.
- *Hydraulically bound stone (HBS3) for base:* see Chart HB1.
- *Bitumen stabilised material (BSM50) for sub-base:* see Chart BM1.
- *Capping material:* see GM2, GM3, GM4, GM6, GM8, GM9, GM11 and BM1.

Pavement Cross-Section

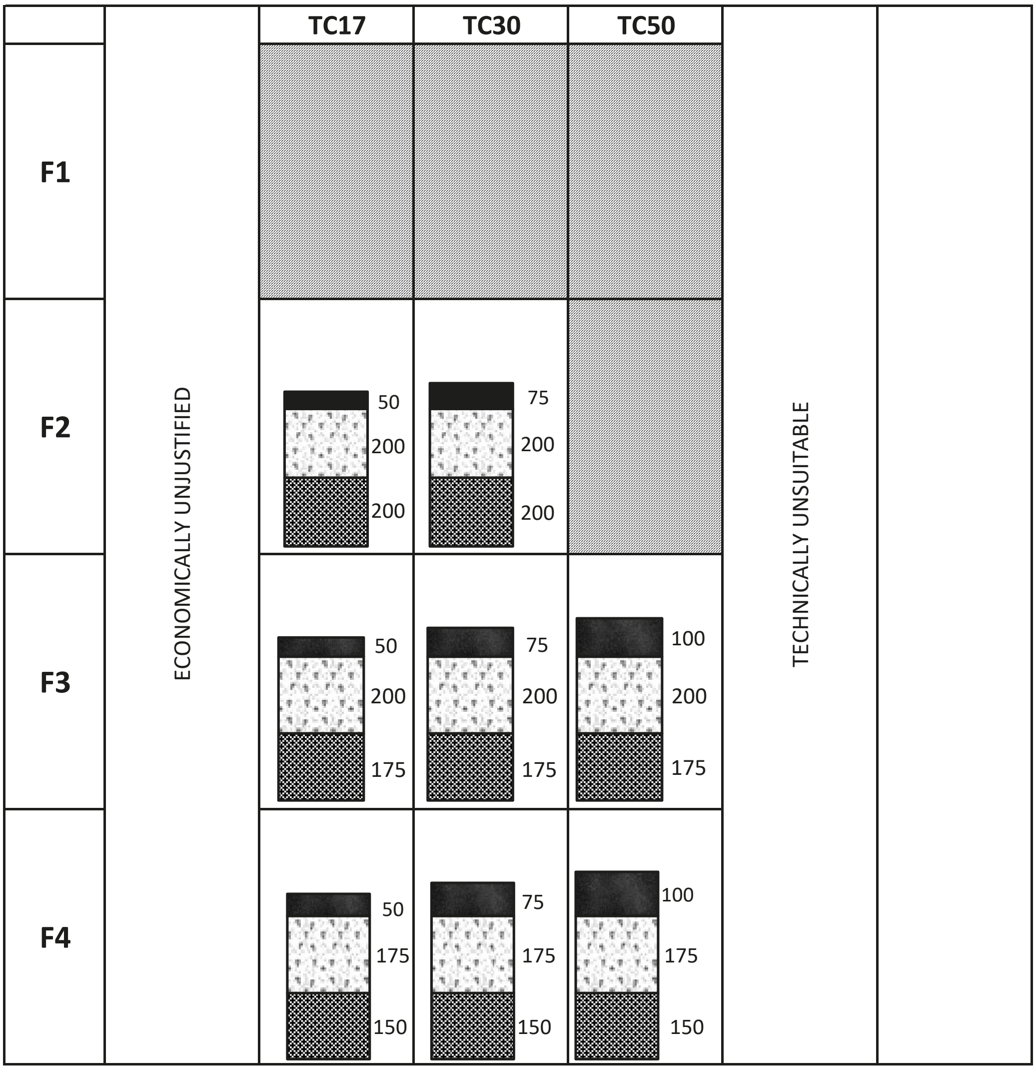
Type C (see Chapter 4.6.3)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 13**

SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing
BASE:	Hydraulically Bound Stone (HBS3)
SUB-BASE:	Bitumen Stabilised Material (BSM50)



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (M CESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3.

4.5.14 Standard Pavement Structure Type 14

General

This type of pavement is economically justified only for traffic classes TC10 to TC30.

The applicable residual bitumen content is usually 1.5 % - 2.5 % and cement content of less than 1 %. The bitumen used can be foamed or emulsified bitumen.

This base type is very effective in enhancing climate resilience (against increased moisture ingress and detriment).

Materials Required

- *Surfacing*

  Asphalt concrete Type I (High stability) + Single Surface Dressing. The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

  Bitumen stabilised materials made from high-quality GCS-A or from recycled asphalt.

- *Sub-base*

  Graded crushed stone (Class A), or wet or dry-bound Macadam.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete:* see Chart SU9.
- S*urface dressing:* see Chart SU1.
- *Bitumen stabilised material (BSM100 or BSM175) for base:* see Chart BM2 and BM3.
- *Graded crushed stone for sub-base (Class A) or Wet-bound or dry-bound Macadam for sub-base:* see Chart GM12 or GM14.
- *Capping material:* see GM2, GM3, GM4, GM6, GM8, GM9, GM11 and BM1.

Pavement Cross-Section

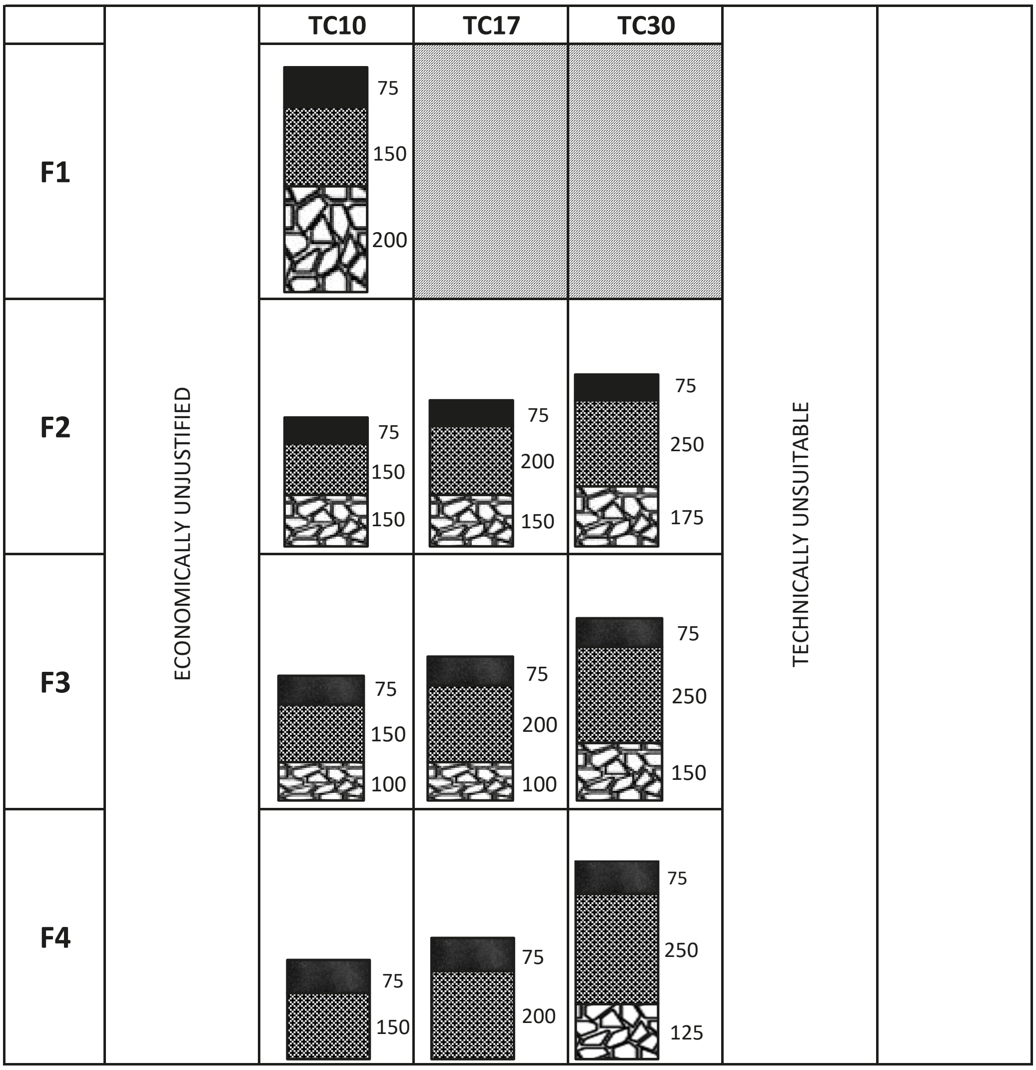
Type C (see Chapter 4.6.3)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 14**

SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing
BASE:	Bitumen Stabilised Material (BSM100/BSM175)
SUB-BASE:	Graded Crushed Stone (GCS-A) or Wet/Dry-bound Macadam



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. TC10 base is BSM100, TC17 and TC30 base is BSM175. All sub-base is GCS-A or Wet/Dry-bound macadam.

4.5.15 Standard Pavement Structure Type 15

General

This type of pavement is economically justified only for traffic classes TC10 to TC30.

The applicable residual bitumen content is usually 1.5% - 2.5% and cement content of less than 1%. The bitumen used can be foamed or emulsified bitumen.

This base type is very effective in enhancing climate resilience (against increased moisture ingress and detriment).

Materials Required

- *Surfacing*

  Asphalt concrete Type I (High Stability) + Single Surface Dressing. The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

  Bitumen stabilised materials made from high quality GCS-A or from recycled asphalt.

- *Sub-base*

  Hydraulically improved granular material or clayey/silty sand or hydraulically modified stone.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete:* see Chart SU9.
- *Surface dressing:* see Charts SU1.
- *Bitumen stabilised material (BSM100 or BSM175) for base:* see Chart BM2 or BM3.
- *Hydraulically improved granular material (HIG160 or hydraulically modified stone (HMS1) for sub-base:* see Chart HM4 or HM5.
- *Capping material:* see GM2, GM3, GM4, GM6, GM9, GM11, BM1, HM3 and HM4.

