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MINISTRY OF ROADS AND TRANSPORT

RDM 3.5

Road Design Manual

Volume 3: Materials and Pavement Design for New Roads

Part 5: Rigid 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. This second generation of the 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 the provision of road infrastructure that is safe, secure, and efficient.

Under the Kenya Vision 2030 long term plan, infrastructure expansion and modernisation are some of the foundations for the realisation of economic, social and political transformation of Kenya 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 of 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 Plans (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 under MTP I, II and III, respectively, totalling 17,450 km. This was a massive infrastructure development program intended to double the paved road network in 10 years compared to 8,600 km developed from independence in 1963 to 2008.

Implementation of MTP I to III resulted in the construction of 14,000 km of paved roads, which extended the paved road coverage to Arid and Semi-Arid regions, that had been 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; the emergence of 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 costs and delays in payments of land acquisition; lack of harmonisation of cross-border transport regulation and operational procedures; rapid urbanisation; increased traffic volume with 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 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 to the aspirations of the Kenya Vision 2030 and the Kenya Kwanza Government's 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 through 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 6,000 km of new roads, maintaining rural and urban roads, rail, air and seaport facilities and services; expand communication and broadcasting systems; and promote 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.

The plan 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 with the Government’s strategy will provide guidance 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 Government 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.

On behalf of the Government of Kenya, I would wish to thank the European Union for financing the development of the first drafts of the manuals in 2009 and the African Development Bank for the financial support in the review and updating of the manuals. I would also like to thank the members of the National Steering Committee and the Technical Task Force for their input. The Technical Administrators, and the Kenya National Highways Authority (KeNHA) for the procurement and able administration of the consultancy Contract. I also thank the Consultant, TRL Limited for their role in providing technical expertise that was essential for the success of the manuals updating exercise. I also wish to express my deepest appreciation to our stakeholders and all those who have contributed to this process and the staff of the Ministry for their continued input.

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

Preface

This manual provides information and methods for designing concrete roads (pavements). Many road engineers may be unfamiliar with concrete as a road construction material. For this reason, this Manual is more detailed than a standard design document, providing additional information about concrete as a material. It explains the main features of a concrete road, describes the main types of concrete road and gives information about when/where they are best suited.

This manual includes methods to design the following types of concrete roads: Block Paving, Jointed Unreinforced Concrete Pavement, Jointed Reinforced Concrete Pavement, Roller Compacted Concrete Pavement, Continuously Reinforced Concrete Base (with a thick asphalt surfacing) and Continuously Reinforced Concrete Pavement (with a concrete or thin asphalt surfacing). Cobblestone Paving is also included in this manual as it is generally similar to Block Paving.

For concrete overlay designs (of various concrete pavement types) to an existing asphalt or concrete road, see **RDM Volume 5, Part 2**.

By following the steps set out in this manual, Design Engineers should be able to decide when and where to use a concrete pavement, be able to select the most appropriate type of concrete pavement and to design it. The information obtained shall be used to produce an economic and safe design that meets tender and construction requirements.

Eng. Joseph M. Mbugua, CBS
Principal Secretary, Ministry of Roads and Transport

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 latest practices in the road sector, both regionally and internationally.

Sources of the Document

Copies of the document can be obtained from:
The Principal Secretary, State Department for Roads, Ministry of Roads and Transport, Works Building, Ngong Road, P.O. Box 30260 - 00100, NAIROBI Email: ps@road.go.ke

A secured PDF copy may be downloaded from: www.roads.go.ke/downloads

Notification of Errors and Requests for Amendments

While all care and consideration has been applied in the compilation of this document, the Ministry accepts no responsibility for failure in any way related to the application of this manual or any reference documents cited in it.

Requests for edits and corrections can be freely sent to the following address:
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Amendments Request Form

Request No.	Name	Organisation	Chapter	Page	Section/ Clause	Ref. to: Figure/ Table/	Type of Request	Request

Type of request: General – G; Editorial – E; Technical - T

Amendments to Date

Amendment No.	Description	Amendment Effective Date	Amended Approved by

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Abbreviations

ASR	Alkali-Silica Reaction
BP	Block Paving
BS	British Standard. See list of Standards in Appendix A
BSM	Bitumen Stabilised Material
CBP	Concrete Block Paving
CC	Curing Compound
CESA	Cumulative Equivalent Standard Axles
CRCB	Continuously Reinforced Concrete Base
CRCP	Continuously Reinforced Concrete Pavement
DESA	Daily Equivalent Standard Axles
EACS	Exposed Aggregate Concrete Surface
EAS	East African Standard. See list of Standards in Appendix A
EN	European Standard. See list of Standards in Appendix A
ESA	Equivalent Standard Axle
FRC	Fibre Reinforced Concrete
G8, G1, etc	A natural gravel material used as a layer in a road foundation
GBA	Ground Beam Anchor (aka base anchor/anchor beam/ground anchor beam)
GCS	Gravel Crushed Stone
GGBS	Ground Granulated Blast-furnace Slag
HBM	Hydraulically Bound Material
HBS	Hydraulically Bound Stone
HGV	Heavy Goods Vehicle
HIG	Hydraulically Improved Gravel
HPS	Hand Packed Stone
HSM	Hydraulically Stabilised Material
JRC	Jointed Reinforced Concrete
JUC or JPC	Jointed Unreinforced Concrete. Also known as Jointed Plain Concrete
KS	Kenyan Standard. See list of Standards in Appendix A
LCA	Life Cycle Assessment (or Life Cycle Analysis)
LCCA	Life Cycle Cost Analysis
LIC	Labour Intensive Construction
LVR	Low Volume Road (Usually <1M CESA)
MESA	Millions of Equivalent Standard Axles
NMT	Non-Motorised Transport
OPC	Ordinary Portland Cement
PCB	Precast Concrete Block
PFA	Pulverised Fuel Ash
RCC	Roller-Compacted Concrete
SCS	Saw-Cut and Seal
SM	Surface Modulus
TBA	Transverse Bar Assembly
TRL	Transport Research Laboratory (UK)
URC	Unreinforced Concrete
WFB	Wide-Flange Beam
WLC	Whole-Life Cost

Definitions and Glossary of Terms

Air Entrainment — The addition of microscopic air bubbles to concrete during mixing, usually with a surfactant. It is often used to protect against frost damage, but it also increases workability, reduces segregation/ bleeding /laitance and sulphate resistance, however it can reduce strength and increase porosity.

Alkali Silica Reaction — Known as concrete cancer, this damaging swelling reaction occurs over time between the alkaline cement and reactive silica in some aggregates. A closely spaced crack pattern is observed with fatty silica gel excretions. There is no treatment, but it can be prevented by a) limiting the cement's alkali content, b) limiting the aggregate's reactive silica content, c) adding fine pozzolan, fly ash, etc to neutralise the cement alkalinity and d) limit external alkalis contacting the concrete.

Approach Slab — Also called a run-on slab or transition slab. A concrete slab (often reinforced) between a concrete pavement and different type of pavement (e.g. asphalt) or bridge, etc.

Bay — Same as a slab. A section of jointed concrete pavement between longitudinal and transverse joints.

Bay Replacement — Full depth repair technique for jointed concrete pavements. It involves the full depth replacement of concrete across single or multiple bays with joint reinstatements.

Block Paving — This uses small precast interlocking concrete paving blocks laid on a sand layer to create a pavement suitable for low volume roads (0.1-1 M CESA) with traffic speeds below 60 km/h. Blocks come in different thickness and compressive strength.

Blow Up — See 'Compression Failure'.

British Standard — British Standard (BS). See List of various Standards in Appendix A.

Capping — An improvement layer on top of the subgrade, protecting the subgrade from damage and/or increasing the stiffness at formation level.

Cement — This is a powdered binder that reacts with water to set hard. It is formed by a) crushing and grinding suitable limestone rock, b) blending with aluminosilicate materials (such as clay), c) burning the mix in a kiln to produce 'clinker' and d) grinding the clinker with approximately 5 % gypsum or natural pozzolans, to control the setting time. To form concrete, cement is mixed with coarse aggregate, fine aggregate, water and sometimes other chemical admixtures/additives to retard setting or increase workablity, etc.

Characteristic Strength (of Concrete) — This is the strength level at which a specified proportion (usually 95%) of test results will exceed. For example, to achieve a characteristic compressive strength of 30 MPa, the mean (i.e. average) strength will be approximately 40 MPa.

Clinker — This is a material that is half-way to becoming cement. It comprises 3-25 mm sized nodules produced by sintering (burning) limestone and clay in a cement kiln. Clinker is then ground into fine powder with additives (e.g. pozzolana) to form cement.

Cobblestone Paving — This comprises naturally occurring rounded stones (cobbles) or manually cube shaped stones (called setts) sized 100-150 mm. They are placed on a sand layer (using labour-based methods) and sand is packed in the gaps between stones. They form a surfacing suitable for low-speed (<50 km/h), low-volume (<1 M CESA) often urban roads/pedestrian areas.

Compacting Factor Test — This is an indicator test for the consistency/workability of a fresh concrete mix. Other tests include the slump test and Vebe test.

Definitions and Glossary of Terms

Compression Failure	Compression failure ('blow-up'): localised upward movement or shattering of a slab at a transverse joint or crack. These occur in extreme heat when a crack/joint is not wide enough to permit the concrete slab's thermal expansion.
Compressive Strength	R_c = compressive (i.e. crushing) strength to failure of concrete. Test is usually on a prepared 100 or 150 mm concrete cube sample, but trimmed cylinder core samples can also be tested. Concrete gets stronger with age, so the strength is given at 7 or 28 days. There is also a relationship between compressive and flexural strength.
Concrete	Material formed by mixing cement, coarse and fine aggregate, and water, (may include admixtures, additives and fibres). A reaction between the cement and water causes the material to become solid.
Concrete Pavement (Rigid Pavement)	A concrete (rigid) pavement has a main structural layer of pavement quality concrete with either a concrete running surface or up to 100 mm asphalt surfacing. A rigid pavement with ≥180 mm asphalt overlay is regarded as a flexible pavement. A rigid pavement with 100-180 mm asphalt is regarded as a hybrid pavement.
Construction Joint	A transverse joint made in a concrete pavement at the end of a working day or when paving is stopped by severe weather, plant breakdown, etc.
Contraction Joint	A transverse (or longitudinal) joint made in a concrete pavement (by saw-cutting or placing crack inducers) to make the concrete crack (as it cures/contracts) along a straight line that can easily be sealed.
Cracks	A split or break in the concrete pavement. These may be shallow (see 'crazing' and 'plastic shrinkage crack') or full concrete depth. Full depth cracks are categorised as: **Hairline cracks:** are very narrow and only detectable with difficulty. **Narrow cracks:** are less than 0.5 mm wide. Aggregate interlock across the crack is likely to be maintained. Considered too narrow to permit ingress of water and incompressible material. **Medium cracks:** are 0.5-1.5 mm wide. Aggregate interlock across the crack is likely to be partial. May permit ingress of water and incompressible material. **Wide cracks:** are greater than 1.5 mm wide. Aggregate interlock across the crack is likely to be none. Any reinforcement present is likely to have failed.
Crack Inducer	An insert fixed on the sub-base before the concrete is poured and/or pressed into the top of the fresh concrete to create a straight plane of weakness to 'induce' where the crack will form. This neat crack will become a joint.
Cranked	The term given to tie bars that are bent (cranked) to 90o before they are inserted into the fresh concrete, to ensure that they are perpendicular to the joint.
Crazing	Crazing (or 'map cracking') is the development of fine, shallow cracks in the upper surface of the concrete, caused by shrinkage of the surface layer. It can be prevented by good curing techniques.
CRCB	Continuously Reinforced Concrete Base (CRCB). This type of pavement comprises: a layer of continuously reinforced concrete with no intermediate transverse expansion or contraction joints, surfaced with a relatively thick asphalt overlay (100 mm or more).

Definitions and Glossary of Terms

CRCP Continuously Reinforced Concrete Pavement (CRCP). This type of pavement comprises: a layer of continuously reinforced concrete, with no intermediate transverse expansion or contraction joints. It usually has a concrete surface but is still called a CRCP even with a thin asphalt surfacing (<100 mm).

Cumulative Equivalent Standard Axles This is the Kenyan term for cumulative traffic loading over the design life (usually 40 years for concrete pavements) and is used for pavement design purposes. Values are usually expressed as millions of CESA e.g. 80 M CESA (equivalent to 80 MESA or 80 MSA). The terminology emphasises that the traffic is a cumulative value rather than an annual value. See ESA.

Curing The process whereby wet concrete forms internal bonds and sets as hardened concrete. Good curing techniques are essential for the concrete to attain its maximum strength. These include covering the wet concrete with tentage and damp hessian to keep it moist or spraying with a curing compound and preventing wind drying. 7 days is usually considered a minimum curing period for PQ concrete.

Curing Compound An alternative to wet curing. This liquid substance is sprayed onto fresh concrete, after texturing, to form a membrane which reduces water/heat loss and helps the concrete to cure. It is usually white/grey in colour to ensure full coverage and to reflect solar energy. There are 4 main compound types: Synthetic resin, Acrylic, Wax and Chlorinated rubber.

Defective Joint Seal All-encompassing term for joint seals which are not performing their function of keeping detritus and water out of the joint.

Deformed steel bar A ribbed steel bar (also known as rebar), usually 12 or 16 mm diameter, that is used as steel reinforcement or as a tie bar in concrete roads. The ribbed surface provides a better bond with the concrete than smooth steel. See Reinforcement and Tie bar.

Design Life This is the number of years that the pavement is expected to last before rehabilitation. For concrete it is 40 usually years. The total cumulative traffic (in millions of ESAs) over the design life is used to design the pavement.

Diamond Grooving / Grinding This is a rehabilitation process to restore the macrotexture (i.e. high-speed skid resistance) of a worn concrete pavement surface by cutting grooves into the surface with multiple diamond-tipped circular blades. In some countries this is also known as 'Diamond grinding', but this term can also apply to a separate process to smooth the pavement surface by grinding off high spots.

Dowel Bars Smooth steel bars, generally 20-32 mm diameter and 400-600 mm long, that are placed at approximately 300 mm intervals across a transverse contraction or expansion joint to allow load transfer across the joint. One end is usually coated to prevent bonding to the concrete, which allows the slabs to expand/contract at the joint, but still achieve load transfer across the joint.

Dowel basket /cage / cradle This is usually a frame of bent metal wires used to position a row of dowel bars at the correct height & direction at a transverse joint. A frame (with dowels) is then fixed to the top of the sub-base at each planned transverse joint location, before concreting. It should be in two halves with none of the metal frame (only the dowel bars) crossing the joint or this could prevent movement at the joint.

Early Strength Concrete Concrete designed to achieve adequate strength to permit early trafficking (usually within four hours after placement). Mostly used for repairs.

Definitions and Glossary of Terms

East African Standard	East African Standard - see Standards in Appendix A.
Edge Strip	It is important for the life of a concrete pavement that heavy traffic does not run near the unsupported edge of a slab. This can be achieved by providing a hard shoulder or edge strip. The edge strip should be at least 0.5 m wide (preferably 1 m) and can be created by widening the slab or adding a tied concrete shoulder.
Efflorescence	This is the phenomenon when salts and other water dispersible materials come to the concrete surface by vapour migration, leaving a fine white powder. A waterproofing admixture and/or wet curing can help prevent efflorescence.
Equivalent Standard Axles	ESA. Where a standard axle is an axle exerting a force of 80 kN, equivalent to an 8.16 tonne axle load. Weighed HGV (Heavy Goods Vehicles) axles are converted into ESAs, so that the damaging effect of axles of different weight can be included in the design. See CESA.
European Standard	European Standard (EN). These were adopted by Kenya to replace British Standards in 2021. A list of concrete and other relevant Standards is given in Appendix A.
Expansion Cap	This is a small piece of compressible material (e.g. foam) that is fixed to one end of each dowel bar at a transverse expansion joint. These allow greater slab movement than at a contraction joint, protecting bridges, etc.
Expansion Joint	A special 25 mm wide transverse concrete pavement joint with a compressible filler material (e.g. foam). It allows greater concrete movement than a contraction joint. Used for protecting bridges, concrete to asphalt transitions and preventing blow ups.
Exposed Aggregate	A type of surface texture for concrete roads see below.
Exposed Aggregate Concrete Surface	Exposed Aggregate Concrete Surface (EACS). A type of low-noise surface texture for concrete roads.
Fibre Reinforced Concrete	This is concrete containing short, discrete fibres (usually steel) that are uniformly distributed and randomly orientated. They can also be glass, synthetic or natural materials. The fibres generally do not increase the flexural/compressive strength of the concrete, and can diminish it, but when the hardened concrete cracks, the fibres can help to hold cracks together.
Flexural Strength (of Concrete)	Rt = The direct tensile (i.e. flexural) strength of a concrete beam sample loaded to failure. Concrete gets stronger with age, so it is normally referred to as flexural strength at 7 or 28 days. There is a conversion from flexural to compressive strength.
Formation	Level upon which the sub-base is placed.
Form Work	Wooden or metal forms that are locked together and held in place by pins knocked into the ground. They contain the sides of the wet concrete and can mould the shape of the slab edge into a stepped shape.
Foundation	For Kenyan concrete pavement design the ‘foundation’ refers to all layers beneath the PQ concrete slab. This needs to be a class F4 (bound) or F5 (bound) foundation, which both include an HBS3 (Hydraulically Bound Stone) layer, which is generally a cement bound material (CBM). It should be noted that in Kenyan flexible pavement design, the term ‘foundation’ includes all materials up to (but not including) the sub-base, whereas in the UK (where many of the concrete pavement designs originate) the foundation includes all materials up to, and including, the sub-base.

Definitions and Glossary of Terms

G8, G10…G45	A natural gravel material used as a layer in a road foundation.
Graded Crushed Stone	Graded crushed stone is one of the most widely used base materials in Kenya. The material requirements, traffic limitations and construction procedures are summarised in Volume 3 Part 3.
Green Concrete	This is concrete that has started to set, but not appreciably hardened. When saw-cutting transverse joints, the concrete must be hard enough to allow saw-cutting but has not yet formed contraction cracks.
Grooving/Grinding	See Diamond Grooving/Grinding.
Ground Beam Anchor	GBA (aka base anchor/anchor beam/ground anchor beam) is a reinforced concrete 'block' constructed into the foundation and tied to a reinforced slab above. It is part of the 'termination' at the ends of a CRCB/CRCP pavement, which usually includes four GBAs/slabs with expansion joints. The function of a GBA is to restrict longitudinal movement and prevent damage to adjacent bridges and roads.
Ground Granulated Blast-furnace Slag	GGBS. This powder is a by-product of the iron industry and is often added to cement to increase the concrete strength/durability, reduce voids/permeability, enhance workability, increase resistance to sulphate attack/ASR /efflorescence, and it also lightens the concrete colour. GGBS is more environmentally friendly than cement as no CO_2, SO_2 or NOx is released in its production.
Hand Packed Stone	For paving this consists of a layer of large broken stone pieces (typically 200- 300 mm thick), tightly packed together and wedged in place with smaller stone chips rammed into the joints, with the remaining voids filled with sand. The Hand Packed Stone is normally bedded on a thin layer of sand/gravel. For use by heavy traffic, the layer should be compacted with a vibrating or heavy non-vibrating roller. An edge restraint /kerb will improve durability. This can form a base or a surfacing for low-speed roads.
Hydraulically Bound Stone	HBS. Also known as Hydraulically Bound Material. This is a form of cement (or other hydraulic binder) bound material (weaker than concrete) usually used for the upper foundation (sub-base) beneath the main concrete slab, to prevent erosion that could occur with a granular material. HBS3 = Hydraulically Bound Stone (minimum G60 or GCS-E) of minimum UCS 3.0 MPa after a 7-day cure and 7-day soak.
Heavy Goods Vehicle	HGV. This is a commercial vehicle with a gross vehicle weight (i.e. total laden weight including cargo) of more than 3.5 tonnes (3500kg).
Hydraulically Improved Gravel	HIG. A material used in road foundation, strengthened with cement or lime.
Induced Crack	Concrete will naturally crack at approximately 5 m spacings. To create a neat, straight crack (transverse or longitudinal) that can be sealed (i.e. a joint), a full depth crack is intentionally created ('induced') in the concrete surface at the required locations by saw-cutting the top surface or inserting a crack-inducer.
Intersection Stones	In a cobblestone surfacing, intersection stones comprise the first two rows of cobblestones laid adjacent to the kerbstone.
Joint Groove	Groove (usually saw-cut) at the top of a joint to receive the joint sealant.
Joint Sealant	A flexible material that adheres to the vertical faces of the joint groove. Its purpose is to prevent detritus/water from entering the joint whilst the joint is opening/closing.

Definitions and Glossary of Terms

Jointed Reinforced Concrete	Jointed Reinforced Concrete. This type of pavement has transverse (dowelled) joints at 20-25m intervals. These joints may be contraction or expansion joints. The bays (between the joints) contain longitudinal and transverse steel reinforcement.
Jointed Unreinforced Concrete	Jointed Unreinforced Concrete. Also known as Unreinforced Concrete (URC) or Jointed Plain Concrete (JPC). This type of pavement has no steel reinforcement and has transverse contraction joints at 4-6 m intervals (usually with dowel bars for load transfer across the joint). Undowelled joints can be used for very low traffic roads.
Kenyan Std	Kenyan Standard (KS). See Standards. Available from Kenya Bureau of Standards (KEBS) website: www.kebs.org.
Laitance	A weak, milky layer of cement/fines on a concrete surface caused by incorrect curing e.g. an overly wet mixture, overworking the mixture, and/or improper finishing.
Lap	See Overlap.
Life Cycle Assessment	Life Cycle Assessment (or Life Cycle Analysis) assesses the environmental impacts associated with all stages of a product's life cycle from raw material extraction, though processing/manufacture, distribution and use, through to final disposal or recycling.
Life Cycle Cost Analysis	An economic analysis tool to determine the most cost-effective option to use, e.g. is it more economic to build a concrete or an asphalt road.
Labour Intensive Construction	Less automated form of construction requiring people to do manual labour. Examples include Block Paving and hand laid JUCP.
Load Transfer	The distribution of load from one slab to the next, i.e. from one side of a joint (or crack) to the other (unloaded) side. Load transfer is normally performed by aggregate interlock (if the joint/crack is narrow) and/or with dowel bars.
Longitudinal Crack	A crack that is oriented roughly parallel to the pavement edge or longitudinal joint.
Longitudinal Joint	A joint between lanes that is parallel to the pavement edge.
Low Volume Road	(LVR). Also called a Low Traffic Road. A road designed to carry low volumes of traffic, with a design life of <1M CESA, usually over a period of 15 years.
Millions of ESA	Millions of Equivalent Standard Axles (ESA). A unit of traffic loading that the pavement will carry over its design life (usually 40 years for a concrete pavement). See ESA.
Ordinary Portland Cement	This is the common type of cement that is grey in colour. It is produced by grinding Ordinary Portland clinker and high purity gypsum.
Overlap	The minimum overlap when joining reinforcing steel bars.
Pavement	All layers of construction material above the formation. Includes Sub-base, Base and Surfacing.
Plasticiser	These are chemical compounds added to concrete that allow a reduction in water content by approximately 15 %. Superplasticisers (also known as 'high range water reducers') allow a reduction in water content by 30 % or more. Plasticisers and superplasticisers also retard the setting and hardening of the concrete and can reduce the porosity of the hardened concrete.
Pop Out	An isolated loss of concrete surface material in a small area. Also see punchout.

Definitions and Glossary of Terms

Pozzolan	A naturally occurring material (siliceous/aluminous material) which has little/no cementitious properties, but in powdered form will react with calcium hydroxide (in the presence of water) at ordinary temperatures to form compounds with cementitious properties. Often added to OPC to control setting, increase durability, reduce cost and reduce pollution without compromising compressive strength.
Pozzolana	A naturally occurring pozzolan of volcanic origin, e.g. volcanic ash. See Pozzolan.
PQ Concrete	Pavement Quality Concrete. A concrete of sufficient quality/strength to be used in pavement construction for heavy traffic volumes and loads. Often a better quality (with larger aggregate and a lower slump value) than Building Concrete.
Precast Concrete Block	Precast Concrete Block. Used in Block Paving surfaces for roads, footways, parking areas, etc. Blocks come in different thicknesses and compressive strengths.
Pulverised Fuel Ash	A fine ash by-product of burning coal in power stations, often added to cement to reduce costs, improve workability, reduce concrete porosity and hence increase resistance to sulphate attack, ASR, carbonation & efflorescence.
Pumping	A significant defect where vertical deflections from HGVs at a transverse joint/crack cause water and fine particles of erodible subbase/subgrade to be pumped out of the joint/crack. This can lead to voids, stepping and slab cracking. Pumping stains of fine dried material are often visible on the shoulder or near the joint/crack. It can be avoided with a non-erodible sub-base, good pavement drainage and good joint seals.
Punchout	A localised defect (usually in CRCP) where intersecting transverse and longitudinal cracks or joints create loose fragments of concrete (usually at the pavement edge), which are 'punched out' by traffic downwards into the underlying subbase layer.
Roller Compacted Concrete	This pavement type uses a drier, stiffer (zero slump) concrete mix that can be walked on after laying (with a paver). It is rolled almost immediately with vibratory rollers for compaction and to induce micro-cracking. Wet joints can also be used in construction to induce cracks. For high-speed roads, an asphalt surfacing is added, due to RCC's uneven surface and poor texture.
Rebar	See Deformed Steel Bar.
Reflection cracking	When an asphalt overlay is put on a jointed concrete pavement, 'reflection' cracks often form in the asphalt above the concrete joints due to concrete movements.
Reinforcement	Usually 12-16mm diameter deformed steel bars (longitudinal and, to a lesser extent, transverse), tied together with wire to form a mesh that is embedded in reinforced concrete pavements at approximately one third slab depth to resist tensile stresses and keep the concrete cracks tightly closed.
Retarder	A chemical that can be sprayed onto the fresh concrete surface to delay the setting process e.g. for an 'exposed aggregate' surface texture. It can also be a concrete additive often used in hot temperatures to give additional working time.
Retexturing	Surface treatment to road surface that mechanically adds texture to restore texture depth/skid resistance e.g. diamond grinding.
Retrofitting Dowel Bars	Technique to improve or restore load transfer efficiency at a transverse joint by cutting out the old joint, replacing the concrete and incorporating new dowel bars.
Rigid Pavement	Alternative name for concrete pavement, i.e. a pavement where the main structural layer (base)is made of Pavement Quality Concrete (PQC).

Definitions and Glossary of Terms

Road Bed	The natural in-situ subgrade material upon which the pavement is constructed. Note that a bound layer (sub-base) is always recommended below a concrete pavement.
Run-On Slab	See Transition slab.
Sand Patch Test	The sand patch test is used to calculate the macrotexture of the road surface, which is required for good high speed skid resistance.
Saw-Cut and Seal	A treatment to minimise reflection cracking of a thin asphalt overlay over a JUC or JRC concrete pavement. Partial-depth transverse saw-cuts are made in the asphalt overlay directly above underlying transverse joints and sealed.
Scabbling tool	A specialist tool that acts like a mini pneumatic breaker to break away small areas of concrete, to enable spall repairs to be carried out.
Separation Membrane	See Slip Membrane.
Sintering	Fusing together without melting to the point of liquification. This process is used in the production of cement where limestone and clay are sintered together in a cement kiln to produce clinker, which is ground up with additives to make cement.
Skid Resistance	See Texture.
Slab	See Bay.
Slip Membrane	In a JUC/JRC pavement, a slip (aka separation or waterproof) membrane is put on top of the sub-base before the concrete is laid. During curing it reduces water loss and allows greater slab movement. A plastic sheet (giving a full debond) used to be standard, but more recently an emulsified bitumen spray is preferred (giving a partial debond). A slip membrane is not usually used under a CRCB/CRCP pavement.
Slump Test	A simple test to measure the workability of fresh concrete and ensure uniformity in different batches. It indirectly measures concrete stiffness and indicates how much water is in the mix. A standard slump test cone (300mm high, with 200mm and 100mm diameter holes at each end) is wetted and placed on a flat surface (wider end at the bottom). It is filled with fresh concrete mix (3 layers), any excess concrete is struck off and the cone is removed, allowing the concrete to ‘slump’ under gravity. The difference between the top of the concrete and the inverted cone (to nearest 5mm) is the slump value. The Vebe test or compacting factor test can also be used.
Surface Modulus	An elastic modulus (also known as modulus of elasticity) is the unit of measurement of the object's resistance to being deformed elastically (i.e. non-permanently) when a stress is applied to it. Usually obtained from FWD or LWD. The deflection measurements can be used to produce surface modulus plots, which can be used to study the profile of stiffness with depth.
Spall	An area of surface concrete that has broken away from the rest, usually at a slab edge, joint or crack. Classed as: **Shallow:** A small area, usually within 600 mm of the joint/corner, extending up to 1/3 slab depth. Can be repaired using partial slab depth repair techniques. **Deep:** Indicated by a larger area & extending more than 1/3 slab depth. These usually require full slab depth repair techniques, e.g. joint replacement.

Definitions and Glossary of Terms

Stabilisation Treatment of a granular material (subgrade, fill or other pavement layer) by the addition of a cementitious binder to enhance the strength and load carrying ability (and reduce the erodibility) of the material.

Standard In line with the Standard ACT CAP 496, it is important that any material, design, test method or code of practice used, shall be specified in the relevant Kenyan standard. Where a Kenyan standard is not available, then an alternative standard of equal or better performance may be used. Appendix A shows stndards listed in this Manual to assist the design engineer. These are given in subject groups and ordered in terms of Kenyan Stds (KS), East African Stds (EAS), Eurocode (EN), International Standards Organisation (ISO) and British Stds (BS), each in number order. Dates are removed, so documents don't become obsolete when a standard is updated. The latest version of a standard should always be used, except where stated.

Stepping A difference in elevation (greater than 3 mm) across a joint or crack.

Striking This is the process of removing formwork from set concrete.

Sub-base The layer on which the main concrete slab is constructed. It is both part of the foundation and pavement.

Subgrade Soil or fill underlying a pavement.

Surface Texture Surface Texture (aka 'Texture') is the visible and tangible characteristic of the surface. Usually added manually by dragging a tined rake or wire brush across the semi-hardened concrete surface. Categorised as:
Microtexture: the microscopic properties of the surface that enable it to develop friction. It is the dominant factor in providing wet skid resistance at low speed.
Macrotexture: the visible roughness of a surfacing material, it enables surface water drainage/noise dissipation & has a significant effect on high-speed wet skid resistance.

Terminations Terminations are the ends of concrete pavements. For example, where a concrete pavement changes to an asphalt pavement at a bridge. The longitudinal movement needs to be restricted using transition slabs and ground anchors.

Texture Depth A measure of macrotexture of the concrete surfacing, e.g. using a sand patch test.

Tie Bars Tie bars (aka tie rods) are lengths of deformed steel (generally 0.75-1.0 m long, and 12-20 mm diameter) that are placed at intervals (usually 600mm) along a joint to tie two concrete slabs together, e.g. at a longitudinal joint between lanes.

Tine and Burlap A type of concrete pavement surface texture. Burlap sack material (hessian) is towed behind the paver, then a metal 'tined' rake is manually drawn across the fresh concrete surface inducing a deep texture to aid skidding resistance and surface water drainage.

Transition Slab An intermediary concrete/asphalt slab between a concrete pavement and an asphalt (or other) pavement.

Transverse Bar Assembly A transverse steel reinforcement bar that is pre-welded with feet and clips for the longitudinal reinforcement (at the required spacing). This can speed up the reinforcement setting out process.

Transverse Crack A crack that is roughly orientated perpendicular to the pavement centreline.

Unreinforced Concrete Concrete without reinforcement (usually steel bars). When referring to a pavement, it refers to Jointed Unreinforced Concrete (JUC).

Definitions and Glossary of Terms

Vebe Test An indicator test for the consistence/workability of fresh concrete. The concrete is compacted (3 layers) in an upside-down hollow cone, set on a vibrating table (Vebe Meter). The cone is removed and if a 'true slump' is achieved (i.e. does not shear to one side) then this initial slump (mm) is recorded. A clear disc (230 mm diameter) is set to touch the slumped concrete top. The vibrating table and timer are turned on and the 'Vebe time' (in seconds) is recorded until the additional slump causes the clear disc to be fully in contact with the concrete. If the Vebe time is <5s or >30s, then the Vebe test is unsuitable for the concrete consistence.

Whole-Life Cost This is a cost-benefit analysis that includes the construction costs, road user costs, maintenance, and rehabilitation costs. It can also include variables such as safety and pollution. The option with the lowest Net Present Value (NPV) provides the lowest WLC. It is important that the same analysis period is used e.g. 40 years. This can be used to decide whether to build an asphalt or a concrete road.

Wide Flange Beam This is a system for concrete pavement terminations. They are put at the ends of concrete roads, particularly CRCB/CRCP, to stop longitudinal movements damaging adjacent bridges & pavements.

Workability Workability of fresh concrete is an important function of the mix design. It needs to be different for each concrete pavement type and laying method. It can depend upon many factors including the water/cement ratio, aggregate grading, if fibres are present, admixtures, etc. While there is no test to measure workability directly, useful indicator tests include the slump test, the Vebe test and the compacting factor test.

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1 Introduction

1.1 General

This Manual was prepared by the Ministry as part of the Roads Manual that attends to the project cycle for the provision, maintenance, and operation of roads in Kenya.

The Manual is applicable to roads at a national, municipal and county levels and incorporates best practices, climate change considerations, and modern technologies thereby enabling the provision of road infrastructure that is safe, secure and efficient.

The Roads Manual is composed of the following documents:

Table 1.1 References to Different Manuals Available for the Relevant Project Cycle

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	

The Road Design Manual (RDM) is composed of the following documents:

Table 1.2 References to the Road Design Manual for Different Site Investigation Aspects

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 and 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 designer. Compliance with the guidance given in the manual does not relieve designers of the responsibility for establishing that their design is suitable, appropriate, safe and adequate for the purpose stated in the project requirements.

In line with the Standard ACT CAP 496, it is important that any material, design, test method or code of practice used, shall be specified in the relevant Kenyan standard. Where a Kenyan standard is not available, then an alternative standard of equal or better performance may be used. Appendix A of this manual shows Kenyan Standards (KS), East African Standards (EAS), Eurocode (EN) and British (BS) Standards that are listed in the text, to assist the designer.

1.2 Objective of this Part

This part of RDM (**Volume 3, Part 5: Rigid Pavement Design**) is new to the Road Design Manual and introduces the design of concrete pavements for the first time.

This part should provide a Design Engineer in Kenya the information they need to assist them in choosing the most suitable type of new concrete pavement for their requirements (which are likely to be mainly based on traffic and the local environment) and to give them the methodology to design it.

1.3 Scope of this Part

This part of the RDM includes ~~new~~ pavement designs for the following pavement types:

- Cobblestone Paving (CP).
- Concrete Block Paving (BP).
- Jointed Unreinforced Concrete Pavement (JUCP).
- Jointed Reinforced Concrete Pavement (JRCP).
- Roller Compacted Concrete (RCC).
- Continuously Reinforced Concrete Base (CRCB).
- Continuously Reinforced Concrete Pavement (CRCP).

All of these pavement types are explained, with diagrams, in Section 2.4.

It is recognised that many design engineers may be unfamiliar with concrete as a pavement construction material and basic concrete pavement features and terminology.

Since this part is new to the RDM, it includes a lot of basic information about concrete and concrete pavements that would not normally be in a design manual. This includes concrete as a material, features associated with concrete pavements, descriptions of the different types of concrete pavement, pros/cons of each pavement type to help the design engineer choose the most appropriate type, and detailed design methods for each type of concrete pavement.

A list of Abbreviations and Definitions/Glossary of Terms related to concrete pavements is also given at the start of this part.

1.4 Organisation of this Part

This **RDM Vol. 3 Part 5: Rigid Pavement Design** is split into three main areas as shown below:

Introduction (Chapters 1-3)

Definitions and Glossary of Terms related to concrete pavements.

- Chapter 1: An introduction to this Part of the RDM.
- Chapter 2: An introduction to concrete as a road construction material and concrete pavements. This Chapter summarises the benefits and challenges of concrete roads. It also directs the reader to other Sections which explain some of the basic features of concrete pavements (joints, dowel bars and tie bars)(see Sections 4.11 - 4.14). It is important that these are understood in terms of how they relate to the different types and design of concrete pavement. It includes a detailed description of each of the main concrete pavement types included in this manual.
- Chapter 3: Includes a comparison of the different pavement types including suitability for traffic levels, cost, etc. giving information aimed at helping the design engineer select an appropriate pavement type. This information includes indications of their relative cost, the suitability of each pavement type to various traffic levels, examples when concrete roads might perform better than asphalt roads and the type of concrete pavement that would be most suitable for a particular situation.

Design (Chapters 4 and 5)

- Chapter 4: Explains general design topics including traffic, foundations, concrete strength, shoulders, joints, dowel bars, tie bars, reinforcement, transitions to asphalt pavements, anchorages and surface texture, etc.
- Chapter 5: Shows detailed design methods for calculating the concrete thickness for each concrete pavement type. This includes foundations, concrete strengths, with/without shoulders, joint spacings and steel reinforcement design. Example calculations are also included.

Pavement Catalogues, References and Standards (Chapters 6, 7 & Appendix A)

- Chapter 6: Pavement Structure Catalogues for each type of rigid pavement, showing various design traffic/foundation/concrete strength combinations.
- Chapter 7: References and Bibliography.
- Appendix A: Listed standards for concrete, steel, etc. that are referenced in the text.

2 Introduction to Concrete Pavements

2.1 Introduction

~~Kenya has a proud history of undertaking innovative pavement designs and intruding new surfacing techniques.~~ The benefits of concrete pavements have long been recognised in Kenya; indeed, many concrete roads have been built over the years in different parts of the country using various design standards. Many of these sites occur at highly stressed locations on the network with high levels of HGVs and/or steep slopes (e.g. climbing lanes) and make use of the inherent strengths of concrete as a road construction material.

~~It is hoped that the introduction of~~ this ~~new~~ Part (~~**Volume 3, Part 5: Rigid Pavement Design**~~) ~~into the Kenya Road Design Manual~~ will give designers a greater choice of pavement types and encourage the use of concrete pavements throughout Kenya, bringing economic benefits and more durable pavement options to the Kenyan Road network.

~~Kenya produces its own cement but has to import bitumen, so economically it makes sense to use concrete instead of asphalt as the main road-building material.~~

When deciding whether to construct an asphalt or a concrete pavement it is acknowledged that the initial costs of a concrete pavement may be higher (especially if steel reinforcement is included), however it is crucial to look at: (a) the same design period of 40 years for all pavement types and (b) the whole life costs (WLC) over the 40 year period (which include maintenance costs, rehabilitation costs and road user costs).

There are many different types of concrete pavements. Section 1.3 lists the concrete pavement types that are covered in this **RDM Vol.3, Part 5: Rigid Pavement Design**.

Where possible locally available materials should be used for economic and environmental benefits. This will also reduce damage to the road network.

2.2 Understanding Concrete as a Material

Concrete is usually made up of four main components: cementitious binder (mainly cement*), coarse aggregate, fine aggregate (i.e. sand) and water.

When a sufficient quantity of water is added to the aggregate and cement mix, chemical reactions take place and, if the quantities and conditions are correct for the 'curing' process to occur, chemical bonds are formed, leading to a strong concrete. Curing is one of the many important stages in the construction of a concrete pavement.

Hardened concrete is a very strong, durable material, with a long life and good load spreading abilities which make it a good material to use for roads. Indeed, it's strength increases for many years after construction. It does not rut or erode easily, is not damaged directly by fuel spills, fires or floods and does not suffer from age-hardening and surface cracking that asphalt does.

The main ~~things~~ to know about the behaviour of concrete are cracking, expansion/contraction and warping. These are discussed in the next sections.

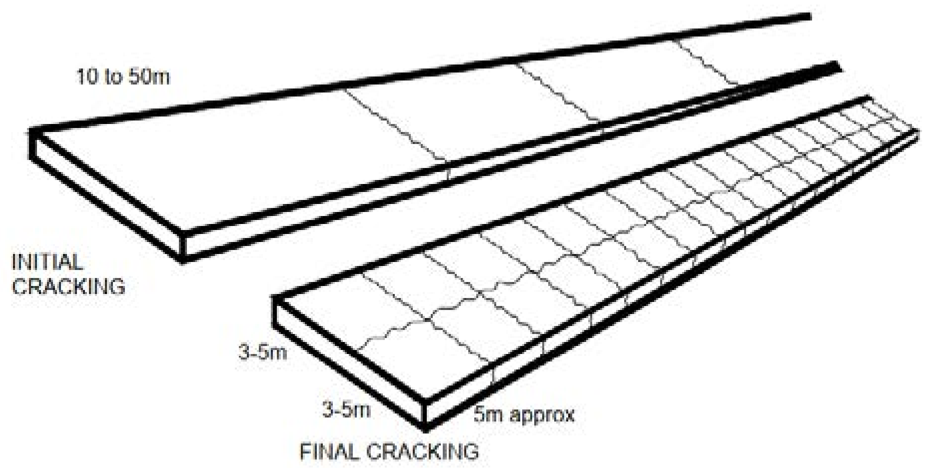
* *Cement usually comes from sintering (burning) limestone rock and aluminosilicate materials (such as clay) in a cement kiln and then grinding the remaining 'clinker' into a fine powder with gypsum or natural pozzolans, etc. This powder is highly reactive to water. Chemical admixtures can also be added to the cement, if required, to retard setting or increase workability, etc.*

2.2.1 Cracking

The main issue with concrete is that when transforming from a wet mix to a hard material (the curing process) it usually shrinks in volume and hence cracks are likely to appear. Hardened concrete is good in compression and weak in tension, hence any parts of concrete that are subjected to tensile forces will usually crack.

If plain concrete (i.e. no steel mesh reinforcement) was laid in a long strip one or two lanes wide then the concrete would generally crack during curing at approximately 5m intervals, with a meandering crack that is difficult to seal (see Figure 2.1 below).

Figure 2.1 Natural Crack Development in a Concrete Pavement Without Joints



In unreinforced concrete pavements, to make these meandering transverse cracks neater and easier to seal, 'contraction joints' are created every 5m along the road. A straight, transverse saw-cut is made in the top of the semi-cured concrete (before it cracks) so that the natural shrinkage crack forms below the saw-cut. This separates the concrete into individual slabs, with a neat joint that can be sealed. Contraction joints are discussed later in Section 4.11.1.

In reinforced concrete (i.e. concrete containing longitudinal and transverse steel bars), many fine cracks are produced during curing, but the concrete is held tightly together by the steel reinforcement, so that the pavement generally acts as a single long slab.