Pavement Cross-Section

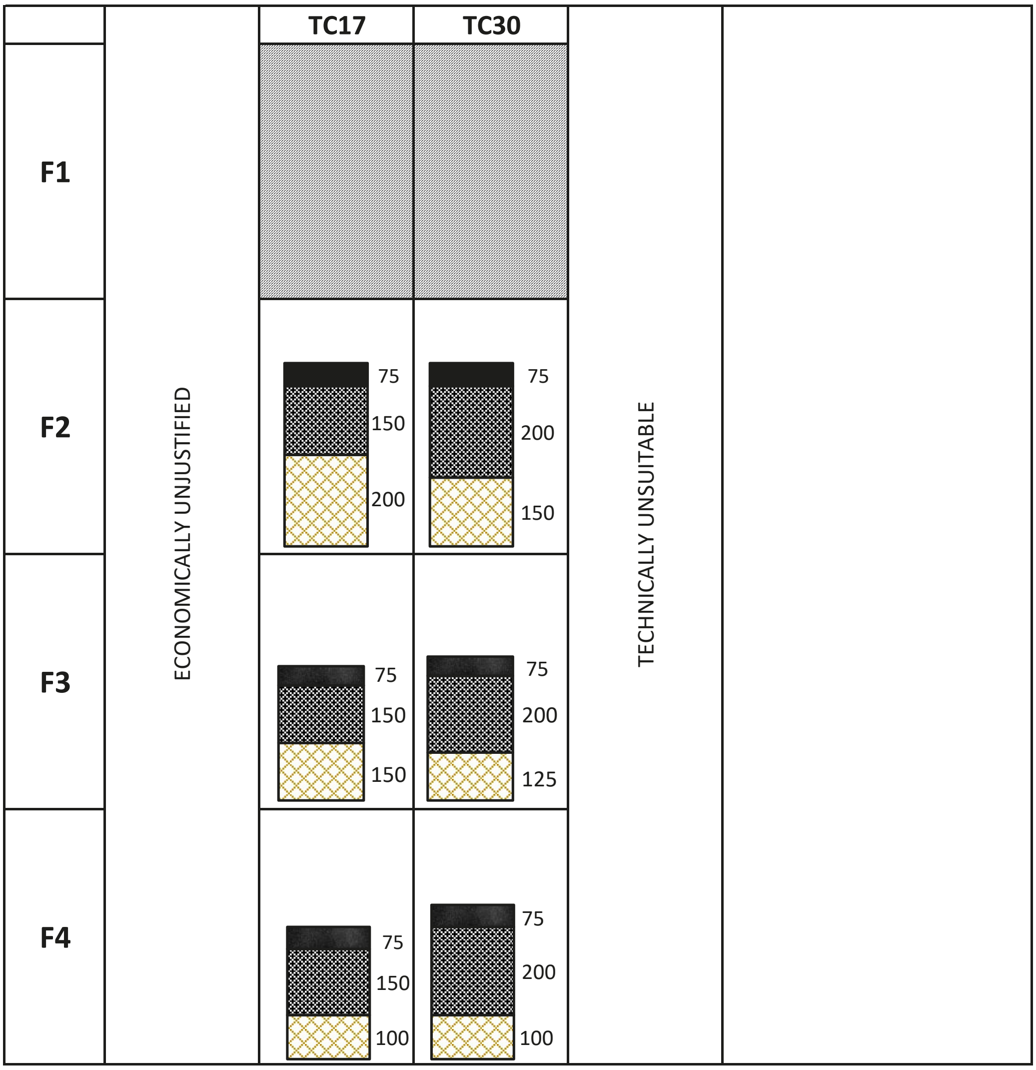
Type B or D (see section 4.6)

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE 15**

	SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing
	BASE:	Bitumen Stabilised Material (BSM100/BSM175)
	SUB-BASE:	Hydraulically Improved Granular Material (HIG160) or Hydraulically Modified Stone (HMS1)



TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. TC10 base is BSM100, TC17 and TC30 base is BSM175. For F2 and F3, sub-base thickness may be reduced by 25 mm if HMS1 is used.

4.5.16 Standard Pavement Structure Type 16

General

This type of pavement is economically justified only for heavy traffic classes TC50 and higher.

Specific difficulties may be encountered in dry areas due to excessive evaporation hindering the setting of cement and shrinkage. Attention is drawn to the time limitations for compaction and protection, and to the necessity of proper curing of hydraulically bound stone.

These structures are rigid, and widely spaced cracks, due to shrinkage, and thermal stresses, are almost inevitable. But such cracks are harmless if the base and sub-base are properly constructed and drained.

Materials Required

- *Surfacing*

  Asphalt concrete Type I (High Stability) + Single Surface Dressing, or Stone mastic asphalt. The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Base*

  Enrobé à module élevé (EME) High modulus asphalt. The nominal maximum aggregate size selected should be two to four times less than the layer thickness.

- *Sub-base*

  Hydraulically bound stone.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Asphalt concrete or stone mastic asphalt:* see Chart SU9 or SU11 for TC50 and higher..
- *Surface dressing:* see Charts SU1.
- *Enrobé à module élevé (EME) for base:* see Chart BB2.
- *Hydraulically bound stone (HBS3) for sub-base:* see Chart HB1.
- *Capping material:* see GM2, GM3, GM4, GM6, GM9, GM11, BM1, BM2, HM3, HM4 and HM5.

Pavement Cross-Section

Type A (see section 4.6.1).

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR MEDIUM, HEAVY AND VERY HEAVY VOLUME ROADS

STANDARD PAVEMENT STRUCTURE — TYPE 16

SURFACING:	Asphalt Concrete Type 1+ Single Surface Dressing: or *Stone Mastic Asphalt
BASE:	High Modulus Asphalt (EME)
SUB-BASE:	Hydraulically Bound Stone (HBS3)

		TC50	TC80	TC150
F1	ECONOMICALLY UNJUSTIFIED			
F2				
F3		50 100 175		
F4		50 100 125	75 100 150	100 100 150

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (MCESA)
TC3	1-3
TC10	3-10
TC17	10-17
TC30	17-30
TC50	30-50
TC80	50-80
TC150	80-150

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

Other capping options available in RDM 3.3. * Stone Mastic Asphalt is not economically viable for TC30 and lower. For TC80 and TC150, a surfacing alternative is DBM + double surface dressing. The DBM should be of nominal maximum aggregate size 25 mm.

4.6 Pavement Cross-sections

The following six cross-sections illustrate the various pavement layer combinations in relation to internal drainage, (cross-sections for geometric purposes are found in RDM 1.3). Variations may be designed, provided that strength, surface protection, edge restraint and surface and internal drainage are adequate.

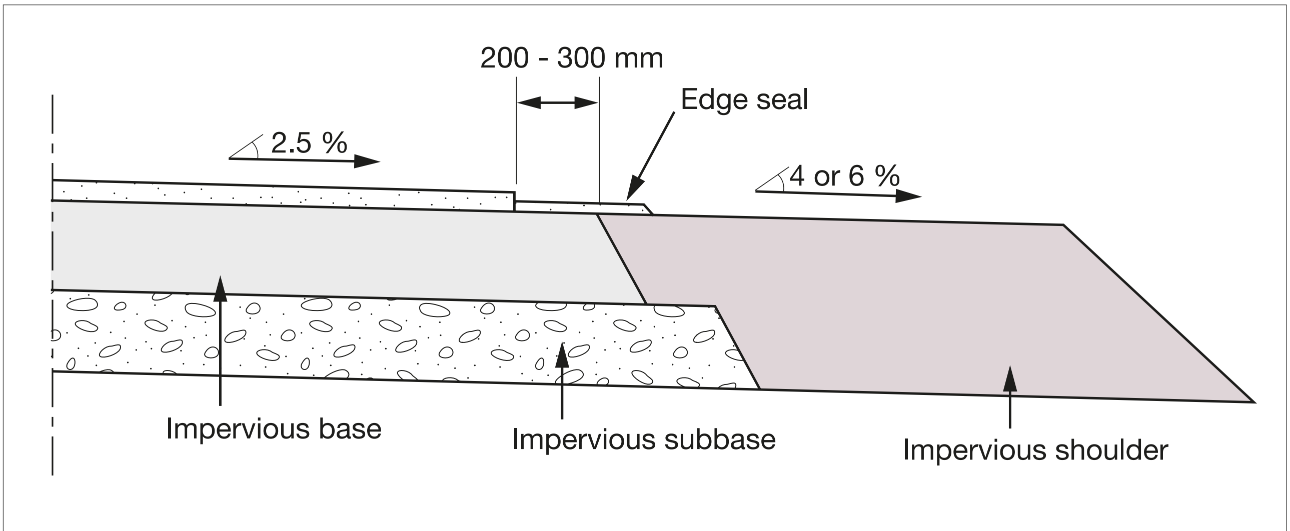
4.6.1 Type A

This is normally used where the base material is impermeable, for example any of the following:

- Plastic natural gravel.
- Cement/lime treated.
- Cement stabilised gravel.
- Bitumen stabilised silty or clayey sand.
- Dense bituminous macadam.
- Hydraulically bound stone.

The shoulders provide adequate strength for parked or moving vehicles. The pavement structure extends 200-300 mm to allow the pavement to be fully compacted. The impervious materials and the crossfalls ensure that all surface water is disposed of directly into the side drains. The seal extends 200-300 mm to prevent small quantities of water permeating into the pavement.

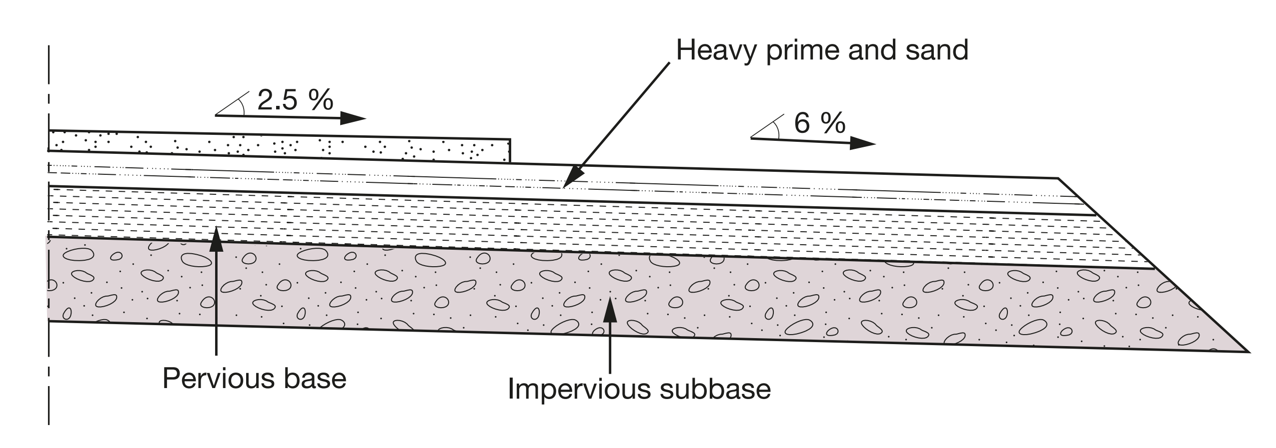
Figure 4.1 Pavement Cross-section Type A



4.6.2 Type B

This is normally used with permeable, non-plastic base materials and impermeable sub-bases. The pavement materials extend to the edge of the shoulders, allow the pavement to be fully compacted, and provide adequate strength for parked and moving vehicles. The sand seal on the shoulder protects the shoulder, sheds water directly into the side drains and prevents water permeating into the pavement. For cost reasons, this cross-section is not normally used for base thicknesses more than 150 mm.

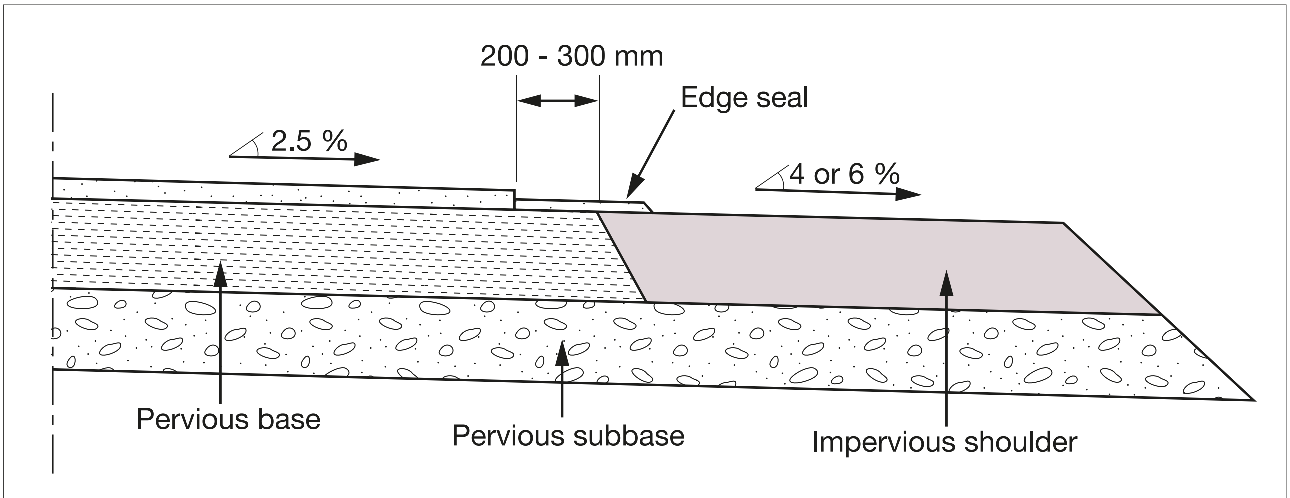
Figure 4.2 Pavement Cross-section Type B



4.6.3 Type C

This is normally used with permeable, non-plastic base and sub-base materials, or if the permeability of the materials is unknown. The shoulders provide adequate strength for parked and moving vehicles. The base extends 200-300 mm to allow the pavement to be fully compacted. The extended seal reduces the water permeating into the pavement, but any water that does enter the pavement will be disposed of through the permeable sub-base and into the side drains.

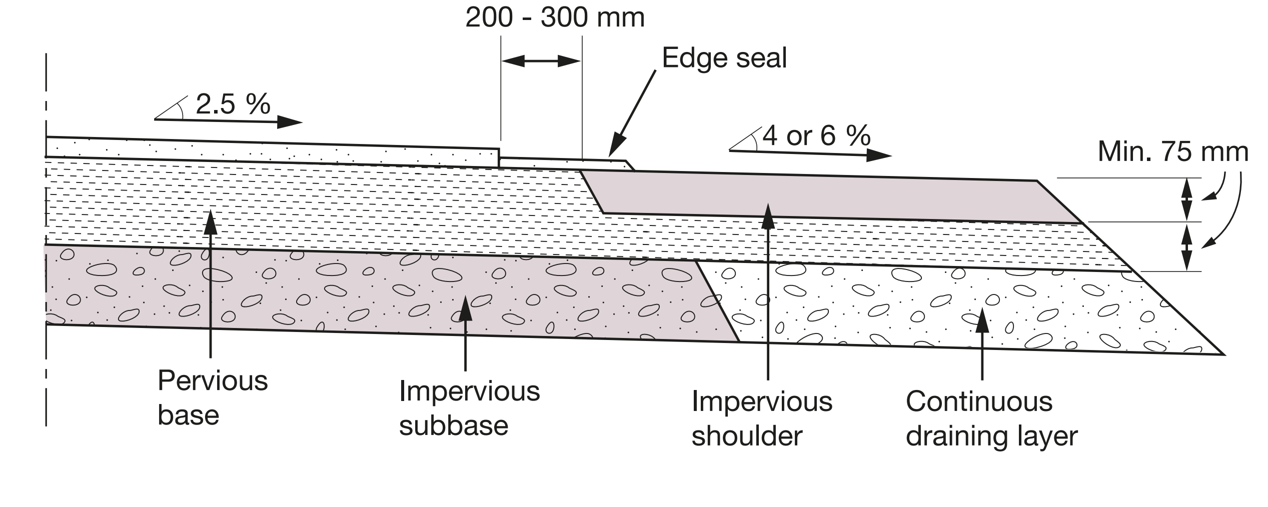
Figure 4.3 Pavement Cross-section Type C



4.6.4 Type D

This is a variation of type B, used when the base is thicker than 150 mm. The additional thickness of the base allows the majority of the pavement materials to be replaced with lower cost materials, leaving in place a thin permeable drainage layer level with the underside of the base. This also removes the need for a costly sand seal on the shoulder, which can be covered with topsoil and grass.

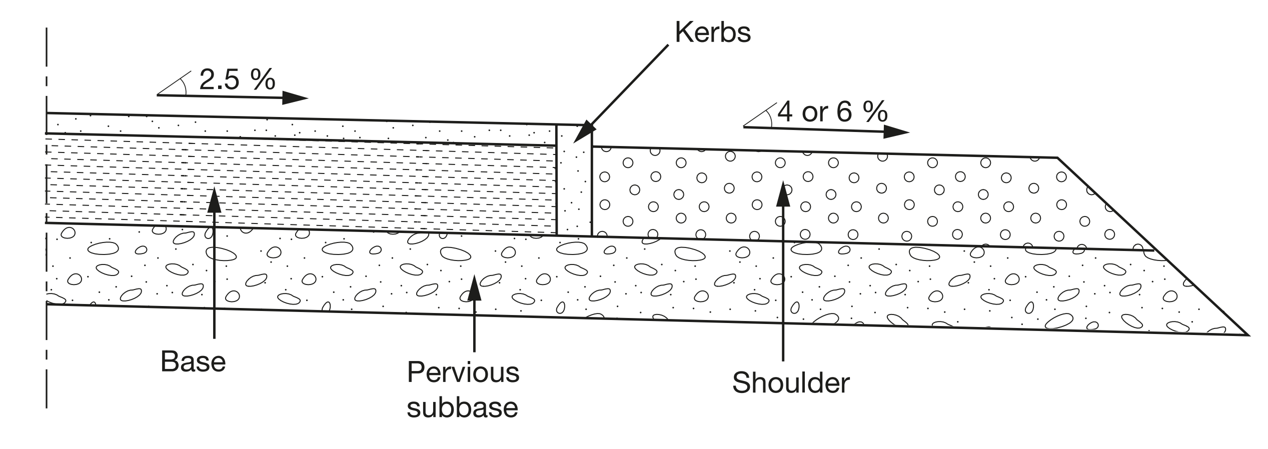
Figure 4.4 Pavement Cross-section Type D



4.6.5 Type E

This can be used with permeable, non-plastic base materials and permeable sub-bases. The shoulders provide adequate strength for parked or moving vehicles. A sunken kerb allows the pavement to be fully compacted. Water that enters the pavement cannot pass through the kerb so will be disposed of through the permeable sub-base and into the side drains.

Figure 4.5 Pavement Cross-section Type E



Standard Pavement Structures

1 2 3 4

4.6.6 Type X

The pavement structure (base and sub-base) is extended right across the shoulders up to the edge of the side drain. The shoulders allow the pavement to be fully compacted and provide adequate strength for parked vehicles and occasional moving vehicles. A plastic or cement/lime treated surface will be resistant to wear, erosion and water entry, and topsoil and grass can be added. If the base material is unbound, a sand seal or surface dressing should be constructed on the shoulders to protect the surface and shed water into the side drains. For cost reasons, this cross-section is not normally used for shoulders wider than 1.5 metres.

4.7 Shoulders

The shoulders have several functions:

- Contributing to road safety by:
  - Carrying pedestrian traffic.
  - Increasing visibility round corners.
  - Providing refuge areas alongside the carriageway for disabled vehicles.
  - Increasing width for emergency use.
- Providing lateral support (edge restraint) to the pavement.
- Forming part of the surface and internal drainage systems of a carriageway and keep water away from lower pavement layers.

This section describes the shoulders alongside the pavement. It is necessary for the shoulders to be able to carry parked and moving vehicles, be resistant to erosion and tyre wear, provide lateral support to the pavement, and form part of the surface and internal drainage systems.

The ways in which this is done are described in the following paragraphs, and then illustrated in a set of six cross-sections.

4.7.1 Unpaved Roads

The shoulders of earth and gravel roads are formed by simply widening the road so that it can provide a running surface with additional width for pedestrians, visibility, and refuge. The shoulders of a gravel road can be left with an earth surface, but in most cases, gravel is spread and compacted across the shoulders. The shoulders can then be covered with topsoil and grass as in Chapter 4.6.6 above to protect against erosion and tyre wear.

4.7.2 Paved Roads

The pavement structure can be extended to the shoulders. This is a simple construction, with straightforward surface drainage, but can be expensive so they should only be used if economically justifiable or if it serves a technical requirement such as the possibility of using the shoulder for occasional traffic use. If the base material is plastic or cement/lime treated, no surfacing is needed on the shoulder, but if the base is unbound, a sand seal, a surface dressing, or asphalt surfacing is required. These constructions are shown in Chapter 4.6.2 as Type B for thin bases or Type X in Chapter 4.6.6 for narrow shoulders.

Alternatively, the shoulder can constructed using different materials to the pavement. These constructions are more complex but generally cheaper. They are shown in Chapter 4.6 above as Types A, C, D and E. A range of materials can be used, as shown in the following Table 4.2.

Table 4.2 Shoulder Material Requirements

Material	Low Traffic TC1	Medium Traffic TC3 to TC30	High Traffiic TC30 and Higher
Cement/lime treated			Be sub-base quality Comply with Chart HM1
Natural gravel	CBR 15% at 95% MDD AASHTO T180	CBR 20% at 95% MDD Comply with Chart GM4 5 < PI < 30	CBR 30% at 95% MDD AASHTO T180 Comply with chart GM4
Natural gravel of volcanic origin (scoria)	CBR 15% at 95% MDD AASHTO T180	CBR 20% at 95% MDD AASHTO T180 Comply with Chart GM4 5 < PI < 30 200 < PM < 1200	n/a
Recycled materials	CBR 15% at 95% MDD AASHTO T180	CBR 20% at 95% MDD AASHTO T180 LL < 40 1.5 < LS < 6.5	CBR 30% at 95% MDD AASHTO T180 LL < 35 1.5 < LS <4.5
Earth	Can be used for earth and gravel roads	Can be used in lower layers if it is of S3 quality, but not at the surface	
Concrete pavers, cobble stones, hand packed stone	See Volume 3 Part 5		

5 Low-Volume Sealed Roads and Non-Motorised Traffic Lanes

5.1 General

This chapter presents the standard pavement structures for low volume sealed roads (LVSRs) and for non-motorised traffic (NMT) lanes in urban areas. For pavement design purposes in Kenya, low volume roads are defined as roads whose design traffic has been estimated as 1 million equivalent standard axles or less. This is for a 10-to-15-year design period. If a 20-year design period is considered, the design traffic could be greater than 1 MCESA, in which case the road is no longer considered as low-volume and should be designed in accordance with the pavement structures provided in Chapter 4.

There are 5 design traffic classes for low volume sealed roads (LVSRs) as shown in Table 5.1.

Table 5.1 Design Traffic Classification for Low-volume Roads

Design Traffic Class	Cumulative Equivalent Standard Axles
TC0.025	< 25,000
TC0.10	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.50	250,000 – 500,000
TC1	500,000 – 1 million

5.2 Standard Pavement Structures for LVSRs

5.2.1 Catalogues

Eleven pavement combinations and the applicable traffic classes are as shown in Table 5.2. For each of the 11 types of pavements considered, the design for each class of soil and each class of traffic is presented in one chart. Rigid pavement options are available in RDM Volume 3 Part 5. Brief comments on the peculiarities, advantages, and disadvantages of each type of pavement have been given. The pavement materials required for use in each chart have been indicated and referenced to materials specification charts (See RDM 3.3).

Selection of the possible types of pavements has been based on the following principles:

- The sub-base material should not be of unnecessarily higher standard than the base material.
- It is unsafe to place expensive bound materials on natural materials which are often deformable and heterogeneous, or on materials whose moduli are less than one tenth of the modulus of the base.