Other types of concrete pavement behave differently. For example, Roller Compacted Concrete (RCC) starts with a much stiffer mix which can be walked on as soon as it is laid. It is deliberately cracked after laying using a roller and other techniques, to create multiple fine cracks.

The main features associated with concrete roads i.e. joints, dowel bars and tie bars - are explained later in Sections 4.11 to 4.14.

2.2.2 Expansion / Contraction and Warping

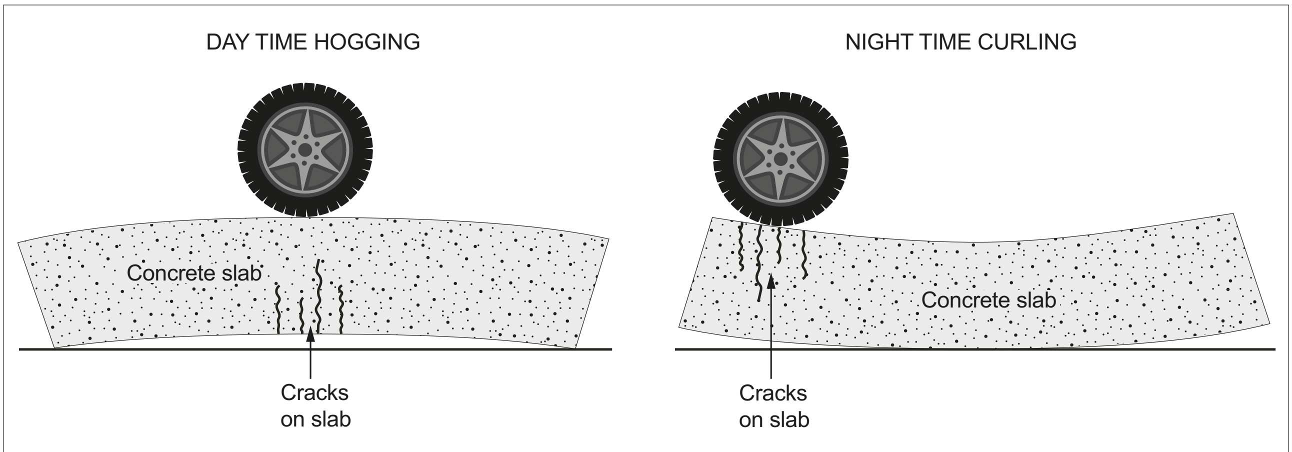
It may not be evident, but concrete expands / contracts and warps (i.e. it curls up and down) with daily changes in temperature and, to a lesser extent, moisture. These movements are small, but if they are not contained then the daily movements can damage adjacent structures e.g. bridges and cause asphalt overlays to crack above joints.

For jointed unreinforced concrete, these changes in volume are accommodated with transverse contraction joints constructed every 4-5m, that open and close on a daily basis. For reinforced concrete, the concrete is generally held in place by the steel reinforcement, but there can still be significant movement at the ends of a CRCB/CRCP pavement, so ground anchors and expansion joints (described later) are used to control this movement and protect bridges, etc.

Vertical temperature gradients in the concrete can cause the slab to 'hog' during the day (where the slab top centre is higher than the top corners) or 'curl' during the night (where the top corners are higher than the slab top centre).

This diurnal movement at the joints can cause stresses both at the joints and at unsupported locations (such as slab ends or the centre of the slab, as shown in Figure 2.2). This can lead to cracking, especially under wheel loads. The movement at joints also explains why asphalt overlays on jointed concrete pavements frequently crack above the concrete joints.

Figure 2.2 Concrete Slab Movement and Warping (Different Temperature Gradients)



2.3 Benefits and Challenges with Concrete Roads

~~A lack of knowledge about concrete pavements can contribute to a reluctance to use concrete as a road building material.~~

In Kenya, as in all countries, there will be locations where a concrete road is more appropriate than an asphalt or gravel road. The choice of pavement type can often be made on the basis of economics and suitability of the pavement to the local environment and traffic.

2.3.1 Benefits of Concrete Roads

The benefits of using concrete as a road building material include:

- Kenya produces its own cement, so could be self-reliant in terms of concrete as a road building material, rather than having to rely on imported asphalt and oil-based products with expensive and unpredictable price variations.
- Traffic volumes and axle loads are increasing in Kenya and worldwide, requiring stronger pavements. This is leading to a growing acknowledgement of the inherent strength and load-carrying ability of concrete.

- Concrete pavements typically have a design life of 40 years or more, compared with 20 years for asphalt pavements.
- The increasing cost of asphalt and other oil-based products can make construction and maintenance costs of a concrete road less than those of a fully flexible pavement over the same time period.
- A concrete surface is more durable than an asphalt surface. Concrete is not affected by rutting, ultraviolet (UV) degradation or age hardening. Also being less porous, it can be less prone to flood damage.
- Well-built concrete roads typically require less maintenance than asphalt roads, although this depends on the pavement type and construction quality.
- Environmental benefits: some studies have found that HGVs use significantly less fuel (with savings of up to 6.7 %) and emit less $C0_2$ when using concrete roads, compared with asphalt roads, mainly due to the reduction in rolling resistance, which aids fuel economy (Eupave, 2011). Another environmental benefit of concrete roads is that by-products can be used as part of the concrete mix and at the end of its life, concrete can be 100 % recycled.
- Concrete roads can better withstand extreme weather conditions, which may become more frequent, due to climate change. For example, they do not soften and rut during periods of high summer temperatures and can be less damaged by flooding.
- Reinforced concrete, in particular, can 'bridge' small weak areas in the supporting layer, through 'beam action'. This allows it to be placed on relatively weak supporting layers and areas prone to subsidence such as old mine working areas, etc.

2.3.2 Challenges with Concrete Roads

- Quality control during construction is key. Misaligned dowels, too few expansion joints, or inadequate curing can cause significant maintenance issues, for many years.
- Concrete pavements with joints are usually cheaper to build than reinforced concrete roads but will usually require more maintenance, often due to joint related issues such as spalling at corners and joints, joint sealing and dowel related issues.
- Concrete repairs to a concrete road often take longer than repairs to an asphalt road, mainly due to the curing time of the repair material, although delays to road users can be minimised by the use of specially designed concrete with high early strengths.
- Concrete road repairs are often more costly than asphalt to repair and may require specialist equipment e.g. scabbling tools, drills for retrofitting dowel bars, etc.
- The performance of unreinforced concrete roads is very dependent on the support and erosion resistance of the sub-base. If this is inadequate, the pavement can fail at the joints.
- External factors such as overloading and running vehicles close to an unsupported edge can significantly affect the lifespan of a concrete road. These are mitigated by the use of integral or tied shoulders, etc.
- The normal production method for cement produces a lot of greenhouse gases, often significantly more than asphalt production. The effects of this can be reduced by (i) the use of blended cements produced by adding other materials to the cement, e.g. naturally occurring pozzolanas, slag, limestone, fly ash, etc, (ii) the fact that the life of the pavement is approximately double that of an asphalt pavement, and (iii) there can be significant fuel savings by road users from reduced rolling resistance (EUPAVE, 2011), etc.
- A concrete road surface is reflective, and, in extreme sunlight, the surface glare can make it difficult for drivers to see white lines and can also disturb drivers' concentration.
- Access to buried services, such as water mains, sewers and electric cables, is more difficult than with an asphalt road.

- It is essential to get the surface texture of a concrete pavement right, so that the texture does not wear smooth within a few years (e.g. metal tines produce a better finish than brushing). The surface texture of a concrete road should last much longer than an asphalt surfacing but will inevitably wear out after about 20 - 30 years and require resurfacing or retexturing. The success of asphalt surfacings will mainly depend on the concrete pavement type – those with transverse joints will often develop reflection cracks in the asphalt above the joints. Retexturing (e.g. diamond grooving) is an expensive process.

2.4 Types of Pavements Listed – Rigid and Cobblestone Paving/Block Paving

This chapter describes the following main types of pavement:

- Cobblestone Paving (CP).
- Block Paving (BP).
- Jointed Unreinforced Concrete Pavement (JUCP).
- Jointed Reinforced Concrete Pavement (JRCP).
- Roller Compacted Concrete (RCC).
- Continuously Reinforced Concrete Base (CRCB).
- Continuously Reinforced Concrete Pavement (CRCP).

~~The use of large pre-cast slabs, i.e. modular concrete pavements, are not included in this Manual.~~

Rehabilitation in the form of concrete overlays (on existing asphalt or concrete pavements) or asphalt overlays on concrete pavements are included in **RDM Volume 5, Part 2: Pavement Maintenance, Rehabilitation and Overlay Design**.

2.4.1 Cobblestone Paving (CP)

Although cobblestone paving is not ~~technically~~ a rigid pavement, it has been included here as it is similar to concrete Block Paving ~~which was already in this Part of the RDM.~~

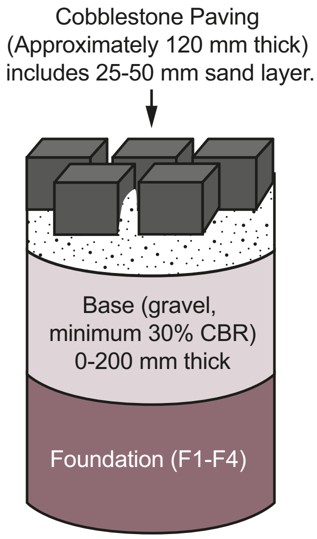
Cobblestone paving comprises manually chiselled cube or rectangular shaped stones (often called setts) that are generally sized 100-150 mm. They are packed together (often in particular patterns, e.g. fan) on a bed of sand (or crushed rock fines) using labour-based methods. Sand is then vibrated into the gaps between the stones to hold them tightly together. Excess sand is then swept away. Permanently fixed edges (e.g. moulded/chiselled stone kerbs fixed with concrete) are essential to containing the stones in place.

This type of paving is suitable for low volume Traffic up to 1M CESA, although it may be economically unjustifiable for design traffic below 0.25M CESA.

It should be noted that this type of paving often has low skidding resistance and poor ride quality. It should therefore be used in low-speed (<50 km/h) and low volume (<1M CESA), locations, such as mixed vehicle/pedestrian/non-motorised transport (NMT) areas. This type of surfacing is also generally noisy, which can be a negative for people living adjacent to the road but can also be a positive as pedestrians can hear vehicles approaching.

Examples of cobblestone paving and a cross-section showing the layers are given in Figure 2.3.

Figure 2.3 Cobblestone Road/Footpath and Side View



With cubes, for some laying patterns (e.g. fan), some larger/smaller rectangular cubes and some trapezoidal cubes will be needed to complete the pattern. This is normally stated in the specification so that the supplier can include up to 10 % off these 'oddball' cubes.

This type of pavement structure is highly economic for use in areas (especially urban areas) where base-quality gravel is scarce, but suitable stone is easily obtained.

The use of locally available materials will reduce materials and haulage costs. In cases where stabilisation or improvement of the properties of locally available materials is required, the first choice of hydraulic binder is lime.

Because the construction of cobblestone surfacing is mostly hand laid, this type of pavement can provide an opportunity to employ local people in the production of construction stone and laying/packing the stone on the road.

If occasional passage of very heavily loaded axles is expected, then the designer should be aware that these could cause instantaneous deformation of the pavement. When such axles are presumed likely to occur, the base should be constructed of graded crushed stone, crushed stone gravel/crusher-run, or hand-packed stone.

More information about the design of Block paving is given in Section 5.3 and Catalogues CLV2 and CMV1 in Chapter 6.

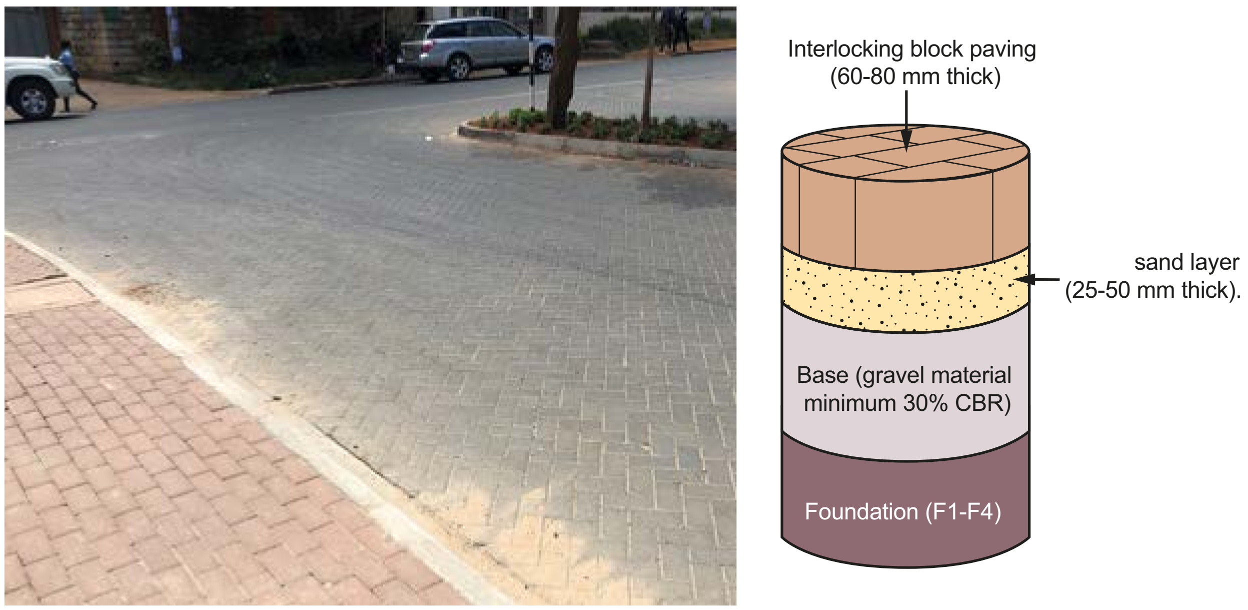
2.4.2 Concrete Block Paving (BP)

Although concrete block paving (BP) is not a rigid pavement, it has been included here as the blocks are made of concrete and is a better match than gravel roads or asphalt roads.

BP consists of small, interlocking, individual high strength, precast concrete blocks, nominally rectangular size: 100 mm x 200 mm and varying thickness (60-80 mm), laid on a bedding course of sand (or crushed rock fines) and contained within edge restraints (kerbs).

The individual blocks are constructed in a mould to accurate dimensions, so that they can be tightly packed together to form a pavement surface. BP can support large loads (it is frequently used at port storage areas) but if heavy traffic is channelised, then rutting is likely to occur (caused by displacement of the underlying sand layer). In areas of repeated braking or acceleration (e.g. junctions), particularly if there is a gradient, blocks can move (‘creep’). To reduce this movement, a herringbone pattern must be used.

Figure 2.4 Block Paved Road/Footpath (in Nairobi) and Side View



An example of block paving on a road/footpath and the cross-section layers are shown in Figure 2.4. It should be noted that this cross-section is for a low volume road (with no HBS layer).

This type of pavement is usually used for low volume roads (< 1 M CESA) with speed limits less than 50 km/h and locations where ride quality is not an issue. The skidding resistance of concrete blocks is also generally low. It is particularly suitable for residential areas used by both pedestrians and vehicular traffic.

For road use, heavy-duty concrete blocks (60-80mm thick with a compressive strength of > 49 N/mm^2) are generally considered suitable as a road surfacing for main roads. Lesser grade blocks (e.g. 50 mm thick) are available, but these should be used for footpaths and parking areas, not road surfaces.

If the blocks are tightly packed (with sand filling any gaps between the blocks) then a vertical load applied to one block is distributed to the adjacent and surrounding blocks, meaning that the block paving behaves in a semi flexible manner. Interlocking the blocks improves strength and durability characteristics to resist the punching loads and horizontal shear loads caused by the manoeuvring of heavy goods vehicles.

BP is resistant to oil spillages and may be used in a variety of heavily stressed locations, including intersections, weigh bridges, customs and toll barriers, service station forecourts, container and bus terminals.

BP is highly economic for use as a road material especially in urban areas where blocks can easily be obtained, but gravel of base quality may be scarce. Moreover, in urban areas it provides an opportunity to employ local people producing or laying the blocks.

More information about the design of Block paving is given in Section 5.3 and Catalogues CLV2 and CMV1 in Chapter 6.

2.4.3 Jointed Unreinforced Concrete Pavement (JUCP)

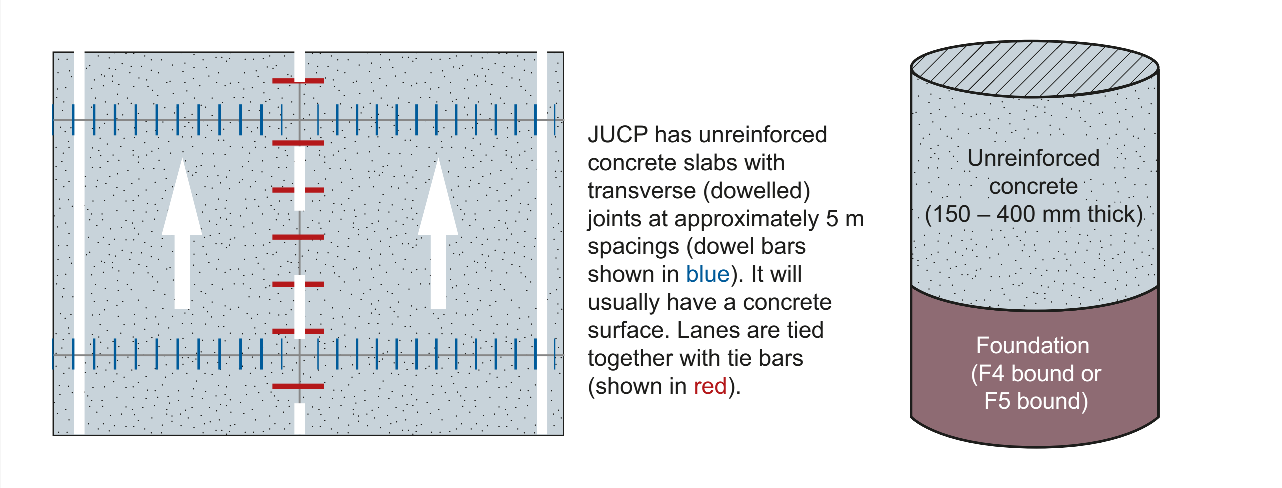
A Jointed Unreinforced Concrete Pavement (JUCP) is one of the most basic and cheapest form of concrete pavement. It can be hand-laid and compacted with a vibrating poker or screed.

Transverse contraction joints are created at 4-5 m spacings in each lane. Dowel bars (at 300 mm spacings) are normally used at these joints to provide load transfer across the joint and minimise the vertical movement of the slab ends as traffic runs from one slab to the next. For very low traffic roads (with few HGVs) dowel bars can be omitted for cost reasons.

Lanes will need to be tied together with tie bars, irrespective of whether the lanes are constructed at the same time or at different times.

Diagrams of the layout of a JUC pavement are shown in Figure 2.5.

Figure 2.5 Jointed Unreinforced Concrete Pavement – Top View and Side View



Whilst this form of concrete pavement is the cheapest to construct, it can often require significant maintenance over its lifetime. Most problems occur at the joints, which need to be correctly constructed and adequately maintained. For example, during construction dowel bars must be correctly aligned (vertically and horizontally) and protected from corrosion. Joints must be regularly resealed to prevent detritus and water from entering the joint and causing: (i) erosion of sub-base under the joint, (ii) detritus (small stones) stopping the joint from opening, leading to stress cracking, spalling and joint failure or (iii) corrosion of the dowel bars, leading to a 'lock up' of the joint requiring costly joint replacement.

There should also be enough expansion joints to allow for exceptionally hot weather and to protect adjacent bridges etc. from lateral expansion.

To achieve a long lifespan, it is recommended that all JUCPs, apart from very minor roads with few HGVs, should have a non-erodible sub-base (preferably cement bound material).

JUC slabs are usually constructed with no steel reinforcement in the concrete, however some slabs may need to be reinforced (particularly in urban areas) to control cracking and increase the life of particular slabs, including odd-shaped slabs, slabs containing utility access covers, pits and other structures, and slabs with mismatched joints.

More information about the design of Block paving is given in Section 5.4 and Catalogues CLV3 and CHV1 in Chapter 6.

2.4.4 Jointed Reinforced Concrete Pavement (JRCP)

A Jointed Reinforced Concrete Pavement (JRCP) is between a JUCP and a CRCP in terms of both construction costs and maintenance requirements.

There are still transverse joints, but these are much further apart at 20-25 m (compared with 4-5 m for a JUCP). Because the joints are further apart, there can be greater movement at each transverse joint, so dowel bars should definitely be used for load transfer at each transverse joint. Because of this greater movement at transverse joints, it is common to construct every third transverse joint as an expansion joint.

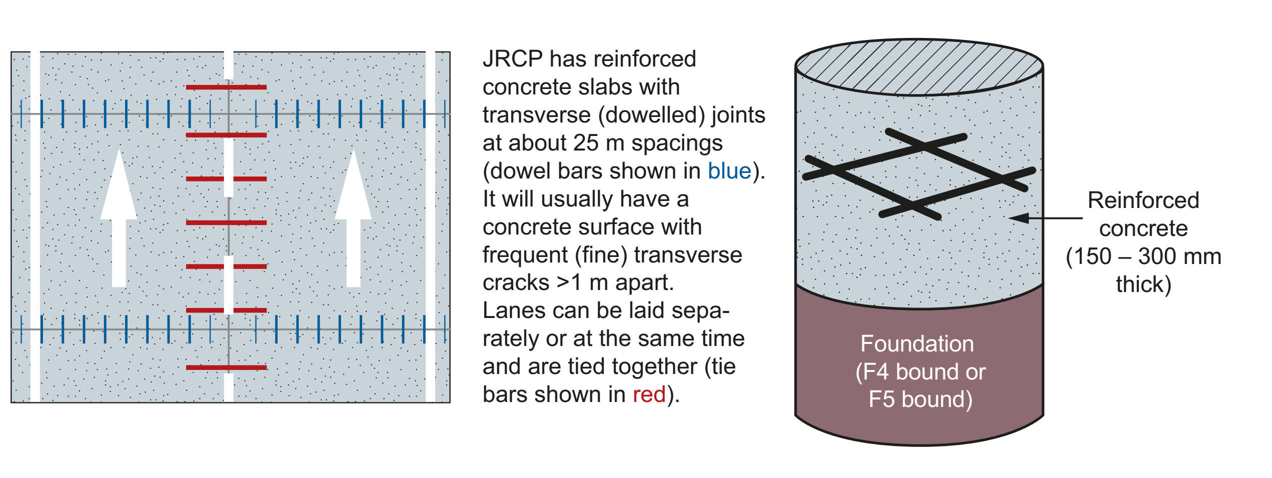
~~Each slab contains transverse and longitudinal steel reinforcement bar (rebar) to provide additional strength, as concrete is weak in tension, while steel is strong in both tension and compression. Steel~~

~~and concrete have similar coefficients of thermal expansion, so a concrete slab reinforced with steel will experience minimal stress as the temperature changes.~~

During curing, fine transverse cracks will occur every 1-2 m. As long as they remain fine cracks, then they do not need sealing. JRCP are usually laid with a paver – they can be hand-laid but the ride quality will be less good

Diagrams of the layout of a JRC pavement are shown in Figure 2.6.

Figure 2.6 Jointed Reinforced Concrete Pavement – Top View and Side View



JRCP are likely to be more expensive to construct than JUCP because of the additional steel reinforcement, but this can be offset in the future by reduced maintenance costs. The main advantages that a JRCP has over a JUCP are that:

a. There are fewer joints so should be less issues and maintenance (since most of the problems of jointed concrete pavements occur at the joints),

b. A JRCP will give less problems in areas with differential settlement (and also when there is doubt regarding materials and workmanship).

However, JRCP are often less popular than CRCB/CRCP due to their lack of transverse joints.

More information about the design of JRC pavements is given in Section 5.5 and Catalogues CHV2 to CHV5 in Chapter 6.

2.4.5 Roller Compacted Concrete (RCC)

Roller Compacted Concrete (RCC) takes its name from the way that it is constructed. The RCC concrete mix is usually prepared in a mixing plant, delivered to site and then laid using a paver in layers up to 250 mm compacted thickness and 13 m wide.

The concrete mix is stiff enough such that the pavement can be laid with a modified asphalt paver and then compacted by steel wheel vibratory rollers (which induce cracking). If required, final compaction can be provided by rubber-tyred rollers.

The stiff RCC concrete mix has a lower cement content, a tight aggregate grading with a higher proportion of fine aggregate and uses mostly < 20 mm crushed rock (rather than river gravel), which gives it the consistency of a zero slump concrete. It can be walked on as soon as it is laid.

RCC does not require formwork, reinforcement, dowel bars for load transfer or transverse/ longitudinal contraction joints (although if appearance is important, then joints can be saw cut into the RCC to control crack locations).

Figure 2.7 Roller Compacted Concrete being Laid and Side View

A photo of RCC being laid and a layer diagram are shown in Figure 2.7.

RCC combines strength, long-term performance and minimal maintenance. In motorways and main highways, it provides an economical alternative to CRCP, even though it usually requires an asphalt surfacing to achieve adequate skidding resistance and surface evenness. RCC has significant potential for the Kenyan road network, particularly for truck lanes and main road widening projects. RCC can have high flexural, compressive and shear strengths, which allow it to support multiple heavy, repetitive loads without failure (such as in heavy industrial and mining applications) and to withstand highly concentrated loads and impacts.

RCC is a strong material, with a typical compressive strength of more than 25 MPa at 28 days. It should not be confused with weaker cement treated materials /cement bound materials. When cured (i.e. the material has gained sufficient strength), it can be directly trafficked by large numbers of heavy vehicles. Proper curing will ensure a strong and durable pavement. The finished RCC surface is usually hard and durable, but smooth with low skidding resistance and texture depth.

For lower speed roads (<60 km/hr) (e.g. estate roads) the untreated surface is generally suitable. To increase skid resistance, the fresh RCC surface can be broomed or tined as for a conventional vibrated concrete.

For higher speed roads, an additional asphalt surface (e.g. surface dressing or thin asphalt overlay) will be required to achieve adequate skidding resistance and ride quality (i.e. longitudinal profile.) Alternatively, it may be possible to treat the hardened RCC surface by grooving and/or grinding to gain the required surface features.

More information about the design of RCC pavements is given in Section 5.6 and Catalogue CHV6 in Chapter 6.

2.4.6 Continuously Reinforced Concrete Base (CRCB)

Continuously Reinforced Concrete Base (CRCB) comprises reinforced concrete with a thick structural asphalt layer (at least 100 mm thick) on top of the concrete.

~~The concrete contains transverse and longitudinal steel reinforcement bar (rebar) to provide additional strength, as concrete is weak in tension, while steel is strong in both tension and compression. Steel and concrete have similar coefficients of thermal expansion, so a concrete slab reinforced with steel will experience minimal stress as the temperature changes.~~

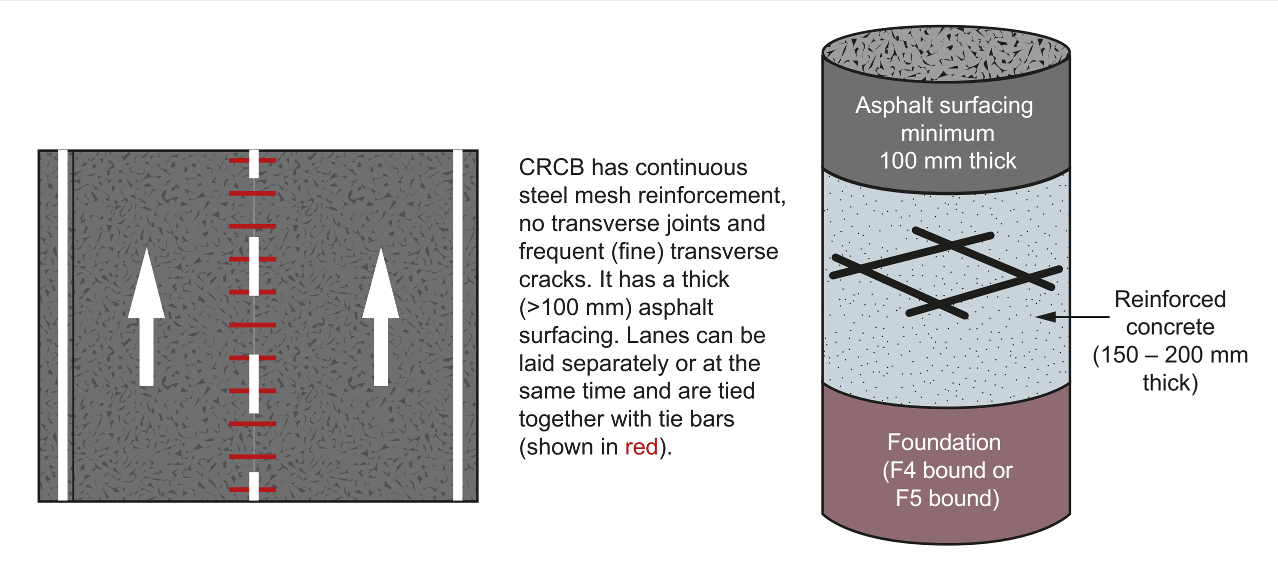
CRCP (see Section 2.4.7) is very similar to CRCB, but has thicker concrete, thicker longitudinal steel reinforcement and no asphalt (or a very thin <30 mm asphalt surfacing layer), with steel reinforcing bars (or mesh) placed at approximately the mid-depth of the concrete slab along the entire length of the pavement. The longitudinal bars are most important and greater in number, as they hold the multiple transverse cracks together. This ensures good aggregate interlock and load transfer across the cracks, which maintain the structural performance of the pavement. Transverse reinforcing bars are less frequent but will hold any longitudinal cracks together.

During curing, fine transverse cracks will naturally occur every 1-5 m in the reinforced concrete, but these do not need sealing.

Diagram of the layout/features of a CRCB pavement are shown in Figure 2.8.

A CRCB pavement is used for major, heavily trafficked, inter-urban roads. This dual material pavement

Figure 2.8 Continuously Reinforced Concrete Base – Top View and Side View



combines the inherent strength of a reinforced concrete pavement with the flexibility of an asphalt surfacing. The asphalt surfacing means that: a) it is quieter than a concrete surfaced pavement and b) the surfacing can easily be planed off and replaced (for example if damaged or when skidding resistance gets low) - unlike a concrete surface.

This type of construction is one the most expensive types of concrete pavement, usually with a construction cost similar to CRCP.

Because there are no transverse joints, reflection cracking in the asphalt is not usually a problem, in contrast to Jointed Unreinforced and Jointed Reinforced Concrete Pavements.

CRCB is normally laid by a paver and will have a good longitudinal profile and ride quality. Depending on the size of the paver and on-site arrangements, one or two lanes can be paved at the same time. If two lanes are paved at the same time, then, depending on the width of the construction, a longitudinal construction joint with tie bars may need to be constructed to form separate lanes.

For CRCB, deep reinforced ground anchors are required at each end to restrict any horizontal end movement that could damage adjacent bridges etc. Run-on slabs with expansion joints may also be required when changing from CRCB to a different type of pavement (see Section 4.18 and 4.19).

More information about the design of CRCB pavements is given in Section 5.6 and Catalogue CHV7 in Chapter 6.

2.4.7 Continuously Reinforced Concrete Pavement (CRCP)

A Continuously Reinforced Concrete Pavement (CRCP) is constructed with steel reinforcing bars (or mesh) placed at approximately the mid-depth of the concrete slab along the entire length of the pavement.

The concrete contains transverse and longitudinal steel reinforcement bar (rebar) to provide additional strength, as concrete is weak in tension, while steel is strong in both tension and compression. Steel and concrete have similar coefficients of thermal expansion, so a concrete slab reinforced with steel will experience minimal stress as the temperature changes.

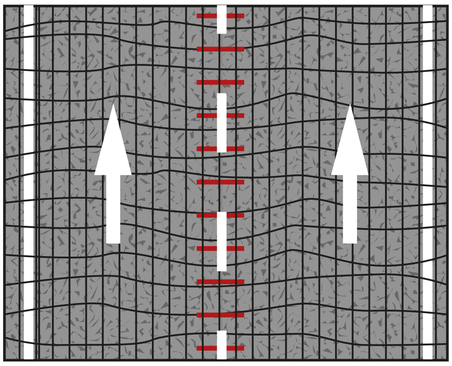
The longitudinal bars are most important and greater in number, as they hold the multiple transverse cracks together, ensuring good aggregate interlock and load transfer across the cracks, which maintain the structural performance of the pavement. Transverse reinforcing bars are less frequent but will hold any longitudinal cracks together.

As the concrete cures, fine transverse cracks will occur at 1 - 2 m intervals. These fine cracks do not need sealing. The cracks are held tightly together by the reinforcement and do not compromise the structural integrity of the pavement. As with any concrete pavement, thermal expansion and contraction of the concrete still takes place, but this consists of very small movements at each of the fine cracks, rather than a larger movement at a transverse contraction joint. Because the fine cracks are held together and there are no transverse joints, water penetration into the pavement is minimal, leading to enhanced foundation durability.

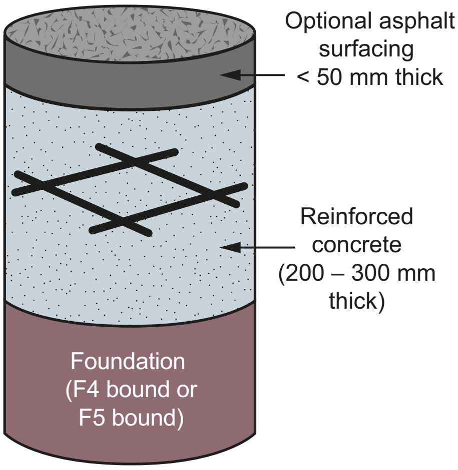
As there are no transverse joints along the main length of the pavement, the CRCP acts as a single large slab, which provides a continuous, even surface capable of withstanding the heaviest traffic loads and the most adverse environmental conditions. The CRCP is not affected by the transverse joint problems that occur on a jointed concrete pavement. Traffic loading is effectively spread over a large area, so this type of payment can often be used in conditions with poor and uneven subgrade or locations where abnormal differential ground movements are expected. Also with CRCP it is less crucial that the sub-base is non-erodible, compared to JUCP or JRC.

Diagrams of the layout/features of a CRCP pavement are shown in Figure 2.9.

Figure 2.9 Continuously Reinforced Concrete Pavement – Top View and Side View



CRCP has continuous steel mesh reinforcement, no transverse joints and frequent (fine) transverse cracks. It can have a concrete surface or a thin asphalt surfacing. Lanes can be laid separately or at the same time and are tied together with tie bars (shown in red).



Because there are no transverse joints, reflection cracking in an asphalt overlay is not usually a problem, in contrast to Jointed Unreinforced and Jointed Reinforced Concrete Pavements.

CRCP is normally laid by a paver, so ride quality is usually very good. Depending on the size of the paver and site layout, one or two lanes can often be paved at the same time. If two lanes are paved together then, depending on the construction width, a ‘wet’ longitudinal construction joint with tie bars may need to be constructed in the fresh concrete to form separate lanes.

If a thin asphalt layer (50 mm or less) is added at the time of construction, or indeed later, the pavement is still classed as a CRCP. The thin asphalt surfacing is not considered structurally significant, so does not allow any reduction in the design thickness of the CRCP concrete slab.

For CRCPs, deep reinforced ground anchors are required at each end to restrict any horizontal end movement that could damage adjacent bridges etc. Run-on slabs with expansion joints may also be required when changing from CRCP to a different type of pavement (see Sections 4.18 and 4.19).

More information about the design of CRCP pavements is given in Section 5.7 and Catalogue CHV8 in Chapter 6.

2.5 Classifying a Rigid Pavement with an Asphalt Overlay

The following guidance is useful in classifying a rigid pavement that has had an asphalt overlay of varying thickness:

- A rigid pavement with up to 50 mm of asphalt overlay is still regarded as **a rigid pavement**. (e.g. a Continuously Reinforced Concrete Pavement (CRCP) with a 30 mm asphalt overlay).
- A Continuously Reinforced Concrete Base (CRCB) pavement is designed with an asphalt overlay at least 100 mm thick and is still regarded as **a rigid pavement**.
- A rigid pavement with 51 to 179 mm of asphalt overlay (or a previously cracked, seated and overlaid pavement), requires special consideration in the behaviour, assessment and treatment design options and is regarded **a hybrid pavement**.
- A rigid pavement with 180 mm or more of asphalt overlay is regarded as **a flexible pavement**.

3 Selection of Pavement Type

For new build pavements, if there are no over-riding factors to dictate what type of pavement is most suitable, then designs for both asphalt and concrete pavements should be priced with a decision based on economic whole life costs. The cost comparisons should have the same design period (usually 40 years), and take into account the costs of construction, maintenance and rehabilitation, reconstruction (for an asphalt pavement with a design life of 20 years) and road user costs and delays, etc. It should be noted that few pavements are abandoned at the end of their design life and often continue to serve as part of the future pavement structure.

At some locations, there will be over-riding factors that dictate that one type of pavement would be preferable to another, e.g. for a steep uphill slope (climbing lane) with many loaded HGVs a concrete pavement would be more suitable than an asphalt pavement (because of the better load spreading abilities of concrete, the fact that it doesn't rut or age harden and can cope better with high stress locations).

If a concrete pavement is the preferred type of pavement, there are also factors that dictate what type of concrete pavement would be most suitable. Examples of these are given below.

3.1 Choice of Concrete Pavement Type

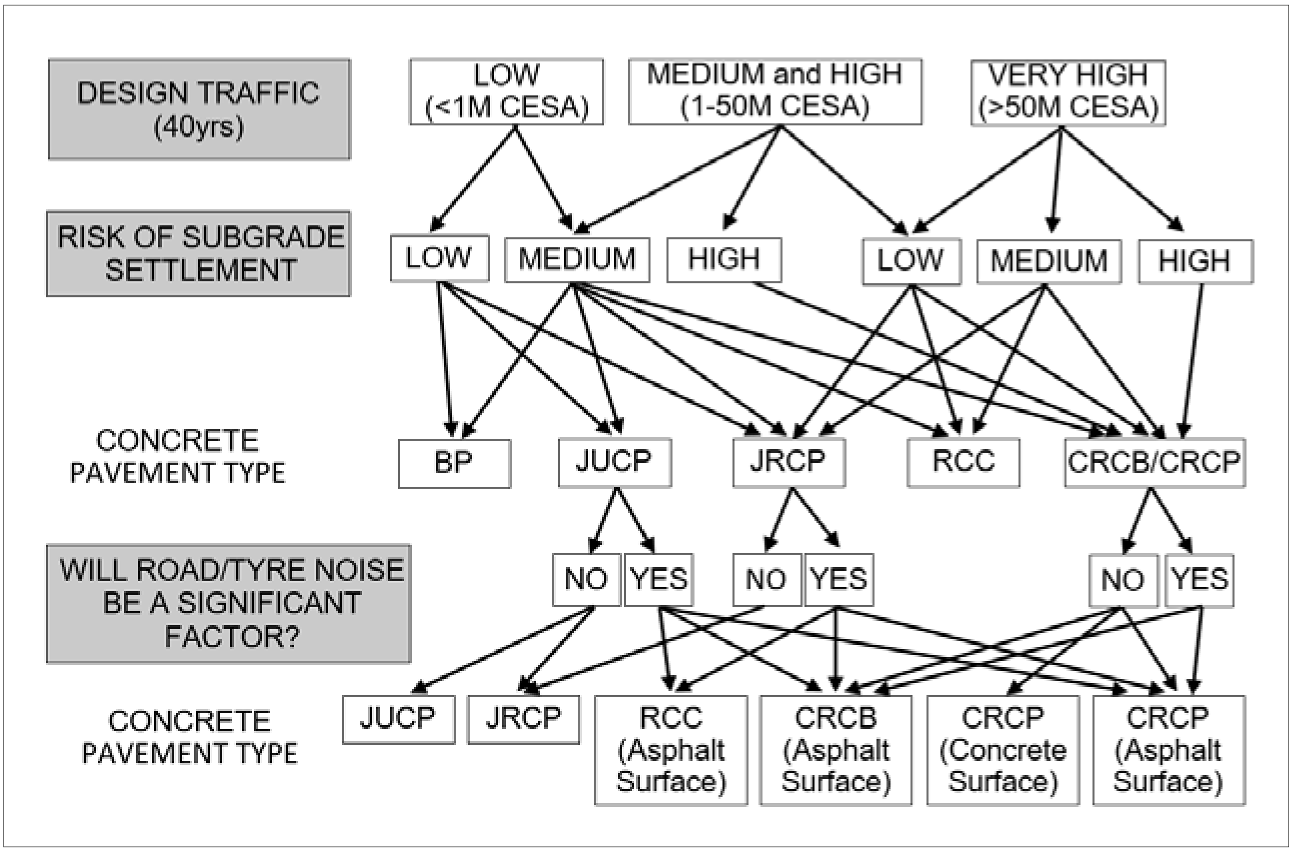
The choice of ~~which~~ concrete pavement type will depend on many factors, including:

- **Traffic levels.** Some types of concrete pavement are better suited to high traffic levels due to their high cost, ~~whilst other types may be unsuitable for high and very high traffic levels.~~
  - **i.** Low (<1M CESA): BP, JUCP
  - **ii.** Medium (1-10M CESA): JUCP, JRCP, RCC, CRCB/CRCP
  - **iii.** High (10-50M CESA): CRCB/CRCP, RCC, JRCP, JUCP
  - **iv.** Very High (>50M CESA): CRCB/CRCP, RCC, JRCP
- **Economics.** A CRCP is the best type of concrete pavement with few maintenance requirements over its lifetime, but it is the most expensive type of pavement to build.
- **Environmental - Risk of subgrade settlement**:
  - **i.** Low: BP, JUCP
  - **ii.** Medium: JRCP, CRCB/CRCP
  - **iii.** High: CRCB/CRCP
- **Environmental - Noise**:
  - **i.** Quieter: (designed and built with asphalt surfacing): RCC, CRCB/CRCP
  - **ii.** Noisier: (designed and built with concrete surfacing): BP, JUCP, JRCP, CRCP
- **Maintenance**. Less maintenance is required in concrete pavements with fewer transverse joints.
- **Ride quality required**, e.g. paver-laid CRCB and CRCP usually have a good ride quality, but block paving and JUC often have a poor ride quality. RCC requires an asphalt surfacing to improve the ride quality and skid resistance.
- **Type of Plant available**, e.g. CRCB/CRCP and JRC are best laid with a concrete paver; RCC can be laid using a modified asphalt paver, while BP and JUCP can be laid by hand.
- **The availability of local labour**, which might favour labour-intensive options such as BP or JUCP.