Table 5.2 Guide to Pavement Type Selection

No.	Pavement Materials		Traffiic Application of Catalogue
	Base	Sub-base	
LV1	G30	Not required	TC0.1, TC0.025
LV2	G45	G25	TC0.5, TC0.25
LV3	G80	G30	TC1
LV4	HIG60	Not required	TC0.1, TC0.025
LV5	HIG100	G25	TC0.5, TC0.25
LV6	HIG160	G30	TC0.5, TC0.25
LV7	HIG100	HIG50	TC1
LV8	HIG160	HIG60	TC1
LV9	BSM50	G25	TC1, TC0.5, TC0.25
LV10	BSM50	G30	TC1
LV11	HPS	G30	TC1

Not required = the traffic is so low that the base layer without any sub-base is already sufficient.

For low volume urban roads, all the structures listed in Table 5.2 apply with the major alteration that ACII (30 mm after compaction) is the preferred surfacing ahead of cold mix asphalt. Surfacing dressing should be used as a last option given the difficulty in construction in urban areas and trafficking restrictions.

5.2.2 Non-Motorised Traffic (NMT) Lanes

In providing pavement structures for NMT lanes, a key determinant is whether the NMT lane is accessible by motorised traffic or if it is cordoned-off (e.g., by use of kerbing or bollards) from motorised traffic.

On urban roads, access by motorised traffic is sometimes permissible and occasional use should be catered for. This is because in urban environments, motorised traffic can run on the NMT lanes either as emergency vehicles or illegally. For this, suitable and cost-effective structure types are LV2, LV4, LV9, and LV11. The preferred surfacing is 30 mm thick AC II.

Where motorised traffic cannot access the NMT lane legally (or illegally), the structure types LV1 or LV4 with single surface dressing, double sand seal, double slurry seal, are sufficient and cost-effective.

5.2.3 Method of Use

The following steps shall be taken in the use of these charts to arrive at a suitable pavement structure for a given set of conditions:

1. Undertake traffic volume surveys as described in RDM 1.2.
2. Undertake axle load surveys as described in RDM 1.2.
3. Determine the design traffic class as summarised in section 2.5 and described in RDM 3.3.
4. Undertake ground investigations as described in RDM 3.1.
5. Determine design subgrade class as described in RDM 3.3.
6. Review drainage and environmental considerations as described in section 2.7 and 2.11.
7. Conduct a study of available road construction materials, including materials for capping.
8. Prepare pavement design options, based on the available materials.
9. Select a suitable pavement foundation (see RDM Volume 3 Part 3).
10. Conduct cost and technical comparisons of the pavement design options.
11. Select the most appropriate pavement design and prepare construction specifications.

5.2.4 Pavement Structure Type LV1

This is a flexible pavement structure is highly economic for design traffic TC0.025 and TC0.1. However, base quality natural gravels are scarce in Kenya. In many cases, mechanical stabilisation may be necessary to achieve a material complying with the specification.

Materials

Base Materials: Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, scarified pavement material or milled bituminous pavement material.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* see Charts SU1 to SU5. Use as double or triple seals, or combination seals.
- *Natural gravels (G30) for base:* see Chart GM8.
- *Capping material:* see GM2, GM3, GM4, and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV1**

SURFACING:	Double Surface Dressing or Other LVSR Bituminous Surfacing
BASE:	Natural Gravel (G30)
SUB-BASE:	-

		TC0.025	TC0.1		
F1		DSD 150	DSD 200	TECHNICALLY UNSUITABLE	
F2		DSD 125	DSD 175		
F3		DSD 100	DSD 125		
F4		DSD 100	DSD 100		

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing

5.2.5 Pavement Structure Type LV2

This is a flexible pavement structure is highly economic for use for design traffic TC0.25 and TC0.5. However base quality natural gravels are scarce in Kenya. In many cases, mechanical stabilisation may be necessary to achieve a material complying with the specification.

Materials

- *Base Materials:* Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, scarified pavement material or milled bituminous pavement material.
- *Sub-base Materials:* Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, and clayey/silty sand.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* see Charts SU1 to SU5. Use as double or triple seals, or combination seals.
- *Natural gravels (G45) for base:* see Chart GM9 or *Graded crushed stone for base:* Chart GM11 (Class E).
- *Natural gravels (G25):* see Chart GM7.
- *Capping material:* see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV2**

SURFACING:	Double Surface Dressing or Other LVSR Bituminous Surfacing
SUB-BASE:	Natural Gravel (G50)
SUBBASE:	Natural Gravel (G25)

		TC0.25	TC0.5		
F1	ECONOMICALLY UNJUSTIFIED	DSD 150 100	DSD 150 150	TECHNICALLY UNSUITABLE	
F2		DSD 200	DSD 150 125		
F3		DSD 150	DSD 175		
F4		DSD 150	DSD 175		

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing or Surfacing for Low Volume Roads.

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5
Low-volume Sealed Roads and Non-motorised Traffic Lanes

5.2.6 Pavement Structure Type LV3

This is a flexible pavement structure is highly economic for design traffic TC1. However base quality natural gravels are scarce in Kenya. In many cases, mechanical stabilisation may be necessary to achieve a material complying with the specification.

Materials

- *Base Materials:* Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, scarified pavement material, wet or dry-bound Macadam, or milled bituminous pavement material.
- *Sub-base Materials:* Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, and clayey/silty sand, scarified pavement material or milled bituminous pavement material.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* see Charts SU1 to SU5. Use as double or triple seals, or combination seals.
- *Natural gravels (G80), or graded crushed stone (GCS-D), or wet-bound or dry-bound Macadam for base:* see Chart GM10, or Chart GM11 (Class D), or Chart GM13.
- *Natural gravels (G30):* see Chart GM8.
- *Capping material:* see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV3**

	SURFACING:	Double Surface Dressing or Other LVSR Bituminous Surfacing
	BASE:	Natural Gravel (G80), or GCS-D, or Wet/Dry-bound Macadam
	SUB-BASE:	Natural Gravel (G30)

		TC1.0
F1	ECONOMICALLY UNJUSTIFIED	DSD 150 175
F2		DSD 150 125
F3		DSD 125 100
F4		DSD 175

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing.

5.2.7 Pavement Structure Type LV4

This pavement structure is comparatively economic for design traffic TC0.025 and TC0.1, and materials suitable for treatment can be found in most regions of Kenya. However, specific difficulties may arise in arid areas due to lack of water, excessive evaporation, and shrinkage.

Materials

- *Base Materials:* Hydraulically improved granular material or clayey/silty sand. The natural gravel can be lateritic gravel, quartzitic gravel, or other suitable gravel of G20 or G25 quality.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* see Charts SU1 to SU5. Use as double or triple seals, or combination seals.
- *Hydraulically improved granular material (HIG60) for base:* see Chart HM2.
- *Capping material:* see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV4**

SURFACING:	Double Surface Dressing or Other LVSR Bituminous Surfacing
BASE:	Hydraulically Improved Granular Material (HIG60)
SUB-BASE:	-

		TC0.025	TC0.1		
F1		DSD 125	DSD 175	TECHNICALLY UNSUITABLE	
F2		DSD 100	DSD 150		
F3		DSD 100	DSD 125		
F4		DSD 100	DSD 100		

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing

5.2.8 Pavement Structure Type LV5

This pavement structure is comparatively economic for design traffic TC0.25 and TC0.5, and materials suitable for treatment can be found in most regions of Kenya. However, specific difficulties may arise in arid areas due to lack of water, excessive evaporation, and shrinkage.

Materials

- *Base Materials:* Hydraulically improved natural gravel or clayey/silty sand. The natural gravel can be lateritic gravel, quartzitic gravel, or other suitable gravel of G20 or G25 quality. If the foundation class is F4 and the treated material is clayey sand or other fine material, then the base thickness may be reduced to 100 mm.
- *Sub-base Materials:* Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, and clayey/silty sand.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* see Charts SU1 to SU5. Use as double or triple seals, or combination seals.
- *Hydraulically improved granular material (HIG100) for base:* see Chart HM3.
- *Natural gravels (G25) or hand packed stone for sub-base:* see Chart GM7 or GM12.
- *Capping material:* see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV5**

SURFACING:	Double Surface Dressing or Other LVSR Bituminous Surfacing
BASE:	Hydraulically Improved Granular Material (HIG100)
SUB-BASE:	Natural Gravel (G25), or Hand Packed Stone*

		TC0.25	TC0.5		
F1	ECONOMICALLY UNJUSTIFIED	DSD 125 100	DSD 125 150	TECHNICALLY UNSUITABLE	
F2		DSD 125 100	DSD 125 125		
F3		DSD 125	DSD 125 100		
F4		DSD 125	DSD 125		

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing. For hand packed stone sub-base, the thickness shall be at least 150 mm.

5.2.9 Pavement Structure Type LV6

This pavement structure is comparatively economic for design traffic TC1, and materials suitable for treatment can be found in most regions of Kenya. However, specific difficulties may arise in arid areas due to lack of water, excessive evaporation, and shrinkage.

These structures are essentially flexible. Care must be taken to ensure that the base material is not too rigid, as this would result in overstressing and cracking of the base. The base modulus should not exceed 1000 MPa and therefore the UCS must not exceed 2.5 MPa.

Materials

- *Base Materials:* Hydraulically improved natural gravel or clayey/silty sand. The natural gravel can be lateritic gravel, quartzitic gravel, or other suitable gravel of minimum quality G25 before treatment.
- *Sub-base Materials:* Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, and clayey/silty sand, scarified pavement material or milled bituminous pavement material.

Materials Specifications and Construction Procedures (see RDM 3.3)

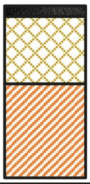
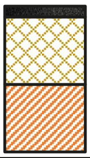
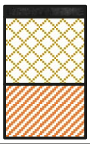
- *Surfacing:* see Charts SU1 to SU5. Use as double or triple seals, or combination seals.
- *Hydraulically improved granular material (HIG160) for base:* see Chart HM4.
- *Natural gravel (G30) or hand packed stone for sub-base:* See Chart GM8 or Chart GM12.
- *Capping material:* see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV6**

	SURFACING:	Double Surface Dressing or Other LVSR Bituminous Surfacing
	BASE:	Hydraulically Improved Granular Material (HIG160)
	SUB-BASE:	Natural Gravel (G30), or Hand Packed Stone*

		TC1.0
F1	ECONOMICALLY UNJUSTIFIED	 DSD 125 175
F2	ECONOMICALLY UNJUSTIFIED	 DSD 125 125
F3	ECONOMICALLY UNJUSTIFIED	 DSD 125 100
F4	ECONOMICALLY UNJUSTIFIED	 DSD 125

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing. For hand packed stone sub-base, the thickness shall be at least 150 mm.

5.2.10 Pavement Structure Type LV7

This pavement structure is comparatively economic for design traffic TC0.25 and TC0.5, and materials suitable for treatment can be found in most regions of Kenya. However, specific difficulties may arise in arid areas due to lack of water, excessive evaporation, and shrinkage.

These structures are essentially flexible. Care must be taken to ensure that the base material is not too rigid, as this would result in overstressing and cracking of the base. The base modulus should not exceed 1000 MPa and therefore the UCS must not exceed 2.5 MPa.

Materials

- *Base Materials:* Hydraulically improved natural gravel or clayey/silty sand. The natural gravel can be lateritic gravel, quartzitic gravel, or other suitable gravel of minimum quality G20 before treatment.
- *Sub-base Materials:* Hydraulically improved natural gravel or clayey/silty sand. The material before treatment should be of G15 or G20 quality.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* see Charts SU1 to SU5. Use as double or triple seals, or combination seals.
- *Hydraulically improved granular material (HIG100) for base:* see Chart HM3.
- *Hydraulically improved granular material (HIG50) for sub-base:* see Chart HM1.