The following section presents the advantages and shortcomings of each pavement type, in the context of different traffic levels.

Figure 3.1 is a simple flow diagram for deciding which type of concrete pavement to choose, based on design traffic levels, risk of subgrade settlement and whether road/tyre noise would be a significant factor.

Figure 3.1 Example Flow Diagram for Deciding Which Type of Concrete Pavement



3.2 Advantages and Shortcomings of Each Concrete Pavement Type

Each concrete pavement type is best suited to a particular traffic level. The different types also have distinct advantages (pros) and disadvantages (cons).

Table 3.1 (overleaf) lists these for the main rigid pavement types in the context of different traffic levels.

Table 3.1 Main Types of Rigid Pavement – Advantages and Disadvantages

No.	Pavement Type	Traffic Level Suit-ability	Cost	Advantages (Pros)	Disadvantages (Cons)
1	**Cobblestone Paving** (CP)	Low (0.1 M to 1 M CESA) and speeds < 50 km/h.	$	• Basic (low cost) form of pavement. • Often local material available. • Easily laid with minimum plant and unskilled labour. • Dry construction - can be trafficked immediately. • Can be dug up and relaid if required.	• Poor ride quality& skid resistance • Unsuitable for high-speed roads • Noise & rutting may be issues.
2	**Block Paving** (BP)	Low (0.1 M to 1 M CESA) and speeds < 50 km/h.	$	• Basic (low cost) form of pavement. • Durable, factory-made blocks. Range of shapes, colours • Easily laid with minimum plant and unskilled labour. • Dry construction - can be trafficked immediately. • Can be dug up and relaid if required.	• Unsuitable for high-speed roads • Poor ride quality& skid resistance • Noise & rutting may be issues. • Can need frequent maintenance if high traffic.
3	**Jointed Unreinforced Concrete pavement** (JUCP). (Unreinforced, square joints **with dowels**).	Low/Medium/ High (0.1 M to 50 M CESA)	$$	• Basic (low cost) form of concrete pavement. • Less steel required than CRCP. • Better performance than undowelled JUCP. • Good ride quality if paver-laid. • Durable pavement, if timely repairs.	• Joints are the main weakness and can be a source of problems throughout life. • Recurring maintenance required. • Less suitable for high temp range areas • Concrete surface - noise may be an issue
4	**Jointed Unreinforced Concrete pavement** (JUCP). (Unreinforced, skew joints **without dowels**).	Low traffic routes such as rural roads (< 1 M CESA)	$	• Lowest cost form of concrete pavement. • Can be hand-laid with minimum plant. • Less steel required than CRCP. • Good ride quality if paver-laid.	• Only suitable for low volume roads. • Joints will cause problems throughout life. • Skew joints prone to corner cracks. • Poor load transfer -HGVs will damage joints. • Concrete surface - noise may be an issue
5	**Jointed Reinforced Concrete Pavement** (JRC).	Medium/High (1 M to 50 M CESA)	$$$$	• > 80 % fewer joints than JUCP (joints at 25 m rather than 4-5 m), so far fewer joint problems. • Reinforced, so fewer cracking issues than JUCP. • Less joint movement and end movement. • Good ride quality if paver-laid. • Better than JUCP if subgrade settlement issues.	• Joints are a weakness and can cause problems. • Recurring maintenance required. • Concrete surface, so noise may be an issue.
6	**Roller Compacted Concrete Pavement** (RCC). (With > 90mm asphalt). *For design guide see references*	Medium/High/ Very High (1 M to 600 M CESA) (See cons re-surfacing)	$$$	• Quick/easy/cheap to construct. No steel/formwork. • Can be used by traffic/overlaid soon after paving. • Asphalt surfacing so low noise, etc. • Lower cement content so less shrinkage cracking. • Lower maintenance costs than asphalt over lifetime. • Can be used in areas with poor subgrades.	• Likely poor ride quality/skid resistance. • Higher-speed roads (> 60 kph) will need an asphalt surfacing for good skid resistance and surface evenness.
7	**Continuously Reinforced Concrete Base** (CRCB). (with minimum 100mm thick asphalt surfacing).	High/Very high (10 M to 400 M CESA). Particularly for very high traffic levels (> 50 M CESA).	$$$$$	• Combines concrete strength & quiet asphalt surface. • Excellent durability. No problematic joints. • Suitable for very heavy traffic loadings. • Very long-life expectancy (40-60+ years). • Lower maintenance costs over its lifetime. • Good ride quality if paver-laid. • Can be used in areas with poor subgrades.	• High construction cost. • Laying formwork and tying reinforcement is labour-intensive. • Specialist plant required to pave.
8	**Continuously Reinforced Concrete Pavement** (CRCP). (with/without asphalt surfacing maximum 30 mm thick).	High/Very high (10 M to 400 M CESA). Particularly for very high traffic levels (> 50 M CESA).	$$$$$	• Greater durability. No problematic joints. • Suitable for very heavy traffic loadings. • Very long-life expectancy (40 - 60+ years). • Lower maintenance costs over its lifetime. • Good ride quality. • Can be used in areas with poor subgrades. • In high temperature range areas, CRCP will perform better than JUCP.	• High construction cost. • Laying reinforcement is labour-intensive. • Specialist plant required to pave. • If concrete surface, noise may be issue.

***Note:** Cobblestone paving, Block paving and JUCP with no dowels are only suitable for low volume roads*

3.3 Effects of Kenya's Climate on Concrete Pavements

The climate can have a significant influence on the design of road making materials, road performance, drainage and anti-erosion systems. This is true for both asphalt roads (e.g. high temperatures can cause a poorly designed asphalt mix to soften and rut) and concrete roads (where exceptionally high temperatures can cause the concrete to expand and buckle).

Concrete pavements are less susceptible to this type of damage but can still be affected by climate. For example, curing is a crucial stage in the hardening process when the concrete develops most of its strength. More care must be taken in areas with high temperatures and/or strong winds to stop the surface drying out and producing weaker concrete.

Concrete pavements will be built on granular embankments. The embankment and subgrade materials can be affected by erosion, moisture content and other variations in the foundation affecting bearing strength and ultimately pavement life.

For maps of Kenya's temperature, rainfall and geology see **RDM Volume 3 Part 3**.

Kenya's climate varies across the country with three main climatic zones. Each of these zones has factors that are relevant to concrete pavements and should be considered by the design engineer and contractor.

These are discussed in Table 3.2.

Table 3.2 Kenyan Climate and Relevance to Concrete Pavements

1	**Most of the North, East and South-east of Kenya is arid to very arid grassland (with high temperatures* of 28-40°C and low rainfall** <500 mm/year).** • This area is very hot and dry. Concrete surfaced pavements may perform better than asphalt surfaced roads as they won't be negatively affected by age hardening from solar/ultraviolet light. • Much of this area is flat and can be prone to flooding. Concrete can be more resistant to flood damage than asphalt, but both pavements depend on having a sound sub-base and foundation, which ~~can~~ be eroded. • Concrete pavements require a lot of water to construct and must not dry out during the curing process, so the high temperatures and arid terrain will require additional care and supervision during construction. • High daily/annual temperature variations will lead to greater joint movements for jointed concrete pavements (JUCP, JRC) with the potential for joint issues and increased maintenance costs.
2	**The Central and Western highland areas are semi humid to humid, tropical areas (cooler temperatures* of 11-26°C, high rainfall** >1800 mm/year).** • Concrete is an excellent road building material for high stress areas such as steep uphill slopes (climbing lanes), particularly if high numbers of heavy HGVs. • Concrete roads can be more durable than gravel/asphalt for high rainfall areas. • Less temperature variation means less joint movement, and reduced risk of joint problems for jointed concrete pavements (JUCP, JRC).
3	**Along the coast and central lowland areas is a tropical semi arid/semi humid area with (high temperatures* of 30-36°C and medium-high rainfall** >1000 mm/year).** • Concrete is a good material to use in this high temperature and rainfall area, as it does not melt or rut (as asphalt can) and is less susceptible to water damage.

Notes: **Mean maximum temperature (°C), **average annual rainfall (mm).*

~~*(Data from various internet sources, including: www.climatestotravel.com/climate/kenya, www.britannica.com/place/Kenya/Climate and africanian.com/travel/guides-tips/weather in Kenya).*~~

3.4 Suitability for Local Environment

The local environment in which a concrete pavement is built can have a significant effect upon its lifespan. The design of the pavement, including the pavement type (e.g. JUC, JRC, RCC, CRCB/CRCP), joint type, joint spacing, whether it has an asphalt surfacing and even the concrete mix design (cement type and admixtures), should be tailored to its environment, to reduce damage and maximise its life.

3.4.1 Proximity to Sea (Salt Water Damage)

Concrete can be damaged by salt compounds, hence the construction materials (including the large aggregate, sand and water used for the mix) should be checked to limit the presence of salts.

For more information about aggregate testing see **RDM Volume 3 Part 2: Materials Field and Laboratory Testing**.

If a concrete road is near the sea or is regularly flooded with salt water, then the concrete and any exposed steel can be significantly damaged. In areas where this is likely to occur, steps can be taken to counter this, including use of cement with a resistance to chloride ion penetration, using concrete pavement types with fewer or no transverse joints, ensuring all reinforcement is galvanised or coated to inhibit corrosion, etc.

3.4.2 Ground with Sulphates

In areas with ground sulphates then a sulphate resistant cement should be used. See list of relevant Standards in Appendix A or see **RDM Volume 3 Part 2**.

3.4.3 Temperature

Hardened concrete undergoes significant changes in volume with temperature changes and, to a lesser extent, with changes in moisture. In JUC and JRC pavements, this volume change must be accommodated by contraction and expansion joints. In some climates there is hardly any change in daily and annual temperatures, so expansion joints can be quite widely spaced. In other regions (notably deserts) there can be large fluctuations in both diurnal and annual temperatures, so joint design and spacing are crucial. A high diurnal temperature range will mean significant movement at joints and a higher risk of joint failure. To combat this, slab lengths can be reduced to lower stresses on joints caused by curling / hogging.

For concrete pavements constructed in high temperatures, extra care must be taken during curing to reduce evaporation. Curing is a crucial stage in the development of concrete strength, when bonds are formed within the concrete, and fresh concrete is extremely susceptible to the drying effects of sun and wind. In dry climates, particular care must be taken to protect fresh concrete, keeping it damp for at least seven days after laying.

In areas with a high annual temperature range, concrete pavements constructed at a cooler time of the year will need additional expansion joints to reduce the risk of ‘blow-ups’ that can occur at hotter times of the year, particularly in exceptional heatwaves. A blow-up might occur when the concrete has already expanded as much as it can at the joints, but needs to expand more, causing the ends of slabs to move vertically and severely damage the road.

3.4.4 Rainfall

In drier areas, there should be an emphasis on keeping water out of the pavement through cross-section design and sealing gaps, etc, and drainage layers within the pavement should not be needed.

In high rainfall regions that are subject to high groundwater levels and tunnels / underpasses, the use of a properly designed drainage layer underneath the pavement (using a coarse filter material such as a graded Macadam or no-fines concrete) may be an effective means of removing water that has infiltrated the surface or the shoulders, or from beneath the pavement.

3.4.5 Noise

Concrete-surfaced roads are generally noisier than asphalt-surfaced roads. For roads in an urban environment where vehicle tyre/road surface noise is considered to be an issue, then concrete roads with an asphalt surfacing, e.g. RCC, CRCB or CRCP with a thin asphalt surfacing, can provide a quieter alternative.

The concrete pavement type and/or asphalt surfacing should be carefully chosen.

There is also the option of providing an exposed aggregate concrete surfacing (EACS) which can be significantly quieter than a conventional brushed/tined concrete surface (see Section 4.22.5).

EACS, however, is expensive and can be technically challenging to construct. The skidding resistance will depend almost entirely on the aggregate characteristics and hence a higher quality aggregate with good skidding resistance and greater durability than conventional concrete aggregate would be required for a high-speed road. To reduce costs, the concrete can be laid in two layers with only the upper layer (say 50 mm thick) containing the higher quality aggregate. However, for best performance, both layers of concrete should be laid 'wet on wet' within a few hours, which can be challenging. Also exposing the aggregate is a skilled, time-critical operation, where mistakes can be costly and difficult to rectify.

3.4.6 High-Stress Environments (Slopes, Bus Stops, Junctions, etc)

Concrete pavements can be used in localised high-stress environments where asphalt might not be so robust and could rut. These can include locations with slow-moving or stationary vehicles, heavily-loaded HGVs, tight bends with significant shear forces.

Example locations include: roads to/from ports, tight bends, laybys, bus stops, weighbridge approaches/exits, approaches to traffic lights /roundabouts / junctions, steep uphill slopes (climbing lanes), truck parking areas, etc.

For more information about concrete pavements on steep slopes see Section 4.20.

4 General Design of Concrete Pavements

4.1 Introduction

This Manual provides guidance on the design of concrete pavements for rural and urban roads. It is not intended to be used in the design of residential pavements, car parks or industrial pavements, as these are likely to carry significantly different HGV traffic levels.

The design of a concrete pavement usually comprises six parts:

1. **Calculate the Design Traffic.** This should be calculated in millions ~~of~~ CEAS over the required design period, usually 40 years. See **RDM Volume 3 Part 3**.

2. **Select the type of pavement** (or types) required from: Cobblestone Paving (CP), Block Paving (BP), Jointed Unreinforced Concrete (JUC), Roller Compacted Concrete (RCC), Jointed Reinforced Concrete (JRC), Continuously Reinforced Concrete Base or Pavement (CRCB/CRCP). Guidance on the type of concrete pavement to choose for various traffic levels and local environment was given in Section 3.1: ‘Choice of Concrete Pavement Type’. The selection of the overall pavement configuration should be based on its suitability for a particular project (e.g. is an asphalt surfacing required for reduced noise) and on economic considerations. If CP or BP go straight to Sections 5.2 and 5.3.

3. **Choose the Foundation Class**. Select the type and thickness of foundation beneath the concrete pavement (i.e. up to and including the recommended cement bound sub-base). This will depend upon the existing subgrade CBR and the design traffic. The foundation beneath a concrete slab must be bound and should not be erodible – this is different to an asphalt pavement. A minimum foundation class F4 (bound)(E>200 MPa) or F5 (bound)(E>400 MPa) is required for JUC, JRC, RCC, CRCB and CRCP. Further details are given in Section 4.5 and Table 4.3. The foundations for Cobblestone Paving and Block Paving are different and are given in Sections 5.2.1 and **RDM Volume 3 Part 3**.

4. **Select or calculate the amount of Longitudinal Reinforcement (R)**. For JRC choose the bar diameter (12/16 mm) and the amount of longitudinal reinforcement = 500/600/700/800 mm^2/m with associated R value.

   If reinforcement is required for the selected type of pavement, then decide on the level of longitudinal reinforcement (note that transverse reinforcement is the same for all types of reinforced concrete pavement). The longitudinal reinforcement for CRCB and CRCP have set requirements (R = 0.6 %). For JRC choose the bar diameter (12/16 mm) and R value (for the percentage of longitudinal steel reinforcement), the options are:

   - R = 8.812 for 500 mm^2/m width reinforcement
   - R = 9.071 for 600 mm^2/m width reinforcement
   - R = 9.289 for 700 mm^2/m width reinforcement
   - R = 9.479 for 800 mm^2/m width reinforcement

5a. **Calculate the thickness of concrete slab required**. See Chapter 5. The design thickness equations/charts will require:

  a. Design traffic over required design life - usually 40 years (in terms of million CESA).
  b. Foundation class or equivalent Foundation Modulus (E) from item 2 above. The foundation class should be F4 (bound) or F5 (bound). A bound sub-base is recommended for all concrete pavements to: (i) resist erosion of the sub-base and limit 'pumping' at joints and slab edges; (ii) provide uniform support under the pavement; and (iii) reduce deflection at joints and enhance load transfer at joints (especially if dowels are not used).
  c. Concrete strength (note that the equations for JUC/JRC use mean compressive cube strength at 28 days, and Charts for RCC/CRCB/CRCP use mean flexural strength at 28 days).
  d. For JRC, the amount of longitudinal reinforcement from Item 3 above.

5b. **For JUC/JRC pavements only, reduce the concrete thickness if an integral/tied shoulder will be provided**. Use Equation 5.2 (which is the same as Equation 5.4) or Table 5.1. Note that Pavement Catalogue Charts in Chapter 6 for RCC/CRCB/CRCP concrete thickness already assume that an integral/tied shoulder will be constructed. Traffic running close to the outer unsupported edge of a concrete slab will cause damage in the form of corner cracking and/or edge cracking. To reduce this damage, it is sensible to either widen the slab by at least 600 mm and mark this area with white lines to keep traffic away from the edge or have a tied concrete shoulder (i.e. an additional slab, the same thickness as the main slab, at least 1 m wide and joined to the main concrete lane with tie bars). If this is not possible, then, for all types of concrete pavement the slab thickness needs to be increased to reduce damage to the edges / corners.

6. **Calculate the other features of the selected pavement type**.

  a. Contraction and Expansion Joint spacing. For JUC see Table 5.2 and for JRC see Table 5.3.
  b. Longitudinal Reinforcement spacing. For JRC see Table 5.4. For CRCB (12 mm diameter) and CRCP (16 mm diameter), calculate the spacing between longitudinal bars using Equation 5.6 or Table 5.6.
  c. Transverse reinforcement (JRC, CRCB, CRCP) will be 12 mm at 600 mm spacings.
  d. Dowel bar details (JUC and JRC) see Table 4.11.
  e. Tie bar details (all concrete pavement types) see Table 4.12.

Table 4.1 (overleaf) lists the Equations, Figures and Tables, etc, that are needed to calculate the design for each concrete pavement type. It also shows the location of example pavement structures and the range of concrete thicknesses for each pavement design type.

Table 4.1 Information Required for a Concrete Pavement Design in this Manual

No.	Pavement Design Variable	Pavement Type: CP	BP	JUC	JRC	RCC	CRCB	CRCP
1	**Concrete Thickness** (needs info below)	Approx.100 mm stone/ sand layer	60-80 mm blocks	Eqn. 5.1 No shoulder	Eqn. 5.3 No shoulder	Figure 5.2 With shoulder	Figure 5.3 With shoulder	
	Information Required							
1a	**Design Traffic** (M CESA)	0.1 to 1	0.1 to 1	0.1-400	Not stated. Assumed 1-400	1-600	1-400	
1b	**Foundation Class**	F1-F4	F1-F4	F4 (bound) or F5 (bound)	F4 (bound) or F5 (bound)	F4 (bound) or F5 (bound)	F4 (bound) or F5 (bound)	
1c	**Foundation Modulus**	n/a	n/a	F4 (bound) = 200 MPa, F5(bound) = 400 MPa				
1d	**Cube Comp. strength at 28 days** (MPa)	n/a	n/a	Y	Y	n/a	n/a	
1e	**Beam Flexural strength at 28 days** (MPa)	n/a	n/a	n/a	n/a	5.0	4.5/5.0/5.5/6.0	
1f	**Longitudinal Reinf.** (mm^2/m width)	n/a	n/a	n/a	500/600/ 700/800	n/a	Not needed for slab thickness, see below	
1g	**Concrete Type (see Table 4.8)** Unless contract specifies other	n/a	n/a	C40/50 or C32/40	C40/50 or C32/40	C40/C50	C40/50 or C32/40	
2	**+/- Concrete thickness if tied shoulder** (mm)	n/a	n/a	Eqn.5-2 or Table 5.1	Eqn.5-4 or Table 5.1	Assumes tied shoulder	+30mm if no tied shoulder	
3	**Contraction Joint Spacing**	n/a	n/a	Table 5.5 +Notes	Table 5.6 +Notes	n/a	n/a	n/a
4	**Expansion Joint Spacing**	n/a	n/a		Table 5.6 + Notes	n/a	n/a	n/a
5	**Dowel Bar Details**	n/a	n/a	Table 4-11	Table 4-11	n/a	n/a	
6	**Tie Bar Details**	n/a	n/a	Table 4.12	Table 4.12	Table 4.12	Table 4.12	
7a	**Transverse Reinforcement Details**	n/a	n/a	n/a	Same as CRCP	n/a	12mm diam. at 600mm centres	
7b	**Longitudinal Reinforcement Details**	n/a	n/a	n/a	Already decided in 1f	n/a	12mm at tbc centres Eqn. 5.6 + Table 5.11	16mm at tbc centres
	Completed Pavement Design							
8	**Pavement Structure Catalogue**	Fig 6.1	Fig 6.2	Fig 6.3 + 6.4	Fig 6.5 to 6.8	Fig 6.9	Fig 6.10	Fig 6.11
9	**Concrete Thickness Range for 1-150M CESA** (mm)	n/a	60-80 mm blocks	150-370	150-340	165-200	150-190	200-215

Notes: *n/a = not applicable, Reinf. = Reinforcement, diam. = diameter, tbc = to be confirmed (from calculations).*

4.2 Stresses in Concrete Pavements

Structural deterioration mechanisms in rigid pavements are very different to those in flexible pavements with an asphalt base.

The combined effects of wheel loading and thermally induced internal and warping stresses generate horizontal tensile stresses. These stresses can, under certain conditions, lead to cracking of the concrete slab. Slab cracking is often associated with poor slab support caused by drainage problems or water ingress at joints.

In jointed concrete pavements (JUC and JRC) there is no reinforcement to hold the sides of the crack together. Joint failure (caused by detritus blocking the joint or locking up of the dowel bars e.g. corrosion) can also occur and lead to high stresses and the development of cracks and subsequent failure. Where expansion joints have lost their capacity to absorb movement 'blow ups' may occur in hot weather. Two consecutive slabs rise up in an inverted 'V' as a result of debris filling the expansion gaps or dowels becoming locked.

Reinforced pavements can tolerate small amounts of transverse cracking provided that good load transfer is maintained. Structural defects manifest themselves mainly in the form of various types of cracking.

Internal thermally-induced stresses within the concrete slab during construction are relieved by transverse cracks ~~at 1-2 m spacings~~, which are held tightly closed by the reinforcement. Most of the longitudinal movement of a CRCP (when subjected to changes in temperature); takes place at the ends and is restrained by terminations (GBA or WFB) and JRC slabs with expansion joints.

‘Punchouts’ can also occur in CRCP when closely spaced transverse cracks are connected by longitudinal cracks, causing small blocks of concrete to become loose and eventually detach from the pavement under repeated traffic load applications.

~~4.3 Design Life~~

~~When choosing which type of pavement to build, it can often be decided by comparing costs. When doing this for different types of pavement, it is important that:~~

1. ~~**The same design period is used for all pavement types.**~~

   ~~An asphalt road with a design life of 20 years will inevitably be cheaper than a concrete road with a design life of 40 years. However, the asphalt road will require continuous patching maintenance and may need resurfacing at ten years and reconstruction at 20 years. If the costs are compared over a 40 year period, then the concrete pavement will be more competitive and may even be cheaper. It is important that the same time period is used when comparing asphalt and concrete pavements, usually 40 years.~~

2. ~~**Whole life Costs.**~~

   ~~To achieve the design life, it is crucial that adequate routine and periodic maintenance is carried out during the working life of the road. At the end of the design period the deterioration that has occurred should be such that a suitable remedial treatment such as a strengthening overlay of some kind should be carried out, however it may be that major rehabilitation or even complete reconstruction is necessary.~~

   ~~Acceptable levels of pavement deterioration will vary according to the class of road and the volume of traffic i.e. the higher the geometric standard (and vehicle speeds), the lower the level of acceptable pavement distress.~~

~~As well as construction, maintenance and rehabilitation costs, other costs should be included in whole life cost analysis and comparisons. These include:~~

~~a. Road user costs including delays/diversions etc during maintenance.~~

~~b. Operator costs.~~

4.3.1 Failure Criteria for JUC

For JUC pavements, failure of a slab (i.e. a length of concrete separated by a transverse contraction or expansion joint) is defined as:

i. A crack of width equal to or greater than 0.5 mm (i.e. a medium or wide crack) crossing the bay longitudinally or transversely.

ii. A longitudinal and transverse crack intersecting, both starting from an edge and greater than 0.5 mm wide, and each longer than 200 mm.

iii. A corner cracking wider than 1.3 mm and more than 200 mm radius.

iv. A bay with pumping at a joint or edge.

v. A bay with significant settlement.

vi. A replaced or structurally repaired bay.

For Kenyan roads, it is proposed that the definition of a JUC road has reached failure if more than 50 % of slabs per 100 m lane length have failed (using the definitions above) or have been replaced.

~~It should be noted that this value is higher than the failure criteria of 30 % slabs given for UK roads, upon which the Kenyan design method is based. This is because the 30 % appears to be too strict. Even when a road has reached this 'failed' state, the road may still be both useable and safe to drive on but is likely to need an upgrade in the relatively near future.~~

4.3.2 Failure Criteria for RCC

~~There is currently no agreed definition of failure for RCC pavements~~.

4.3.3 Failure Criteria for CRCB/CRCP

For CRCB/CRCP pavements, a severe level of deterioration (intervention level) is defined as greater than 15 significant defects per 100 m lane length with significant defects as given below:

i. Transverse cracks at spacings less than 1 m.

ii. Transverse cracks with widths greater than 1 mm.

iii. Longitudinal cracks (medium or wide, i.e. > 0.5 mm width).

iv. Areas of polygon cracking.

v. Loose or missing blocks of concrete (punchouts).

vi. Crack bifurcations.

vii. Failing repairs.

viii. Spalling.

4.4 Design Traffic

It is well established that light vehicles contribute little to structural deterioration, so the design traffic loading usually includes the construction traffic and commercial vehicles (buses and medium/heavy goods vehicle with gross vehicle weight exceeding 3500 kg) over the design life.

The design traffic (in millions of Cumulative Equivalent Standard Axles i.e. M CESA) should be estimated over the design period using the process given in **RDM Volume 3, Part 3**. ~~Where a standard axle is defined as an axle applying a force of 80 kN, equivalent to an 8.16 tonne axle load.~~

For low volume roads the design life is usually 15 years. For heavy and very heavy trafficked concrete pavements the design life should be 40 years. ~~When comparing the design for a new pavement with an asphalt pavement the same design period (40 years) should be used for both.~~

~~Kenyan~~ traffic flow and axle-load surveys have shown that traffic classes given in Table 4.2 satisfactorily account for all traffic categories likely to be carried by the various road classes.

Table 4.2 Design Traffic Classes

Design Traffic Class	Cumulative Equivalent Standard Axles	Design Value (M CESA)	DESA* with 5% growth rate. For 15 year design period (LVR i.e. <1m CESA) and 40 year design for >1m CESA		Traffic Load Category
			Min.	Max.	
TC0.025	< 25,000	0.025	0.0	0.3	Low
TC0.10	25,000 - 100,000	0.10	0.3	13	
TC0.25	100,000 – 250,000	0.25	13	32	
TC0.50	250,000 – 500,000	0.50	32	63	
TC1	500,000 – 1 million	1	63	127	
TC3	1 million – 3 million	3	23	68	Medium
TC10	3 million – 10 million	10	68	227	
TC17	10 million – 17 million	17	227	386	Heavy
TC30	17 million – 30 million	30	386	680	
TC50	30 million – 50 million	50	680	1134	
TC80	50 million – 80 million	80	1134	1814	Very Heavy
TC150	80 million – 150 million	150	1814	3402	
TC150+	> 150 million	Based on specific value	> 3402		

Notes

*1. * DESA = Daily Equivalent Standard Axles (in the design lane, one way). If given DESA then this figure can be used as a rough guide to estimate the Design Traffic Class as shown above. ~~Note that the design life of a low volume road (< 1M CESA) is usually 15 years and the design life of a concrete road (and an asphalt road if comparing costs of both types) is 40 years.~~*

2. The "150+" in TC150+ class requires specific considerations and performance design based on the actual value of design traffic determined. The designer should refer to the class based on the specific design traffic determined. For example, if the calculated design traffic is 160 MCESA, then the design class will be TC160.

When designing a pavement for a new carriageway, all lanes, including the hard shoulder and lay-bys, should be constructed to carry the design traffic (one way) in the heaviest loaded lane ~~(i.e. the left-hand lane in Kenya)~~.

4.4.1 Overloading

Rigid pavements can be sensitive to axle load magnitudes (e.g. overloading) but they are relatively insensitive to axle load repetitions (i.e. the volume of traffic = repeated loads within legal weight limits). Concrete pavements should therefore be designed for the maximum axle loads that they are likely to carry. It is recommended that a sensitivity analysis for design traffic could be carried out.

When considering which pavement type to choose, if overloading is a known factor, then it may be prudent to select a stronger pavement type, such as a CRCB or CRCP which is more forgiving than a JUCP.

4.5 Foundation Design

For concrete pavement designs (JUC, JRC, RCC, CRCB & CRCP), the 'foundation' refers to the platform that the concrete slab is built on, i.e. all layers beneath the concrete slab. ~~This differs slightly to Kenyan flexible pavement design, where 'foundation' includes the subgrade, capping and all layers up to (but not including) the sub-base.~~

A jointed concrete pavement (JUC and JRC) can; (i) allow water to penetrate the pavement at poorly sealed joints/cracks and (ii) concentrate stresses on the sub-base below transverse joints (which can lead to pumping/voids), so require a strong non-erodible sub-base.

The Foundation class for a concrete pavement (JUC, JRC, RCC, CRCB & CRCP) needs to be either an F4 (bound) or F5 (bound). It should have a Surface Modulus of 200 MPa (F4 bound) or 400 MPa (F5 bound) and include a non-erodible hydraulically bound (usually cement bound) layer at the top.

For CRCB and CRCP designs, a Foundation of F4 (bound) is usually used for design traffic up to 100 M CESA. Above 100 M CESA, either F4 (bound) or F5 (bound) can be used (see Figure 5.3 in Section 5.7.1.

For each natural subgrade class, the material/thickness of additional layers that are required to achieve a Foundation Class F4 (bound) and F5 (bound) are shown in Table 4.3 (from **RDM Volume 3 Part 3**).

The stiffness requirements and minimum CBR strength for foundation classes F4 (bound) and F5 (bound) are shown in Table 4.4 (from **RDM Volume 3 Part 3**).

The sub-base usually needs to be wider than the concrete base that is to be built on it. This width will depend upon the type (and make) of paver to be used. ~~The manufacturer should be consulted.~~ For slip form paving the sub-base will probably need to be approximately 1 m wider than the slab width (on each side) and for fixed-form paving the sub-base will probably need to be approximately 350 mm wider than the slab (on each side).

CRCP (and CRCB) have three distinct advantages over JUC and JRC pavements:

1. There are no transverse joints to allow water penetration to the foundation.
2. There are no transverse joints in the concrete and hence no localised areas of stress concentration and erosion in the layer beneath these joints.
3. It has an increased load spreading ability due to its mono-slab construction.

The advantages listed above mean that the sub-base under a CRCP/CRCP pavement has an enhanced durability and it therefore may be possible to be constructed with a less stringent material requirement, possibly using secondary/recycled materials.

It should be noted that if the sub-base is cement bound, then the higher the strength of the layer ~~then~~ there is a tendency to get wider cracks at a larger crack spacing. Wide cracks in the sub-base have the risk of being reflected through into the overlying concrete slab. For cement bound sub-bases with an average 7-day compressive cube strength of 7 MPa or more then it may be good practice to induce frequent transverse cracks during construction.

For further information about foundations, see **RDM Volume 3 Parts 3** and **4**.

Table 4.3 Material Thickness Required to Achieve an F4/F5 (bound) Foundation

Native Subgrade Class	Imrpoved Subgrade/Capping		New Subgrade Class	Foundation Class
	Material	Minimum Thickness (mm)		
S1 (2-5 % CBR) Median = 3.5 % CBR	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 (5-10 % CBR) Median = 7.5 % CBR	G10	150	S3	F1
	G14	150	S3	F1
	G14	175	S4	F2
S3 (7-13 % CBR) Median = 10 % CBR	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 (10-18 % CBR) Median = 14 % CBR	G23	150	S5	F3
	G45	200	S6	F4
	HIG100	200	S6	F4
	BSM50	225	S6	F4
S5 (15-30 % CBR) Median = 22.5 % CBR	G45	150	S6	F4
	GCS/BSM50	275	S6	F4
	HIG160/HMS1	125	S6	F4 (bound)
	HIG160	250	N/A	F5 (bound)
	HMS1	225	N/A	F5 (bound)
S6 (30-60 % CBR) Median = 45 % CBR	GCS	250	N/A	F5
	HIG160	200	N/A	F5 (bound)
	HMS1	175	N/A	F5 (bound)
	BSM100	150	N/A	F5 (bound)

Notes:

1. *BSM = Bitumen Stabilised Material, G = Granular, GCS = Graded Crushed Stone, HIG = Hydraulically Improved Gravel, HSM = Hydraulically Stabilised Material.*

2. *HBS3 = Hydraulically (Cement/Hydraulic Road Binder) Bound Stone (minimum G60 or GCS-E) of minimum UCS 3.0 MPa after a 7 day cure and 7 day soak. See KS EAS 981: Hydraulic Road Binders - Specification.*

3. *For concrete pavements (JUC, JRC, RCC, CRCB, CRCP), only foundations F4 (bound) and F5 (bound) may be used and the capping must be HBS3 or higher quality BOUND material. These are highlighted in Table 4.3 & Table 4.4.*

4. *S1 and S2 subgrades must first be improved to minimum of S3 (F1) or S4 (F2) subgrade class before final improvement to F4 (bound) and F5 (bound).*

5. *Foundations for Block Paving are given in Section 5.3.*

Table 4.4 Minimum Stiffness Modulus and CBR for Foundation Classes

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

4.6 Drainage

For all concrete pavements (particularly those with transverse joints), emphasis should be on keeping water out of the pavement through sealing joints, adequate layer crossfalls, efficient surface water drainage, use of side drains in cuttings, etc.

Specific drainage layers under the concrete should not generally be needed. However, there may be localised areas where additional drainage is required e.g. locations with a spring or high water table. Additional sub-soil drainage can consist of:

1. **Granular-filled trench filter drains**

   This is the usual method and consists of longitudinal perforated pipes (usually <100 mm diameter) laid in trenches at each side of the pavement. They are backfilled with free draining material (e.g. graded crushed stone) with a non-woven geofabric placed around the drain material to prevent silt/fines entering and clogging the drain. The trench is usually 0.5 m wide, with the depth depending upon the water table, but it is usually at least 1m deeper than the formation level. If perforated pipe is used, then inspection chambers and silt traps should be built at least every 100m or change of direction to allow cleaning.

2. **Fin drains**

   A fin drain is a thinner alternative to a granular filled trench filter drain and is particularly useful for lowering the water table, draining wet ground or verges. It can be laid in a very narrow trench, at each side of the pavement, with most of the excavated material used as backfill, leaving little surplus soil to be disposed of.

   It consists of a high crush-strength porous flexible "sandwich", about 25 mm thick. The walls of the sandwich are a geotextile material, bonded on one side to a polythene backing sheet; the other wall is also geotextile, but with no backing sheet. These walls are joined together by polyethylene injection-moulded spacers. Water leaves the fin drain via outlet pipe spigots fixed to the end or side.

3. **Blanket drains**

   Blanket drains are used within the foundation layers to remove seepage water appearing in the base of cuttings or in the subgrade. The blanket shall consist of a filter layer in contact with the soil, and a coarser collector layer. If it is used on a fine-grained subgrade, then a non-woven geofabric should be used on both sides of the blanket drain, to prevent fines from blocking the draining layer.

   The filter layer should consist of an open-graded 20 mm crushed rock (with < 3% material finer than 75 μm), produced by blending 20 mm, 14 mm and 10 mm aggregates with coarse, washed sand. This material can also be cement-stabilised, to improve its strength when wet.

4.7 Slip Membrane or Separation Membrane

A slip membrane is required under some types of concrete pavement. It's main role is to encourage/inhibit crack formation, but it has other functions including to reduce water loss into the sub-base, to reduce future moisture changes, etc.

The preferred slip membrane is an emulsified bitumen spray (with minimum 40% bitumen). This gives a partial bond, resulting in better joint cracking in JUC/JRC pavements. If this has already been sprayed on the underlying layer as a curing membrane, then only areas which have been damaged or degraded, need to be resprayed before laying the concrete.

In the past, the slip membrane was a plastic or polythene sheet (125 microns thick) that would be fixed (studded) to the surface of the underlying layer, preventing any bonding. This can still be used, but is not the preferred option.

The surface of the layer directly below the concrete can either be:

a. smooth with the addition of a slip membrane (to help the concrete slab slide over the sub-base) or

b. rough (with sufficient friction to help develop cracks in the concrete).

This will depend on the pavement type being constructed as discussed below.

4.7.1 JUC and JRC Pavements - Slip Membrane

During the construction of JUC and JRC concrete pavements, a Slip (or Separation) membrane is put on the HBS3 (Hydraulically Bound Stone) sub-base (before laying the concrete) to perform the following functions:

- Prevent loss of moisture/fine material from the PQ concrete mix into the layer below.
- Reduce the friction between the PQ concrete slab and the underlying layer during curing. This can prevent mid-slab cracking and help with induced contraction joint cracks.
- Prevent any loose material from the underlying layer becoming attached to the underside of the fresh PQ concrete slab. This could increase stresses as it expands and contracts.
- Prevent reflection cracks in the concrete slab above shrinkage cracks in the HBS3 layer.
- After curing, it allows easier slab expansion/contraction movement with thermal and moisture changes, which reduce stresses in the concrete and thus inhibits the formation of mid-bay cracks.
- After curing, it can minimise slab curling. In the longer term the membrane will act as a moisture barrier, reducing moisture transference from the subgrade to the concrete slab, which can reduce moisture variation within the slab and help to minimise slab curling.

4.7.2 CRCB and CRCP Pavements - Slip Membrane

A slip/separation membrane is **NOT** required for most CRCP or CRCB pavements, where friction between the underlying layer and the concrete is required to restrict pavement movements and help to ensure that a good crack pattern is formed during curing.

A short length of slip/separation membrane is used at terminations (i.e. ends of the CRCB/CRCP concrete) with Wide Flange Beams (WFBs) see Section 4.18 and the termination drawing Figure 4.20.

4.8 Concrete Strength

Concrete strength testing (compressive and flexural strength) can be carried out on prepared samples (cubes, cylinders or beams) or samples from the road (cores). Specifications for sampling and testing fresh/hardened concrete are given in KS ISO 1920: Testing of concrete, BS EN 12350: Testing Fresh concrete, BS EN 12390: Testing hardened concrete, and BS EN 12504-1: Testing concrete in structures. For more information about tests see **RDM Volume 3, Part 2: Material - Field and Laboratory Testing**. Information about specifying concrete grade/class is given in BS EN 206, KS EAS 131-1, etc.

4.8.1 Introduction to Concrete Strength

A knowledge of the different classes of concrete, the different types of strengths and the interactions between compressive/flexural strength, 7/28-day strengths, cylinder/cube strengths, characteristic/mean strengths, etc is important for pavement design, so are explained below.

For a given cement and aggregate type, the largest factors in the strength of a fully compacted concrete are:

1. Ratio of water/cement. A low water/cement ratio will give a high strength but stiff mix (i.e. low workability) and a high water/cement ratio will give a low strength but very workable mix.
2. Ratio of cement to aggregate.
3. Grading, surface texture, shape, strength and stiffness of aggregate particles.
4. Maximum size of aggregate (a max 20 mm aggregate concrete will be stronger than a max 40 mm aggregate concrete).

The type of large aggregate can also have a significant effect on concrete strength (this will depend on water content). For water/cement rations below 0.4, use of a crushed aggregate can result in compressive strengths 38 % higher than with a river gravel. However, at higher water/cement ratios above 0.65, there will be no difference in strength.

If cured correctly, concrete continues to increase in strength from the day water is added to the mix until many years later. Indeed it is reported that concrete only reaches its peak strength after 10-25 years, achieving a strength of about 2.3 times the 28 day strength.

Because of this increase in strength over time, the strength needs to be specified at a certain age. Currently concrete strength is usually specified at 28 days. There is usually a good relationship between the concrete strength at 7 days and at 28 days (see Section 4.8.5).

It is important that the concrete pavement is not trafficked until it has reached a specific strength or it can be damaged, hence making and testing the strength of concrete samples is a crucial part of the construction process.

There are two main ways to measure concrete strength.

- **Compressive strength.** This can be carried out on prepared cube samples (usually 100 or 150 mm) or prepared cylindrical specimens (usually 100mm diameter x 200 mm length or 150 mm diameter x 300 mm length) or cores taken directly from the road.
- **Flexural strength** (known as 'Modulus of Rupture' or 'bend strength') is measured by the Indirect tensile test (also called the 4 point flexural test or 2 point loading test) carried out on a prepared beam sample (called a prism in some international standards). The beam size is usually 100 x 100 x 500 mm or 150 x 150 x 700 mm - the length is less critical as long as it's length is greater than three times it's diameter). The most important factor in the flexural strength of concrete is the type of aggregate used - if angular crushed rock is used as the aggregate, it increases aggregate interlock and the bond between the cement paste and the aggregates which increases the flexural strength of the concrete.

It should be understood that concrete roads don't fail by compression, they fail by 'snapping' under tension i.e. flexural strength. So, in theory the flexural strength is the more critical strength indicator and compressive strength is only an indicator of the flexural strength.

However, it is often the compressive strength (cube and cylinder) that is specified for concrete to be used in roads (even though it is not in itself critical) because concrete cube crushing tests, which determine compressive strength, are simple, accurate and well understood. ~~The flexural strength test is reported to be expensive, difficult and is not particularly accurate.~~

Also, when testing concrete from an already built road, it is easier to extract cores (cylindrical samples) which can be trimmed and crushed to give a compressive strength (which can be converted to an equivalent cube compressive test result), rather than try to saw cut and trim beam samples from a pavement.

While the compressive strength is not important in itself, it does correlate with the flexural strength and also gives an indication of the concrete density and permeability. For this reason, compressive strength is still specified and measured in concrete pavements.

~~It should be noted that many of~~ the concrete strength relationships given (e.g. between concrete strength at 7/28 days, conversions from flexural/compressive strengths and mean/characteristic strengths are derived for concretes from UK and elsewhere. Whilst these relationships may be useful initially, data from Kenyan concrete should be used to develop more accurate relationships specifically for Kenya.

It should be noted that all concretes will gain strength after 28 days. The amount they gain will be related to the cement class. For example, a more rapid setting concrete (Class R) may have the same 28-day strength as a slower setting concrete (Class S), but after 1 year the class S cement may be 15 % stronger than the Class R cement.

4.8.2 Characteristic and Mean Concrete Strength

The strength value that is widely used to define concrete is usually the characteristic strength (f_{ck}). This is the strength below which a specified proportion of test results (called 'defectives') are allowed. It is often set to 5 %, thus 95 % of values tested should be above this strength.