Capping material: see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV7**

SURFACING:	Double Surface Dressing or Other LVSR Bituminous Surfacing
BASE:	Hydraulically Improved Granular Material (HIG100)
SUB-BASE:	Hydraulically Improved Granular Material (HIG50)

		TC0.25	TC0.5		
F1	ECONOMICALLY UNJUSTIFIED	DSD 125 100	DSD 125 125	TECHNICALLY UNSUITABLE	
F2		DSD 125 100	DSD 125 100		
F3		DSD 125	DSD 125 100		
F4		DSD 125	DSD 125		

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	**-**	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing

5.2.11 Pavement Structure Type LV8

This pavement structure is comparatively economic for design traffic TC1, and materials suitable for treatment can be found in most regions of Kenya. However, specific difficulties may arise in arid areas due to lack of water, excessive evaporation, and shrinkage.

These structures are essentially flexible. Care must be taken to ensure that the base material is not too rigid, as this would result in overstressing and cracking of the base. The base modulus should not exceed 1000 MPa and therefore the UCS must not exceed 2.5 MPa.

Materials

- *Base Materials:* Hydraulically improved natural gravel or clayey/silty sand. The natural gravel can be lateritic gravel, quartzitic gravel, or other suitable gravel of minimum quality G25 before treatment.
- *Sub-base Materials:* Hydraulically improved natural gravel or clayey/silty sand. The material before treatment should be of G20 or G25 quality.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* see Charts SU1 to SU5. Use as double or triple seals, or combination seals.
- *Hydraulically improved granular material (HIG160) or hydraulically modified stone (HMS1) for base:* see Chart HM4 or HM5.
- *Hydraulically improved granular material (HIG160) sub-base:* see Chart HM2.

Capping material: see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV8**

SURFACING:	Double Surface Dressing or Other LVSR Bituminous Surfacing
BASE:	Hydraulically Improved Granular Material (HIG160)
SUB-BASE:	Hydraulically Improved Granular Material (HIG60)

		TC1.0
F1	ECONOMICALLY UNJUSTIFIED	DSD 125 150
F2		DSD 125 100
F3		DSD 125 100
F4		DSD 125

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing

5.2.12 Pavement Structure Type LV9

This type of pavement structure is comparatively expensive due to the use of expensive bitumen emulsion to treat the neat materials. Nevertheless, this type of pavement offers protection to materials with fines that are highly susceptible to moisture change (in wet climatic conditions).

In arid areas, materials treated with bitumen are generally preferable to those treated with cement.

These structures are flexible in nature.

In order for this type of pavement to perform satisfactorily, special care should be taken to ensure uniformity and compaction of the mix.

Materials

- *Base Materials:* Bitumen emulsion treated natural gravel or clayey/silty sand, scarified pavement material or milled bituminous pavement material. The natural gravel can be lateritic gravel, quartzitic gravel, or other suitable gravel of G30 minimum quality. Pre-treatment with lime may be required to reduce the PI of the natural material.
- *Sub-base Materials:* Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, and clayey/silty sand.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* see Charts SU1 to SU5. Use as double or triple seals, or combination seals.
- *Bitumen stabilised material (BSM50) for base:* see Chart BM1.
- *Natural gravels (G25) or hand packed stone for sub-base:* see Chart GM7 or GM12.
- *Capping material:* see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV9**

SURFACING:	Double Surface Dressing or Other LVSR Bituminous Surfacing
BASE:	Bitumen Stabilised Material (BSM50)
SUB-BASE:	Natrual Gravel (G25), or Hand Packed Stone*

		TC0.25	TC0.5	TC1.0	
F1	ECONOMICALLY UNJUSTIFIED	DSD 100 125	DSD 100 175	DSD 100 225	TECHNICALLY UNSUITABLE
F2		DSD 100 100	DSD 100 125	DSD 100 175	
F3		DSD 100 100	DSD 100 100	DSD 100 125	
F4		DSD 100	DSD 100	DSD 100	

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	**-**	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. DSD = Double Surface Dressing. For hand packed stone sub-base, the thickness shall be at least 150 mm except for TC1, where the thickness shall be at least 200 mm.

5.2.13 Pavement Structure Type LV10

This type of pavement structure is comparatively expensive due to the use of expensive bitumen emulsion to treat the neat materials. Nevertheless, this type of pavement offers protection to materials with fines that are highly susceptible to moisture change (in wet climatic conditions).

In arid areas, materials treated with bitumen are generally preferable to those treated with cement.

These structures are flexible in nature.

In order for this type of pavement to perform satisfactorily, special care should be taken to ensure uniformity and compaction of the mix.

Materials

- *Base Materials:* Bitumen emulsion treated natural gravel or clayey/silty sand, scarified pavement material or milled bituminous pavement material. The natural gravel can be lateritic gravel, quartzitic gravel, or other suitable gravel of G30 minimum quality. Pre-treatment with lime may be required to reduce the PI of the natural material.
- *Sub-base Materials:* Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, and clayey/silty sand.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* - Asphalt concrete Type I (9.5 mm nominal aggregate and 30 mm compacted layer thickness) + single surface dressing - See Chart SU9, and SU1.
- *Bitumen stabilised material (BSM50) for base:* see Chart BM1.
- *Natural gravels (G30) or hand packed stone for sub-base:* see Chart GM8 or GM12.
- *Capping material:* see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE — TYPE LV10

SURFACING:	Asphalt Concrete Type I + Single Surface Dressing
BASE:	Bitumen Stabilised Material (BSM50)
SUB-BASE:	Natural Gravel (G30), or Hand Packed Stone*

		TC1.0
F1	ECONOMICALLY UNJUSTIFIED	30 75 225
F2		30 75 175
F3		30 75 125
F4		30 75

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	**-**	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. For hand packed stone sub-base, the thickness shall be at least 150 mm except for F1, where the thickness shall be at least 200 mm.

5.2.14 Pavement Structure Type LV11

This is a flexible pavement structure; highly economic for design traffic TC1, especially in urban areas and other areas with frequent traffic activity such as market towns. In areas where gravel of base quality to carry traffic of TC1 is scarce and yet large, fractured rock is available, this is an ideal type of pavement. Moreover, in urban areas this provides an opportunity to employ local people in the production of construction stone and laying/packing the stone on the road. If enough stone masons are employed the process is rapid, but if there are an insufficient number of stone masons the process can be rather slow. The stones must be 'wedged' into place by the application of specified filler aggregate and smaller stone chips between the stones.

This pavement requires a fairly thick bituminous surfacing (25-35 mm thick cold mix asphalt) if a good riding quality is to be guaranteed. As a result of these superior materials, if constructed well it is a very durable pavement.

Materials

- *Base Materials:* Stones from trachyte, basalt, granite, hard sandstone or wet or dry-bound Macadam.
- *Sub-base Materials:* Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, and clayey/silty sand.

Materials Specifications and Construction Procedures (see RDM 3.3)

- *Surfacing:* - Asphalt concrete Type I (9.5 mm aggregate and 50 mm compacted layer thickness) + single surface dressing - See Chart SU9, and SU1.
- *Hand packed stone or wet or dry-bound Macadam for base:* see Chart GM12, or Chart GM13.
- *Natural gravels (G30) or hand packed stone for sub-base:* see Chart GM8 or GM12.
- *Capping material:* see GM2, GM3, GM4 and GM6.

MINISTRY OF ROADS AND TRANSPORT

STANDARD PAVEMENT STRUCTURES FOR LOW VOLUME ROADS

STANDARD PAVEMENT STRUCTURE **TYPE LV11**

SURFACING:	Asphalt Concrete Type I + Single Surface Dressing
BASE:	Hand Packed Stone, or Wet/Dry-bound Macadam
SUB-BASE:	Natural Gravel (G30), or Hand Packed Stone*

		TC1.0
F1	ECONOMICALLY UNJUSTIFIED	50 150 125
F2		50 150 100
F3		50 150
F4		50 150

TRAFFIC CLASSIFICATION

Design Traffic Class	Design Traffic Range (CESA)
TC0.025	<25,000
TC0.1	25,000 - 100,000
TC0.25	100,000 – 250,000
TC0.5	250,000 – 500,000
TC1.0	500,000 – 1,000,000

SUBGRADE CLASSIFICATION

Subgrade Class	CBR Range (%)	Median CBR (%)
S1	2 – 5	3.5
S2	5 – 10	7.5
S3	7 – 13	10
S4	10 – 18	14
S5	15 – 30	22.5
S6	30 – 60	45

FOUNDATION CLASSIFICATION

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class
F1	75	S3
F2	95	S4
F3	130	S5
F4	200	S6
F5	400	-

IMPROVED SUBGRADE

Native Subgrade	**S1**			**S2**			**S3**			**S4**	
Capping Material	G8	G10	G14	G10	G14	G14	G14	G23	G45	G23	G45
Thickness (mm)	375	400	425	150	150	175	150	150	150	150	200
New Subgrade	S2	S3	S4	S3	S3	S4	S4	S4	S5	S5	S6
Foundation Class	**-**	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

*Other capping options available in RDM 3.3. For hand packed stone sub-base, the thickness shall be at least 150 mm.

6 Design of Unpaved Roads

6.1 General

Unpaved roads are formed or engineered from natural, in-situ soil and covered with gravel if the soil is unable to carry the required traffic. When no gravel material is added to the formed road, it is referred to as an earth road. When gravel is added, it is referred to as a gravel road. They do not include unimproved tracks on bare soil. When constructed well, they can carry low levels of traffic reliably and safely and at lower cost than a sealed road, but because the earth or gravel wears away, they need regular addition of material and frequent maintenance. Unpaved roads can be constructed and maintained using labour-based methods and locally available skills, materials, and equipment.

Traffic is counted as heavy commercial vehicles per day (HCV/d) which consists of commercial vehicle whose tare weight exceeds 6720 pounds (3048 kg) as detailed in RDM 1.2. Other smaller vehicles should not be included in the count. Normal traffic counting procedures should be followed.

6.2 Earth Roads

6.2.1 Suitability

Earth roads are engineered roads that typically consist of the excavated in-situ material (subgrade) in the vicinity of the alignment which is shaped to form a camber that is generally raised above existing ground level and includes side drainage. When constructed with adequate quality materials, provided with a proper camber (4-6%), adequately drained and properly maintained, the performance is enhanced, and they will normally carry higher volumes of traffic than unformed roads.

Earth roads are appropriate in the following situations:

1. Very low traffic, typically less than 25 HCV/d.
2. Soil which does not ravel or generate large quantities of dust when dry.
3. Soil which does not become weak or slippery when wet.

It is normally obvious during site visits if the natural, in-situ soil is capable of carrying these very low traffic levels. Simple practical hand tests can be used on site by an engineer to check that the plasticity is not too high or that the material is not slippery. Visual methods determine the size of soil particles down to sizes which can be seen with the naked eye (a broad classification only) and the colour of the soil. Manual methods are applied to fine-grained soils to determine:

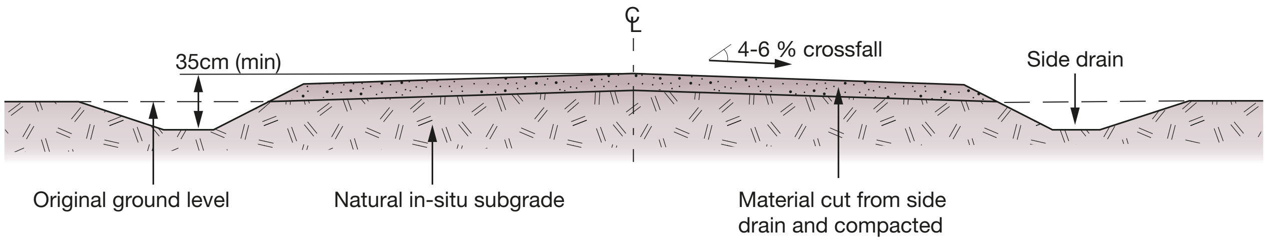
1. Dry-state stability do lumps break apart easily when dry or do they resist pressure? If they resist pressure, then they are clayey and could present problems when wet.
2. Reaction of the soil, particularly silty ones, to shaking in the hand; For silty soils, water/moisture will collect on the top surface. For clayey soils, only minor change in moisture will be seen on the top surface.
3. The plasticity of a soil and its silt and clay content by kneading. Soils which can be rolled and formed into a ball by hand are usually clayey or silty and therefore not desirable for earth roads.
4. The proportion of sand, silt, and clay by rubbing a small sample between the fingers, sometimes under water; Sandy soils will feel rough (desirable for earth roads), silty soils will feel partly smooth and partly rough, clayey soils will feel smooth (undesirable).

6.2.2 The Design of Earth Roads

The design of earth roads consists of ensuring adequate crown height, a minimum in-situ soil strength, and a minimum acceptable thickness.

The key to successful earth roads is to ensure that the formation is done well to ensure that the road surface is above the general surrounding ground and a minimum crown height of 0.35 m is achieved as shown in Figure 6.1. The minimum thickness of in-situ material that is formed, scarified, and compacted should be at least 150 mm. Adequate compaction (minimum of 95% MDD AASHTO T180) must be undertaken during initial construction. Although earth roads can be constructed from in-situ soils with an in-service CBR of less than 15%, the high maintenance requirements, costs, logistics and risk related to the lower strength soils mean that a soil of CBR 15% should normally be used as the minimum target in-situ soil strength. This will require a significant proportion of sand and gravel in the natural soil. It should also be noted that in dry weather, and when surface water can run-off quickly, the in-situ CBR is likely to be considerably higher and the capacity of the earth road increases rapidly. Conversely, in the saturated state its capacity will be very low.

Figure 6.1 Formation of an Earth Road



6.2.3 Spot Improvement

The design of high-volume roads normally result in a road with a durable sealed surface along its entire length. However, a continuous length of earth or gravel road may be slippery on hills and tight curves, and dusty through villages. Consideration should be given to improving such sites to low-volume sealed standard (see Chapter 5), or to the use of non-erodible and dust-free surface, while leaving the rest of the road unpaved, to produce a road that is safe, healthy and cost-effective to construct and maintain.

Such sites are referred to as spot improvements. Spot improvements may also include works to solve the problems caused by expansive clays, ground water and soil creep.

Spot improvement may can bealso be undertaken by the use of Do-Nou technology or by the use of low-volume sealed standards presented in Chapter 5.

6.3 Gravel Roads

A gravel road consists of a wearing course and a structural layer (base) which covers the in-situ material. The minimum thickness of the structural layer is maintained in service by providing a wearing course throughout the design life of the road.

If in-situ soil is unable (less than S5 subgrade) to carry the traffic, it is often appropriate to construct a gravel pavement to protect the soil below.

Gravel roads are appropriate if all of the following apply:

1. Material addition and maintenance (surface repair, drain cleaning) are guaranteed.
2. Good quality gravel can be found within a reasonable distance in sufficient quantities for construction and up to 10 years of regravelling.
3. Annual rainfall is less than 2000 mm.
4. Traffic levels are low, typically less than 500 HCV/d.
5. The maximum gradient along the road is 10%.
6. The road is not in a residential area where dust may be unsafe and unhealthy.
7. Gravel loss is expected to be less than 50 mm per year.

It is emphasised that in order for gravel roads to perform well, quality control must be ensured in the selection of suitable gravel in accordance with the specifications in Table 6.3 and materials Chart GM5. Importantly, adequate compaction (minimum of 95% MDD AASHTO T180) must be undertaken during initial construction, maintenance grading, and regravelling.

6.4 Gravel Road Pavements

Gravel roads cannot be designed in the same way as paved roads, since there is no proper failure criterion for a gravel wearing course, and the damaging effects of different axles on gravel roads are not well-known. The required gravel thickness shall be determined as follows:

1. Determine the minimum thickness necessary to avoid excessive compressive strain in the subgrade (D1).
2. Determine the extra thickness needed to compensate for the gravel loss under traffic during the period between regravelling operations (D2).
3. Determine the total gravel thickness required by adding the above two thicknesses (D1+D2).

The pavement (structural layer as shown in Figure 6.2) of a gravel road depends upon the strength of the in-situ soil from which the cross-section has been formed, as shown in Table 6.1 and the capping options for S1 subgrade as shown in Table 6.2. It is emphasised that the thicknesses in Table 6.1 do not include the thickness of the wearing. Wearing course materials specifications and thickness should be provided separately as discussed in Chapter 6.5.

To ensure consistency and quality, gravel should always be placed and compacted in layers with compacted thickness of 150 mm and should extend onto the shoulders of the road.

Table 6.1 Gravel Pavement Structures (D1)

Gravel Road Pavement Structures (~~excluding wearing course, 10-year design life~~)				
Subgrade Strength Class	**Initial ADT of heavy commercial vehicles** (both directions)			
	<15	**15-50**	**50-150**	**150-500**
S1	Improve to S2 subgrade using the foundation options below, then apply gravel layers required for S2			
S2	150 G20	200 G20	250 G20	300 G20
S3	150 G20	200 G20	225 G20	275 G20
S4	125 G20	175 G20	200 G20	250 G20
S5*	150 S5	150 S5	200S5	225 S5
S6	When a CBR of 30 or higher is available, then scarify to 150 mm depth, shape and compact to specifications.			

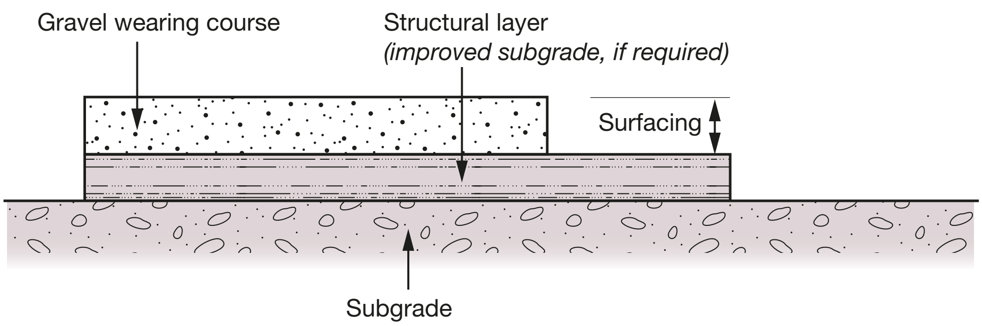
** For S5 subgrade, scarify to the depth in this chart for S5 subgrade, shape and compact to specifications.*
***Notes:** The initial ADT of heavy commercial vehicles should be obtained from 7-day counts as described in Volume 1 Part 2 and is the sum of both directions. The term heavy commercial vehicle shall refer to a commercial vehicle whose tare weight exceeds 6720 pounds (3048 kg).*

Table 6.2 Foundation for Gravel Road Pavements

Foundation for Gravel Road Pavement (minimum S2)			
Native Subgrade Class	**Improved Subgrade/Capping**		**New Subgrade Class**
	Material	**Minimum Thickness** (mm)	
S1	G8	375	S2
	G10	300	S2
	G14	250	S2

A minimum CBR (after 4 days' soak) of 20 is required. However, for very light traffic, less than 15 commercial vehicles/day, a minimum CBR of 15 may be accepted if no better material can be found economically. The grading modulus should be between 0.8 and 2.0.

Figure 6.2 Pavement Structure of Gravel Roads



6.5 Materials for Gravel Wearing Course

Materials for gravel wearing course should comply with the following somewhat conflicting requirements:

- They should have a sufficient cohesion to bind the particles and prevent the surface from ravelling and becoming corrugated in dry seasons.
- The amount of fines and the plasticity should be limited, so as to avoid the occurrence of a slippery surface in wet weather.

Ideally, the plasticity index should not exceed 15 in wet areas. Unfortunately, more plastic gravels are generally found in the wettest areas. For dry areas, a minimum plasticity index of 10 is required. Otherwise, corrugations and gravel loss will be excessive.

To account for the scarcity of gravels that meet the plasticity index requirements, the following method considers both plasticity and grading (Equation 6.1 and Equation 6.2). This enables the use of, for example, low plasticity gravel that have more fines or high plasticity gravels with low fines content. Ideally, gravel material should comply with the following specifications shown in Table 6.3, but failing this blending should be undertaken and the selection undertaken in accordance with Figure 6.3. Figure 6.3 shows the same specification graphically, and also indicates the likely performance if the material is non-compliant. This specification uses the properties of Grading Modulus and Plasticity Product, which are defined below.

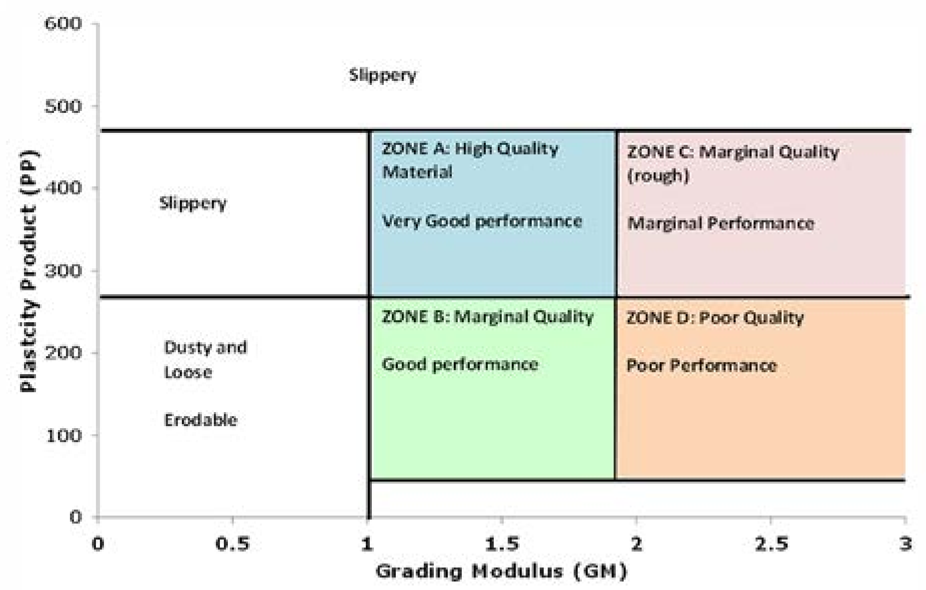
The minimum initial wearing course thickness shall be 150 mm on completion of construction. This is in addition to the pavement thicknesses shown in Table 6.1. Regravelling should be undertaken when the wearing course thickness is 50 mm or less.