The strength class (i.e. grade) of concrete is usually defined as the characteristic compressive strength (in N/mm^2) for a cylinder and a cube (at 28 days) e.g. C32/40. Concrete strength classes are explained further in Section 4.8.3.

The concrete strength requirements specified for concrete pavements are given in Table 4.8 and specify that a C40/50 concrete should be used (or C32/40 for CRCB with asphalt surfacing).

Another important value when specifying the strength of a concrete, is the **mean strength** (f_{cm}) that must be achieved.

~~The concrete pavement design methods used in this document are based on the UK Design Manual for Roads and Bridges (DMRB) CD226.~~ These thickness designs use **mean compressive** strengths for URC and JRC, **mean flexural** strengths for CRCB and CRCP pavements and a standard characteristic compressive strength (C40/50) for RCC pavements.

Methods for converting characteristic strengths to mean strengths are given below.

4.8.2.1 Converting Characteristic to Mean Concrete Strength

For concrete, there are various methods for converting characteristic strength to mean strength (at 28 days)~~.~~. They can be used for ~~both~~ characteristic compressive cube strength ($f_{ck,cube}$), characteristic compressive cylinder strength ($f_{ck,cyl}$), mean compressive strength (f_{cm}) and flexural strengths.

It is suggested that the designer uses all three methods given below to gain an understanding of the relationship between the characteristic and the mean strength for the concrete mix. For compliance testing, the exact conversion method should be agreed in advance.

During the concrete mix design and quality control process during production, the individual/ mean concrete sample test results need to be compared with the specified Concrete Design Strength in order to fulfil the necessary specification requirements.

The main method of converting Characteristic to Mean concrete strength is given below.

Method 1: $f_{cm} = f_{ck} + (1.48 \times \sigma)$

Equation 4.1

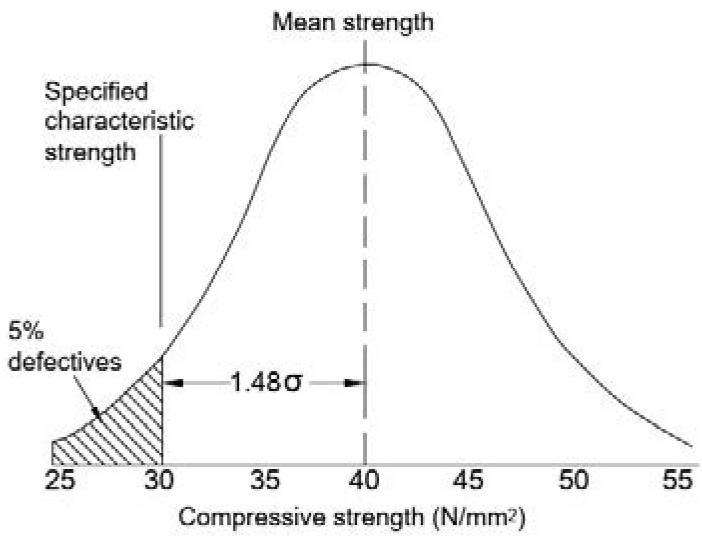
where σ = standard deviation of the concrete mix.

This is shown in BS EN206: (Concrete - Specification, Performance, Production & Conformity), Sections 8.2.1.3.2, H3 and KS EAS 131-1 (Concrete - Part 1: Specification, performance, production, and conformity), Section 8.2.1.3. This applies to both cylinder and cube compressive strengths.

It should be noted that this is mainly for compliance testing of continuous concrete production where the mean strength of all test results should be greater than or equal to 1.48 x Standard Deviation, for a number of samples (> 15) from the same family of concrete and at least 35 consecutive test results should be used to calculate the Standard Deviation.

In Figure 4.1, for concrete strengths following a distribution that is similar to a Normal distribution, but more peaked, it can be seen that for 95 % of values to have strength > 30 N/mm^2, the mean needs to be 30 + (1.48 x std dev). If std dev = 6.8 then mean strength = 30 + (1.48 x 6.8) = 40 N/mm^2.

Figure 4.1 Distribution of Concrete Strength Showing Characteristic Strength



For a concrete with 5% defectives and a Standard Deviation = 6.81 N/ mm^2

For a more accurate relationship, actual concrete strength data in Kenya should be used.

An alternative method for converting Characteristic to Mean concrete cylinder strength is given below in Method 2.

Method 2: $f_{cm,cyl} = f_{ck,cyl}$ + 8 MPa

Equation 4.2

EN 1992-1-1 (Table 3.1) uses the above approximate relationship to calculate the mean compressive cylinder strength from the characteristic compressive cylinder strength of concrete at 28 days.

A C32/40 class of concrete (explained in the next section) will have a minimum characteristic compressive cylinder strength of 32 MPa at 28 days and a minimum characteristic compressive cube strength of 40 MPa. The mean cube compressive strength at 28 days will be approximately 50 MPa. Using Equation 4.3 (conversion from compressive to flexural strength), the mean flexural strength at 28 days will be about 5 MPa for siliceous gravel aggregate.

4.8.3 Concrete Strength Class

Concrete strength class is usually specified as the characteristic compressive strength or flexural strength e.g. C32/40, but can also be specified as characteristic flexural strength e.g. F4.

4.8.3.1 Compressive Strength Class (from cylinders/cubes)

The concrete strength class specification includes both cylinders and cube compressive strengths as when constructing a concrete structure, such as a road, it is easier to make and test cube samples, but when testing a built concrete road it is easier to take core samples (i.e. cylinders) and test these.

The characteristic compressive strength for normal-weight and heavy- weight concrete at 28 days of cylinders ($f_{ck,\ cyl}$) (size 150 mm diameter by 300 mm length) or cubes ($f_{ck,\ cube}$) (size 150 mm) tested in accordance with EN 12390-3 is used for classification, as shown in Table 4.5 (taken from KS EAS 131-1).

Table 4.5 Compressive Strength Classes (for Normal-weight and Heavy-weight Concrete)

Concrete Compressive Strength Class	Minimum Characteristic Cylinder Strength at 28 days ($f_{ck,cyl}$) (MPa) N/mm^2	Minimum Characteristic Cube Strength at 28 days ($f_{ck,cube}$) (MPa) N/mm^2
C8/10	8	10
C12/15	12	15
C16/20	16	20
C20/25	20	25
C25/30	25	30
C30/37	30	37
C35/45	35	45
C40/50	40	50
C45/55	45	55
C50/60	50	60
etc	etc	etc

From KS EAS 131-1: Concrete - Part 1: Specification, performance, production and conformity, Table 7 and BS EN206+A2: Concrete - Specification, performance, production and conformity. The above values are for Characteristic compressive strength (see Section 4.8.2).

4.8.3.2 Compressive Strength from Cores

Concrete pavement strength can be determined from cores, taken from the full depth of the slab. The core compressive strength shall be determined in accordance with KS ISO 1920-6 (Testing of concrete - Part 6: Sampling, preparing & testing concrete cores) or BS EN 12504-1 (Testing concrete in structures. Cored samples. Pt 1: Taking, examining & compression testing).

For non-standard size cores, the test correction factors given in Table 4.6 should be applied.

Table 4.6 Correction Factors for Compressive Strength of Different Sized Cores

Length/Diameter Ratio	Correction Factor
1.00	1.00
1.25	1.07
1.50	1.12
1.75	1.16
2.00	1.18

From BS EN13877-2: Concrete Pavements Part 2: Functional requirements for conc. pavements, Table 1.

For functional reasons it is recommended that the minimum strength class for pavement concrete should not be less than ~~C~~C20.

If cores are not tested at a maturity of 28 days at 20°C, the result should be modified either by using maturity concepts to give estimated strength at 28 days at 20°C or in accordance with specifications in the place of use.

4.8.3.3 Flexural Strength Class (from beams)

The designs for CRCB/CRCP require the concrete strength to be input as mean flexural strengths.

The Kenyan standard KS EAS 131-1: Concrete - Part 1: Specification, performance, production, and conformity currently only has concrete classifications based on compressive strength (i.e. not flexural strength).

The characteristic flexural strength for normal weight and heavy weight concrete at 28 days of beams (ffk,beam) (size 150 mm width/height x 450mm long) tested in accordance with EN 12390-3 is used for classification, as shown in Table 4.7.

Table 4.7 Class of Flexural Strength

Strength Class	Characteristic Flexural Strength at 28 days (f_{fk}) in MPa	Strength Class	Characteristic Flexural Strength at 28 days (f_{fk}) in MPa
F2	2.0	**F5.5**	5.5
F3	3.0	**F6.5**	6.5
F3.5	3.5	**F8.5**	8.5
F4	4.0	**F9**	9.0
F4.5	4.5	**F10**	10.0

From BS EN 13877-1:2013 Concrete Part 1: Method of specifying & guidance for the specifier, Table 2.
Where f_{fk} is the characteristic flexural strength at 28 days.

4.8.4 Typical Values of Concrete Strength Classes

The concrete in concrete pavements (for use in traffic classes greater than low volume roads) shall comply with the appropriate strength class given in Table 4.8.

Pavement quality (PQ) concrete shall conform with the requirements of BS EN 206: Concrete - Specification, Performance, Production & Conformity. It should also comply with KS 594 (Specification for concrete) and KS EAS131-1: (Concrete - Part 1: Specification, performance, production and conformity) and the requirements of this manual. ~~It should be noted that KS EAS 131-1 references:~~

- BS EN 13877-2: Concrete Pavements Pt 2: Functional requirements for concrete pavements.
- BS EN 206: Concrete - Specification, Performance, Production & Conformity.
- BS 8500-1 Concrete Part 1: Method of specifying & guidance for the specifier.
- BS 8500-2 Concrete Part 2: Specification for constituent materials and concrete and/or
- BS EN 13877-1: Concrete Pavements Part 1: Materials.

The class of concrete to used for concrete pavement slabs (JUC, JRC, RCC, CRCB, CRCP) should be C40/50, unless specified otherwise in the contract documents. However slabs to be overlaid with at least 30 mm asphalt during construction can be of a slightly lower strength e.g. concrete class C32/40 (see Table 4.8).

Table 4.8 Concrete Strengths for JUC, JRC, CRCB and CRCP

Pavement Layer		BS EN 206, BS8500-2, BS EN 13877-2 Designed Concrete	BS8500-1, BS EN 13877-1
1	Surface Slabs for JUC, JRC, CRCB and CRCP	C40/50*	C32/40*
2	Ground Beam Anchors for CRCB and CRCP		C25/30**

Source: *MCHW, Vol 1, Clause 1001*
*Where * = Minimum permitted strength class, ** = No cores to be taken from ground anchors.*
For an explanation of C40/50 concrete, see Table 4.5 (in Section 4.8.3). For Ground Beam Anchor design see Section 4.18.

Concrete strengths to be used in the concrete pavement design Charts/Equations (given later in this manual), are as follows:

- **For JUC and JRC**

  The design equations: Equation 5.1 (JUC) and Equation 5.3 (JRC) use

  $f_{c,\ cube}$ = mean compressive cube strength at 28 days (N/mm^2 or MPa).

  With $f_{c,\ cube}$ values = 30, 35, 40, 45, 50, 55, 60 MPa.

  Note: *that mean values will be higher than characteristic values – see Section 4.8.2*

  For JRC: *a mean value of 50 MPa was used at the time of the designs (equivalent to a C40 concrete). The dataset used in the designs included values of 30-60 MPa.*

- **For CRCB and CRCP**

  The design chart in Figure 5.3 uses f_f = mean concrete flexural strength (MPa) at 28 days measured in accordance with BS EN 12390-5: Testing hardened concrete. Flexural strength of test specimens. With f_f values of 4.5, 5.0, 5.5, 6.0 MPa.

  Note: *that mean values will be higher than characteristic values – see Section 4.8.2.*

- **For RCC**

  The concrete details for Roller Compacted Concrete are given in Section 5.6.

4.8.5 Conversion from 7 day to 28-day Strengths

For site control purposes, the concrete may be assessed on the basis of 7-day strengths (or other agreed age), provided that a robust correlation is established between the 7 and the 28-day strengths using representative cement, aggregates and additive samples from the works.

~~For Kenya, it is proposed that~~ the compressive strength at 28 days should be taken as being 1.3 times the compressive strength at 7 days. ~~This is the same as the USA and slightly lower than the UK value of 1.5.~~

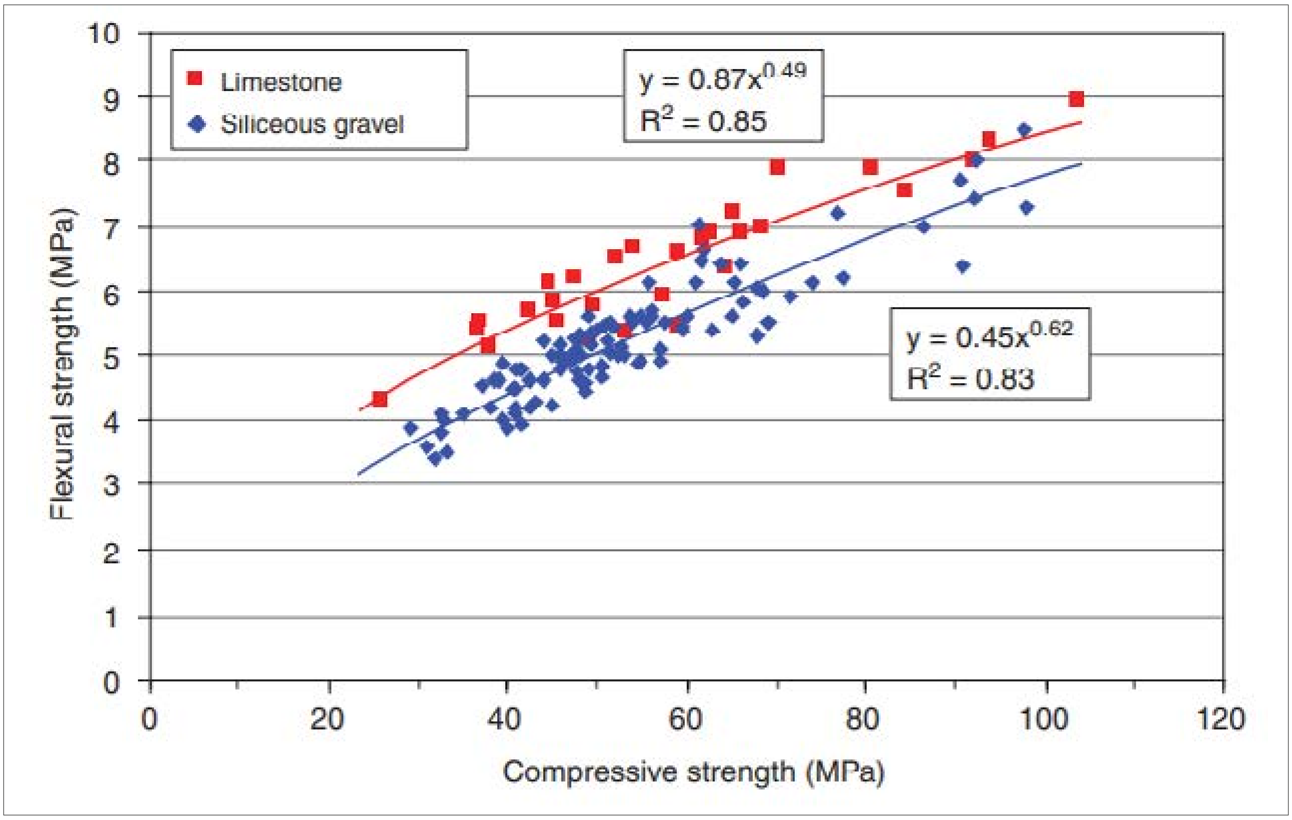
4.8.6 Conversion from Flexural to Compressive Strength

One way of determining the relationship between flexural and compressive strength is to test the flexural strength of beam samples until failure and then trim and carry out compressive strength tests on the discarded beam ends.

There are various equations to convert flexural strength to compressive strength and vice-versa. The plot in Figure 4.2 below and the following equations for converting 28-day compressive strength to 28-day flexural strength for concrete with different aggregate types were reported in the UK by Hassan (2005).

For more accurate conversion equations for Kenyan concretes, there is a need to carry out Kenyan trials to establish relationships between flexural and compressive strength for different concrete mixes in Kenya. Until that time, these equations can be used. Note that although limestone aggregates are not widely used in Kenya, the equation has been included in case it is required.

Figure 4.2 Relationship between Flexural and Compressive Strength at 28 days



Equations for converting Compressive (cube) strength to Flexural (beam) strength.

$$f_f = 0.45\left(f_{c,cube}\right)^{0.62} \quad \text{(for siliceous gravel aggregate)}$$

Equation 4.3

(From Hassan, 2005)

$$f_f = 0.87\left(f_{c,cube}\right)^{0.49} \quad \text{(for limestone aggregate)} \textit{(see text above)}$$

Equation 4.4

(From Hassan, 2005)

Where,

f_f = Indirect Tensile (i.e. Flexural) strength of beam at 28 days.

$f_{c,\,cube}$ = Compressive strength of cube at 28 days.

4.8.7 Conversion of Compressive Strength from Cylinder to Cube

Testing the concrete strength of a finished concrete road, is usually carried out by compression testing of cylinder-shaped cores from the pavement.

Cylinders for compressive strength testing may be made from concrete filled moulds or cores taken from the finished concrete pavement. Standard cylinder (core) samples are 150 mm diameter x 300 mm long, although tests can be carried out on samples with a length: diameter ratio of 1-2.

Before testing, cores should be trimmed and prepared to the requirements of BS EN 12390-1: Testing hardened concrete. Part 1 - Flexural strength of test specimens. The top and bottom faces of the core should be ground.

For testing non-standard sized cores, correction factors given in Table 4.6 should be applied. A generally used correction factor for compressive strength from cylinder to cubes is:

$$\textit{Cylinder compressive strength} = 0.85 \times \textit{Cube compressive strength}$$

Equation 4.5

(From BS EN 1992)

4.9 Concrete Constituents, Admixtures and Mix Design

For more information about Concrete as a construction material and its components, including Cement, Aggregate, Water, Reinforcement Admixtures and Mix Design see **RDM Volume 3, Part 3: Pavement Foundation and Material Design**.

For details of tests for cement, aggregate, concrete, steel, etc see **RDM Volume 3 Part 2: Materials Field and Laboratory Testing**.

For a list of standards mentioned in this document, see Appendix A.

4.10 Shoulders/Edge Strips

For more information about shoulders, including suitable materials, crossfall and widths see **RDM Volume 1, Part 3**.

When designing shoulders for concrete pavements, consideration of utilities should be made, particularly in urban areas. This could include construction of carrier pipes and/or ducts of sufficient size to cater for both existing and future requirements. The designs should include locations where utilities cross the carriageway – and will need to be included in the pavement foundation construction.

Consideration of utilities at the design stage will avoid later issues. Retrofitting of utility ducting (i.e. adding ducting after the pavement and/or shoulder has been constructed) can be problematic, expensive and disruptive.

4.10.1 Non-Concrete Shoulders

If there is no concrete hard shoulder/edge strip to spread the traffic load, then the main concrete slab thickness will need to be increased. A 230 mm thick concrete slab that is well supported with a tied concrete shoulder provides the equivalent robustness to that of a 300 mm thick concrete slab with no shoulder support.

In order to adjust the concrete slab thickness for the addition/removal of a concrete shoulder, the designer must add or subtract a thickness based on whether the concrete pavement design equation or chart includes (or does not include) a concrete hard shoulder, as shown below:

- JUC/JRC (Equation 5.1 to Equation 5.4 in Sections 5.4 and 5.5). The first equations assume that there **IS NOT** a 1 m shoulder/edge strip and a second equation is given to reduce the design thickness of slabs if a 1m shoulder/edge strip is provided.
- RCC (Figure 5.2 in Section 5.6). This assumes that a 1m shoulder/edge strip **IS** provided at the nearside edge of lane 1.
- CRCB/CRCP (Figure 5.3 in Section 5.7) this assume that a 1 m edge strip or tied shoulder **IS** provided - if it is not, then the CRCB/CRCP concrete thickness (for all lanes) should be increased by 30 mm.

If a conventional sealed shoulder (i.e. asphalt) is used, then consideration should be given to having a 2 m wide shoulder to aid construction (as rollers are generally 2 m wide).

It should be noted that a heavily stabilised shoulder should not be used as this can ‘shrink’ away from the concrete edge, leading to a wide gap that is difficult to seal.

4.10.2 Concrete Shoulders/Edge Strips

Almost all concrete pavement designs acknowledge the benefits of keeping heavy traffic away from an unsupported slab edge in order to extend the life of the pavement. This can be achieved by providing a concrete hard shoulder (usually full lane width), or a shoulder/edge strip (partial lane width). A nearside widening of 0.4 m has been shown to be as structurally effective as a hard shoulder.

The incorporation of a concrete shoulder/edge strip can have additional benefits, such as minimising the infiltration of water under the pavement edge (which can extend the pavement life) and provide a small safety zone for the road user.

Concrete shoulders/edge strips should be the same concrete and thickness as the main concrete lane, and are either:

i. ’integral’ (sometimes called structural) where the main running lane is cast slightly wider than the normal lane width and a white line is used to keep traffic away from the edge. They should be at least 0.5 m (preferably 1 m) wide and dowel bars should be spread across the whole joint width including the shoulder.

ii. ‘tied’ where the edge strip is tied to the main running lane with tie bars and a longitudinal joint. This can be constructed at the same time as the main lane (i.e. with tie bars supported on cages before the concrete is poured, and a longitudinal joint created with crack-inducers or a wet saw-cut) or cast at a later date, with tie bars pushed into the edge of the main lane when it is laid and the edge strip cast up against the main lane edge. The edge strip should be at least 1 m wide and include dowel bars at transverse joints where there are dowel bars in the main carriageway.

If the edge strip slabs are narrow, then they are more likely to crack during construction (due to the long/thin shape). Edge strip (or layby) slabs with a length to width aspect ratio > 2.5:1 should be reinforced to lock any cracks together. For a JUC edge strip (or layby) against a JUC pavement, additional transverse warping joints may need to be created in the edge strip at mid slab positions to keep the slab aspect ratio ≤ 2.5.

For a reinforced concrete pavement (JRC/CRCB/CRCP), a JUC edge strip (or layby) is not recommended. If it is used then additional transverse joints may be required at 2.5-5 m spacings, in addition to transverse joints matching those in the JRC.

It should be noted that it is often easier to construct a wider main slab than to add a narrow, tied concrete shoulder, particularly if a paver is being used.

If the main lane is JUC/JRC then transverse joints should be made at the same locations with the same joint type (i.e. contraction/expansion) in the edge strip as those in the main lane so that the edge strip moves with the main slab (that it is tied to) and hence reduce additional stresses. For a jointed concrete pavement (JUC/JRC), a CRCP shoulder/edge strip is not recommended.

4.11 Concrete Joints

> Concrete joint sealants should comply with: KS 1744: Specification for cold-applied joint sealants for concrete pavements or KS 1759: Specification for hot-applied joint sealants for concrete pavements. For additional information consult: BS EN 14188 Pts 1-3: Joint fillers and sealants, specifications.

Joints are made in most concrete pavement to control cracking, relieve stresses, allow movement of the concrete and enable breaks in construction.

They are deliberate discontinuities in the concrete that either:

a. join two slabs/lanes (constructed at different times) together or

b. are locations where the concrete (which would normally crack in a meandering, random location) is effectively ~~told~~ where to crack – usually by saw cutting the fresh concrete surface in neat lines (before it cracks).

There are different types of transverse and longitudinal joints, and these perform different functions, these are summarised in Table 4.9, with more details given in subsequent sections.

Table 4.9 Main types and Purpose, of Concrete Joints

No.	Joint Type	Purpose of Joint	Joint Fixing
1	**Transverse Contraction Joint**	**Used in JUCP or JRCP.** These transverse joints are created using saw-cut or crack inducers to force the natural shrinkage crack to occur in a straight line at a chosen location, which can be easily sealed.	Dowel bars (note: these can be omitted for very low volume roads).
2	**Transverse Expansion Joint**	**Used in most concrete pavement types.** A deliberate transverse gap (approximately 25 mm wide) is made between slabs to allow them to expand. These are crucial in times of extreme heat to protect bridges and other pavement types, etc. The joints are filled with compressible material (foam, etc.) and dowel bars are used to transfer loads across the joint.	Dowel bars.
3a	**Transverse Construction Joint** (a type of Tied Joint)	**Used in all concrete pavement types.** This type of transverse joint locks two vertical slab ends firmly together, e.g. where today's fresh concrete meets yesterday's hardened concrete.	Tie bars.
3b	**Longitudinal Construction Joint** (aka Hinged or Warping Joint) (a type of Tied Joint)	**Used in all concrete pavement types.** Where two lanes (laid separately) are tied together to stop them moving apart. If both lanes are laid at the same time, then a joint is created in the wet mix using tie bars and saw-cut / crack inducers. The joint allows the slabs to slightly 'flex' up and down. Such a joint can also be used at manhole positions or in long, narrow JUC slabs between normal joint positions, to reduce the length / width ratio of the slabs to < 2.	Tie bars.

Notes: ** Most joints incorporate dowel bars for load transfer or tie bars to lock the slab sides together (and load transfer is provided by the aggregate interlock). Dowel bars and tie bar design details are given later in Sections 4.13 and 4.14.*

Transverse contraction/expansion joints on each side of a longitudinal joint shall be in line with each other and of the same type and width.

If there are transverse or longitudinal joints in both the main concrete slab and the cement-bound sub-base at approximately the same location, then the joints shall be staggered by at least 300mm so that they are not directly above each other.

The different types of concrete joint are discussed in the following sections.

4.11.1 Contraction Joints

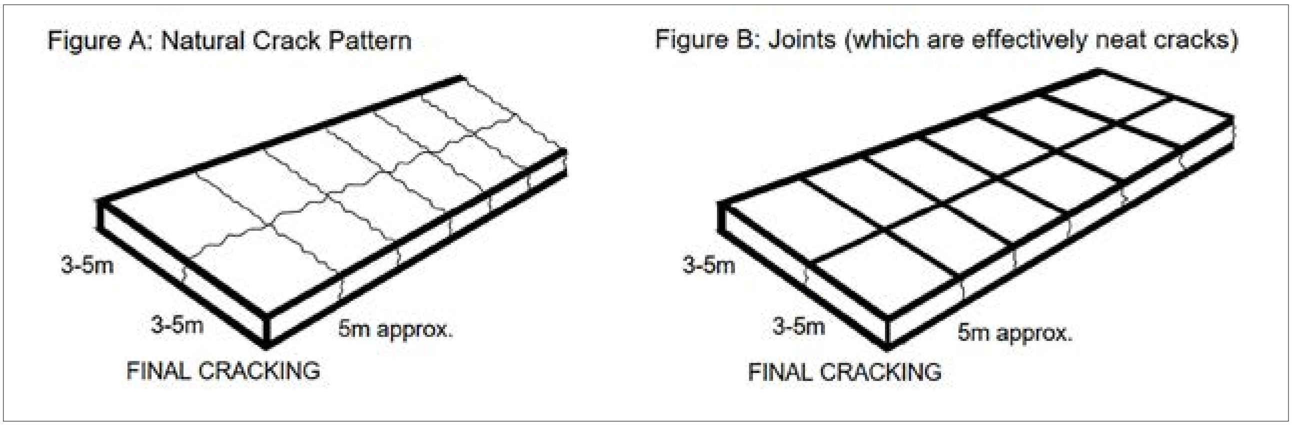
In an unreinforced jointed concrete pavement (JUCP), transverse contraction joints will be created every 5 m or so along each lane.

In an unreinforced concrete pavement with no joints, the wet mix concrete would naturally crack at approximately 3 - 5 m intervals as it shrinks due to the curing (i.e. concrete hardening) process. These meandering cracks would be difficult to seal, so, in a JUC pavement, contraction joints are created at approximately 4 - 5 m intervals, to control the shape and location of these cracks. They are usually created by saw-cutting transversely in the semi-hardened concrete to ¼ slab depth in order to force the naturally occurring shrinkage crack to occur at this location.

A ‘contraction joint’ is basically a shrinkage crack that separates the concrete into individual slabs, but the crack has a neat, straight top that can be sealed. A joint is a discontinuity in the concrete; it is basically a weakness in the pavement, where problems can occur. To aid load transfer across the joint (and reduce the traffic-induced vertical movement and stresses at the ends of the slabs), dowel bars (25 mm thick smooth metal rods) are usually placed across the transverse (see Section 4.13).

Figure 4.3 below shows (in an unreinforced concrete pavement) what would happen if the concrete was left to crack naturally (Figure A) and neat induced contraction joints that can be sealed (Figure B). Figure 4.4 shows saw-cutting a transverse construction joint.

Figure 4.3 Natural Shrinkage Cracking VS Contraction Joints (Controlled Cracks)



Note: *For Clarity No Dowel Bars or Tie Bars are shown*

Figure 4.4 Saw Cutting Transverse Contraction Joint & Induced Crack (i.e. Joint)

It should be noted that transverse contraction joints should be in the same location for all lanes across the carriageway i.e. they should not be staggered as this would lead to differential movement of the slabs and lead to cracking. The same type of joint should be used across the carriageway for example if an expansion joint is put in lane 1 then the same type and width of joint should be used across all lanes.

To create a contraction joint, there are alternatives to saw-cutting - including adding top and bottom plastic crack inducers (before and during concrete laying) at the required locations which do the same job as the saw-cut. Both methods introduce a plane of weakness into the concrete that will cause the natural shrinkage crack in the concrete to form at this location, leaving a neat transverse ‘joint’ at the surface.

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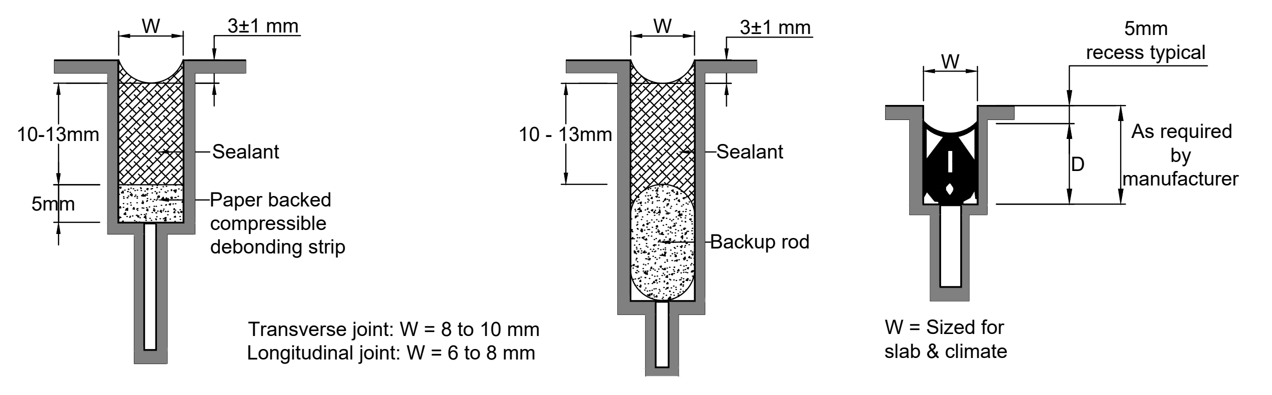
When saw-cutting, after the initial transverse saw cut to induce the crack, a twin saw is used to cut a sealing groove. This widens the top of the saw-cut, allowing the joint to be neatly sealed with an elastomeric (hot or cold-poured) material or preformed neoprene strip. This sealant will allow the slab's ends to move as the concrete expands / contracts / warps (due to daily temperature and moisture changes) but will stop detritus from entering the joint, which could prevent movement at the joint that might lead to a build-up of stresses and possible joint failure. The sealant will also stop water entering the pavement, which could cause the dowel bars to rust and cause damage to underlying pavement layers.

Detailed diagrams of contraction joints are given in Figure 4.5 below. Details of the joint and sealant should be as per the sealant manufacturer's recommendations.

Figure 4.5 Contraction Joint Details (Hot/Cold Poured Sealant and Pre-formed Strip)



The spacings between contraction joints for JUC pavements are given in Section 5.4.3 and for JRC pavements are given in Section 5.5.2.

4.11.2 Expansion Joints

Concrete is a material that expands when hot and contracts when cold. Expansion joints (also known as Isolation joints) are used in all types of concrete pavements to protect adjacent bridges, etc, from damage due to concrete expansion e.g. during extreme hot weather.

Expansion joints are generally 25 mm wide transverse joints, filled with a compressible material (such as foam matting, polystyrene or fibreboard) which can allow for greater expansion of the concrete slabs than contraction joints.

If expansion joints are required, they are deliberately built into the concrete pavement at either specific locations (e.g. at a bridge) or at regular intervals along the concrete pavement.

At expansion joints, the concrete faces do not touch, so there is no aggregate interlock to provide load transfer across the joint. All expansion joints need dowel bars to provide load transfer across the joint. The dowel bars will need a compressible material cap (e.g. foam) at the de-bonded end, at least 25 mm thick to allow the joint to open and close.

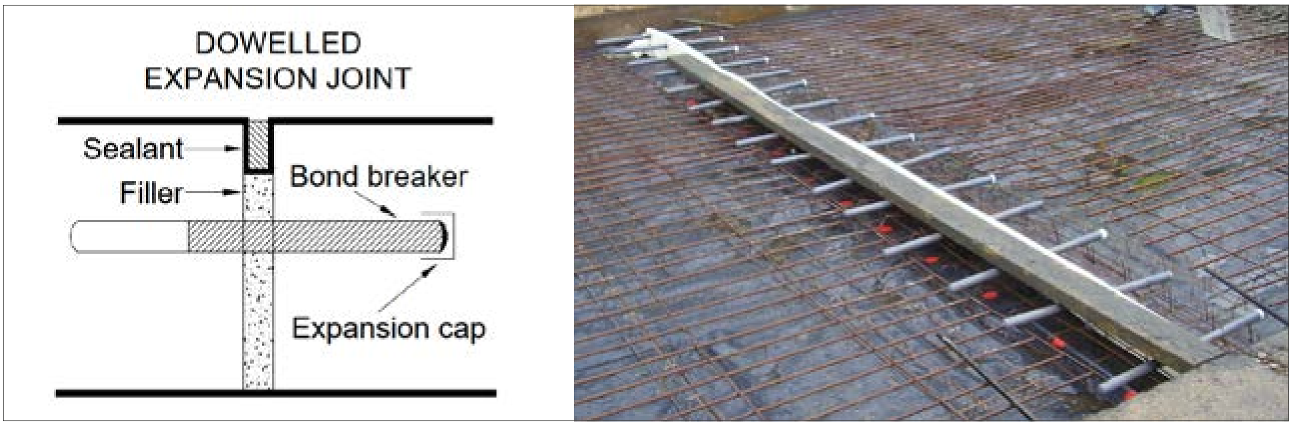
Expansion joints are usually required when:

- the concrete pavement reaches a permanent structure, e.g. a bridge, a culvert or another type of pavement. Even an increase in the length of each slab by a few millimetres can lead to significant movement and damage to an adjacent bridge, or the concrete slabs themselves, unless this additional movement is accommodated with expansion joints.
- the concrete pavement is laid at a cooler time of the year. At the hottest time of the year (particularly during a heatwave), the higher temperatures mean the concrete will expand to occupy a greater volume than when the concrete was laid. Without expansion joints the concrete could cause blow ups and significant damage.

If reinforcement is present in the slabs adjacent to the expansion joint (e.g. JRC slabs or at the transition slabs at the ends of CRCP), the reinforcement must be discontinuous (i.e. omitted) at the expansion joint, to enable the slabs to move separately.

A diagram and photo of an expansion joint are shown in Figure 4.6.

Figure 4.6 Expansion Joint Diagram and Construction (Before Concreting)

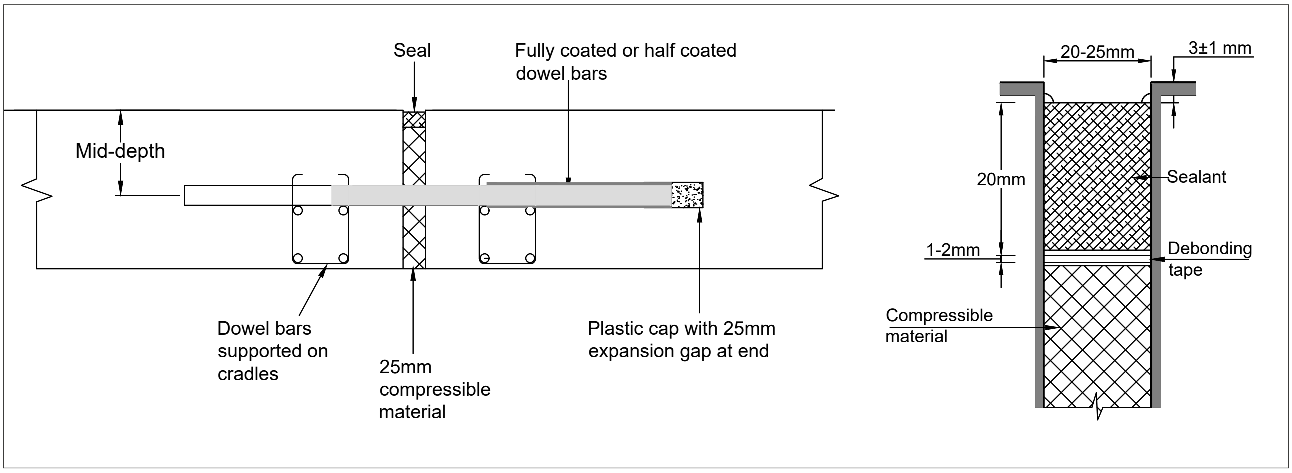


Expansion joints are almost always in a transverse direction across the carriageway – they are not used at longitudinal joints, where the lanes are tied together with tie bars. An exception to this is at an intersection or junction, where an isolation joint (an undowelled expansion joint)~~.~~ May be required to restrict conflicting movements among the different pavements.

In roads with multiple lanes, the expansion joint must be located at the same location in all lanes (including a hard shoulder or tied edge).

Close-up details of an expansion joint showing the compressible material, debonding tape and the joint sealant are shown in Figure 4.7.

Figure 4.7 Diagram of an Expansion Joint and the Sealant



~~In Kenya it is recommended that~~ every fourth joint for JRCP should be an expansion joint; with the other joints being contraction joints.

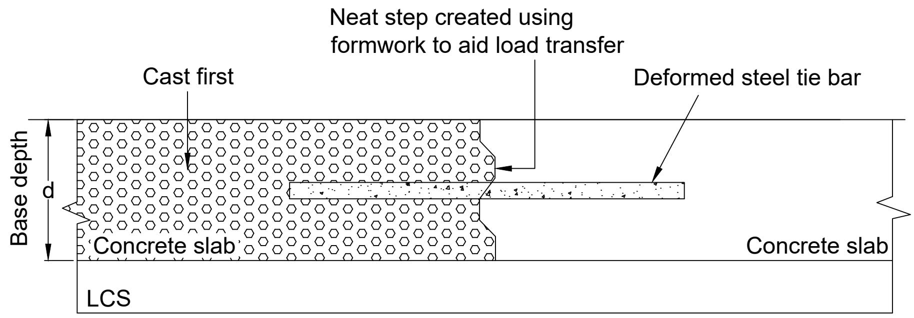
This is based on the ~~UK~~ recommendation for every third joint to be an expansion joint combined with the fact that most parts of Kenya have more consistent temperatures and a reduced daily/seasonal temperature variation.

4.11.3 Transverse Construction Joints

A transverse construction joint is created (usually mid slab) at the end of each day's work, (or when a stoppage is required). Transverse formwork is secured in place and the wet concrete is laid up against this formwork, creating a vertical or stepped face (depending on the shape of the formwork). Tie bars can then be pushed half-way into the end of the concrete at mid-slab depth, through holes in the formwork. To protect the tie bars from corrosion, at least 150 mm of the centre tie bar (which will be at the centre of the joint) should have been protected with a polymeric coating or painted with a bituminous paint or similar impervious material.

When laying restarts, the formwork is removed and the new concrete is laid against the old concrete, with the tie bars locking the two sections together. Load transfer is provided by the aggregate interlock and the stepped shape of the formwork – see Figure 4.8.

Figure 4.8 Tie bar at Transverse Construction Joint



Note: *the diagram above shows stepped or keyway shaped concrete at a joint – see section 4.11.5.*

Details of tie bar sizes and spacings are given in Section 4.14.

Transverse construction joints in jointed unreinforced and jointed reinforced slabs (JUCP and JRCP) shall be not less than 2.5 m from the preceding or succeeding joint positions.

For CRCB and CRCP, transverse construction joints require additional tie bars (1.5 m long and of the same grade and diameter as the longitudinal reinforcement) to be inserted midway between alternate existing longitudinal reinforcement bars. The tie bars should be at the same level as the longitudinal reinforcement and tied to the transverse reinforcement so that 750 mm ± 50 mm extends each side of the joint.

Note that a transverse construction joint should not be constructed within 1.5 m of any lap in the longitudinal reinforcement and the stop end formwork shall be sufficiently rigid to ensure that the longitudinal reinforcement and the tie bars which project through the joint are held in the correct position.

4.11.4 Longitudinal Construction Joints

When lanes are laid separately, the lanes are tied together with tie bars pushed into the longitudinal side of the fresh concrete at 600 mm spacings. When the second lane is laid, the two lanes will be held tightly together with the tie bars and prevent water entering the joint. Tie bars do not provide load transfer across the joint – this is provided by aggregate interlock as the two faces are held tightly together.

A longitudinal construction joint with tie bars to lock the lanes together is shown in Figure 4.9.

Figure 4.9 Longitudinal Construction Joint Showing Tie Bars

Note: *Concrete for second lane hasn't been laid yet.*

If a wide paver is used that lays two lanes of concrete at once, then a wet-formed longitudinal joint will need to be created by pre-placing the tie bars and a bottom crack inducer at the planned longitudinal joint location and then saw-cutting or using a top crack inducer to make the longitudinal joint. This longitudinal construction joint separates the concrete into two separate lanes, preventing a meandering crack that would naturally occur down the middle of the 2 lanes.

In CRCB or CRCP, where two lanes of concrete are laid at once, the tie bars may be replaced by continuous transverse reinforcement across the joint for a minimum of 500 mm or 30 times the diameter of the transverse reinforcement bars, whichever is the greater, provided that the transverse reinforcement is at least 12 mm diameter bars at 600 mm centres. The transverse reinforcement in these circumstances shall be protected by suitable bituminous paint or equivalent coating for a distance of at least 75 mm either side of the joint.

Details of maximum slab widths are given in Section 4.12 and details of tie bar sizes/spacings are given in Section 4.14. It should be noted that longitudinal joints should be located such that they are at the edges (or centre) of the traffic lanes, so that they are not constantly trafficked by HGVs.

A joint sealing groove is not required in longitudinal construction joints in continuously reinforced concrete bases. Joints in the surface slab should not be directly above joints in the underlying layer (base or sub-base). They should be staggered so that they are not coincident vertically and are at least 300 mm apart.

Where the edge of the concrete slab is damaged it shall be made good before the adjacent slab is constructed.

Longitudinal joints shall be constructed within the following tolerances:

i. Deviations of the bottom crack inducer from the intended line of the joint, parallel to the axis of the road shall be not greater than ± 13 mm;

ii. The joint groove shall be located vertically above the bottom crack inducers within a horizontal tolerance of ± 25 mm;

iii. The best fit line along the constructed joint groove, shall be not more than 25 mm from the intended line of the joint;

iv. Deviations of the joint groove from the best fit line of the joint shall be not greater than 10 mm.

4.11.5 Keyway or Key Joints – Step Shaped Concrete

For longitudinal and transverse construction joints, a stepped face called a 'keyway' or simply 'key' joint is frequently used for construction joints that will remain tightly closed. It is created by the shape of the metal formwork, which is only present in fixed form paving. The 'tongue and groove' shape reportedly does not increase load transfer across the joint but is reported to reduce the deflection of the concrete pavement.

It should be noted, however, that there are many reports of cracking/spalling above standard shaped keyway joints particularly where the key is too close to the slab surface.

It is now recommended that if keyway joints are to be used, then:

a. they should only be used on concrete pavements over 250 mm thick.

b. they must be used with tie bars.

c. they use a more modern crack resistant keyway shape design (see Figure 4.1, FHWA, 2019) or an alternative keyway design such as the Australian corrugated keyway designs (see Figure 4.3, FHWA, 2019).

4.12 Slab Widths

Concrete slabs widths should be about 3.7 - 4.2 m. If there is no hard shoulder or off-slip lane/ concrete layby, etc, to the left of the slow lane providing support to the nearside edge, then the slow lane slabs should be wider than the normal lane width - with an integral or tied concrete shoulder to stop traffic running near the edge of the slab which could cause premature failure.

All longitudinal joints should be tied together with tie bars at 600 mm spacings. The maximum number of tied lanes is usually four (approximately 16 m) for JUC, and 30 m for JRC and CRCP.

Longitudinal joints should be located away from concentrated heavy vehicle wheelpaths. Joints in the surface slab, base or sub-base shall be staggered so that they are not coincident vertically and are at least 300 mm apart. Maximum slab widths are shown in Table 4.10.

Table 4.10 Maximum Slab Widths

Pavement Type	Typical Slab Width	Maximum Slab Width	
		All other Aggregates	Limestone Aggregate
JUC	3.7 - 4.2 m	4.2 m	5.0 m
JRC/CRCB/CRCP	3.7 - 4.2 m	6.0 m	7.6 m

Notes:
1. *In CRCB, longitudinal joints in the concrete shall be provided between lanes or in the centre of lanes.*
2. *In CRCB, where 2 lanes of reinforced concrete are laid together, a joint sealing groove is not required in the longitudinal joint.*

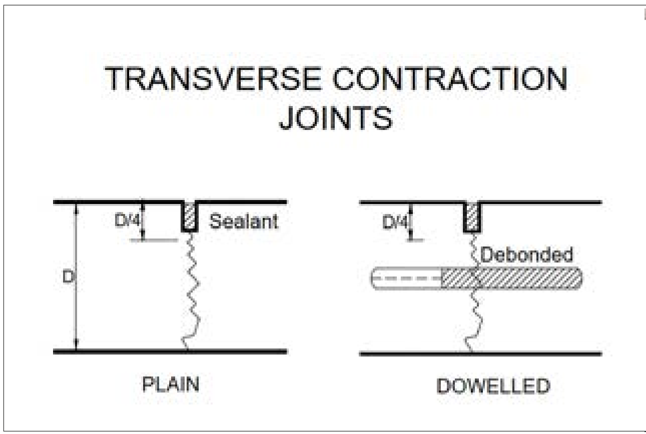
4.13 Dowel Bars

Apart from KS EAS 412: Steel for the reinforcement of concrete, there does not appear to be a specific Kenyan standard for dowel bars. If not then they should meet the requirements of 'BS EN 13877-3: Concrete Pavements Part 3 - Specifications for dowels in Concrete Pavements' with a minimum tensile strength of 250 MPa. They shall be straight, free from oil, dirt, loose rust and scale, burrs and other irregularities and the sliding ends sawn cleanly with no protrusions outside the normal diameter of the bar.

Dowel bars are usually solid lengths of smooth steel with a circular cross section and size 20 - 32 mm diameter and 400-600 mm long. They are used across transverse joints (so mainly used in JUCP and JRCP) but are also used in all types of concrete pavements at transition slabs from concrete to asphalt and at bridges, etc.

They are placed at 300 mm intervals across transverse contraction and expansion joints, usually before the concrete is laid, so that they 'bridge' the joint. Their role is to provide **load transfer** across a transverse joint, while still allowing the concrete slab to expand and contract with daily/annual temperature changes. See Figure 4.10.

Figure 4.10 Dowel Bars to Provide Load Transfer Across Transverse Joints



As a vehicle travels across each transverse joint (which is effectively a crack), the dowel bars spread the load from one slab to the next and hence minimise the vertical movement at the joint. Without dowel bars there would be significant vertical movement at each joint, causing damage/erosion of the underlying layer, which could lead to pumping/stepping at the joint.

Dowel bars are usually wired onto a metal cradle/cage/basket. This can be lifted into place and securely fixed to the sub-base at the planned joint location, ahead of concreting. The metal cradle must be in two parts, so that no part extends across the joint line, as this could lock the joint together and stop it opening/closing. The dowels must be able to slip freely in their cradle in a longitudinal direction, but the dowels and cradles must be secure enough to prevent them from moving when the concrete is poured around them. See Figure 4.11.

Figure 4.11 JUCP - Dowel Bars at each Transverse Joint Before Concreting

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Transverse contraction or expansion joints are then formed at the dowel bar locations. Contraction joints will be formed by either inserting a crack inducer into the fresh concrete above a previously placed bottom crack inducer or saw-cutting the semi-cured concrete above the centre of the dowel bars.

Expansion joints will have the compressible filler board, or equivalent, already in place (which the dowels pass though). Only at expansion joints, the dowel bars should be provided with a cap at the de-bonded end. This cap should contain compressible material (that will allow an expansion space 10 mm greater than the thickness of the joint filler board) between the end of the cap and the end of the dowel bar. This will allow the expansion joint to open and close to its maximum. See Figure 4.6.

It is crucial that dowel bars are accurately positioned both horizontally, and parallel to the centre line and each other; otherwise, joint failure could occur. Recommended dowel bar sizes are given in Table 4.11.

Table 4.11 Minimum Dowel Bar Sizes for Concrete Pavements

Joint Type	Concrete Design Thickness D (mm)	Dowel Bar		
		Diameter	Length	Spacing
Contraction Joint	150 < D < 239	20 mm	400 mm	300 mm
	D > 240	25 mm	600 mm	300 mm
Expansion Joint	150 < D < 239	25 mm	600 mm	300 mm
	D > 240	32 mm	600 mm	300 mm

Notes:
1. *In some cases, dowel bars may be omitted from JUC transverse joints, usually for cost reasons. This should, however, only be for low volume roads where the concrete pavement is less than 150 mm thick or has a design life of less than 0.15 M CESA.*

The most common type of dowel bar is a traditional round steel cylinder, but dowel bars of other shapes and materials are being developed, including flat bars and Glass Reinforced Plastic (GRP) material.

Instead of a dowel cage, some modern slip-form pavers can automatically insert dowel bars into the fresh concrete, using a dowel bar inserter. Joints will still need to be created at these locations, for example with the use of crack inducers.

Traditionally, dowel bars were bare steel, with (i) one half painted with a debonding agent (e.g. bituminous paint) to ensure effective debonding from the concrete on that side of the joint and (ii) the other half left uncoated, so that it would bond with the concrete and become fixed to one slab. However water getting down the joint often corroded the dowel bar over time, so it is now recommended that all steel dowel bars are coated in a smooth, flexible, polymeric corrosion-resistant coating to protect against corrosion.

If the dowel bars are to be covered by a flexible polymeric corrosion resistant coating, then this should be bonded onto a previously cleaned bar. The coating shall be smooth and free of indentations, with a minimum thickness of 0.3 mm. The coating should also be able to withstand 250 hours immersion in a salt fog cabinet complying with BS EN ISO 13523 (Coil coated metals - Test methods), without showing any visible crazing or corrosion of the protected bar. Bituminous paint is no longer recommended as a dowel bar debonding agent.

It is crucial that dowel bars are accurately positioned both horizontally, and parallel to the centre line and each other; otherwise, joint failure could occur. The outer dowels shall not be less than 250 mm from an edge.

Dowel bars shall be positioned at mid-depth from the surface level of the slab ± 20 mm. They shall be aligned parallel to (i) the finished surface of the slab, (ii) to the centre line of the carriageway and (iii) to each other within the following tolerances:

- **i.** for bars supported on cradles prior to construction of the slab and for inserted bars:
  - **a.** all bars in a joint shall be within ± 3 mm per 300 mm length of bar;
  - **b.** two thirds of the bars shall be within ± 2 mm per 300 mm length of bar;
  - **c.** no bar shall differ in alignment from an adjoining bar by more than 3 mm per 300 mm length of bar in either the horizontal or vertical plane;
  - **d.** cradles supporting dowel bars shall not extend across the line of the joint.
- **ii.** for all bars, after construction of the slab:
  - **a.** twice the tolerances for alignment as in (i) above;
  - **b.** equally positioned about the intended line of the joint within a tolerance of 25 mm.

For some low volume roads, dowel bars may be omitted from JUC transverse joints, usually for cost reasons. This should, however, only be for low volume roads where the concrete pavement is less than 150 mm thick or has a ~~design life~~ of less than 0.15 M CESA.

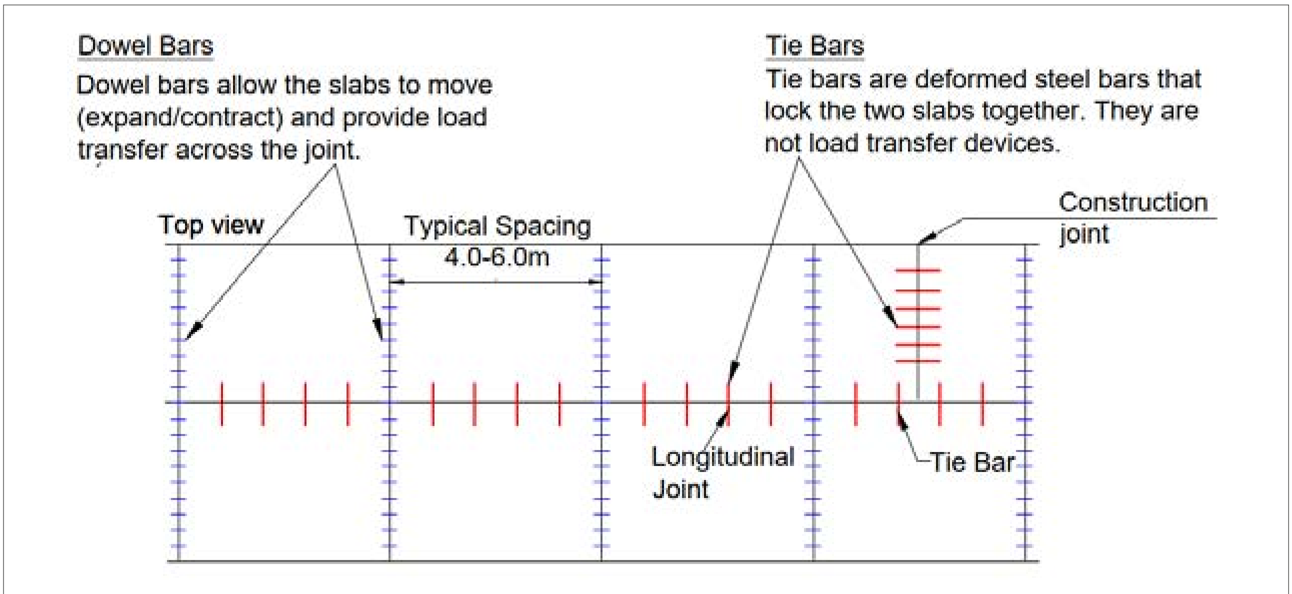
4.14 Tie Bars

Tie bars (sometimes called tie rods) are simple deformed steel bars (most are 12 mm diameter and 0.75 – 1.0 m long) that are placed at mid-height on the concrete and at intervals (usually 600 mm). They are used in all types of concrete pavement and are most frequently used along a longitudinal joint to tie two lanes together (see Figure 4.12). They can also be used at transverse construction joints.

The function of tie bars is to tie two slabs or lanes together at longitudinal joints or transverse construction joints. They are not load transfer devices, but lock concrete slabs together, which allows load transfer across a transverse/longitudinal joint using aggregate interlock.

The locations of dowel bars and tie bars for a JUCP pavement are shown in a site photo before concreting in Figure 4.11 and in diagram format in Figure 4.12.

Figure 4.12 Locations of Dowel Bars (blue) and Tie Bars (red) in JUCP



It is important to understand the differences, in terms of appearance and role, between dowels and tie bars:

- Dowel bars are thicker, shorter, smooth steel bars, whose main role is to provide load transfer across a contraction, or expansion, joint.
- Tie bars are thinner, longer deformed steel bars (with ribs). They are not load transfer devices, but they lock concrete slabs together, which allows load transfer across a transverse/longitudinal joint using aggregate interlock.

Where lanes are constructed separately (i.e. one lane laid before the next), they are usually manually inserted into the fresh concrete at mid-depth through holes in the formwork. They can also be placed before concreting by placing them through holes in the formwork as shown in Figure 4.11. They can also be added to hardened concrete by drilling horizontal holes and fixing the tie bars using an epoxy mortar.

Where two lanes are laid together (with a wide paver) and a longitudinal joint is required to separate the two lanes, the tie bars can be placed on formwork transversely across where the longitudinal joint will be. There must be adequate supports and fixings so that the tie bars remain firmly in position during the construction of the slab. After the concrete has been poured, a longitudinal joint can be created using a crack inducer or by saw-cutting the semi-cured concrete longitudinally at the required location. Alternatively, tie bars at longitudinal joints may be mechanically inserted by vibration from above using a method which ensures recompaction of the concrete around the tie bars.

To protect the tie bars from corrosion, a 200 mm length at the centre of the rod (where the joint will be) should be coated in epoxy material or painted with bituminous paint or a similar material.

Figure 4.13 below shows pre-bent (cranked) tie bars inserted into the concrete at a longitudinal joint. These are bent for site access/H&S purposes and will be straightened before adding the adjacent lane. Use of straight/cranked bars will be site specific.

Figure 4.13 Tie Bars (12 mm Diam. Deformed Steel Bars) to Lock Slabs Together

Where tie bars are used in longitudinal joints in reinforced concrete, they should be placed at the same level as the transverse reinforcement and tied to the longitudinal reinforcement.

Recommended tie bar sizes/spacings for various concrete joint types are given in Table 4.12.

Table 4.12 Minimum Tie Bar Details for Types of Concrete Joints

Type of Concrete Joint	~~Dowel~~ Bar		
	Diameter	Length	Spacing
Longitudinal joint	12	750/1000	600
	~~or~~ 16	600	600
Transverse construction joint in JUC/JRC	12	750/1000	600
Transverse construction joint in CRCB and CRCP	12	1500	600
Transition from rigid to flexible construction	20	1000	300

Notes on Steel Specification:
*Tie bars shall meet the same steel specifications as the reinforcement i.e. Hot Rolled and Cold Worked Carbon Steel Bars conforming to: **1.** KS 22: Hot-rolled mild steel bars for reinforcement of concrete – Specification, **2.** KS EAS 412: Steel for the reinforcement of concrete –Parts 1-3, or **3.** BS EN 10080: Steel for reinforcement of concrete weldable reinforcing steel, or **4.** BS 4449 (Steel for the reinforcement of concrete. Weldable reinforcing steel. Bar, coil and decoiled product. Specification) (Grade B500B or B500C deformed steel bars).*

Tie bar Notes:
- *Tie bars must be kept away from transverse joints where they could inhibit movement.*
- *Tie bars shall be positioned and remain within the middle third of the slab depth, they should be parallel to the surface and perpendicular to the line of the joint. Each bar centre should be on the intended line of the joint within a tolerance of ±50 mm, and with a minimum cover of 30 mm below any top crack inducer of joint groove for slabs 200 mm thick or more, or 20 mm for slabs up to 200 mm thick.*
- *Tie bars in wet-formed longitudinal joints shall be made into rigid assemblies with adequate supports/fixings to remain firmly in position during the slab construction.*
- *At longitudinal joints in CRCB or CRCP, tie bars shall be placed at the same level as the transverse reinforcement and tied to the longitudinal reinforcement.*
- *In CRCB or CRCP, at transverse construction joints, the tie bars shall be 1.5 m long and of the same Grade/diameter as the longitudinal reinforcement. They shall be fixed midway between alternate longitudinal reinforcement bars at the same level as the longitudinal reinforcement and tied to the transverse reinforcement so that 750 mm ± 50 mm extends each side of the joint.*
- *Tie bars for use across joints shall have corrosion protection in the form of a flexible polymeric corrosion resistant coating or painted with bituminous paint, on the central 200 mm of the previously cleaned centre section of the bars. Where tie bars are to be cranked (i.e. pre-bent) before insertion and later straightened, the coating shall be shown to be capable of being straightened without cracking.*
- *The transverse reinforcement may be continued across a longitudinal joint in reinforced concrete if the bars are a minimum 12 mm diameter, are protected from corrosion and the cover is as required.*

4.15 Steel Reinforcement

Deformed steel bars and wire to tie bars together shall conform to the following specifications. ~~Reinforcement shall comply with the following standards and shall be cut and bent in accordance with KS 106 (Specification for bending dimensions and scheduling of bars for reinforcement of concrete).~~

Hot Rolled and Cold Worked Carbon Steel Bars:

i. KS EAS 412 Parts 1 and 2, and KS 22 (Grade B500B or B500C), KS EAS 134.

ii. Steel Wires: KS 105, KS EAS 412 -3 and KS EAS 412 Part 3 (Ribbed Grade B500).

Steel Fabric

iii. KS 105, KS106, KS EAS 412 -3 (Steel for the reinforcement of concrete-Part 3: Welded fabric) (Grade B500A, B500B or B500C). Steel fabric reinforcement shall have a minimum nominal bar size of 6 mm (8 mm for Grade B500A). Steel fabric reinforcement shall be delivered to site in flat mats or pre-bent.

Also see KS 101 Methods of detailing reinforced concrete for information and UK DMRB MCHW Vol 1 Clause 1008 and Vol 2 Clause NG1008 for further details.

Details of the steel reinforcement for JRC pavements are given in Section 5.5.3 and details of the steel reinforcement for CRCB/CRCP are given in Section 5.7.2.

Reinforced concrete (as used in CRCP, CRCB and JRC) is concrete reinforced with longitudinal and, to a lesser extent, transverse steel bars. The reinforcement usually comprises 12 or 16 mm diameter deformed steel bars that are usually tied together with wire to form a mesh that is embedded in reinforced concrete pavements, usually at one third of the concrete slab depth to resist tensile stresses and keep the concrete cracks tightly closed.

Placing the reinforcement and tying the bars together with wire is usually done by hand. The transverse bars are usually placed on bar supports and then the longitudinal bars are placed on top of the transverse bars. It is important that the bars do not move during concreting regardless of whether concreting is done manually or by slip forming.

Increasingly popular are pre-welded transverse bars called Transverse Bar Assemblies (TBA), which can speed up the reinforcement setting process. These have steel supports welded underneath (to act as feet that raise the transverse bar to the correct height) and U shaped clips welded at regular intervals along the top of the bar (set to match the required longitudinal bar spacing). The longitudinal steel bars can then just be fixed into the U clips.

Steel bars usually come in standard lengths. To join two lengths together there must be a minimum overlap (a lap joint) as follows:

- For longitudinal reinforcement: 45 cm or 35 x bar diameter (whichever is greater).
- For transverse reinforcement: a minimum of 30 cm.

It is important to stagger the overlap (lap) of adjacent bars into a staggered or skew pattern to avoid problems that can occur with laps at the same location. Only one third of laps may be in the same location and there should be at least 1.2 m length between sets of laps.

Transverse steel reinforcement should **NOT** be placed at a diagonal, as this can lead to bifurcated transverse cracks and punchouts. Transverse reinforcement has much less contribution to the structural performance of a reinforced concrete pavement than longitudinal reinforcement. The purpose of transverse reinforcement is mainly to enable the fixing of longitudinal reinforcement in the correct location, eliminate the formation of longitudinal cracks and to contribute to the formation of transverse cracks.

The amount of longitudinal reinforcement will influence the pavement performance. A high percentage of steel will induce small crack spacings with narrow transverse cracks and a low percentage of steel will lead to large crack spacings and wider cracks.

It should be noted that small fibres added to Fibre Reinforced Concrete (FRC) should not replace conventional steel bars.

The reinforcement should have 60 mm cover from the surface except for slabs less than 150 mm thick where 50 mm cover should be provided. It should terminate at least 40 mm and not more than 80 mm from the edge of the slab and from all joints.

For details of tests on steel see **RDM Volume 3 Part 2**.

4.16 Fibre-Reinforced Concrete

Currently there does not appear to be a relevant KS or EAS standard for fibres, hence general suitability for fibres ~~is~~ established the following standards:

- Steel fibres conforming to BS EN 14889-1: Fibres for concrete. Part 1 - Steel fibres. Definitions, specifications and conformity
- Polymer fibres conforming to BS EN 14889-2: Fibres for concrete. Part 2 - Polymer fibres. Definitions, specifications & conformity

Fibre reinforced concrete (FRC) (or specifically Steel fibre reinforced concrete, SFRC) is concrete containing short, discrete fibres that are uniformly distributed and randomly orientated. The fibres are usually steel but glass, carbon, fibre, other synthetic materials (e.g. polyester or polypropylene) and organic materials have also been used. Polymeric fibres are reported to be increasingly used for their cost effectiveness and the fact that they do not corrode when exposed to salt water, etc.

Fibres are usually used in concrete to make it more crack resistant and to bind the cracks together if it does crack. The addition of fibres will have little effect on the concrete's compressive strength but does increase the flexural strength. For heavily trafficked roads, **fibres should NOT replace the steel bar reinforcement**. FRC and SFRC are more widely used in thin overlay applications than in new construction.

~~At present~~ **it is recommended that the concrete design thickness for new pavements using FRC is NOT reduced (compared to designs using standard concrete without FRC).**

The most widely used fibres are steel and come in variety of shapes designed to improve their anchorage in the concrete (e.g. wavy, crimped end or enlarged end). Steel fibres are typically 20-100 mm long (with 60 mm being the most common length) and a diameter of at least 0.5 mm.

The steel fibres are distributed into the concrete mix before laying – it can be difficult to get an even distribution. Fibre length is very important - if they are too long then they tend to 'ball up' and interfere with the workability of the concrete. An uneven distribution of fibres can have a negative effect on the concrete strength.

Fibres should NOT normally be used with conventional steel bar reinforcement as the issue of reduced workability of the concrete can lead to poor compaction beneath the reinforcement.

Steel fibres added to FRC are often classed as a 'concrete enhancement'. Steel fibres with zinc coatings should not be used unless it is shown that hydrogen formation in the concrete is prevented.

Specialist knowledge is required for the use of FRC. The amount of fibres added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibres), termed 'volume fraction' (V_f), with typical values ranging from 0.1 to 3 %. Distribution rates should be as recommended by the manufacturer. Often, when using fibres, the concrete mix will need to be adjusted e.g. the aggregate grading, maximum aggregate size may need to be changed and superplasticisers will probably also be required. It is recommended that shrinkage reducing admixtures are used in all FRC and SFRC.

The finished surface of the pavement should also be considered. If it is to remain a trafficked concrete surface then there are the issues of a) sharp steel fibres being exposed with possible risks to causing punctures and injuring people walking on the road and b) rusted exposed steel fibres staining the surface and being unsightly.

4.17 Cracking in CRCP/CRCB

In CRCP, the transverse crack width and pattern are the most important characteristics affecting the long-term performance of the pavement. If the crack spacing is too wide (more than 4 m), then the cracks will usually be wider, with less aggregate interlock, larger movement at the cracks, and their width will allow water to enter leading to increased corrosion of the reinforcement. If the crack spacing is too small (less than 1 m) then, due to their close proximity, there is a risk of cracks joining and leading to a 'punch-out' where a piece of the slab concrete becomes detached.

The crack pattern is affected by the following factors:

- **Longitudinal Steel Area** (expressed as a percentage of the slab cross-section area). This is the dominant factor affecting crack spacing. A 10 % increase in steel area will cause a 20 % reduction in the average transverse crack spacing. ~~For CRCP, the USA has commonly used 0.7 %, Belgium used 0.85 % until it was found to give too small crack spacing, so was reduced to 0.67 %. In the UK the current specification is 0.6 %.~~ For CRCB, the longitudinal steel area can be less, current specification is 0.4 %.

- **Concrete Strength.** Cracks form when the tensile stress in the slab exceeds the tensile strength of the concrete, so the strength of the concrete will affect crack spacing. A 10 % increase in concrete strength has been found to cause a 10 % increase in average transverse crack spacing.
- **Aggregate Type.** Larger crack spacings have been found with limestone aggregate (1.8 – 2.7 m) compared to siliceous gravel aggregate (0.9–1.5 m), however the siliceous aggregate had a greater percentage of medium and wide cracks.
- **Steel Depth.** For both siliceous gravel aggregate and limestone aggregate concrete roads, locating the steel at one third depth reduced both the crack spacing and the number of medium/wide cracks compared to when the steel was at mid-depth.
- **Steel Perimeter and Bond Strength.** The transfer of forces within reinforced concrete is through the steel/concrete bond – a better bond and a smaller bar diameter will give a reduced crack spacing. Hence deformed bars of a particular size are specified.
- **Base Restraint.** Cracks develop from the early thermal shrinkage of the concrete against the foundation's frictional restraint. A 10 % increase in base restraint will cause a 3 % decrease in transverse crack spacing, hence in CRCP, a separation membrane is generally omitted to improve restraint and give a more consistent crack spacing.
- **Construction Joints.** These usually have less aggregate interlock than transverse cracks, particularly if smooth transverse formwork is used. To counteract this deficiency, stop joint erosion and prevent transverse cracks from widening, long tie bars are used to lock the joint together and increase the tensile strength of the slab.
- **Steel Corrosion.** Provided crack widths are small, slight corrosion of the steel should not be a serious problem. Wide cracks, however, can lead to serious corrosion – often confined to individual transverse bars as transverse cracks tend to form above transverse bars. ~~In some countries, placing the transverse bars diagonally (60° to the longitudinal axis) has been successful, but UK trials on M18 led to problems (with diagonal cracks and punch-outs (Chandler et al, 2008).~~ The steel depth also affects corrosion - steel at mid-depth is at less risk of corrosion than steel at one-third depth.
- **Anchorage.** Slab temperature changes can cause large longitudinal forces to develop in the steel reinforcement. Most of the pavement will be prevented from moving by base restraint, with changes in length accommodated at the multiple fine cracks. At the free ends, however, considerable movement can occur and is accommodated by using a universal beam anchorage which allows contraction and expansion, usually up to 25 mm, and then provides a restraint against further expansion. Alternatively, the slab ends are restrained by transverse ground beams under the slab.
- **Surfacing of CRCB.** The asphalt surfacing of CRCB (>100 mm thick) protects the concrete slab from the worst effects of weather and traffic, so a wider crack spacing of 3-4 m is permitted, which allows a reduction in the longitudinal steel area to 0.4 %.

4.18 Terminations at the End of CRCB/CRCP

Terminations are placed at the ends of CRCB and CRCP pavements to fix the ends of the concrete pavement and to contain the large longitudinal thermal movements that can occur and prevent damage to any adjacent structure (e.g. bridge) or pavement.

For culverts etc, where the concrete slabs are above the superstructure and any horizontal movement would not damage the culvert, there is no need for terminations. However, if the concrete slab abuts the culvert structure and horizontal movement could damage the culvert, then terminations will be necessary.

It should be noted that in CRCP, use of siliceous gravel aggregate increases the end movement by about 25 % compared to limestone aggregate.

The amount of end movement can also vary significantly based on the sub-base friction. For a CRCP, when compared to a cement bound sub-base, a planed asphalt surface sub-base will have similar end movements, a granular sub-base will have 30 % greater end movements and a newly laid asphalt layer sub-base (such as an asphalt regulating layer) will have 40 % more end movements (Hassan, 2005).

There are two main termination systems for CRCB/CRCP. These are Ground Beam Anchors (GBA) and Wide-Flange Beams (WFB). Both of these use a series of reinforced concrete blocks buried in the foundation, combined with multiple slabs and expansion joints to accommodate movement.

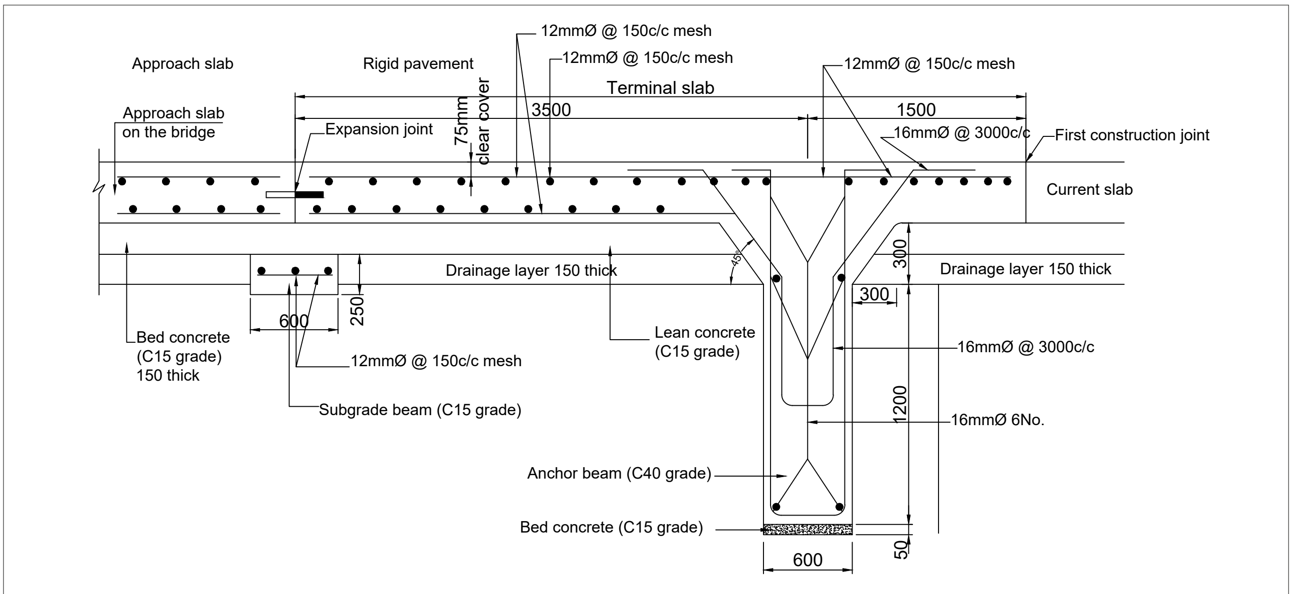
~~To overcome the high costs of constructing both GBA and WFB systems, it is proposed that in the future bridge-type expansion joints should be trialled. It is likely that these could accommodate longitudinal movements of up to 50 mm, at a reduced cost. Ground Beam Anchors and Wide-Flange Beams are discussed in the following Sections.~~

4.18.1 Ground Beam Anchors (GBA)

Also known as 'base anchors', 'anchor beams' or 'ground anchor beams'. The termination of a CRCB/ CRCP usually comprises a series of four vertical GBAs (which are effectively vertical reinforced concrete beams) each approximately 0.6 m wide and 1.2 m deep, that are cast transversely across the carriageway into the sub-base/subgrade approximately 6 m apart and connected to the reinforced slab above. See Figure 4.14 and Figure 4.15.

Figure 4.14 Construction of a Ground Beam Anchor

Figure 4.15 Typical Details of Terminal Slab and Ground Anchor



At the ends of CRCP, four jointed reinforced slabs (each 5 m long with an expansion joint) and a 3 m long stepped transition slab should be constructed between the anchorages and another type of pavement. Between anchorages there will only be construction joints.

At the ends of CRCB, a jointed unreinforced slab with an expansion joint and a 3 m long stepped transition slab should be constructed between the anchorages and another type of pavement. Between anchorages there will only be construction joints.

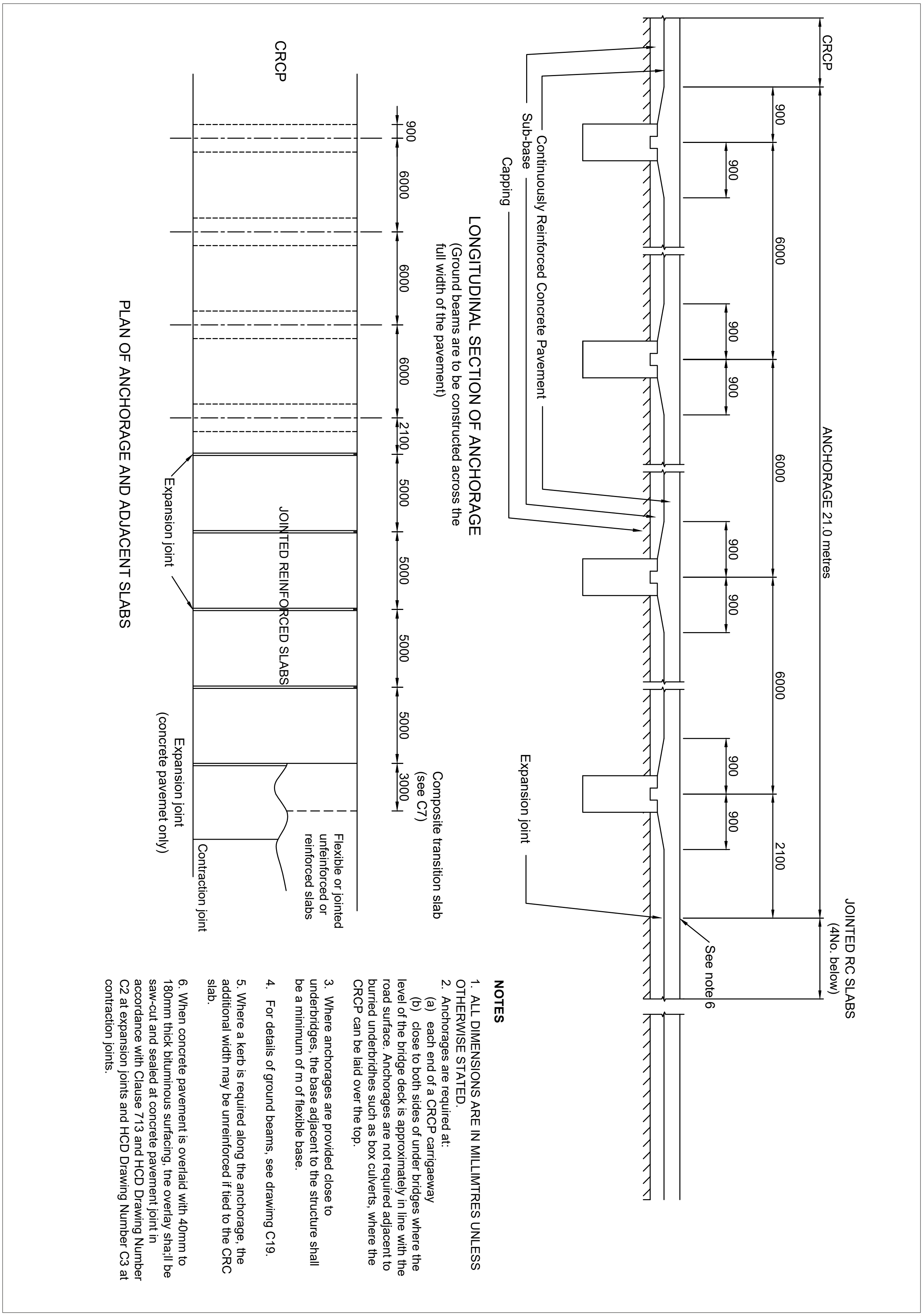
Drawings of the layout for a typical ground beam anchor termination system, each Ground Beam Anchorage and a transition slab are given in Figure 4.16, Figure 4.17 and Figure 4.18.

It should be noted that this system relies on the strength of the foundation to prevent movement at the pavement ends and will be less effective on weak foundations.

For CRCP, ~~Hassan et al. (2005)~~ report that the GBAs only restrain 40 % of the normal end movement with the rest of the movement occurring in the four JRC expansion joints.

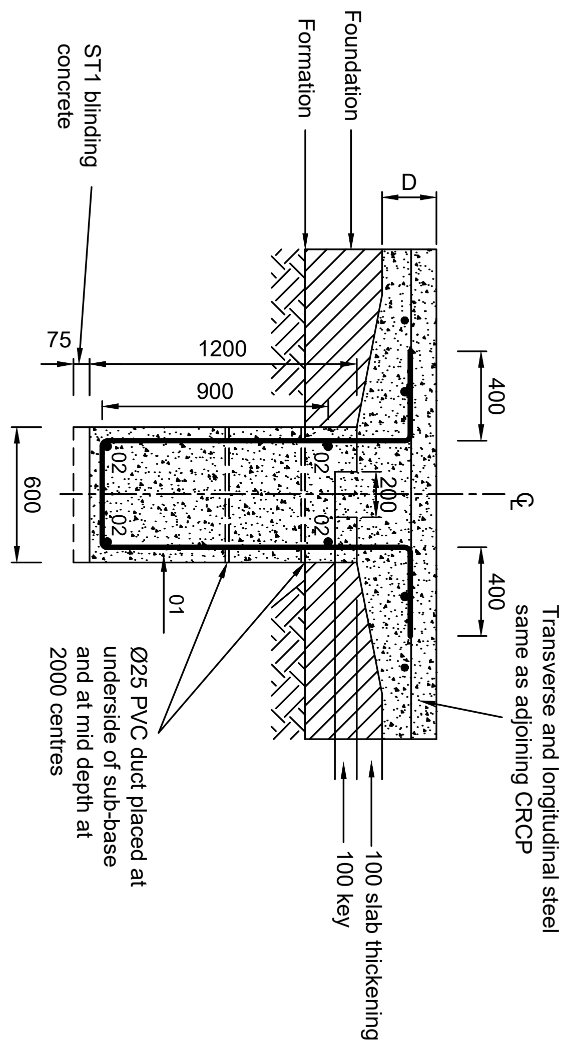
The minimum concrete strength for the ground beam anchor should be C25/30.

Figure 4.16 Ground Beam Anchorage System (for CRCP)



***Source:** Adapted from MCHW Vol.3 HCD Section 1, Drawing No. C18*

Figure 4.17 Detail of Each Ground Beam Anchor (for CRCB/CRCP)



GROUND BEAM
(4 No. in anchorage)

NOTES:
1. All dimensions are in millimetres unless otherwise stated
2. Concrete in ground beams to be class C25/30 cast in trench below formation level or foundation surface
3. Beam reinforcement cover to be 60+/-10

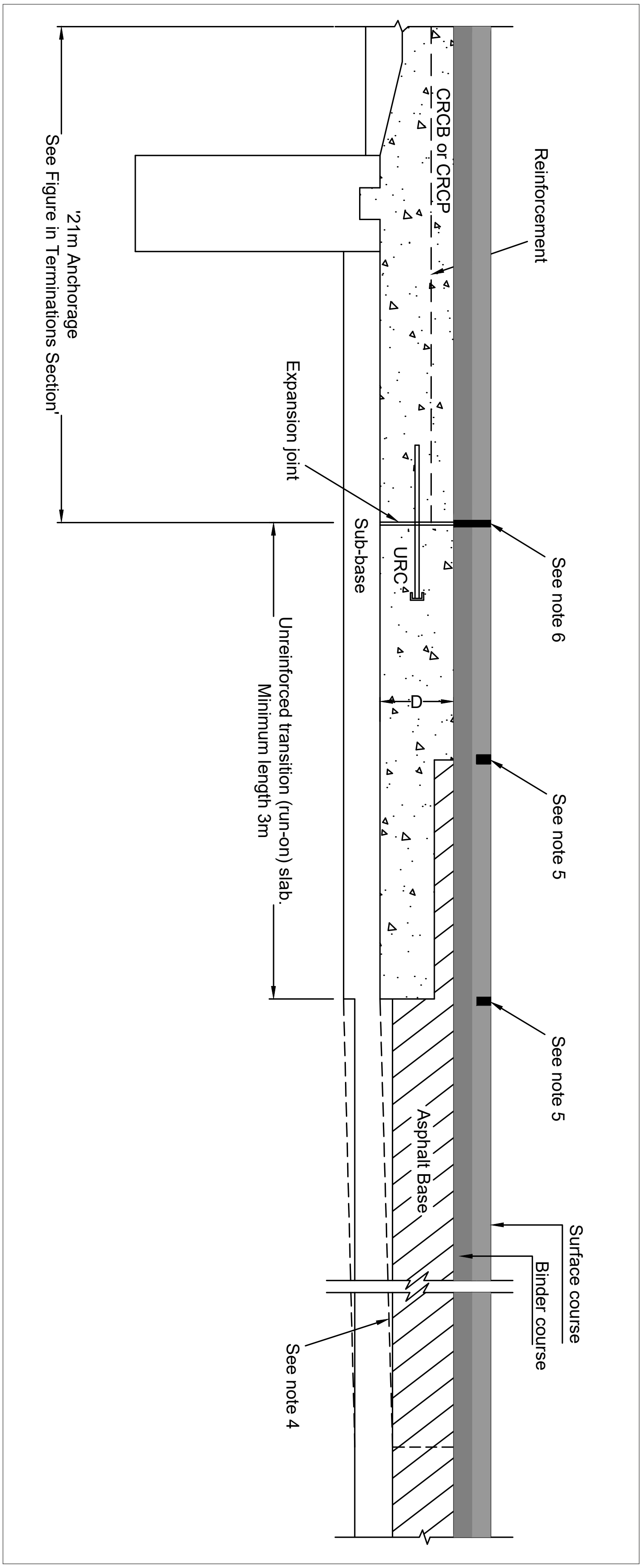
BAR SCHEDULE FOR REINFORCEMENT

MEMBER	BAR Mk	TYPE & SIZE	No. OF MEMBERS	No. IN EACH	TOTAL No.	LENGTH OF EACH #	SHAPE CODE	A*	B*	C*	D*	E*
BEAMS	01	H16	4	**	**	3900	44	400	1375	480	1375	-
BEAMS	02	H16	4	4	16	**	00	**	-	-	-	-

** Varies with width of anchorage
* Specified to nearest 5mm
# Specified to nearest 25mm

Source: *From MCHW Vol.3 HCD Section 1, Drawing No. C19*

Figure 4.18 Transition from CRCB to Asphalt Pavement showing Transition Slab



Notes:

1. All dimensions are in mm, unless otherwise stated.

2. Between an underbridge and the transition slab, there shall be a minimum 5 m length of flexible base.

3. At buried structures, the base and sub-base shall be continued over the structure. There shall be at least 150 mm of granular fill between the sub-base and the buried structure.