Table 6.3 Specifications for Gravel Wearing Courses

Property	Specification
Maximum size (mm)	37.5
Oversize Index (% retained on 37.5mm sieve)	< 5%
Plasticity Product (PP)	280 – 480 [1]
Grading Modulus (GM)	1.0 – 1.9
Soaked CBR at 95% Mod AASHTO	>20% [2]

Notes:* *1:* *PP can be relaxed to 50-480 if traffic is less than 15 HCV/d, annual rainfall is over 500 mm, and better material cannot be found* *2:* *Soaked CBR can be relaxed to >15% if traffic is less than 15 HCV/d and better material cannot be found

Figure 6.3 Gravel Material Specification



1
2
3
4
5
6
Design of Unpaved Roads

Grading Modulus (GM)

$$GM = 3 - \left(\frac{P_{2.36} + P_{0.425} + P_{0.075}}{100}\right)$$

Equation 6.1

Where,

$P_{2.36}$ = the percentage passing the 2.36 mm sieve

$P_{0.425}$ = the percentage passing the 0.425 mm sieve

$P_{0.075}$ = the percentage passing the 0.075 mm sieve

(all using the wet sieving method)

Plasticity Product (PP)

$$PP = PI \times P_{0.075}$$

Equation 6.2

Where,

PI = the Plasticity Index of material passing the 0.425 mm sieve

$P_{0.075}$ = the percentage passing the 0.075 mm sieve

If compliant gravel is not available, it is possible to blend materials. For example, a non-plastic river gravel can be blended with a soil with high PI to achieve compliance. It is necessary to trial such a blended material before it is used in large quantities.

If blending cannot be done, material that is close to Zones A and B (Figure 6.3) can be used in areas of moderate rainfall, moderate gradients, and low traffic.

In case the gravels specified in Table 6.3 and Figure 6.3 cannot be obtained, then gravels Class 1 (HCV/d > 150) and Class 2 (HCV/d < 150) as specified in materials Chart GM5 may be used.

Predictive equations are difficult to use and can be inaccurate. Planning maintenance schedules based on results from these equations can lead to lost access and a badly damaged road. It is recommended that gravel thickness is measured at specific sites along the road at least once a year and regravelling is then planned before the thickness is less than 50 mm with the risk of damage to the cross-section.

Typical gravel loss is 10-50 mm per year and can be managed under a good maintenance system. If gravel loss, either along the entire road or at specific sites, is more than 50 mm per year, consideration should be given to constructing an improved non-erodible surface.

7 Pavement Drainage

7.1 General

This chapter provides summary guidance on the drainage of surface and ground water. Detailed guidance is contained in RDM Volume 2 Part 2. Additionally, the design of side drains, and methods of protecting slopes and ditches from erosion, and the design of cross drainage (culverts) is covered with in RDM Volume 2 Part 2.

7.2 Drainage of Surface Water

Although the short- and long-term effects of climate change are only now being measured and still remain unpredictable, climate change is likely to lead to an increase in surface and sub-surface water.

It is therefore very important to comply with all standards and specifications and to ensure that all parts of a road, including the structure, the drainage system, and the erosion control measures are well designed for the probable increases in rainfall volume and intensity.

It is most efficient if all rainfall landing on the surface of a carriageway is disposed of through the surface drainage system and away from the road.

Any water that permeates into the carriageway must be disposed of through the internal drainage system.

The carriageway surface drainage system comprises the crown the road, the camber of the carriageway and the camber of the shoulder. The water is then shed into the side drains.

The camber of the shoulder is often slightly steeper than that of the pavement alongside, in order to shed the water more quickly and to differentiate between the riding surface and the shoulder.

The crown of a road should be sharp rather than rounded, so that water is less likely to pond and permeate into the pavement. Recommended cambers are shown in the following Table 7.1.

Table 7.1 Recommended Camber for Pavement Edges

Pavement Construction	Pavement Camber	Shoulder Camber
Bituminous and concrete	2.5%	4-6%
Earth and gravel – pavement High plasticity and reliable maintenance	3-4%	4-6%
Earth and gravel – pavement Low plasticity or reliable maintenance	3-4%	4-5%

If a road has a sealed surface, but the shoulders are to remain unsealed, it is recommended that the seal is extended onto the shoulder by 200-300 mm in order to reduce the quantity of water that might permeate into the pavement.

More details on the carriageway surface drainage system are given in RDM Volume 2 Part 2.

7.3 Sub-surface Drainage

7.3.1 General

Ground water may be encountered in the following situations:

- In cuttings, a water table with a level above or near formation, or springs.
- In low-lying or poorly drained flat areas, a water table near formation, likely to affect the subgrade by capillary rise.

7.3.2 Mechanism and Remedies

Some rainfall lands on the surface of a carriageway and permeates downwards and laterally into the carriageway before it can be disposed of into the surface drainage system. In practice, unless the entire pavement is constructed from impermeable materials, it is impossible to prevent water entering the carriageway as the road is used and deterioration starts.

The water that permeates into the carriageway can weaken and damage the pavement. Drainage vertically downwards through the foundation cannot be assured, so it is therefore necessary to remove this water through the shoulder as part of the sub-surface drainage system.

If the shoulders are completely impermeable, often referred to as a trench, water will be trapped, and the pavement will rapidly waterlog and fail.

In the past, cuts were made in such impermeable shoulders at intervals to allow water to drain out of the trench, but these would often block with sediment, and cause waterlogging and failure.

It is therefore necessary to provide a drainage system that can dispose of water at all points along the length of the road. This can be done in one or a combination of the following ways:

1. The crossfalls of the surface and lower layers must be continuously towards the side of the road.
2. The surface of the shoulder can be constructed from impermeable material so that all water is shed off the surface of the road into the side drain.
3. A seal can be constructed on top of permeable shoulder material, again to shed water off the surface of the road.
4. The base and/or sub-base of the shoulder can be constructed of permeable material, so that any water that does enter the carriageway can flow through these lower layers towards the side of the road.
5. A thin layer of permeable material can be constructed within an otherwise impermeable shoulder to carry the water to the side of the road. However, this is suitable only if this thin layer has a minimum thickness of 75 mm and is placed at such a level that water in the pavement is not trapped.
6. Geotextiles can be placed in the shoulder to improve the drainage within the lower layers.

If a road has a sealed surface, it is recommended that the seal is extended by 200-300 mm onto the shoulders of a road to reduce the volume of water permeating into the carriageway. For default design for any paved/sealed road should be to have paved/sealed shoulders.

All pavement and shoulder layers should have cambers equal to the pavement and shoulder surfaces above so that all water will drain out into the side drains of the surface drainage system.

7.3.3 Choice of Alignment

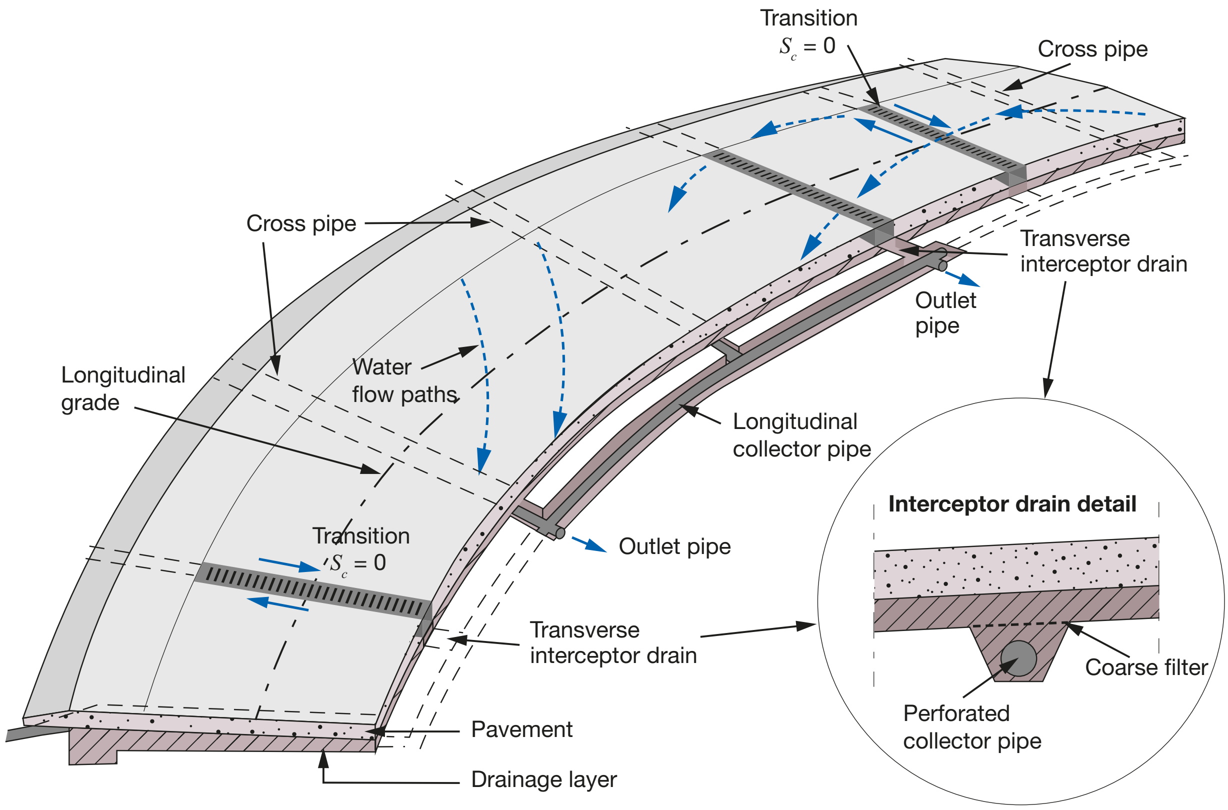
The most expedient way to ensure that there are no drainage problems is to complete detailed surveys in the target area. Alternatively, the horizontal and vertical alignments can be modified to ensure the road is as far away as practicable from water tables or springs.

Particularly in low-lying or poorly drained areas, it is necessary that the road be raised by means of an embankment to avoid surface flooding.

7.3.4 Sub-soil Drains

Longitudinal subsoil drains can be used to locally lower a water table. These will normally consist of porous concrete, open jointed or perforated pipe laid in a trench with a surround and backfill of free-draining material, e.g., graded crushed stone (maximum size: 60 mm), clean coarse gravel or sand. The pipe size will depend on the expected flow of water but will generally not be less than 100 mm internal diameter. Generally, perforated pipes of 150 mm internal diameter are preferred for most soil and pavement type combinations. They should be arranged as shown in Figure 7.1 for superelevated sections, and Figure 7.2 for level sections. The depth of the trench will depend on the level of the water table and the permeability of the soil but normally it should be at least 1 metre deeper than the formation level and 500 mm wide. The bedding for the pipe should be 50 mm of the same filter material.