4. The transition slab thickness shall not be less than 200 mm. The thickness of the last concrete bay/transit slab/asphalt base may be tapered to match so that the foundation surface level is continuous without steps (see dashed line in Figure 4.18 and Figure 4.22).

5. The asphalt surfacing shall be transversely 'saw-cut and sealed' at locations above the step edges and end of the transition slab.

6. If the concrete has an asphalt surfacing, then a 25 mm wide groove the full asphalt depth shall be made above the transverse expansion joint and sealed.

1
2
3
4
General Design of Concrete Pavements

4.18.2 Wide-Flange Steel Beams (WFB)

In this system of CRCP termination, the bottom flange of a universal galvanised steel I shaped beam is fixed into a concrete block (called a sleeper beam that is 3 m wide x 180-220 mm deep) cast into the sub-base. A 30 mm thick compressible material is placed between the I beam and the CRCP concrete to allow the concrete to move within the flange. See in Figure 4.19 below.

Figure 4.19 Photo of a Wide-Flange Beam

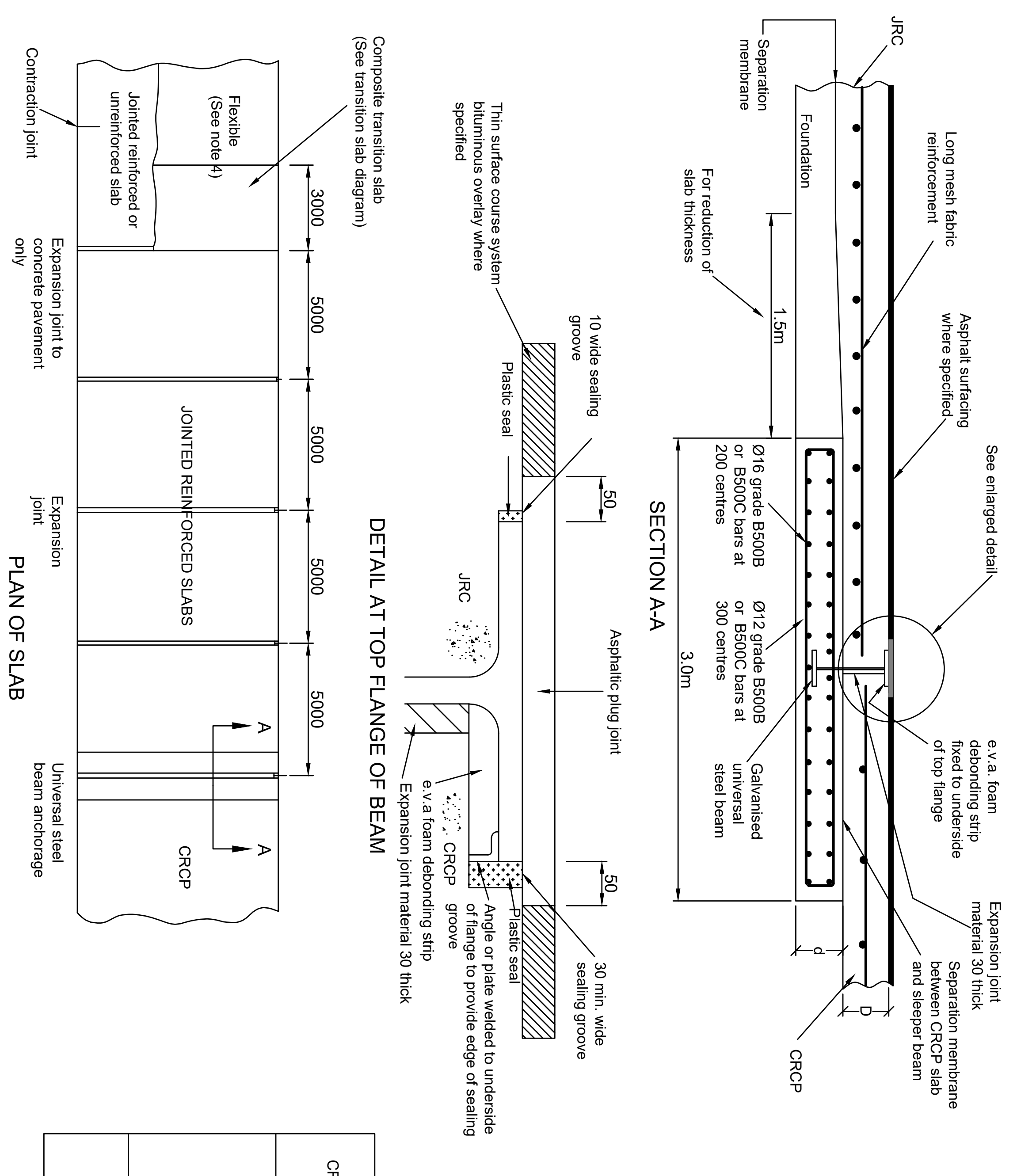
Drawings for the layout of a typical arrangement of terminal slabs and a Wide-Flange steel Beam is given in Figure 4.20 and a transition/run-on slab is shown in Figure 4.18.

The I beam size will depend upon the CRCP concrete slab thickness. For slabs <235 mm thick it should be 305 x 127 x 48 mm and for slabs ≥ 235 mm it should be 356 x 171 x 67 mm. The I beam top should be level with the concrete running surface and any gap should be sealed. If the CRCP has an asphalt surfacing then an asphaltic plug joint is needed above the I beam.

For CRCP (as shown in Figure 4.20) after the WFB there are usually four 5 m JRC slabs with expansion joints followed by a 3 m transition slab. The number of JRC slabs may be reduced to two if there is no adjacent structure that could be damaged by excess movement.

Source: *From MCHW Vol.3 Section 1, Drawing No. C7/2*

Figure 4.20 Wide Flange Beam (WFB) Anchor (for CRCP)



Notes:

1. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE STATED.
2. This type of anchorage is an alternative to the ground beam anchorage for CRCP surface slabs only.
3. Minimum cover to sleeper beam reinforcement to be 50.
4. Anchorages are required at:
   (a) each end of a CRCP carriageway
   (b) close to both sides of underbridges where the level of the bridge deck is approximately in line with the road surface. Anchorages are not required adjacent to buried underbridges such as box culverts, where the CRCP can be laid over the top.
5. Where anchorages are provided close to underbridges, the base adjacent to the structure shall be a minimum of m of flexible base.

CRCP Slab Depth D	Min Sleeper Beam Depth d	BS4 Universal Beam Size
200	210	305 X 127 X 48
210	200	
220	190	
230	180	
240	220	356 X 171 X 67
250	210	

Source: *From MCHW Vol.3 Section 1, Drawing No. C20*

4.19 Transitions from JUC/RCC/JRC to Asphalt Pavements

Section 4.18 already covered the terminations/transitions from CRCP/CRCB to another type of pavement. For transitions from JUC/RCC/JRC pavements to asphalt pavements, terminations are not required. Often all that is required between a JUC/RCC/JRC concrete pavement, and a bridge (or other pavement construction type) is a dowelled expansion joint, a transition slab and a length of full depth asphalt that is at least 5 m long.

If there is no expansion joint, the asphalt will often develop a ridge that could be a hazard to traffic and the movement could cause damage to any adjacent bridge deck.

Detailed diagrams of a transition from JUC/JRC (both with and without an asphalt surface) to asphalt pavement is given overleaf in Figure 4.21 and Figure 4.22. The transition from RCC to asphalt will be similar but the dowel bars in the RCC will probably be retro-fitted.

The transition slab (aka run-on slab) should consist of a short (minimum 3 m long) unreinforced concrete slab with a stepped surface (to match the asphalt layers in the adjacent full depth asphalt pavement). It should be at least 200 mm thick but can have a sloping base to match the original construction.

The asphalt surfacing should be 'saw-cut and sealed' above each transverse joint in this slab (to minimise asphalt cracking). It should be noted that the tie bars in a transition slab are usually larger than normal tie bars – see Table 4.12 (in Section 4.14).

4.20 Concrete Pavements on Slopes

Most conventional road pavements are not constructed at grades greater than 15 % due to construction limitations and/or motor vehicle operator safety concerns; however, there are locations where roads must be built at extremely steep longitudinal slopes.

Concrete pavements on steeply sloped roads have significant advantages over asphalt and gravel pavements due to the increased strength, increased durability, and the ability to better resist damage from severe weather events such as flooding and intense run-off. It has also been shown that overloaded and tall trucks can cause excessive damage to flexible pavements when driving up steep slopes as the loads on the rear axles are increased due to force equilibrium.

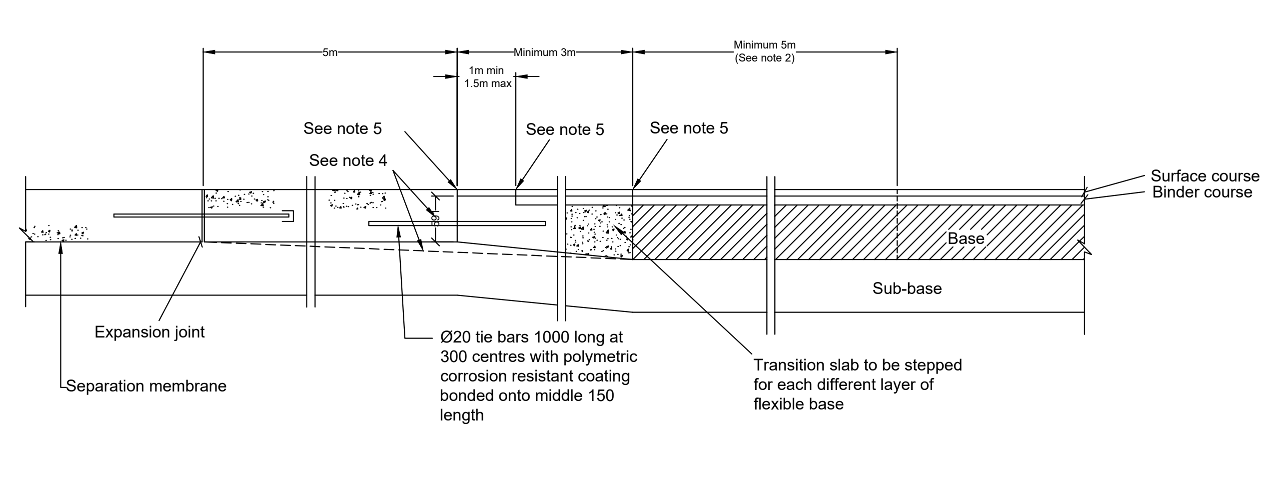
All types of concrete pavement are suitable for use on slopes e.g. climbing lanes. However, the designer should be aware that concrete (and block paving) roads can 'creep' (i.e. gradually move, usually downhill) due to traffic accelerating (uphill) and braking (downhill). This effect will be greater for roads on steeper slopes.

To combat this movement, single or multiple reinforced concrete ground anchors can be constructed at the same time as the pavement. They are constructed in transverse trenches created in the foundation and joined to reinforcement in the overlaying slabs in order to fix the slabs at various locations.

To stop downhill creep of the pavement, the spacing of anchors will depend on various factors including the slope and the subgrade. Ground anchors should generally be at spacings of 15-60 m. For low-volume roads, anchors should be at the bottom of the slope for slopes of 5-10 % and anchors at 30 m intervals for slopes >10 %.

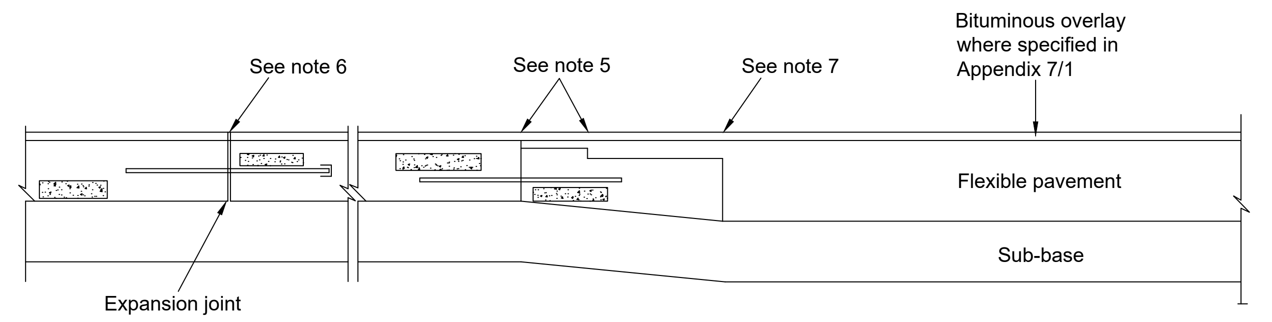
For the surface texture on steeply sloped concrete pavements (in areas which are not noise sensitive), then a 'burlap and tine' surface texture is recommended - with deeper than normal transverse grooves so that the surface texture will last longer.

Figure 4.21 Transition from JUC/JRC (with Concrete Surface) to Asphalt Pavement



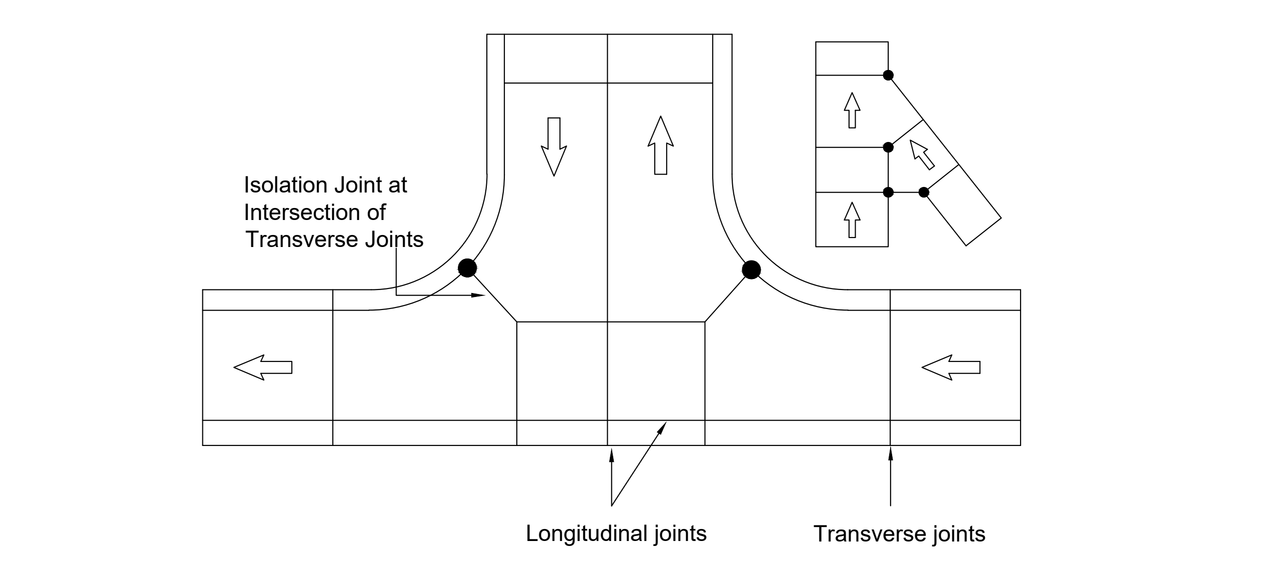
Source: *Adapted from MCHW Vol.3 Section 1, Drawing No. C7/1a*

Figure 4.22 Transition from JUC/JRC (with Asphalt Surface) to Asphalt Pavement



For Notes see Figure 4.18. ***Source:*** *Adapted from MCHW Vol.3 Section 1, Drawing No. C7/1b*

Figure 4.23 Suggested Joint Layout at a Junction



4.21 Concrete Slab Shape and Layout at Junctions

The ideal shape for a concrete pavement slab is square as this will minimise stresses and cracking in the slab. In urban areas, junctions or where space is limited, the layout of the pavement slabs will have to be arranged to minimise long/thin slabs or triangular shapes.

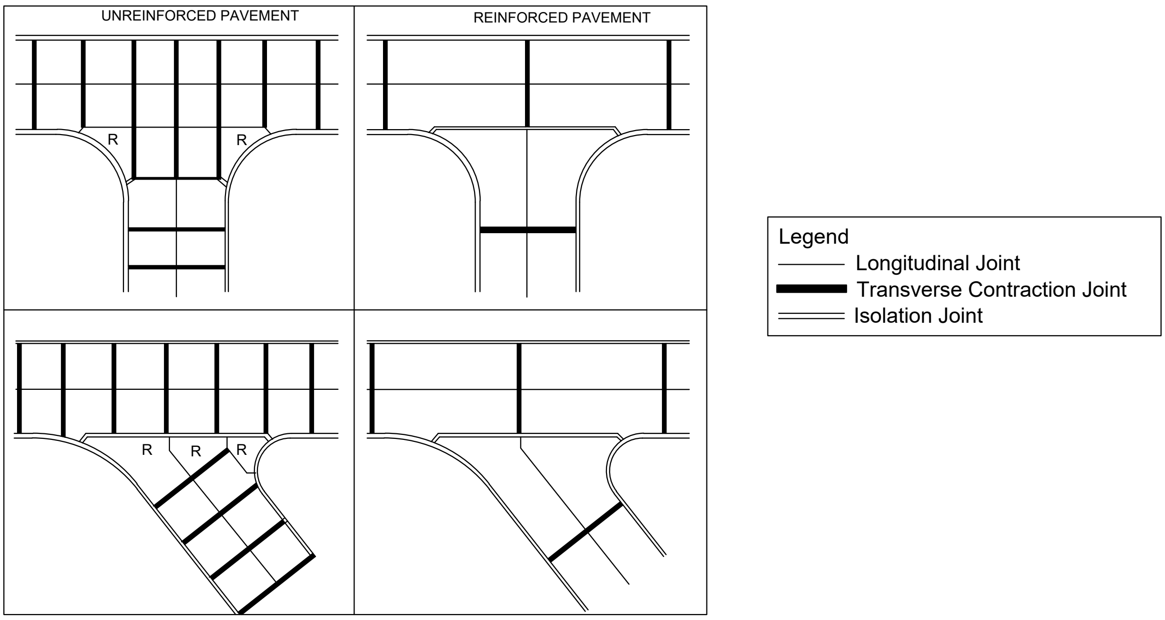
Slab shape should be kept approximately square and usually not exceed a 3/2 (length/width) ratio. However, at locations such as slip roads, junctions, laybys, etc, with non-standard slabs that are long and narrow or tapered, the length/width ratio of the slabs can be reduced to 2 or less. Slabs with an aspect ratio > 2 should use steel reinforcement, as they are more likely to crack and the steel bar reinforcement will hold the crack(s) together.

The shape of slabs can be dictated using formwork and joints. At these joints it is not always clear whether to use tie bars (to lock the slabs together) or to use dowel bars (for joints that allow expansion and contraction of the concrete).

There are various standard joint layout pattens for intersections and connecting slip roads. Whilst the main aim of the layout is to avoid acute angles and mismatched joints, inevitably there will be some odd shapes that are not square or rectangular. It is recommended that all odd-shaped slabs should be reinforced with steel mesh to minimise cracking.

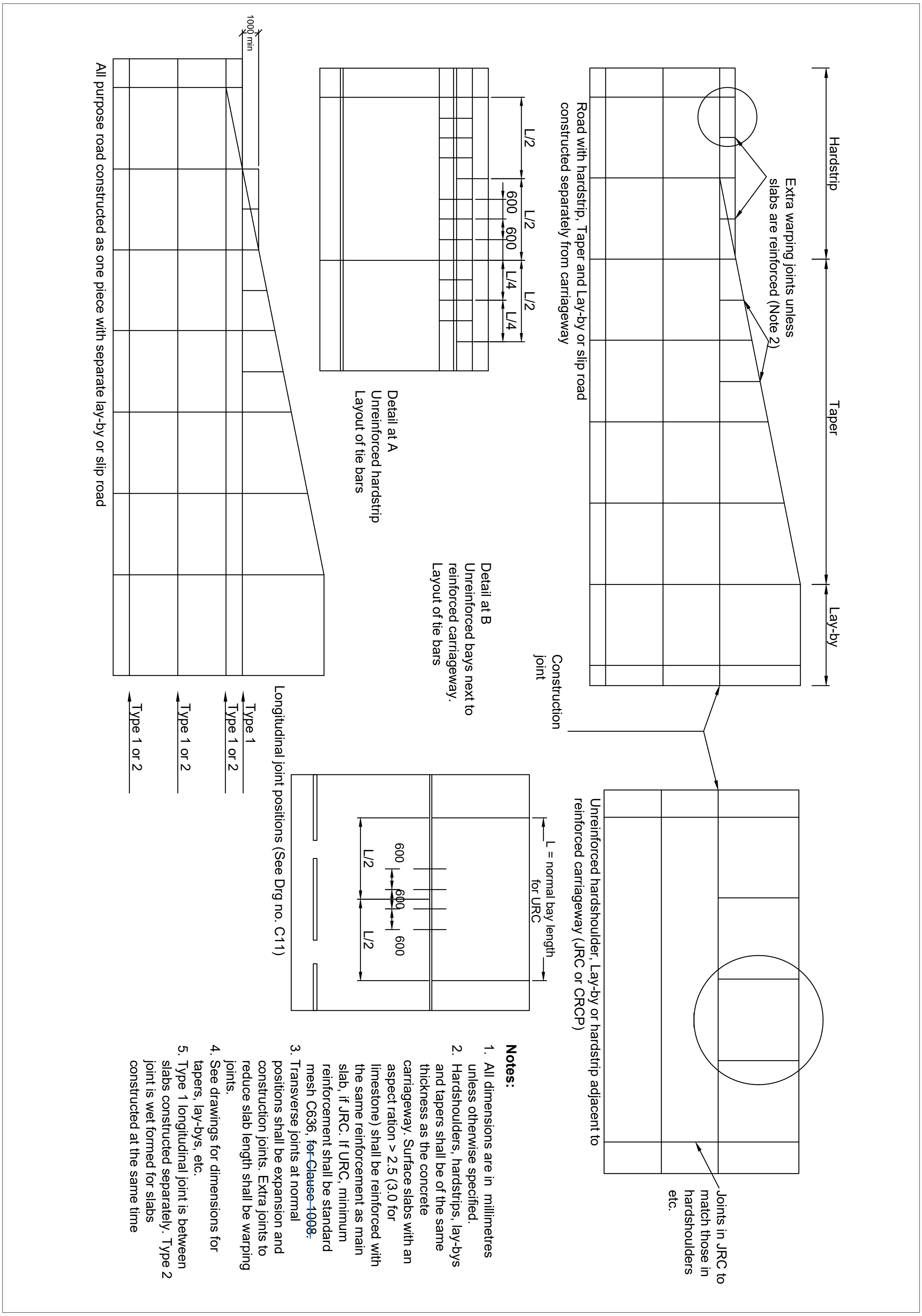
Some example joint layouts are shown in Figure 4.23, Figure 4.24 and Figure 4.25.

Figure 4.24 Suggested Junction Layout for Unreinforced/Reinforced Slabs



Source: *Cement & Concrete Assoc'n of Australia (1997). Interim Concrete Roads Manual*

Figure 4.25 Joint Layout for Hard Shoulders and Lay-bys



Source: *Adapted from MCHW Vol.3 Section 1, Drawing No. C26*

4.22 Surface Texture on Fresh Concrete

Texturing is normally carried out in the fresh semi-hardened concrete after saw-cutting any required transverse contraction joints (for JUCP/JRCP) and before the application of a curing membrane.

A good surface texture will have both microtexture for low-speed skidding resistance (usually provided by the fine aggregate in the concrete) and macrotexture for high-speed wet skidding resistance. The transverse indentations in the concrete surface allow water to quickly drain off the road surface to prevent aquaplaning.

Manual surface texturing can be carried out in many ways. The most popular method is to apply a series of transverse indents using tines, brushes, etc. These are often fixed to a long-handled broom/rake and dragged across the surface. A wooden walkway is sometimes built across the lane(s) and can be moved along the road as the texturing progresses.

The main types of surface texture are:

- Tine and Burlap
- Tine and canvas belt
- Brushed
- Exposed Aggregate (EACS)
- Diamond grooving (for hardened concrete)

As a guide to the design engineer for fresh concrete texturing:

- for low volume / low speed roads:
  - a transverse brushed surface texture should be sufficient.
- for medium/heavy traffic and high-speed roads:
  - the best surface would be an exposed aggregate concrete surface, which is very low noise, but it is expensive and requires great technical skill to achieve.
  - the most common surface would be a ‘Tined’ surface.

For a durable surface texture, it is essential that the mortar is durable. Use of siliceous sand will increase both the durability and friction of the surfacing.

Trials should be carried out before texturing the actual pavement in order to perfect the technique and demonstrate to the Overseeing Organisation that the requirement given in Table 4.13 can be met.

Concrete surfaces that are to be immediately overlaid with asphalt (CRCB and possibly CRCP) do not need a neatly tined surface texture, but they should be roughened before the application of any curing compound by brushing with a wire brush or stiff broom to achieve a minimum texture depth of 0.5 mm.

4.22.1 Surface Texture - Texture Requirement

The finished surface of the pavement should comply with ~~any Kenyan~~ specifications for Surface Macrotexture (i.e. Texture).

~~If there are no specific requirements for Kenya, then~~ a ~~useful~~ guide to acceptable levels ~~can be~~ provided by the texture depth requirements for Brushed, Tined and Exposed Aggregate surfaces as given in Table 4.13 and Table 4.14. It should be noted that if the macrotexture depth is over 1.25 mm, then it is likely to produce unacceptable tyre noise.

Table 4.13 Surface Texture Depth Requirements (Brushed/Tined)

Surface	No. of Tests	Required Texture Depth (mm)	
		Specified Value	Tolerance
Concrete surface to be trafficked.	Average of 10 measurements	1.00	+0.25 -0.10
Wet laid concrete base prior to asphalt surfacing	Average of 10 measurements	Minimum 0.5 *	n/a

** A transverse brushed surface texture should be sufficient to achieve this.* ~~***Source:*** *UK MCHW Vol 1, Series 1000, Clause 1026, Table 10.8 and sub- clause 28.*~~

Table 4.14 Surface Texture Depth Requirements (Exposed Aggregate)

Surface	Coarse Aggregate Size (mm)	Required Texture Depth (mm)		
		Minimum	Average	Maximum
High speed roads (>90 kph)	6.3/10	1.10	1.2+/-0.25	1.60
Low speed Roads (<90kph)	4/8	0.75	1.0+/-0.20	1.50

It should be noted that as well as the above texture requirements for the running surface of a new concrete pavement, there may be other surface requirements, such as (i) high-speed skid resistance and (ii) road/tyre noise levels. ~~***Source:*** *From UK MCHW, Vol 1, Series NG1000 Clause 1044, Table NG 10/2.*~~

The texture depth shall be determined by the 'sand patch' test method (see BS EN 13036-1: Road and airfield surface characteristics. Test methods. Part 1: Measurement of pavement surface macrotexture depth using a volumetric patch technique). Tests should be taken within 100 m of commencement of paving and thereafter at least once for each day's paving in the following manner: 10 individual measurements of the macrotexture depth shall be taken at least 2 m apart anywhere along a diagonal line across a lane width between points 50 m apart along the pavement. No measurement shall be taken within 300 mm of the longitudinal edges of a concrete slab constructed in one pass.

If the measured macrotexture depth is found to be deficient, the Contractor shall make good the texture across the full lane width over lengths necessary to comply with the requirements of Table 4.14, by retexturing the hardened concrete surface.

Failure to achieve a satisfactory minimum macrotexture depth by random grooving shall result in the removal of the full thickness of the slab to the extent required to permit reconstruction of the slab in accordance with the specification. Alternatively, diamond grooving of the hardened concrete surface can be carried out to restore macrotexture.

4.22.2 Tine and Burlap

Tining is the most commonly used texturing method for concrete pavements, ~~particularly in the USA.~~

Tine and Burlap is an effective, low-cost technique in which a wetted burlap (i.e. hessian) cloth drag is drawn longitudinally (often behind the paver) to roughen up the surface, then a tined rake (with flat, square-ended, metal teeth called 'tines', each about 100mm long) is dragged (usually transversely) across the slab to make a series of grooves. This process can be done by hand or automated. See Figure 4.26.

Narrower, deeper grooves are reported to be better at minimising noise than wider/shallower grooves. Australian research trials in 1994 to identify a Tine and Burlap concrete surface texture with good skid resistance and low noise, showed that the best results came from using a short hessian drag (0.6 m), 3 mm wide tines, tine depths of 2-3 mm and 'random' tine spacings e.g. 10, 14, 16, 11, 10, 13, 15, 16, 11, 10, 21, 13, 10 mm.

Figure 4.26 Metal Rake Tines, Burlap Drag and Finished 'Tine and Burlap' Surface

If applying a transverse tine texture manually, then it can be useful to fit a wheel on the back of the rake so that at the end of the pull towards you (creating the texture), the broom/rake can be turned over and pushed back to the far side on a narrow wooden bridge, where someone can turn the broom over and place it in the concrete for the start of the next pull.

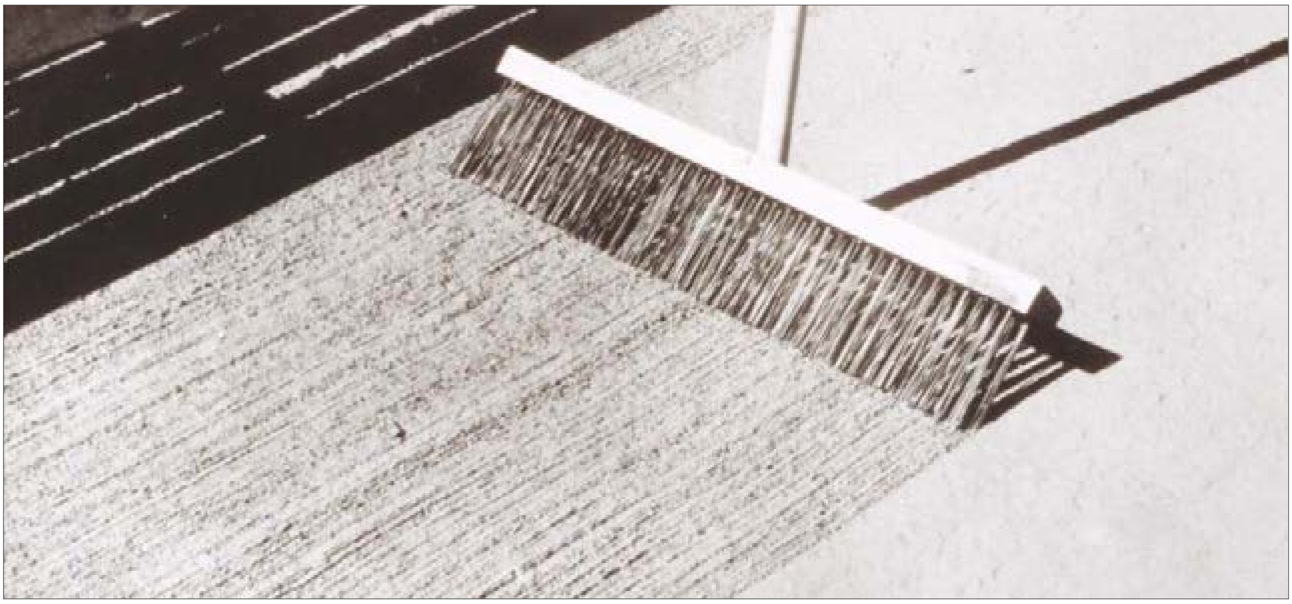
4.22.3 Canvas Belt and Tine

As an alternative to a burlap drag, a canvas belt (150-300 mm wide and longer than the width of the lane) with handles at each end, can be used in a saw-cut motion transversely and longitudinally to roughen up the concrete surface, prior to the tine grooves being added.

4.22.4 Brushed

This uses a brush with metal, nylon or coir filaments that is at least 450 mm wide. The macrotexture is applied evenly across the slab in one direction by a brush at right angles to the longitudinal axis of the carriageway. The macrotexture should be uniform both along and across the slab. See Figure 4.27.

Figure 4.27 Brushed Texture



It should be noted that a brushed texture is usually not as deep as the texture from a tine rake and so a brushed texture is more likely to be worn away in the wheelpaths by traffic. In order to maintain good skid resistance, a high-speed road with a worn surface texture will require retexturing by diamond grooving, ~~which is a very expensive process.~~

A simple wire brush can consist of 32-gauge tape wires grouped together in tufts and initially 100 mm long. The brush should have two rows of tufts, 20 mm apart with the tufts in one row opposite the centre of the gap between tufts in the other row. The brush should be replaced when the shortest tuft wears down to 90 mm long.

If the macrotexture depth is over 1.25 mm, then it is likely to produce unacceptable tyre noise. This should be closely monitored, particularly in the pre-construction trial(s). If the macrotexture depth is outside the required limits then adjustments can be made to the pressure on the brush, the consistence of the concrete, the time when brushing is carried out, and/or the type of brush used.

4.22.5 Exposed Aggregate Concrete Surface (EACS)

This is a less-used surface texture type that can be difficult to achieve due to its time sensitivity. It should only be used with approval from the Overseeing Organisation after ~~the Contractor~~ has successfully demonstrated with trials, the capability to produce this type of surfacing. The technique is expensive and requires co-ordinated material production/ transport and high skill levels in knowing when to expose the aggregate.

To achieve this surface texture, the concrete is normally laid in two-layers, 'wet-on wet' (i.e. the second layer is laid within a few hours of the first, so that both layers are still wet and bond together, acting as one layer). The upper concrete layer is thinner (minimum 40 mm) and contains mostly high-quality aggregate with good skid resistance, durability ~~(AAV)~~ and low polishing properties ~~(PSV)~~, so that when the aggregate is exposed (by brushing) it provides high levels of skidding resistance.

During construction, a retarder is sprayed onto the wet concrete surface immediately after it has been levelled and finished. The retarder delays the hardening of the surfacing, which must be protected from rain, contamination, etc, using plastic sheeting/hessian mats. When the concrete is semi-hardened (after approximately 16 hours at 20°C), the cement mortar is brushed off the surfacing, exposing the top surface of the aggregate within the concrete, see Figure 4.28.

Timing of the brushing is crucial in order to get a good surface texture and must be determined from the construction trial. After exposing the aggregate, the surface will need an additional application of curing compound or wet hessian to finish curing the concrete.

For low-speed roads, two-layer construction may not be required, and the normal concrete aggregate is 'exposed' but this is likely to have low skidding resistance, depending upon the properties of the concrete aggregate.

Figure 4.28 Exposed Aggregate Surface and Core Showing Two Layer Construction

Source: *Photos from TRL LR291*

For high-speed roads, a higher specification aggregate with good skidding resistance and durability, plus low polishing properties will need to be used. If a two-layer construction system is not used, then a high quality aggregate will need to be used throughout the full depth of the concrete, at increased cost.

4.22.6 Diamond Grooving

Diamond grooving (sometimes called Diamond grinding) is ~~an expensive~~ process for adding transverse or longitudinal texture to a new or old concrete surface. It has been shown to be effective, but due to the high cost is usually reserved for retexturing a worn concrete surface.

Spacing, depth, width, and orientation of the grooves will have a significant influence on the friction and noise characteristics of the finished surface. It is important to randomise the groove spacing to minimise single frequency 'humming' noise created by the texture.

The Specification for Transverse Grooving is as Follows:

Grooves shall be irregularly spaced and shall be not less than 2 mm and not more than 5 mm wide. The sequence of distances between groove centres in mm shall be:

40, 45, 35, 45, 35, 50, 30, 55, 35, 30, 50, 30, 45, 50, 30, 55, 50, 40, 35, 45, 50, 40, 55, 30, 40, 55, 35, 55.

A tolerance of ± 3 mm shall be allowed on each of the spacings. The minimum width of grooving head shall be 500 mm and a head not providing a complete sequence of spacings shall use the number of spacings appropriate to its width commencing at the start of the sequence.

Groove depths shall be measured using a tyre tread depth gauge and measurements shall be taken as follows:

i. At 10 locations at least 2 m apart along a diagonal line across a lane width between points 50 m apart longitudinally. No measurement shall be taken within 300 mm of the longitudinal edge of a slab.
ii. At each of the 10 locations the depth of 10 adjacent grooves shall be measured.
iii. Where a grooved area is less than 50 m long the measurement locations shall be as (i) but the number shall be proportional to the requirements for 50 m.
iv. The average of each set of 10 measurements shall be not less than 3 mm, nor greater than 7 mm.

Slurry from the sawing process shall be prevented from flowing into joints, drains or into lanes being used by traffic, and all resultant debris from the grooving shall be removed.

The Specification for Longitudinal Grooving Shows Slightly Different Requirements:

The width of the cutting head shall be at least 1200 mm.

The maximum depth of the grooves shall be 5 mm.

The width of the grooves shall be between 2 mm and 4 mm.

The spacing between grooves (land area) shall be between 1.75 mm and 3.25 mm.

4.22.7 Transverse or Longitudinal Surface Texture

Texturing of new pavements should usually be carried out transversely to aid drainage of water off the carriageway. Diamond grooving (retexturing) can be either transverse or longitudinal.

Longitudinal texturing ~~(popular in the USA)~~ has some advantages including ease of construction, some noise reduction (although some studies report greater objection to the noise from longitudinally grooved concrete surfaces) and slightly reduced rolling resistance. However, disadvantages include: it doesn't aid water drainage off the carriageway and could lead to aquaplaning in high rainfall situations and it can channel water into the pavement through transverse joints with imperfect seals (if joints are present) and cause deterioration.

If skew transverse contraction joints are used (for very low trafficked roads), then the transverse texturing should be parallel to the skew joints in order to minimise the amount of water being channelled into the joints. Figure 4.29 shows the texture not parallel to the transverse joint. This can 'funnel' rainwater into a poorly sealed joint.

Figure 4.29 Skew Joint with Poor Texturing (i.e. Not Parallel to Joint).

4.23 Design - Asphalt Surfacing on Concrete Pavements

A concrete pavement will usually be built with a concrete surface, unless it is known that noise will be an issue from the start, in which case it can be built with an asphalt surface or a design option chosen that includes an asphalt surface e.g. CRCB rather than CRCP. If, after many years of service, the concrete surface texture has worn away such that a skidding hazard exists, then a new asphalt surfacing can be added (as a cheaper treatment option to grooving), to restore skid resistance, etc.

Particular care should be taken when applying a bituminous surfacing to an existing concrete road as not all emulsions adhere well to concrete. It is likely that one specially formulated for this application or a tack or bond coat will be needed. (Note that a bond coat generally has; (i) a higher binder content (with modifiers) and (ii) is usually used at a higher rate of spread, than a tack coat). A bond coat is used to improve adhesion (bond strength) and/or waterproofing e.g. where an asphalt material is to be laid that is less than 30 mm thick.

A cationic bituminous tack coat should be applied ~~at a rate between 0.35 to 0.55 l/m²~~ immediately prior to laying the bituminous surfacing or upper base.

4.23.1 Asphalt on Jointed Concrete

Jointed concrete pavements (JUCP or JRCP) are usually constructed with a concrete surfacing. Any asphalt surfacing is usually added later as a remedial treatment for low skid resistance, etc.

An asphalt surfacing without SCS (see below) on a jointed concrete pavement will generally have a short life. This is because daily thermal lateral movements and vertical movements at the joints caused by traffic, will often cause the asphalt above the joints to crack and spall within a few years. It will then require frequent ongoing maintenance for safety and road user comfort. Once the asphalt has cracked above joints, it can be tempting to treat these with another asphalt overlay. This cycle can repeat itself until there are multiple asphalt overlays, all cracked above the joints, which is an expensive waste of time and materials.

Use of the saw-cut and seal (SCS) technique on jointed concrete pavements has been shown to be effective in preventing reflection cracking above transverse joints, ~~although it can be expensive and time consuming.~~ With SCS, a thin asphalt surfacing (30 - 70 mm thick) is laid and then a joint groove is cut into the asphalt (to partial depth) directly above all transverse joints, which are pre-marked before overlay. The asphalt joint grooves are then filled with a flexible joint sealant material, allowing each concrete joint to open and close without damaging the asphalt. This technique requires great accuracy in marking and sawing above the (hidden) joints and, when the surface is eventually replaced, the whole process (and cost) will have to be repeated.

Use of a surface dressing (chip seal) is not recommended on a jointed concrete pavement, as dislodged aggregate (which will increase over time) can enter the joints and cause the joint to lock up, which could lead to significant pavement issues.

4.23.2 Asphalt on CRCB/CRCP

A CRCB is constructed with at least 100 mm asphalt surfacing. A CRCP is usually constructed with a concrete surfacing, but in locations where noise will be an issue, it can be constructed with a thin asphalt surfacing (usually less than 50 mm).

For more information about asphalt surfacings on CRCB/CRCP see Section 5.7.3.

4.24 Opening to Site Traffic and Main Traffic

Concrete slabs can generally be trafficked when the compressive cube strength reaches 25 N/mm^2 for pavement surface slabs (or 20 N/mm^2 for CRCB bases with >90 mm thick asphalt surfacing).

The strength development of concrete can be affected by many factors including: mix design, compaction and curing (i.e. temperature, humidity and moisture content).

The timing of when the pavement achieves this strength can be assessed by either:

1. Pairs of cubes are made for each 400 m² (or less) of site concrete and stored alongside the pavement in containers or in such a way that their sides are well insulated. These cubes can then be (compressive) strength tested at the intervals specified in the contract (Appendix 7.1) or
2. The strength development rate is predetermined from cubes (made from the same concrete mix, stored at 20°C) combined with maturity meters placed in the pavement. [Ref: UK DMRB, MCHW Series 1000, Clause 1004: Pavement Concrete Strength].

Vehicles with rubber tyres with an axle loading **less than 2 tonnes**, or wheels or tracks of concreting plant, should **NOT** run on concrete slabs **within 7 days** of placing the concrete.

Vehicles with an axle load **greater than 2 tonnes** should **NOT** run on concrete slabs **within 14 days** after placing the concrete.

For ordinary concrete mixes, the pavement can be opened to traffic after 28 days of curing, however this will need to be increased if the 7-day cube strength is below the required specification.

If rapid hardening cement is used, then 7 days of curing is normally enough. This is only an approximate guide as curing can be affected by factors such as temperature and rainfall.

For full-depth and partial-depth concrete repairs, the use of early Strength Concrete (such as sulfo-aluminate or other specially blended cements) can allow trafficking within four hours of placement.

5 Concrete Pavement Thickness Design (CP/BP/JUCP/JRCP/RCC/CRCB/CRCP)

5.1 Introduction

The concrete pavement thickness designs for Cobblestone Paving (CP) (0.1 to 1 M CESA) and for Block Paving (BP) (0-1 M CESA) and for JUC pavements (0-1 M CESA) are taken from The Kenyan Pavement Design Guidelines 1: Low Volume Sealed Roads (2017).

The concrete pavement thickness designs for JUCP, JRCP, RCC, CRCB and CRCP (>1 M CESA) are for 40-year design lives based on the Design Manual for Roads and Bridges (DMRB, UK) with specific reference to 'CD226: Design for new pavement construction'. ~~The assistance derived from the above sources is hereby acknowledged with thanks.~~

It should be noted that the design methods are empirical and based on temperate climate data with a larger annual temperature range (-27.2°C to +40.3°C) than Kenya's tropical/sub-tropical environment with a temperature range of +2°C to +42.6°C. ~~Thus, means that the designs may be slightly more conservative than needed for Kenyan conditions and there is scope for future Kenyanisation of the designs.~~

~~**It is recommended that after a concrete pavement design (or designs) has been calculated, that another method is used (e.g. USA's ACPA: PavementDesigner.org software) for checking/comparison purposes.**~~

~~Another~~ method for checking the design is to use the Mechanistic-Empirical design method with ALIZE, KENPAVE, Rubicon Toolbox or other similar software. The principles of this are discussed for asphalt pavement design in **Volume 3 Part 4 Sections 3.3** and **3.4** with an example in Appendix A. There is also information in **Volume 5 Part 2**, **Section 9.6** for concrete overlay design, although the principles for new pavement design would be similar. It should be noted that for rigid pavements, the deciding criterion is generally not the compressive strain in the subgrade, but the horizontal tensile strain in the upper layers. The Elastic modulus of PQ concrete can be taken as 15000 MPa with a Poissons ratio of 0.2.

Foundation layer materials and thickness information for concrete pavements is given in Section 4.5.

Methods for calculating the concrete base (i.e. slab) thickness for each different pavement type are given below in Sections 5.3 to 5.7. The thickness design methods are based on:

- Predicted traffic volumes (M CESA) over the design period (usually 40 years).
- The ~~Kenyan~~ foundation class: F4 (bound) or F5 (bound).
- Concrete strength – either the mean cube compressive strength of the concrete at 28 days (JUC and JRC designs use 50 MPa) or mean flexural strength of the concrete at 28 days (CRCB and CRCP designs use 4.5/5.0/5.5/6.0 MPa).

For multiple lane construction, it is recommended that the same slab thickness should be used for all lanes, for ease of construction and not to block drainage routes within the pavement.

In most thickness designs the concrete slab thickness can be reduced (by approximately 30 mm) if the pavement includes an integral/tied shoulder to the most heavily trafficked lane. The designer should note that the concrete thickness design equations in this manual for JUCP/JRCP **DO NOT** include a hard shoulder/edge strip (an additional equation is used to calculate this), whereas the concrete thickness design charts for RCC/CRCP/CRCB DO include a hard shoulder /edge strip.

Concrete material specification charts are included in RDM Volume 3 Part 3.

5.2 Thickness Design - Cobblestone Paving

The stones should conform to: properties given in **RDM Volume 3 Part 3**. They should also conform to '*KS 965: Method of test for natural building stones*'. Also see '*KS2249 Abrasion resistance of stones subjected to foot traffic - test method.*'

For further information, see '*BS 7533-7 and BS7533-101: Pavements constructed with clay, natural stone or concrete pavers, Pt 7: Code of practice for pavement construction*' and Pt10. '*Code of practice for the structural design of pavements*'. ~~However, it should be noted that in the UK, 'cobbles' are naturally rounded stones that are usually set in concrete and 'cropped sided stone setts' are cuboidal/rectangular shaped stones set in sand or mortar.~~

Cobblestone paving has been described in Section 2.4.1. This paving type is suitable for low volume traffic up to 1 M CESA but may be economically unjustifiable below 0.25 M CESA.

This type of paving often has low skid resistance and poor ride quality, so should be used in low-speed locations e.g. mixed vehicle/pedestrian urban areas. It can be noisy, which is bad for people living near the road, but can be good as pedestrians can hear vehicles approaching.

5.2.1 Design

For design purposes, the surfacing (i.e. stones and bedding sand) does not generally vary in thickness. Only the Base layer thickness will vary according to the foundation/design traffic. Information about capping/sub-bases/bases, edge restraint (kerbs), surfacing (stones/sand) are given below and in **RDM Volume 3 Part 3**. The required design layer thicknesses are given in Catalogue CLV1 in Chapter 6.

Capping/Sub-base/Base

Sub-base/Capping Materials:	See **RDM Volume 3 Part 3** and Catalogue CLV1 (Chapter 6).
Base Materials:	Lateritic gravel, quartzitic gravel, 'soft stone', calcareous gravel, coral rag, and clayey/silty sand.

The base layer should be granular material with a minimum CBR of 30 %. The thickness (0-200mm) will depend on the traffic and foundation. A standard crossfall should apply. Before adding the sand layer, the base should be primed with MC 70 or MC 30 cutback bitumen to create a waterproof membrane and prevent water entering the base.

Edge Restraint (kerbs)

Firm edge support is required to prevent ravelling and provide a guide to levels/falls. The best protection is provided by precast/cast in-situ/chiselled stones set in mortar or a fixed feature (e.g. wall). Vertical paving blocks or stretcher stones can also be used but will provide less edge protection. Edge restraints should contain weep holes or gaps to allow water to drain from the sand bedding course.

Transverse restraints should also be provided at joints between pavement types (e.g. cobblestone paving to asphalt pavement), on steep slopes or in large, paved areas where restraints should be a maximum of 15 m apart.

Surfacing - Stones and Bedding/Joint Filler Sand

Stones/sand	Stones from trachyte, basalt, granite or hard sandstone rock.
Stone size:	100–150 mm with minimum UCS 25 MPa.
Sand layer:	20-50 mm thick, naturally occurring clean sand or crushed rock fines, free from clay, lumps or other deleterious material with grading as shown in Table 5.1.

It is important to get the thickness of the sand layer correct for camber and ride quality purposes – it should be approximately 40 mm thick (range 20-50 mm).

Stones should be placed in position one-by-one and then lightly tapped into place. Sand should then be worked into the gaps between stones and a vibrating plate used for compaction. Any excess sand should be brushed off.

5.3 Thickness Design - Block Paving

The materials used in a Block Paving pavement should conform to properties given in **RDM Volume 3 Part 3**. Precast Concrete Block Pavers must conform to: KS 827: '*Specification for precast concrete paving blocks*.' For further information the designer can also refer to BS EN 1338: '*Concrete paving blocks - Requirements and test methods*' and BS 7533 for design.

Block Paving can be used for Low traffic roads (<1 M CESA) with a design life of 15 years or for Medium traffic roads (1-10 M CESA) with a design life of 15-20 years (See **RDM Volume 3 Part 4**, Table 2.1).

Concrete block paving (BP) consists of small, interlocking, individual high strength, Precast Concrete Blocks (PCB), usually size 100 x 200 mm x 60-80 mm thick, laid on a bedding layer of sand (or crushed rock fines) and contained within edge restraints. It is included in this Rigid Pavements section of the Road Design Manual as the blocks are made of concrete. Information about Block Paving was given in Section 2.4.2.

In order to ensure durability, interlocking blocks in heavily stressed locations must be made to a consistently high quality and dimensional accuracy, which usually involves mass production under factory conditions. Precast concrete blocks are graded as Heavy, Medium and Light duty. For use on main roads, only heavy-duty blocks are recommended. They come in a variety of shapes but should generally be laid in the Herringbone pattern – see Figure 5.1.

Figure 5.1 Different Shapes of Block Paving laid in the Herringbone Pattern

Heavy duty concrete blocks (60-80 mm thick with a compressive strength of >49 N/mm^2) are generally considered suitable as a road surfacing for main roads.

This type of pavement is suitable for low volume roads with Design Traffic levels of 0.1 to 1 M CESA. Sites with less than 0.1 M CESA are often considered to be economically unjustified. It should be noted that lesser grade blocks are available for footpaths and parking areas. The use of standard household bricks is not recommended as these are not made to the same size and strength tolerances.

Firm edge support is required to prevent ravelling at the surface edges. The best protection is provided by precast or cast in-situ kerbs, flush edge strips or a fixed feature (e.g. a wall). Vertical paving blocks set in mortar can also be used, but will provide less edge protection.

Joints between blocks should be filled with fine sand to stop single blocks from being displaced. Material for the sand bedding layer shall be naturally occurring clean sand or crushed rock fines, free from clay, lumps, or other deleterious material, with a grading curve that falls within the envelopes shown in **RDM Volume 3 Part 3**. To ensure that as much sand as possible penetrates the joints between blocks, a vibrating plate should be used. Ride quality will depend upon accurate screeding of the sand layer before laying the blocks. It is important to get the thickness of sand layer correct.

After a short time, the joints between the blocks will fill with fine detritus, making the surface almost impermeable. Normal surface water drainage will be required with standard longitudinal and crossfall requirements. Supplementary drainage measures may be necessary in high rainfall areas, to prevent the ingress of water and saturation of the underlying roadbed.

Detailed specifications of the paving blocks, laying course and joint filler material are provided in **RDM Volume 3 Part 3**.

For Low Volume Sealed Roads (LVSR), a single layer Sub-base/Foundation shall be constructed as roadbed to the paving block surfacing. This Sub-base/Foundation should be a G30 material in accordance (see **RDM Volume 3 Part 3**) i.e. CBR of at least 30 % at 95 % MDD AASHTO T180 and 4 day soak. The bed shall be primed with MC-70 or 30 cutback bitumen prior to the laying of the sand bed (laying course) directly supporting the paving blocks.

For Block Paving catalogue designs, see Catalogue structures CLV2: Block paving for low traffic roads (0.1 to 1 M CESA)(this design is based on The Kenyan Pavement Design Guide 1: Low Volume Sealed Roads) and Catalogue structure CMV1: Block paving for medium traffic roads (1-10 M CESA) (this design is based on BS 7533-1).

5.4 Thickness Design - JUC Pavements

The materials used in a JUC pavement should conform to properties given in **RDM Volume 3 Part 3**.

The designs for Jointed Unreinforced concrete (JUC) pavements have been split into two parts based on traffic levels, as follows:

1. Low volume roads (0.1 to 1.0 M CESA). See Section 5.4.1 and Catalogue CLV3 in Chapter 6.
2. Low to very heavy traffic roads (1-200 M CESA). See Section 5.4.2 and Catalogue CHV1 in Chapter 6.

5.4.1 JUC Thickness Design for Low Volume Roads (0.1 - 1.0 M CESA)

The design life for low volume roads (including rigid pavements) should be 15 years (see **RDM Volume 3 Part 4**, Table 2.1).

This design method for low volume JUC pavements (0.1 to 1.0 M CESA) is taken from the Kenyan low volume sealed roads manual (MTRD, 2017).

Due to the high initial cost of this type of pavement, it should only be applied to roads where:

- The road has low design traffic levels of 0.1 to 1.0 M CESA or
- There are steep sections of road where the performance of bituminous surfacings could prove challenging (e.g. road sections with a gradient of ≥ 10 %), or
- At locations where significant numbers of heavy vehicles turn or park (e.g. road junctions, market towns or parking areas).

Initial costs will probably be higher than a thin asphalt pavement, but these should be offset by the longer life of the concrete pavement, if constructed well.

Foundation

The concrete should be laid on at least 100 mm of G30 material compacted to 98 % MDD Mod AASHTO. On subgrades of G30, the material should be scarified and re-compacted to ensure the depth of the in-situ material is in agreement with the recommendations.

Concrete Thickness and Type

For low volume roads, a 75 - 150 mm thick concrete layer covers all the requirements of traffic on all foundation classes.

For slabs 75-100 mm thick, it is recommended that they are constructed as continuously reinforced concrete pavements with wire reinforcement.

For slabs 100-150 mm thick, it is recommended that they are constructed as jointed unreinforced concrete pavements, with a recommended joint spacing of 4 to 5 m. Steel dowels (minimum diameter 16 mm) should be used at each joint. If there are very few HGVs, then dowels can be omitted from the joints to save costs, but the risk of damage to the joints (and especially the sub-base under the joints) will be higher. The joints between slabs should be filled with bitumen slurry.

For roads ≥ 4.5 m wide, the slab width should be half the road width. For roads ≤ 4.5 m wide, the slab width may be equal to the carriageway width.

Concrete Strength and Materials

The concrete should be class C25, i.e. the concrete cube (150 mm) compressive strength should be > 25 MPa at 28 days.

A mix design (using the same materials that will be used on site) should be produced that will achieve the required strength. Gradings and detailed specifications of constituent materials and the resultant concrete pavement are provided in **RDM Volume 3 Part 3**.

Construction

During construction, good formwork should be used at the edges to ensure good vibratory compaction. To improve skid resistance of the surface, transverse grooves should be made on the slab surface using a wire brush or broom after the initial partial set of the concrete.

The key requirements for a well-built pavement are: (i) well-constructed sub-base (camber, thickness, compaction, strength), (ii) well-cured concrete to minimise cracking, and (iii) not trafficked too early.

5.4.2 JUC Thickness Design - Medium to Very Heavy Traffic (1-200M CESA)

The design life for medium to very heavy traffic concrete pavements should be 40 years (see **RDM Volume 3 Part 4**, Table 2.1). When comparing designs of different pavement types, it is important to use the same (longest) design life.

JUC pavements are suitable for normal applications except where differential movement, subsidence or appreciable settlement is expected. It should be noted that at higher traffic levels (say > 50 M CESA), there are likely to be significant maintenance issues requiring frequent repairs (and related road user delays) especially later in the pavement life. This is just a feature of this type of pavement, where transverse joints often cause issues. For very high traffic levels (say > 150 M CESA) then CRCB/CRCP should be the preferred choice.

The concrete slab design thickness of a JUC pavement without a shoulder/edge strip is given in Equation 5.1 below. It should be noted that the concrete strength in the equation is the 'mean compressive cube strength at 28 days'. Hence if you have concrete with a specified characteristic compressive strength, then you may need to convert to a mean strength (see Section 4.8.2) using one of the methods shown e.g. **Method 1**: $f_{cm} = f_{ck} + (1.48 \times \sigma)$ where σ = standard deviation of the concrete mix.

1
2
3
4
5
Concrete Pavement Thickness Design (CP/BP/JUCP/JRCP/RCC/CRCB/CRCP)

The reduction in slab thickness due to having a shoulder/edge strip is then calculated in Equation 5.2 below (or see Table 5.1).

For multi-lane roads, all traffic lanes (including any hard shoulder or layby) should be constructed to the same thickness as the heaviest loaded lane.

Design Thickness of JUC pavement (no tied lane/shoulder or 1m edge strip):

$$Ln(H_1) = \frac{Ln(T) - 3.466Ln(R_c) - 0.484Ln(E) + 40.483}{5.094}$$

Equation 5.1

Effect on design thickness of JUC pavement with a tied lane/shoulder/edge strip):

$$H_2 = 0.934H_1 - 12.5$$

Equation 5.2

Where (for both Equations 5-1 and 5-2),

H_1 = thickness (mm) of the concrete slab without a tied lane or 1m edge strip.

H_2 = thickness (mm) of the concrete slab with a tied lane or 1m edge strip.

Ln = natural logarithm.

T = Design traffic (M CESA).

Rc = mean compressive cube strength (N/mm^2 or MPa) at 28 days.

E = foundation stiffness (MPa) related to the foundation class, where

E = 200 MPa for foundation class F4 (bound).

E = 400 MPa for foundation class F5 (bound).

Notes:

1: Minimum slab thickness (H1) is 150 mm.
2: Maximum design traffic (T) is 200 M CESA.
3: Load induced stresses at slab corners are greater than in the slab centre, necessitating dowel bars to distribute loads between slabs.
4: Thicknesses to be rounded up to nearest 5 mm.
5: For JUC pavements, where the slab thickness is <230 mm, the maximum spacing between transverse joints shall be 4 m.
6: For JUC pavements, where the slab thickness is ≥ 230 mm, the maximum spacing between transverse contraction joints shall be 5 m.
7: See Section 4.8.2 for conversion from characteristic to mean compressive strength.
8: The results of using Equation 5.2. i.e. slab thickness WITHOUT and WITH a tied shoulder/edge strip have been tabulated in Table 5.1.

5.4.3 JUC Design - Transverse Joint Spacing

For jointed unreinforced concrete, the spacing between transverse joints will depend on the concrete the type of joint, the slab thickness and the type of aggregate. Concretes made with an aggregate with a lower coefficient of thermal expansion (e.g. limestone) won't expand/contract as much.

For transverse contraction joints, the maximum joint spacing is shown in Table 5.2.

Transverse expansion joints are usually only required at fixed objects such as bridges, or a change in pavement construction from concrete to asphalt, or when the slabs have been laid at a significantly low temperature, compared to the hottest time of the year.

For information about dowel bar size and spacing, to use at transverse joints, see Table 4.11.

Table 5.1 JUC Slab Thickness 'With' and 'Without' Edge Strip/Tied Shoulder

Concrete Slab Thickness WITHOUT Tied shoulder /Edge Strip (Rounded up to nearest 5mm) (H_1)	Concrete Slab Thickness WITH Tied Shoulder /Edge Strip (Rounded up to nearest 5mm) (H_2)
150	Minimum 150
155	Minimum 150
160	Minimum 150
165	Minimum 150
170	150
175	155
180	160
185	165
190	165
195	170
200	175
205	180
210	185
215	190
220	195
225	200
230	205
235	210
240	215
245	220
250	225
255	230
260	235
265	235
270	240
275	245
280	250
285	255
290	260
295	265
300	270
305	275
310	280
315	285
320	290
325	295
330	300

Table 5.2 JUC – Maximum Transverse Contraction Joint Spacing

Concrete Slab Thickness (mm)	Maximum Transverse Contraction Joint Spacing	
	Aggregate with coefficient of thermal expansion GREATER than 10×10^{-6} per °C (not limestone)	Aggregate with coefficient of thermal expansion LESS than 10×10^{-6} per °C (e.g. limestone)
<229	4m	4.8m
≥230	5m	6m

Concrete Pavement Thickness Design (CP/BP/JUCP/JRCP/RCC/CRCB/CRCP)

5.4.4 JUC Design Example - Calculation of JUC Slab Thickness

Question 1a. Using the following design factors, calculate the design thickness of a JUC pavement with no shoulders/edge strip:

Design factors:

1. Design traffic of 130 M CESA (i.e. T = 130).
2. Concrete has a mean compressive cube strength of 50 MPa at 28 days (R_c = 50).
3. Foundation class F4 (bound) (i.e. E = 200 MPa).
4. Aggregate has a coefficient of thermal expansion greater than 10 x 10^{-6} per °C.

Question 1b. What is the maximum transverse contraction joint spacing for the JUC pavement in (1a) using an aggregate with coefficient of thermal expansion greater than 10 x 10^{-6} per °C.

Question 1c. Calculate the thickness of the same pavement if it had a tied shoulder.

a. Using Equation 5.1.

$$Ln(H_1) = \frac{Ln(T) - 3.466Ln(R_c) - 0.484Ln(E) + 40.483}{5.094}$$

$$Ln(H_1) = \frac{Ln(130) - 3.466Ln(50) - 0.484Ln(200) + 40.483}{5.094} = \frac{29.22707}{5.094} = 5.737548$$

H_1 = 310mm

Answer 1a. The Design thickness of a JUC slab (with no shoulder/edge strip) = 310 mm.

From Table 5.2, with a slab 310 mm thick and an aggregate with a coefficient of thermal expansion greater than 10 x 10-6 per °C, the maximum transverse joint spacing is 6 m.

Answer 1b. The maximum transverse joint spacing for the JUC pavement in (1a) using an aggregate with coeff. of thermal expansion > 10 x 10^{-6} per °C = 6 m.

Answer 1c. Using Equation 5.2

$$H_2 = 0.934H_1 - 12.5$$

H_2 = (0.934 x 310) − 12.5 = 277 mm (rounded up to 280 mm).

The Design thickness of the JUC slab (with shoulder/edge strip) = 280 mm.

5.5 Thickness Design - JRC Pavement

The materials used in a JRC pavement should conform to properties given in **RDM Volume 3 Part 3**.

5.5.1 JRC Design - Slab Thickness

The Design life of a JRC pavement should be 40 years. The concrete thickness design for JRC is given in Equation 5.3 and Equation 5.4 below.

Design Thickness of JRC pavements (no tied lane or 1m edge strip):

$$Ln(H_1) = \frac{Ln(T) - R - 3.171Ln(R_c) - 0.326Ln(E) + 45.150}{4.786}$$

Equation 5.3

Effect on design thickness of JRC pavement with a tied lane or 1m edge strip:

$$H_2 = 0.934H_1 - 12.5$$

Equation 5.4

Where,

H_1 = thickness (mm) of the concrete slab without a tied lane or 1 m edge strip.

H_2 = thickness (mm) of the concrete slab with a tied lane or 1 m edge strip.

Ln = natural logarithm.

T = Design traffic (M CESA).

R = 1.418Ln(Rx). Where Rx = cross section area of longitudinal steel reinforcement per metre width of slab (mm^2/m):

R = 8.812 for R x = 500 mm^2/m reinforcement

R = 9.071 for R x = 600 mm^2/m reinforcement

R = 9.289 for R x = 700 mm^2/m reinforcement

R = 9.479 for R x = 800 mm^2/m reinforcement

R_c = mean compressive cube strength at 28 days (N/mm^2 or MPa)

E = foundation stiffness (MPa) related to the foundation class:

E = 200 MPa for foundation class F4 (bound)

E = 400 MPa for foundation class F5 (bound)

Notes:

1: *Minimum slab thickness (H_1) is 150 mm.*

2: *Maximum design traffic (T) is 300 M CESA.*

3: *Load induced stresses at slab corners are greater than in the slab centre, necessitating dowel bars to distribute loads between slabs.*

4: *Thicknesses to be rounded up to nearest 5 mm.*

5: *For JRC pavements, the minimum level of longitudinal reinforcement shall be 500 mm^2/m.*

6: *For JRC pavements, where the aggregate has a coefficient of thermal expansion ≥ 10x10-6 per °C, the maximum spacing between transverse joints shall be determined using Table 5.3.*

5.5.2 JRC Transverse Joint Spacing

The transverse joint spacing for a JRC pavement will depend upon the slab thickness, the level of longitudinal reinforcement and the coefficient of thermal expansion of the aggregate, as shown in Table 5.3.

Table 5.3 JUC JRC - Maximum Transverse Joint Spacing

Concrete Slab Thickness (mm)	**Maximum Transverse Contraction Joint Spacing** (m)			
	Aggregate with coefficient of thermal expansion **<** 10 x 10^{-6} per °C		Aggregate with coefficient of thermal expansion **≥** 10 x 10^{-6} per °C	
	Level of reinforcement **< 600m²/m**	Level of reinforcement **≥ 600m²/m**	Level of reinforcement **< 600m²/m**	Level of reinforcement **≥ 600m²/m**
<290	30	30	25	25
≥ 290 to <300	28	30	24	25
≥ 300 to <310	27	30	23	25
≥ 310 to <320	26	30	22	25
≥ 320 to <330	25	30	21	25
≥330	24	30	20	25

Notes:

1: *In JRC, the spacing of transverse joints is a function of slab thickness, aggregate type, and the quantity of reinforcement. Joint spacing reflects the capacity of the slab to distribute strain rather than allow damaging strain concentrations.*

2: *Every third joint should be an expansion joint, the others are contraction joints.*

3: *Joints should be square.*

4: *Reinforcement must be discontinuous (i.e. omitted) at both types of joint.*

5: *Dowels are required in all transverse joints, to provide effective load transfer.*

6: *Further information on the design of rigid pavements is given in Mayhew and Harding (1987).*

For information about dowel bar size and spacing, to use at transverse joints, see Section 4.13.

5.5.3 JRC Reinforcement

5.5.3.1 Reinforcement Depth

In a JRC pavement the longitudinal reinforcement should be between 1/3 slab depth and mid-slab depth. The transverse steel reinforcement is usually located below the longitudinal steel reinforcement.

Care must be taken to ensure that the minimum concrete cover to the steel reinforcement is met. This is 50 mm for slab thickness < 200 mm, 60 mm for slab thickness 200-270 mm, and 70 mm for slab thickness > 270 mm.

5.5.3.2 Transverse Reinforcement - Size and Spacing

For JRC, the type and amount of transverse steel reinforcement should be 12 mm diameter deformed steel bars ($T12$) at 600 mm spacing.

Any transverse bars shall be at right angles to the longitudinal axis of the carriageway.

5.5.3.3 Longitudinal Reinforcement – Size and Spacing

For JRC, the amount of longitudinal steel reinforcement can be chosen from 500-800 mm^2/m width. This value is used in Equation 5.3 to calculate the slab thickness. The options are:

Rx = the cross-sectional area of longitudinal steel reinforcement per metre slab width:

Rx = 500 mm^2/m width reinforcement
Rx = 600 mm^2/m width reinforcement
Rx = 700 mm^2/m width reinforcement
Rx = 800 mm^2/m width reinforcement

The calculated spacings for the longitudinal reinforcement (centre to centre) in JRC are shown in Table 5.4. These have been calculated for 12 mm and 16 mm diameter bars and levels of reinforcement from 500-800 mm^2/m width.

Table 5.4 JRC - Spacing between Longitudinal Steel Reinforcement

Longitudinal Deformed Steel Bar Diameter (mm)	Rx **= Amount of longitudinal steel reinforcement per metre width** (mm^2/m)	**Spacing of Longitudinal bars* (centre to centre)** (mm)
12	500	226
	600	188
	700	161
	800	141
16	500	402
	600	335
	700	287
	800	251

Notes: **Rounded down to nearest mm*
Calculation example:
Cross sectional area of each 12 mm diameter bar = πr^2 *= 113.1* mm^2
For 500 mm^2*/m width = 500/113.1 = 4.42 bars per 1 m width.*
Spacing = 1 m/4.42 = 0.2262 m = 226 mm

5.5.4 Example of JRC Thickness Design

Question 2a: Using the following design factors, calculate the design thickness of a JRC pavement without an integral/tied shoulder.

Design factors:

1. Design traffic of 130 M CESA (i.e. T = 130).
2. Reinforcement = 500 mm²/m (i.e. R = 8.812).
3. Concrete has a mean compressive strength at 28 days = 50 MPa (i.e. R_c = 50).
4. Foundation class F5 (bound) i.e. E = 200 MPa.
5. Aggregate has a coefficient of thermal expansion > 10 x 10^{-6} per °C.

Answer 2b. Calculate the maximum transverse joint spacing for the above pavement.

Answer 2c. Calculate the thickness of the same pavement but with a tied shoulder and

Answer 2d. Calculate the maximum transverse joint spacing.

Question 2: Using Equation 5.3:

$$Ln(H_1) = \frac{Ln(T) - R - 3.171Ln(R_c) - 0.326Ln(E) + 45.150}{4.786}$$

$$Ln(H_1) = \frac{Ln(130) - 8.812 - 3.171Ln(50) - 0.326Ln(200) + 45.15}{4.786} = 286.2 \text{ mm}$$

Round 286.2 up to nearest 5 mm = 290 mm.

Answer 2a. JRC slab design thickness is 290 mm (without integral/tied shoulder).

Using Table 5.3 (with 290 mm thick, aggregate with coeff. of expansion ≥10 x 10^{-6} per °C and Reinforcement <600 mm²/m), the maximum transverse joint spacing is 24 m.

Answer 2b. For the above pavement, the maximum transverse joint spacing is 24m.

Using

$$H_2 = 0.934H_1 - 12.5$$

Equation 5.4

Round the result up to the nearest 5 mm = 260 mm.

Answer 2c. Design thickness of JRC slab is 260 mm (with integral/tied shoulder).

Table 5.3 (260 mm thick, aggregate with coeff. of expansion >10 x 10^{-6} per °C and Reinforcement <600 mm²/m), the maximum transverse joint spacing is 25 m.

Answer 2d. For the above pavement, the max. transverse joint spacing is 25 m.

5.6 Thickness Design – Roller Compacted Concrete (RCC)

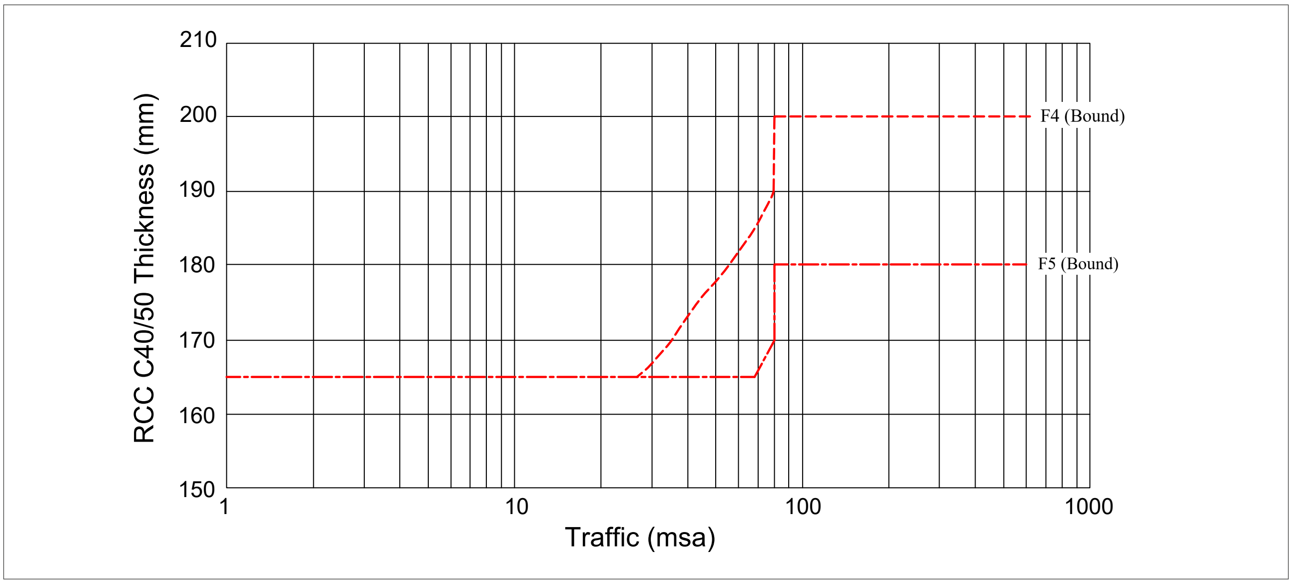
The materials used in an RCC pavement should conform to properties given in **RDM Volume 3 Part 3**. ~~Currently there does not appear to be a specific Kenyan Standard for RCC.~~

The cement type, aggregate type/grading and water content used in RCC is different to that used in other types of concrete pavement in order to produce a drier, stiffer, zero slump concrete. The cement and aggregate details are discussed in **RDM Volume 3 Part 3**.

~~For roads,~~ RCC usually has an asphalt surface to make up for poor skid resistance and ride quality. ~~In the USA,~~ the RCC surface can be treated by a process called 'grooving and grinding' which can deliver the required ride quality and texture/drainage characteristics required for a high-speed road.

The design thickness of the concrete layer in an RCC pavement is given in Figure 5.2 below. It can be seen that the design thickness for the concrete layer ranges from 165 to 200 mm.

Figure 5.2 Design Thickness for the Concrete Layer in an RCC Pavement



Notes:

1: *Thicknesses of materials to be rounded up to the nearest 5 mm.*

2: *The foundations currently allowed are either ~~Kenyan~~ Foundation Class F4 (bound) or Class F5 (bound).*

3: *C40/50 concrete used in RCC is assumed to have the following characteristics: flexural strength = 5.0 MPa, modulus E = 50,000 MPa and Poisson's Ratio = 0.20. Minimum cement content 270 kg/m³.*

4: *Because aggregate interlock is such an important feature of RCC, crushed gravel and recycled aggregates are not permitted.*

5: *To create suitable ride quality for a high-speed road, a minimum total asphalt thickness (i.e. binder course and surface course) of 90 mm is recommended, although 50mm Hot Mix Asphalt (HMA) ~~has been used successfully in the USA.~~*

6: *The minimum RCC thickness of 165 mm was based on achievable laying tolerance.*

7: *The RCC shall only be laid in one layer, multi-lift RCC is not permitted.*

8: *The initial rolling should be carried out by vibratory rollers followed by a PTR (Pneumatic Tyred Roller) if required and, if necessary, finished with a static roller for an even finish.*

9: *Curing compound (CC) shall be applied asap after laying and prior to surface drying. Note that more CC is required for RCC than for conventional concrete. If immediately overlaying with asphalt, then the prime coat of bitumen emulsion can be used as the curing membrane for the RCC layer.*

10: *Transverse and longitudinal day joints should be formed by sawing vertically to full depth. The exposed uncompacted edges of the longitudinal and transverse day joints shall be cut back to a minimum 1.5 times the layer thickness. Dowels and/or Tie bars are not required at day joints - load transfer relies on aggregate interlock.*

11: *The design thickness assumes a 1 metre hard strip at the nearside (NS) edge of lane 1. A longitudinal induced crack is not required between the NS lane and the hard strip.*

12: *The design curves are based on an analytical pavement design method, using multi-layer linear elastic analysis software and constitute long-life pavement designs where phased surfacing replacement prolongs the life of the pavement.*

13: *~~For more information about RCC, see Abouabid et al (2017).~~*

14: *RCC design (fatigue) life can be determined using multi-layer, linear elastic modelling and Equation 5.5.*

RCC Design (Fatigue) Life Equation

$$T = \frac{e^{\frac{Stress\ Ratio - 0.9157}{-0.039}}}{10^6}$$

Equation 5.5

Where,

T = the design traffic (M CESA)

e = the base of the natural logarithm

$Stress\ Ratio$ = the tensile stress at the bottom of the RCC due to a standard wheel load divided by the flexural strength of the RCC.

Induced Cracking in RCC

It has been found that rolling alone does not introduce enough cracks into RCC, so additional crack control joints should be installed by wet-formed induced cracking. Transverse joints (groove induced cracks) should be formed at 2.5 m centres +/-0.3m. This spacing is a balance between maintaining structural integrity and having cracks close enough to control reflective cracking. These joints (cracks) shall be induced in the freshly laid concrete after initial paver compaction but before rolling by grooving the fresh material to form straight vertical grooves not more than 20 mm wide, to a depth of between one quarter and one third of the layer thickness over the full width of the pavement.

Saw cutting of the hardened RCC as an alternative to induced TRANSVERSE cracking is NOT permitted.

Bitumen emulsion shall be poured or sprayed into the grooves prior to final compaction, to form a crack inducing membrane. During final compaction of the mixture, by rolling, the surface of the groove shall be fully closed throughout its full length. The bitumen in the groove shall be fully encased and remain continuous. The depth of bitumen emulsion membrane in the compacted layer shall be sufficient to reduce the effective cross-sectional area of the layer by between one quarter and one third. The effectiveness of the procedure shall be checked as part of the trial.

All longitudinal joints in all layers shall be situated outside wheel track zones.

Longitudinal cracks shall also be induced, using the procedure specified above, under each lane line and the edge line between the nearside lane and a hard shoulder. **Saw cutting of the hardened RCC as an alternative to induced LONGITUDINAL cracking is NOT permitted.**

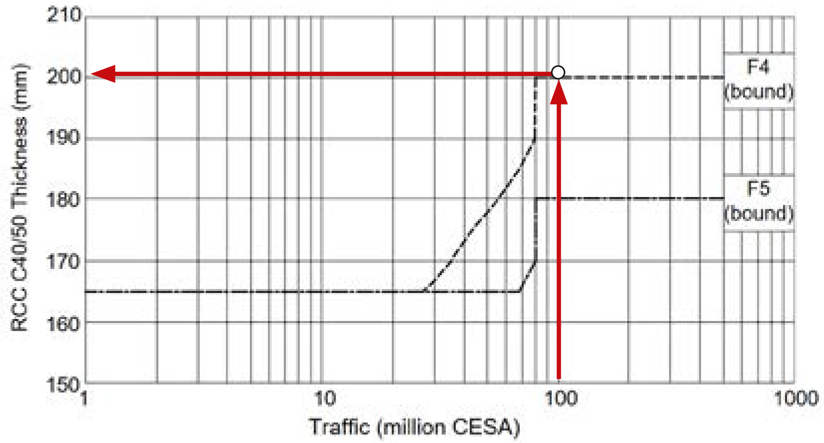
It should be noted that a longitudinal induced crack is not required between the nearside lane and a 1 metre hard strip.

5.6.1 RCC Design Example - Calculating RCC Thickness

Question 3. Calculate the concrete thickness for an RCC pavement with the following design factors:

Design factors:

1. Design traffic of 100M CESA (i.e. T =100).
2. Concrete with flexural strength = 5.0 MPa
3. Foundation Class F4 (bound).



Answer 3. **From** Figure 5.2, **the concrete thickness of RCC concrete with Design factors listed = 200 mm**.

5.6.2 RCC Design Example - Calculating RCC Design Life

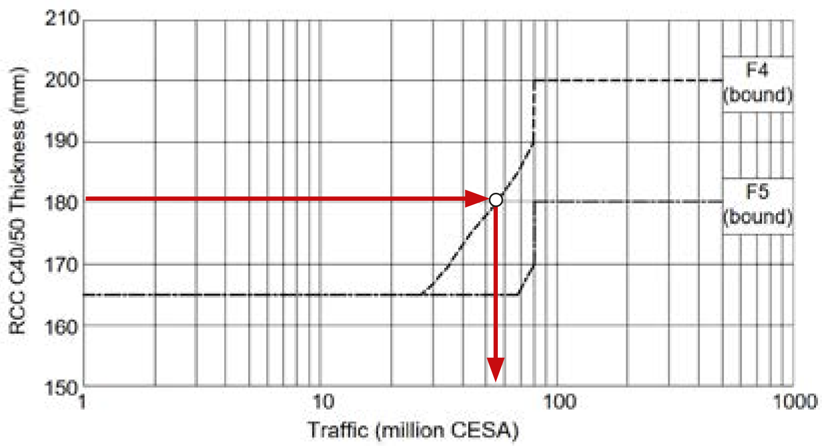
Question 4. Calculate the design life (M CESA) for an RCC pavement with the information shown in Table 5.5.

Answer 4. From Figure 5.2, **180 mm thick RCC on a Class F4 (bound) Foundation will have a design life of approximately 55 M CESA**.

Table 5.5 RCC Design Example - Material Properties

Layer Description	Thickness (mm)	Stiffness (MPa)	Poisson's Ratio
Thin Surface Course (TSC)	40	2000	0.35
HRA binder course	50	3100	0.35
RCC	180	50,000	0.2
Foundation (class F4 Bound)	Infinite	200	0.35

Notes: *Flexural strength of RCC concrete = 5.0 MPa (see Note 3 after Figure 5.2)*



b) Alternatively, use Equation 5.5.

$$T = \frac{e^{\frac{Stress\ Ratio - 0.9157}{-0.039}}}{10^6}$$

$$T = \textbf{the design traffic (M CESA)}\ \frac{e^{\frac{0.220 - 0.9157}{-0.039}}}{10^6} = \textbf{56 M CESA.}$$

Answer 4. (Calculation from Equation 5.5) is: **The RCC will have a design life of approximately 56 M CESA.**

5.7 Thickness Design - CRCB and CRCP

The materials used in a CRCB/CRCP pavement should conform to properties given in **RDM Volume 3 Part 3**.

All traffic lanes (including any hard shoulder or layby) should be constructed to the same thickness as the heaviest loaded lane.

The design thickness includes a (minimum) 1 m wide edge strip or tied lane/shoulder adjacent to the most heavily trafficked lane. If this is **NOT** present then the design concrete thickness should be increased by 30 mm.

5.7.1 CRCB/CRCP Thickness Design Chart

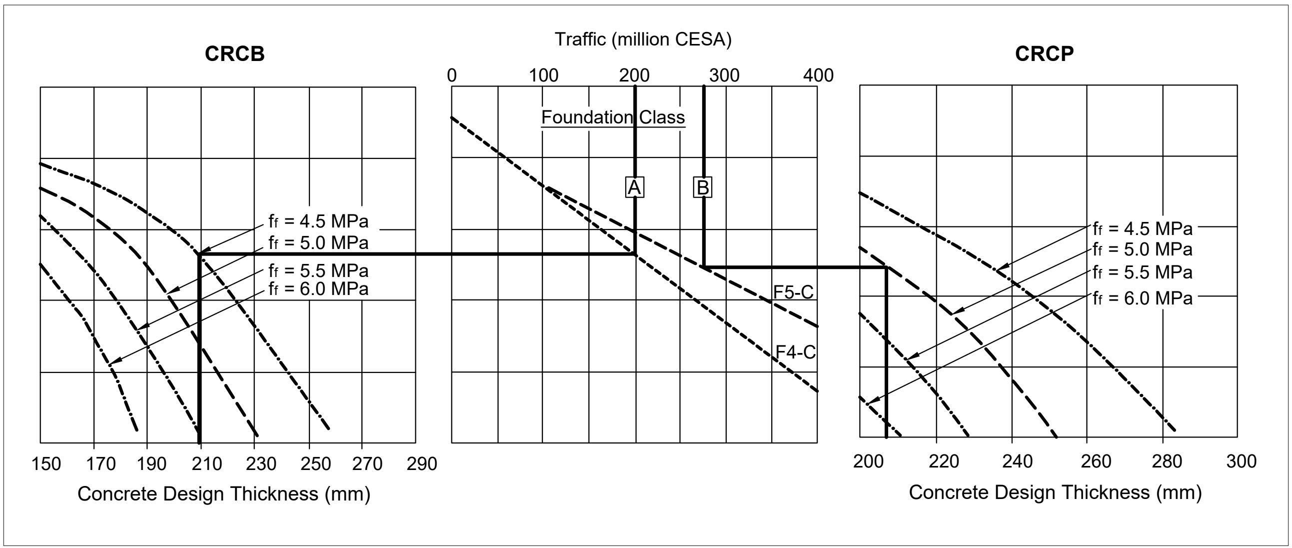
The Concrete thickness design chart for a CRCP or CRCB is shown in Figure 5.3.