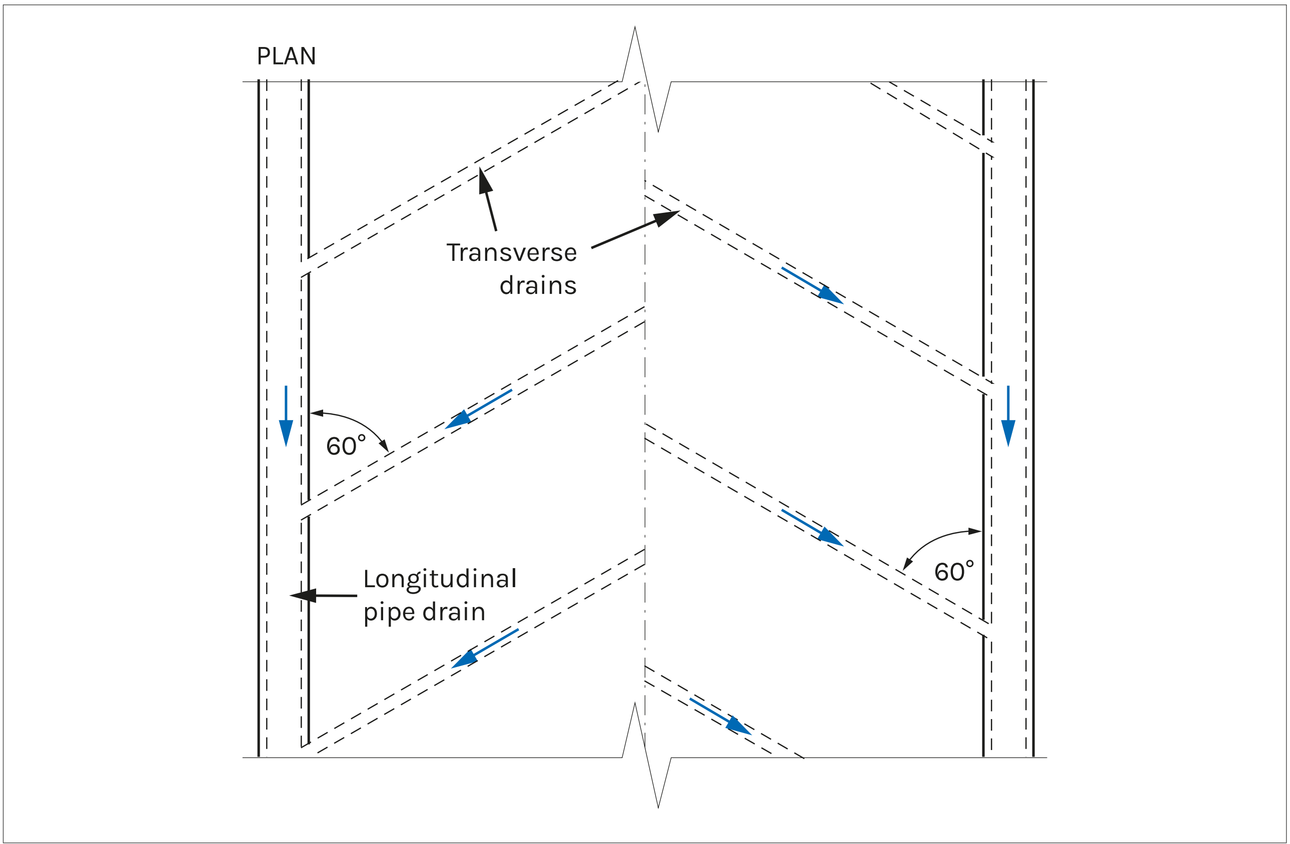
Figure 7.1 Transverse Drains on Super-elevated Curve



The transverse drains should be laid with a suitable slope (1/100 to 1/300) and discharge water into longitudinal drains, which should be inclined at an angle of about 60° and staggered in plan. They should also be placed 6 - 20 m apart, depending on moisture conditions.

In some cases where it is necessary to prevent surface water from entering subsoil drains, the upper 500 mm of the trench shall be backfilled with impermeable clayey material.

Figure 7.2 Longitudinal and Transverse Drains



If the surrounding ground is likely to squeeze or wash into the free-draining material, filter protection is required. This can be achieved by placing filter material as free-draining material in the trench.

Filter materials shall comply with the following (Equation 7.1) requirements:

$$5.s15 < F15 < 5.s85$$

Equation 7.1

Where,

$F15$ = the sieve size (in mm) through which 15% by weight of the filter material passes.

$s15$ = the sieve size (in mm) through which 15% by weight of the natural soil passes.

$s85$ = the sieve size (in mm) through which 85% by weight of the natural soil passes.

Alternatively, the standard materials as shown in Table 7.2 can be used.

Table 7.2 Particle Size Distribution for Filter Materials

Sieve Size (mm)	**Percentage Passing Sieve**		
	Type 1	**Type 2**	
	5-14 mm Sand	**Stage 1**	**Stage 2***
37.5		100	
26.5			100
19.0	100	85-100	70-100
13.2	90-100		0-30
9.50	70-100	65-100	0-10
4.75	28-100	45-82	
2.36	0-28	30-60	0-5
1.18	0-8	15-40	
0.600		5-25	
0.300	0-5	0-10	
0.150		0-5	
0.075	0-3	0-3	0-3
Minimum Pipe Slot Width (mm)	3.3	5.0	15

Notes: ** Stage 1 material is in direct contact with the soil, and Stage 2 is used in between the Stage 1 material and the perforated pipe. Alternatively, Stage 2 material can be used between a geotextile filter and the perforated pipe.*

It is important that the pipe be surrounded by appropriate filter material to prevent fines from clogging the openings.

A non-woven geotextile of an approved type may be placed around the draining material to prevent silt or fine particles from being washed into it.

It may also be useful to place non-woven geotextile around the pipe. The effective pore size of the fabric should comply with the above filter criteria.

Where the flow of water is small and where non-woven geotextile is placed around the draining material, it may be unnecessary to place a pipe.

Where pipe drains are used, inspection chambers with silt traps shall be constructed every 100 m along straight sections and at every change in direction. These will enable the pipe to be rodded or flushed out.

7.3.5 Seepage Remedies

If during construction unanticipated local seepages or springs are encountered in cuttings, they may be controlled by either a counterfort drains or sub-horizontal well. In its simplest form a counterfort drain consists of an excavated 'slot' or deep trench running into the cut slope, which is then backfilled with free-draining material and in large cases a porous pipe.

The filter criteria already stated will apply and some arrangement must be made to lead away the intercepted water. Geotextiles can also be used as already described.

Sub-horizontal wells are formed by drilling into the cut slope at a slight upward angle to intercept water-bearing strata. The hole is then lined with a slotted or perforated pipe to keep it open and to carry the water out. Usual diameters range from 50 to 100 mm and lengths may reach 50 m.

7.3.6 Counterfort Drains

Counterfort drains are similar to sub-soil drains but are deeper and wider. They are often constructed in order to reduce the ground water in an embankment or cutting where a slope failure due to saturation is a risk.

Because of their size, counterfort drains should be carefully designed and constructed for the conditions of each specific site.

7.3.7 Sub-horizontal Wells

Sub-horizontal wells are also similar to sub-soil drains but are constructed by drilling slightly upwards of horizontal from the slope of an embankment or cutting and inserting a porous pipe into the drilled hole. Like counterfort drains, they are often constructed to reduce ground water in an embankment or cutting where a slope failure due to saturation is a risk.

7.3.8 Geotextiles

Geotextiles are particularly useful in sub-surface drainage for three main reasons:

1. They can act as filters to prevent fine material entering porous drains.
2. They can act as thin drainage layers, to allow water to pass laterally through pavement and shoulder layers into side drains and other elements of a drainage system.
3. They can act as reinforcement to prevent sliding between surfaces within a soil mass, for example in an embankment, or in a pavement.

Regardless of the way the geotextile has been manufactured, the important design requirements are that the filter retains the soil, does not clog and has adequate permeability.

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Appendices

Appendix A: Mechanistic Pavement Design Example

It is required to design a pavement for design traffic of 90 MCESA on a subgrade of median CBR 11% (S3). A materials investigation report indicates that suitable materials are available for manufacture of asphalt concrete Type I (AC I), dense bitumen macadam (DBM), and gravel of G45 quality and cement are available to manufacture hydraulically improved granular material (HIG160).

Solution:

Foundation

The first step is to design a suitable foundation for the design traffic 90 MCESA and on a subgrade of median CBR 11%.

The design subgrade class is S3 (see Table 2.2) and the design traffic class if TC150 (see Table 2.3).

Looking at Table 2.3, the minimum foundation class for TC150 traffic is foundation class F4 (200 MPa). Reviewing the materials availability, 200 mm of G45 capping on S3 subgrade could be sufficient to achieve foundation class F4. The top 300 mm of fill below the improved subgrade layer (200 mm G45) should be selected such that its minimum CBR is greater than 10%.

Pavement layer thicknesses and Long-life pavement check

A mechanistic analysis software such as Alize, KENPAVE, Rubicon Toolbox, or other suitable software is used to input the pavement model shown in Figure 3.1, and the materials characteristics in Table A.1.

The critical strains at the locations shown in the pavement model shown in Figure 3.1 are presented in Table A.1. The results show that the AC I surfacing is sufficient and that the subgrade is well- protected (critical strains are less than limiting strains), but the DBM base is not sufficient for the design traffic. The limiting strains are calculated using the failure criteria equations presented in section 3.4. Additionally, the critical strains at the bottom of the asphalt layers and at the top of the subgrade do not meet the requirements for long-life pavements (70 microstrain for asphalt layers, and 200 microstrain for the subgrade). Therefore, a second iteration is required where thicknesses are increased. The results are as shown in Table A.2. Note that the critical strains at the bottom of the asphalt layers and at the top of the subgrade now meet the requirements for long-life pavements.

A check is then undertaken on the effect of supersingle tyres on this pavement using the pavement model shown in Figure 3.2. The results (Table A.3) show that the critical strains are within the same range as that of the standard axle (dual tyres as shown in Figure 3.1) and are still within the requirements for long-life pavements.

1
2
3
4
5
6
7
8
9
Appendices

Table A.1 Material Characteristics and Strains Using the Standard Axle with Dual Tyres (Attempt 1)

Layer	Material	Thickness (mm)	Modulus (MPa)	Poisson's Ratio	Critical Strain (microstrain)		Limiting strain for design traffic of 90 MCESA
					Value	Location	
Surfacing	AC I	50	4000	0.35	28.01	Tensile at bottom of bituminous layer	120
Base	DBM	100	5000	0.35	78.57	Tensile at bottom of bituminous layer	76
Sub-base	HIG160	150	1000	0.25	100.6	Compressive on top of the sub-base	-
Subgrade	F4	-	200	0.45	205.4	Compressive on top of the subgrade	287

Table A.2 Material Characteristics and Strains Using the Standard Axle with Dual Tyres (Attempt 2)

Layer	Material	Thickness (mm)	Modulus (MPa)	Poisson's Ratio	Critical Strain (microstrain)		Limiting strain for design traffic of 90 MCESA
					Value	Location	
Surfacing	AC I	75	4000	0.35	12.23	Tensile at bottom of bituminous layer	120
Base	DBM	100	5000	0.35	51.78	Tensile at bottom of bituminous layer	76
Sub-base	HIG160	150	1000	0.25	95.19	Compressive on top of the sub-base	-
Subgrade	F4	-	200	0.45	139.8	Compressive on top of the subgrade	287

Table A.3 Material Characteristics and Strains Using The Standard Axle With Single Tyres (check)

Layer	Material	Thickness (mm)	Modulus (MPa)	Poisson's Ratio	Critical Strain (microstrain)		Limiting strain for design traffic of 90 MCESA
					Value	Location	
Surfacing	AC I	75	4000	0.35	13.23	Tensile at bottom of bituminous layer	120
Base	DBM	100	5000	0.35	48.08	Tensile at bottom of bituminous layer	76
Sub-base	HIG160	150	1000	0.25	104.9	Compressive on top of the sub-base	-
Subgrade	F4	-	200	0.45	119.7	Compressive on top of the subgrade	287

The coefficients in Table A-4 below should be used for inputs of the fatigue relationships into design software such as ELMOD, RoSy, or other equivalent.

Table A.4 Materials Fatigue Relationship Coefficients for use With Software

Material	A	B	E_0 [MPa]	C (when $E < E_0$)	C (when $E > E_0$)
Asphalt Concrete Type II	335.37	-0.207	2,500	0	0
Asphalt Concrete Type I	289.08	-0.202	4,000	0	0
Dense Bitumen Macadam	220.03	-0.250	5,000	0	0
Bitumen Sand Asphalt	405.55	-0.170	1,000	0	0
Hydraulically Bound Stone (HBS9)	0.864	-0.117	10,000	0	0
Hydraulically Bound Stone (HBS3)	0.367	-0.111	4,000	0	0
Subgrade (High Volume Roads)	885.44	-0.250	75	0	0
Subgrade (Low Volume Roads)	1310.61	-0.250	130	0	0

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