To use the Chart, start at the 40-year design Traffic (M CESA) and go straight down to the Foundation class, usually F4 (bound) or F5 (bound).

For CRCP go horizontally right until you meet the mean flexural strength of the concrete at 28 days (f_f = 4.5, 5.0, 5.5, 6.0 MPa), then go straight down to see the concrete design thickness. Concrete thicknesses range from 200 to 280 mm.

For CRCB go horizontally left until you meet the mean flexural strength of the concrete at 28 days (f_f = 4.5, 5.0, 5.5, 6.0 MPa), then go straight down to see the concrete design thickness. Concrete thicknesses range from 150 to 250 mm.

Figure 5.3 Chart for Determining Concrete Thicknesses for CRCB and CRCP



Notes that accompany Figure 5.3 are given below:

1: *For CRCP, the right-hand side of the chart is used to determine concrete thickness.*

2: *For CRCB, the left-hand side of the chart is used to determine concrete thickness.*

3: *Thicknesses shown are for concrete layer(s) only - they do not include asphalt layers.*

4: *Where a separate concrete surface (e.g. exposed aggregate) is used in a CRCP design, its thickness is included in the total concrete thickness.*

5: *Thicknesses of materials to be rounded UP to the nearest 5mm.*

6a: *ff denotes mean concrete flexural strength (N/mm^2 or MPa) at 28 days measured in accordance with KS ISO 1920-4 (Testing of concrete, Part 4 Strength of hardened concrete) or BS EN 12390-5 (Testing hardened concrete, Part 5: Flexural strength) Where ff = 4.5, 5.0, 5.5, 6.0 MPa*

6b: *If characteristic strengths and/or compressive strengths are to be used, then appropriate conversions will need to be carried out, see Section 4.8.*

7: *The design thickness from the Chart is based on the presence of a (minimum) 1m wide edge strip or tied lane/shoulder adjacent to the most heavily trafficked lane. If this is NOT present, then the design concrete thickness shall be increased by 30 mm.*

8: *Where a CRCP is designed with an asphalt surfacing, no binder course is required.*
A minimum asphalt surfacing thickness of 30 mm is recommended.

9: *CRCB shall be designed with a total minimum asphalt thickness of 100mm.*

10: *CRCP and CRCB pavements need terminations at all ends to limit thermally induced horizontal movements and protect adjacent structures and pavements. Details are given in Section 4.18.*

5.7.2 CRCB/CRCP Reinforcement

5.7.2.1 Depth of Reinforcement

In a CRCB/CRCP pavement the longitudinal steel bars should be located at approximately 1/3 slab depth. Care must be taken to ensure that the minimum concrete cover to the steel reinforcement is met, i.e. 60 mm for slab thickness 200-270 mm and 70 mm for slab thickness >270 mm.

5.7.2.2 Transverse Reinforcement - Size and Spacing

For CRCB and CRCP pavements, the transverse steel reinforcement should be 12 mm diameter deformed steel bars (*T*12) at 600 mm spacing.

These are used for ease and consistency of construction and to prevent longitudinal cracking and local deterioration. They may be incorporated in the support arrangement for the longitudinal bars, but need to maintain their position when the concrete is being poured and compacted.

5.7.2.3 Longitudinal Reinforcement - Size and Spacing

The continuous longitudinal reinforcement comprises multiple parallel deformed steel bars at a calculated spacing. These are designed to hold the transverse cracks tightly closed to ensure high load transfer across the cracks and to maintain the structural integrity of the pavement.

- For CRCP, 16 mm diameter deformed steel bars are specified (T16). The maximum spacing of longitudinal reinforcement is calculated using Equation 5.6. The level of longitudinal reinforcement (% cross section area) (= R) should be 0.6 %. For CRCP the results have been calculated and tabulated in Table 5.6. These show a maximum spacing between longitudinal bars of 120-168 mm, depending on slab thickness.
- For CRCB, 12 mm diameter deformed steel bars are specified (T12). The level of longitudinal reinforcement (% cross section area)(= R) should be 0.4 %. The maximum spacing of longitudinal reinforcement is calculated using Equation 5.6. For CRCB the results have been calculated and tabulated in Table 5.6. These show a maximum spacing between longitudinal bars of 109-188 mm, depending on slab thickness.

The maximum spacing of longitudinal steel reinforcement (centre to centre) for CRCB and CRCP can be calculated using Equation 5.6.

Calculation of CRCB/CRCP maximum longitudinal steel reinforcement spacing.

$$S = \frac{100\pi D^2}{4tR}$$

Equation 5.6

Where,

S = maximum distance, centre to centre, between bars across the width of the slab (mm)

D = diameter of reinforcement bar (mm)

R = level of reinforcement (% of the cross-section area)

t = concrete design thickness (mm)

The results from Equation 5.6 have been calculated and are tabulated in Table 5.6.

Table 5.6 CRCP/CRCB - Maximum Spacing of Longitudinal Deformed Steel Bars

Longitudinal Bar for CRCP or CRCB	Deformed Bar Diameter	Reinforcement Level %	Concrete thickness, mm (t)	Max distance between bars, mm (S)	Concrete thickness, mm (t)	Max distance between bars, mm (S)
New CRCP	16 mm	0.6 %	200	168	245	137
			205	163	250	134
			210	160	255	131
			215	156	260	129
			220	152	265	126
			225	149	270	124
			230	146	275	122
			235	143	280	120
			240	140		
New CRCB	12 mm	0.4 %	150	188	210	135
			155	182	215	132
			160	177	220	129
			165	171	225	126
			170	166	230	123
			175	162	235	120
			180	157	240	118
			185	153	245	115
			190	149	250	113
			195	145	255	111
			200	141	260	109
			205	138		

Notes on CRCP/CRCB Reinforcement:
1: *New CRCP is a minimum of 200 mm thick. A CRCP overlay can be thinner (minimum 150 mm), depending on the ESFM of the existing pavement.*
2: *Longitudinal crack control steel in CRCP shall be 0.6 % of the concrete slab cross-section area, comprising 16 mm diameter, deformed steel bars (T16 reinforcement).*
3: *Longitudinal crack control steel in CRCB shall be 0.4 % of the concrete slab cross-section area, comprising 12 mm diameter, deformed steel bars (T12 reinforcement).*
4: *Transverse steel in CRCP and CRCB shall be 12mm diameter deformed bars at 600mm spacings.*
5: *Transverse bars may be incorporated into the support arrangement for the steel. Where this is done, the required quantities and position of the steel shall be maintained.*
6: *Where concrete of flexural strength ≥ 5.5 MPa is used, this shall use aggregate that has a coefficient of thermal expansion less than 10×10^{-6} per °C.*
7: *Crack inducers shall not be used with CRCP or CRCB designs.*

The termination details of CRCP and CRCB pavements shall be designed to ensure that forces are not transmitted to structures and adjacent forms of pavement construction by thermally induced movements. See Section 4.18.

5.7.3 Asphalt on CRCP/CRCB

Particular care should be taken when applying a bituminous surfacing to an existing concrete road as not all emulsions adhere well to concrete. It is likely that one specially formulated for this application or a tack or bond coat will be needed. See Section 4.23.2.

Where a CRCP is designed with an asphalt surfacing, no base/binder course is required. A minimum asphalt surfacing thickness of 30 mm is recommended.

CRCB shall be designed with a total asphalt thickness (i.e. base/binder course and surface course) of at least 100 mm.

A guide to the type of base/binder course and surfacing materials that should be used are given in **RDM Volume 3 Part 3**. This will depend upon factors such as traffic levels, whether the site is considered 'severe', etc.

For example an Asphalt Concrete Type I (High stability) may be suitable for Heavy and Very Heavy traffic (10-150+ M CESA) and an Asphalt Concrete Type II (Flexible) may be more suitable for Low and Medium traffic (0-10 M CESA).

5.7.4 CRCB Design Example - CRCB Thickness and Reinforcement

Question 5. Using the following Design factors:

Design factors:

1. Design traffic = 200 M CESA.
2. Foundation class = F4 (bound).
3. Design uses concrete with a flexural strength of 4.5 MPa.
4. All CRCB designs require a minimum 100 mm asphalt.
5. The transverse reinforcement for a CRCP/CRCB is 12 mm diameter deformed steel bars (T12) at 600 mm spacings.
6. The longitudinal reinforcement for a CRCB requires 12 mm diameter deformed steel bars (T12) at R = 0.4 %.

Calculate the concrete thickness of a CRCB pavement WITH a 1m edge strip.

Calculate the type and spacing of the longitudinal reinforcement.

Using Figure 5.3 (repeated below), from 200 M CESA -> Class F4 (bound) fdn -> F_f = 4.5 -> 209 mm (rounded up to 210 mm).

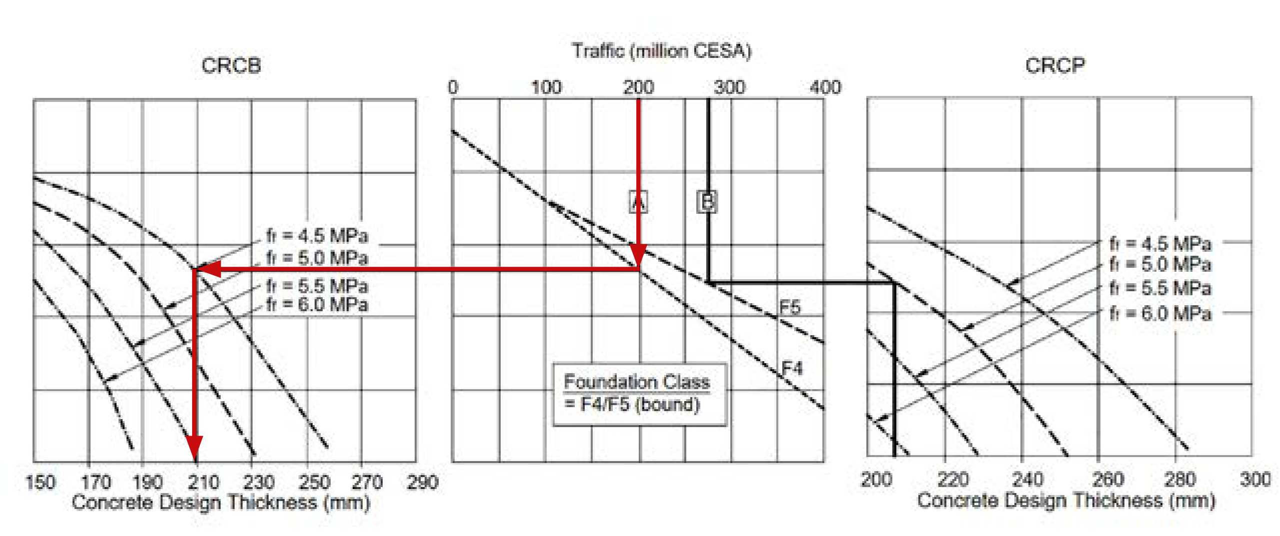


Figure 5-3 reproduced

CRCB Design = 210 mm of concrete (WITH a 1m edge strip).

The spacing of the T12 longitudinal reinforcement is calculated using Equation 5.6.

$$S = \frac{100\pi D^2}{4tR} = \frac{100\pi 12^2}{4 \times 210 \times 0.4} = \frac{45{,}238.934}{336} = 135 \text{ mm}$$

Where,

D = 12 mm

t = 210 mm

R = 0.4 %

The spacing of the T12 longitudinal reinforcement is 135 mm.

5.7.5 CRCP Design Example - CRCP Thickness Compaction of fill material

Question 6.

Design factors:

1. Design traffic = 275 M CESA.
2. Foundation class = F5 (bound).
3. Concrete with a mean flexural strength of 5.0 MPa.
4. The transverse reinforcement for a CRCP/CRCB is 12 mm diameter deformed steel bars ($T12$) at 600 mm spacings.
5. The longitudinal reinforcement for a CRCB requires 16 mm diameter deformed steel bars ($T16$) at R = 0.6 %.

Calculate the concrete thickness of a CRCP pavement <u>without</u> an integral tied lane/ shoulder; and

What type/spacing is the longitudinal reinforcement?

Design factors:

Using Figure 5.3 (repeated below) from 275 M CESA -> Class F5 (bound) fdn -> Conc flex strength Ff = 5.0 -> 208 mm concrete design thickness, which should be rounded up to 210 mm.

Note: *that this is for a pavement <u>WITH</u> a tied shoulder/edge strip.*

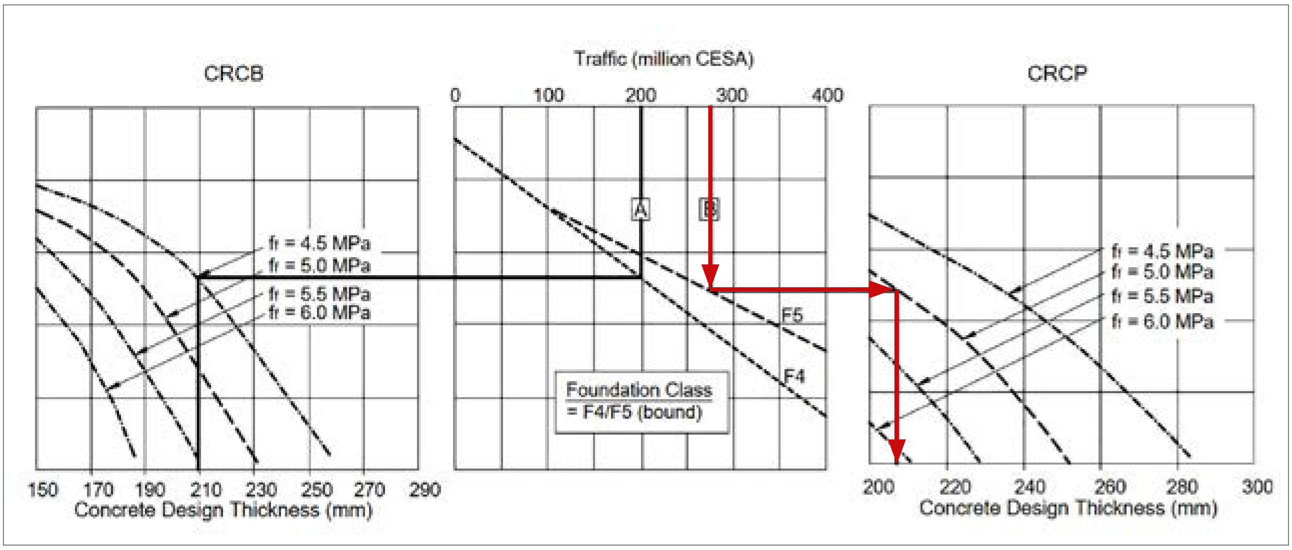


Figure 5-3 reproduced

Since we are calculating the design for a pavement **WITHOUT** a tied shoulder/edge strip, in accordance with Note 7 of Figure 5.3, the design concrete thickness should be increased by 30 mm.

Answer 6a. CRCP Design = 210 mm + 30 mm = 240 mm concrete (WITHOUT tied shoulder/edge strip).

Answer 6b. The T16 longitudinal reinforcement spacing (using Equation 5.6) **is:**

$$S = \frac{100\pi D^2}{4tR} = \frac{100\pi 16^2}{4 \times 240 \times 0.6} = 139.6 \text{ mm}$$

Where,

D = 16 mm

t = 240 mm

R = 0.6 %

i.e. 139.6, rounded up to 140 mm.

6 Pavement Structure Catalogues

Schedule of Pavement Structures

Section No.	Structure Name	Description
6.1	CLV1	Cobblestone Paving for Low Volume Roads. (0.1-1 M CESA).
6.2	CLV2	Block Paving (BP) for Low Volume Roads. (0.1-1 M CESA).
6.3	CMV1	Block Paving (BP) for Medium Volume Roads. (1-10 M CESA).
6.4	CLV3	JUCP for Low Volume Roads. (0.1-1 M CESA).
6.5	CHV1	JUCP for Medium to Very Heavy Traffic Roads. (1-200 M CESA).
6.6	CHV2	JRCP with Rx = 500 mm^2/m Reinforcement. (1-300 M CESA).
6.7	CHV3	JRCP with Rx = 600 mm^2/m Reinforcement. (1-300 M CESA).
6.8	CHV4	JRCP with Rx = 700 mm^2/m Reinforcement. (1-300 M CESA).
6.9	CHV5	JRCP with Rx = 800 mm^2/m Reinforcement. (1-300 M CESA).
6.10	CHV6	Roller Compacted Concrete (RCC) Pavement. (1-400 M CESA).
6.11	CHV7	Continuously Reinforced Concrete Base (CRCB). (1-400 M CESA).
6.12	CHV8	Continuously Reinforced Concrete Pavement (CRCP).(1-400 M CESA).

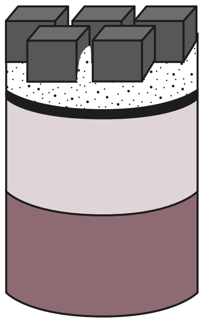
6.1 Catalogue CLV1: Cobblestone Paving (CP) for Low Volume Roads

CLV1

Thickness Design Catalogue for:

COBBLESTONE PAVING

for Low Traffic Roads (0.1 to 1 M CESA)



Cobblestone Paving (total 100 mm),
Includes sand bed (usually 40 mm, range: 20-50 mm)

Base (Gravel Material, minimum 30 % CBR) with MC 70 or MC 30 cutback bitumen seal

Foundation F1-F4

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class	Layer Thickness (Cobblestones/Base) (mm) – Design Traffic (Million CESA): Layer Type	TC0.1 0 – 0.1	TC0.25 0.1 - 0.25	TC0.5 0.25 - 0.5	TC1.0 0.5 – 1.0
F1	75	S3 (7-13 % CBR)	Cobbles/sand	Economically unjustified	100	100	100
			Base		100	125	200
F2	95	S4 (10-18 % CBR)	Cobbles/sand	Economically unjustified	100	100	100
			Base		100	100	150
F3	130	S5 (15-30 % CBR)	Cobbles/sand	Economically unjustified	100	100	100
			Base		100	100	100
F4	200	S6 (>30 % CBR)	Cobbles/sand	Economically unjustified	100	100	100
			Base		0	0	0

Notes:

1. *For low volume roads, a design life of 15 years is recommended.*
2. *It may be necessary to reset the sand/pavers several times during the pavement life, e.g. if severe rutting.*
3. *A cutback bitumen seal should be used (e.g. MC 30) on top of the base.*
4. *Foundation and Improved subgrade design shown below.*

Improved Subgrade

Native Subgrade (% CBR Range, Median)	S1 (2-5, 3.5)			S2 (5-10, 7.5)		S3 (7-13, 10)		S4 (10-18, 14)	
Capping Material	G8	G10	G14	G10	G14	G14	G23	G23	G45
Thickness (mm)	375	400	425	150	175	150	150	150	150
New Subgrade	S2	S3	S4	S3	S4	S4	S5	S5	S6
Foundation Class	-	F1	F2	F1	F2	F2	F3	F3	F4

For further details see Section 5.2.

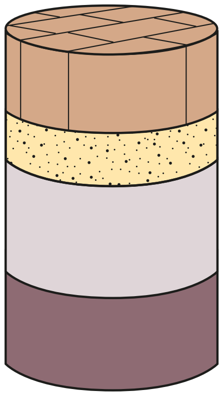
6.2 Catalogue CLV2: Block Paving (BP) for Low Volume Roads

CLV2

Thickness Design Catalogue for:

BLOCK PAVING

for Low Traffic Roads (0.1 to 1 M CESA)



Interlocking Concrete Block Paving (60 – 80 mm)

~~**Sharp**~~ **Sand Layer** (~~25 –~~50 mm)

Base (Gravel Material, minimum 30 % CBR)

Foundation F1-F4

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class	Layer Thickness (Block/Sand/Base) (mm) Design Traffic (Million CESA)	0 – 0.1	0.1 - 0.25	0.25 - 0.5	0.5 – 1.0
F1	75	S3 (7-13 % CBR)	Blocks	Economically unjustified	60-80	60-80	60-80
			Sand		25-50	25-50	25-50
			Base		100	150	200
F2	95	S4 (10-18 % CBR)	Blocks	Economically unjustified	60-80	60-80	60-80
			Sand		25-50	25-50	25-50
			Base		100	100	150
F3	130	S5 (15-30 % CBR)	Blocks	Economically unjustified	60-80	60-80	60-80
			Sand		25-50	25-50	25-50
			Base		100	100	100
F4	200	S6 (>30 % CBR)	Blocks	Economically unjustified	60-80	60-80	60-80
			Sand		25-50	25-50	25-50
			Base		0	0	0

Notes:

1. *For low volume roads, a design life of 15 years is recommended.*
2. *It may be necessary to reset the sand/pavers several times during the pavement life, e.g. if severe rutting.*
3. *Sand layer thickness of 30mm is recommended.*
4. *Paver thickness can be ~~50mm (light duty),~~ 60mm (medium duty) or 80mm (heavy duty).*
5. *A cutback bitumen seal should be used (e.g. MC 30) on top of the base.*
6. *Foundation and Improved subgrade design shown below.*

Foundation and Improved Subgrade Design

Native Subgrade Class		S1					S2				S3			S4		S5
Capping	Upper layer	G8	G10	G10	G15	G15	G10	G15	G25	G30	G15	G25	G30	G25	G30	G30
	Thickness (mm)	300	275	350	150	150	100	175	200	225	100	150	175	100	125	100
	Lower Layer				G8	G10										
	Thickness (mm)				200	175										
Improved SG Class		S2	S2	S3	S3	S3	S3	S4	S5	S6	S4	S5	S6	S5	S6	S6

Adapted from MTRD Pavement Design Guidelines 1: Low Volume Sealed Roads, 2nd Edn.

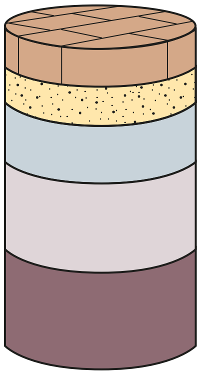
6.3 Catalogue CMV1: Block Paving (BP) for Medium Traffic Roads

CMV1

Thickness Design Catalogue for:

Block Paving

for Medium Traffic Roads (1 M to 10 M CESA).



Interlocking Concrete Block Paving (65/80 mm)

Sand Layer 30mm (25-40 mm)

Cement-Bound or Asphalt Base (HBS3 or DBM)

Sub-Base (Gravel Material, minimum 30 % CBR)

Foundation F1 – F4

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class	Layer Thickness PQ and Base (mm)		
			Layer Type	Design Traffic (Million CESA)	
				1 – 3	3 – 10
F1	75	S3 (7-13 % CBR)	Blocks	65/80	65/80
			Sand	30	30
			Base HBS	145*	245*
			Base DBM	145*	185*
			Sub-Base	270	270
F2	95	S4 (10-18 % CBR)	Blocks	65/80	65/80
			Sand	30	30
			Base HBS	145*	245*
			Base DBM	145*	185*
			Sub-Base	240	240
F3	130	S5 (15-30 % CBR)	Blocks	65/80	65/80
			Sand	30	30
			Base HBS	145*	245*
			Base DBM	145*	185*
			Sub-Base	225	225
F4	200	S6 (> 30 % CBR)	Blocks	65/80	65/80
			Sand	30	30
			Base HBS	145*	245*
			Base DBM	145*	185*
			Sub-Base	0	0

Notes:

1. *For medium trafficked roads, a 20 year design life is recommended. It may be necessary to reset the sand/pavers several times during the pavement life, e.g. if severe rutting.*

2. *If speeds >50kph multiply calculated design traffic by 2. If channelised traffic, multiply design traffic by 3. If both, then only multiply design traffic by 3.*

3. ** Base thickness shown is for 65mm thick paver. If 80mm paver, reduce thickness by 15mm.*

4. *A cutback bitumen seal (MC70 or MC 30) on top of the base is not needed.*

5. *Foundation and improved subgrade design shown below.*

	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	S2	S3	S3	S4	S5	S4	S5	S6	S5	S6
Foundation Class	-	**F1**	**F2**	**F1**	**F1**	**F2**	**F2**	**F2**	**F3**	**F3**	**F4**

Adapted from MTRD Pavement Design Guidelines 1: Low Volume Sealed Roads, 2nd Edition.

6.4 Catalogue CLV3: JUCP for Low Volume Roads (0-1 M CESA)

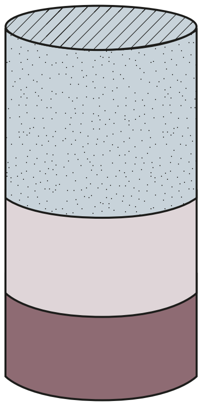
CLV3

Thickness Design Catalogue for:

JOINTED UNREINFORCED CONCRETE (JUC)

(with a Shoulder/Edge Strip)

for Low Traffic Roads (0.1 to 1 M CESA)



PQ Concrete (dowelled joints preferred, but optional)

Base (gravel material, minimum 30 % CBR)

Foundation F1 – F4

Foundation Class	Effective Surface Modulus (MPa)	Equivalent Subgrade Class	Layer Thickness PQ and Base (mm)				
			Layer Type	Design Traffic (Million CESA)			
				0 – 0.1	0.1 – 0.25	0.25 – 0.5	0.5 – 1.0
F1	75	S3 (7-13 % CBR)	Concrete	Economically unjustified	100	100	100
			Sub-Base		100	125	175
F2	95	S4 (10-18 % CBR)	Concrete	Economically unjustified	100	100	100
			Sub-Base		100	125	150
F3	130	S5 (15-30 % CBR)	Concrete	Economically unjustified	100	100	100
			Sub-Base		10	100	150
F4	200	S6 (>30 % CBR)	Concrete	Economically unjustified	100	100	100
			Sub-Base		0	0	0

Notes:

1. *For low volume roads (including rigid pavements), a design life of 15 years is recommended.*

2. *Where: PQ Concrete = Pavement Quality Concrete.*

6.5 Catalogue CHV1: JUCP for Medium to Very Heavy Traffic (1-200 M CESA)

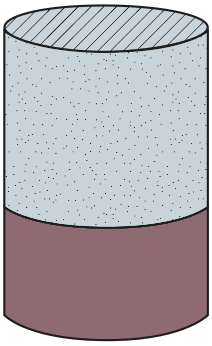
CHV1

Thickness Design Catalogue for:

JOINTED UNREINFORCED CONCRETE (JUC)

(with a Shoulder/Edge Strip)

for Medium to Very Heavy Traffic Roads (1 – 200 M CESA)



PQ Concrete (with dowelled joints)

F4 (bound) or F5 (bound) Foundation
(for options see Table 5.3)

Foundation Class	**Concrete Strength*** (MPa)	**Pavement Quality Concrete Thickness** (mm)								
		Design Traffic (Million CESA)								
		1–3	**3–10**	**10–17**	**17–30**	**30–50**	**50–80**	**80–100**	**100–150**	**>150**
F4 (bound) (SM > 200 MPa	**35**	150	215	235	265	295	325	340	370	Calculate thickness for exact traffic (and round up to nearest 5 mm)
	40	150	195	215	240	270	295	310	335	
	45	150	175	200	225	245	270	285	310	
	50	150	165	185	205	230	255	265	290	
F5 (bound) (SM > 400 MPa)	**35**	150	200	220	250	275	305	320	345	
	40	150	180	200	225	250	275	290	315	
	45	150	165	185	210	230	255	265	290	
	50	150	155	170	195	215	235	245	270	

*Where: * Concrete strength = mean compressive cube strength at 28 days, SM = Surface Modulus.*

Notes:

1: *The design life should be 40 years.*

2: *The design concrete thicknesses shown here are based on the presence of a (minimum) 1 m wide edge strip or tied lane/ shoulder adjacent to the most heavily trafficked lane. If this is NOT present then the design concrete thickness shall be increased by 20-30 mm, see Table 5.1.*

3: *For the maximum transverse joint spacings in JUC pavements see Table 5.2.*

4: *For Foundation options see Table 4.3.*

5: *Maximum Design Traffic = 200 M CESA.*

6.6 Catalogue CHV2: JRCP with Rx= 500 mm^2/m width Reinforcement

CHV2

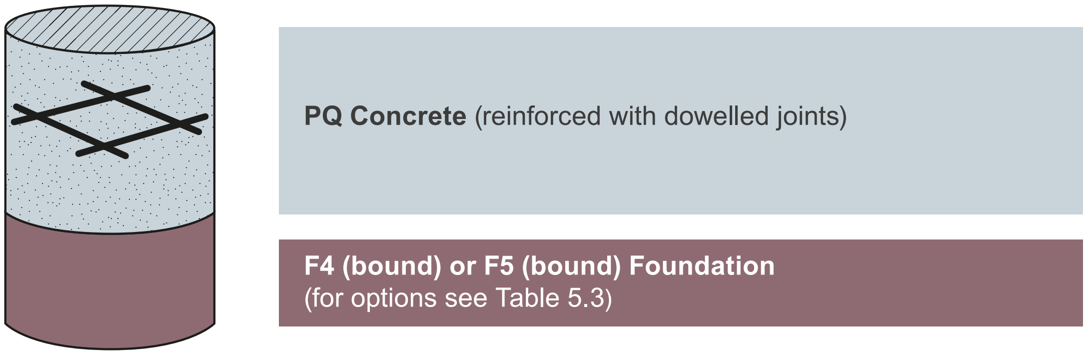
Thickness Design Catalogue for:

JOINTED REINFORCED CONCRETE

(with a Shoulder/Edge Strip)

With Longitudinal Reinforcement Rx = 500 mm^2/m width

for Medium to Very Heavy Traffic Roads (1 – 300 M CESA)



Foundation Class	Concrete Strength* (MPa)	Pavement Quality Concrete Thickness (mm)								
		Design Traffic (Million CESA)								
		1–3	3–10	10–17	17–30	30–50	50–80	80–100	100–150	>150
F4 (bound) (SM > 200 MPa	**35**	150	185	210	240	265	295	310	340	Calculate thickness for exact traffic (and round up to nearest 5 mm)
	40	150	170	190	215	245	270	280	310	
	45	150	155	175	200	225	250	260	285	
	50	150	150	165	185	210	230	240	265	
F5 (bound) (SM > 400 MPa)	**35**	150	180	200	225	255	280	295	320	
	40	150	160	180	205	230	255	270	295	
	45	150	150	170	190	215	235	250	270	
	50	150	150	155	175	200	220	230	250	

** Concrete strength = mean compressive cube strength at 28 days, SM = Surface Modulus.*

Notes:

1: *The design life should be 40 years.*

2: *The design concrete thicknesses shown here are based on the presence of a (minimum) 1m wide edge strip or tied lane/ shoulder adjacent to the most heavily trafficked lane. If this is NOT present then the design concrete thickness shall be increased by 20-30 mm, see Table 5.1.*

3: *The transverse reinforcement for a JRC is 12 mm diameter deformed steel bars (T12) @ 600 mm spacings.*

4: *The longitudinal reinforcement comprises 12 mm or 16 mm diameter deformed steel bars (T12 or T16). To calculate longitudinal reinforcement spacings see Table 5.4.*

5: *To calculate maximum transverse joint spacing see Table 5.3.*

6: *For Foundation options see Table 4.3.*

7: *Maximum Design Traffic = 300 M CESA.*

6.7 Catalogue CHV3: JRCP with Rx = 600 mm²/m width Reinforcement

CHV3

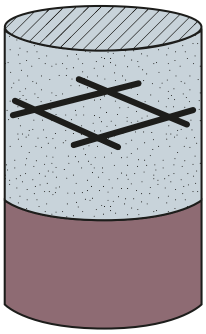
Thickness Design Catalogue for:

JOINTED REINFORCED CONCRETE (JRC)

(with a Shoulder/Edge Strip)

With Longitudinal Reinforcement Rx = 600 mm²/m width

for Medium to Very Heavy Traffic Roads (1 – 300 M CESA)



PQ Concrete (reinforced with dowelled joints)

F4 (bound) or F5 (bound) Foundation
(for options see Table 5.3)

Foundation Class	Concrete Strength* (MPa)	Pavement Quality Concrete Thickness (mm)								
		Design Traffic (Million CESA)								
		1–3	3–10	10–17	17–30	30–50	50–80	80–100	100–150	>150
F4 (bound) (SM > 200 MPa	35	150	175	200	225	250	280	295	320	Calculate thickness for exact traffic (and round up to nearest 5 mm)
	40	150	160	180	205	230	255	265	290	
	45	150	150	165	190	210	235	245	270	
	50	150	150	150	175	195	220	230	250	
F5 (bound) (SM > 400 MPa)	35	150	170	190	215	240	265	277	305	
	40	150	155	170	196	220	240	255	280	
	45	150	150	160	180	200	225	235	255	
	50	150	150	150	165	185	210	220	240	

** Concrete strength = mean compressive cube strength at 28 days, SM = Surface Modulus.*

Notes:

1: *The design life should be 40 years.*

2: *The design concrete thicknesses shown here are based on the presence of a (minimum) 1 m wide edge strip or tied lane/ shoulder adjacent to the most heavily trafficked lane. If this is NOT present then the design concrete thickness shall be increased by 20-30 mm, see Table 5.1.*

3: *The transverse reinforcement for a JRC is 12 mm diameter deformed steel bars (T12) @ 600 mm spacings.*

4: *The longitudinal reinforcement comprises 12mm or 16mm diameter deformed steel bars (T12 or T16). To calculate longitudinal reinforcement spacings see Table 5.4.*

5: *To calculate maximum transverse joint spacing see Table 5.3.*

6: *For Foundation options see Table 4.3.*

7: *Maximum Design Traffic = 300 M CESA.*

6.8 Catalogue CHV4: JRCP with Rx = 700 mm²/m width Reinforcement

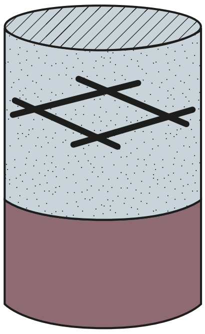
CHV4

Thickness Design Catalogue for:

JOINTED REINFORCED CONCRETE (JUC) *(with a Shoulder/Edge Strip)*

With Longitudinal Reinforcement Rx = 700 mm²/m width

for Low to Very Heavy Traffic Roads (1 – 300 M CESA)



PQ Concrete (reinforced with dowelled joints)

F4 (bound) or F5 (bound) Foundation
(for options see Table 5.3)

Foundation Class	Concrete Strength* (MPa)	Pavement Quality Concrete Thickness (mm)								
		Design Traffic (Million CESA)								
		1–3	3–10	10–17	17–30	30–50	50–80	80–100	100–150	>150
F4 (bound) (SM > 200 MPa	35	150	170	190	215	240	265	280	305	Calculate thickness for exact traffic (and round up to nearest 5 mm)
	40	150	155	170	195	220	240	255	280	
	45	150	150	160	180	200	225	235	255	
	50	150	150	150	165	185	210	220	240	
F5 (bound) (SM > 400 MPa)	35	150	160	180	205	230	255	265	290	
	40	150	150	165	185	210	230	240	245	
	45	150	150	150	170	190	205	225	245	
	50	150	150	150	160	180	200	210	225	

** Concrete strength = mean compressive cube strength at 28 days, SM = Surface Modulus.*

Notes:

1: *The design life should be 40 years.*

2: *The design concrete thicknesses shown here are based on the presence of a (minimum) 1 m wide edge strip or tied lane/ shoulder adjacent to the most heavily trafficked lane. If this is NOT present then the design concrete thickness shall be increased by 20-30 mm, see Table 5.1.*

3: *The transverse reinforcement for a JRC is 12 mm diameter deformed steel bars (T12) @ 600 mm spacings.*

4: *The longitudinal reinforcement comprises 12 mm or 16 mm diameter deformed steel bars (T12 or T16). To calculate longitudinal reinforcement spacings see Table 5.4.*

5: *To calculate maximum transverse joint spacing see Table 5.3.*

6: *For Foundation options see Table 4.3.*

7: *Maximum Design Traffic = 300 M CESA.*

6.9 Catalogue CHV5: JRCP with Rx = 800mm²/m width Reinforcement

CHV5

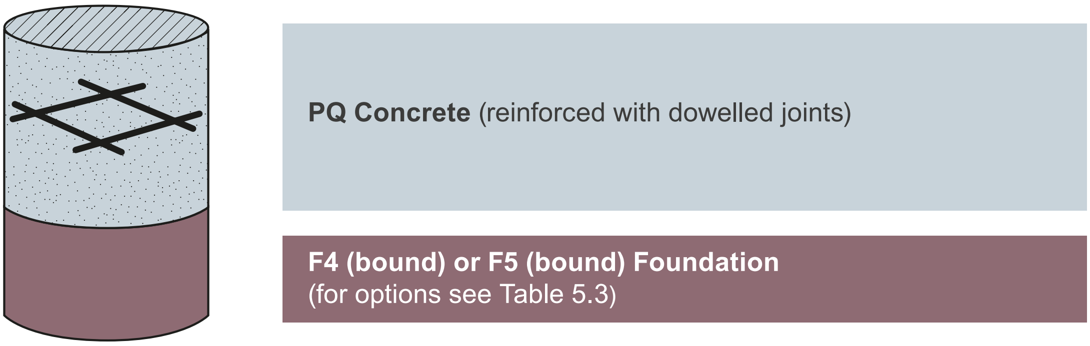
Thickness Design Catalogue for:

JOINTED REINFORCED CONCRETE (JRC)

(with a Shoulder/Edge Strip)

With Longitudinal Reinforcement Rx = 800 mm²/m width
= 0.4 % for 200 mm Thick Concrete

for Medium to Very Heavy Traffic Roads (1 – 300 M CESA)



Foundation Class	Concrete Strength* (MPa)	Pavement Quality Concrete Thickness (mm) — Design Traffic (Million CESA)								
		1–3	**3–10**	**10–17**	**17–30**	**30–50**	**50–80**	**80–100**	**100–150**	**>150**
F4 (bound) (SM > 200 MPa	**35**	150	160	180	205	230	255	270	295	Calculate thickness for exact traffic (and round up to nearest 5 mm)
	40	150	150	165	190	210	235	245	265	
	45	150	150	150	175	195	215	225	245	
	50	150	150	150	160	180	200	210	230	
F5 (bound) (SM > 400 MPa)	**35**	150	155	175	195	220	245	255	280	
	40	150	150	155	180	200	220	235	255	
	45	150	150	150	165	185	205	215	235	
	50	150	150	150	150	170	190	200	220	

** Concrete strength = mean compressive cube strength at 28 days, SM = Surface Modulus.*

Notes:

1: *The design life should be 40 years.*

2: *The design concrete thicknesses shown here are based on the presence of a (minimum) 1 m wide edge strip or tied lane/shoulder adjacent to the most heavily trafficked lane. If this is NOT present then the design concrete thickness shall be increased by 20-30 mm, see Table 5.1.*

3: *The transverse reinforcement for a JRC is 12 mm diameter deformed steel bars (T12) @ 600 mm spacings.*

4: *The longitudinal reinforcement comprises 12 mm or 16 mm diameter deformed steel bars (T12 or T16). To calculate longitudinal reinforcement spacings see Table 5.4.*

5: *To calculate maximum transverse joint spacing see Table 5.3.*

6: *For Foundation options see Table 4.3.*

7: *Maximum Design Traffic = 300 M CESA.*

6.10 Catalogue CHV6: Roller Compacted Concrete (RCC) Pavement

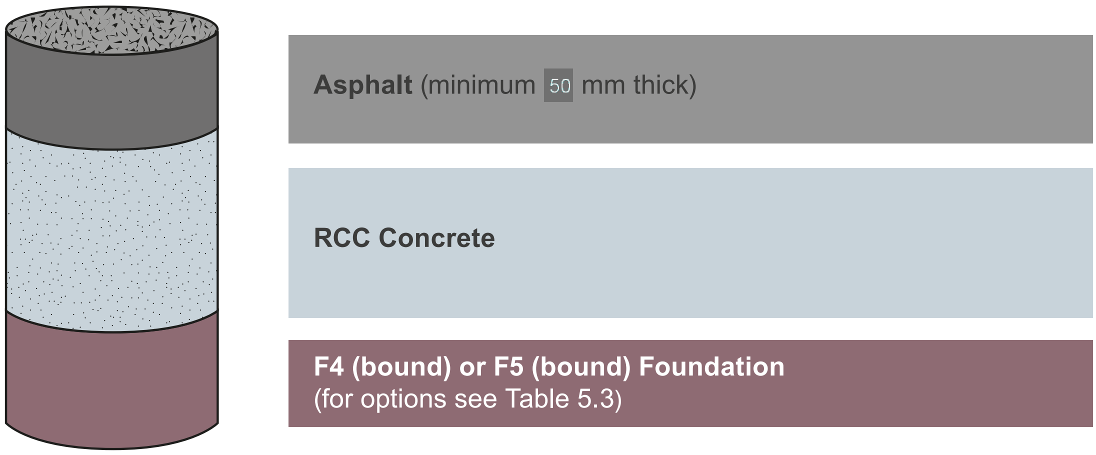
CHV6

Thickness Design Catalogue for:

ROLLER COMPACTED CONCRETE (RCC)

(with a Shoulder/Edge Strip and No Reinforcement)

for Medium to Very Heavy Traffic Roads (1 – 400 M CESA)



Foundation Class	**Concrete Strength*** (MPa)	**RCC Concrete Thickness** (mm)						
		Design Traffic (Million CESA)						
		1–17	**17–30**	**30–50**	**50–80**	**80–100**	**100–150**	**>150**
F4 (bound) (SM > 200 MPa	**C40/50**	165	175	180	200	200	200	200
F5 (bound) (SM > 400 MPa)	**C40/50**	165	165	165	180	180	180	180

Where RCC Concrete = Pavement Quality Concrete design specifically for RCC pavement. SM = Surface Modulus

Notes:

1: *The design life should be 40 years.*

2: ** Design thickness is based on use of C40/50 concrete, i.e. minimum characteristic cylinder strength at 28 days (f_{fk}) = 40 MPa and minimum characteristic cube strength at 28 days (f_{fk})= 50 MPa. The RCC concrete is assumed to have the following characteristics: flexural strength = 5.0 MPa, modulus E = 50,000 MPa and Poisson's Ratio = 0.20. Minimum cement content 270 kg/m^3.*

3: *For pavements without a shoulder/edge strip add 30 mm to concrete thickness.*

4: *To create suitable ride quality for a high-speed road, a minimum total asphalt thickness of 90 mm is recommended, although 50 mm Hot Mix Asphalt (HMA) has been used successfully in the USA.*

5: *Because aggregate interlock is such an important feature of RCC, crushed gravel and recycled aggregates are not permitted.*

6: *For Foundation options see Table 4.3.*

7: *Maximum Design Traffic = 400 M CESA.*

6.11 Catalogue CHV7: Continuously Reinforced Concrete Base (CRCB)

CHV7

Thickness Design Catalogue for:

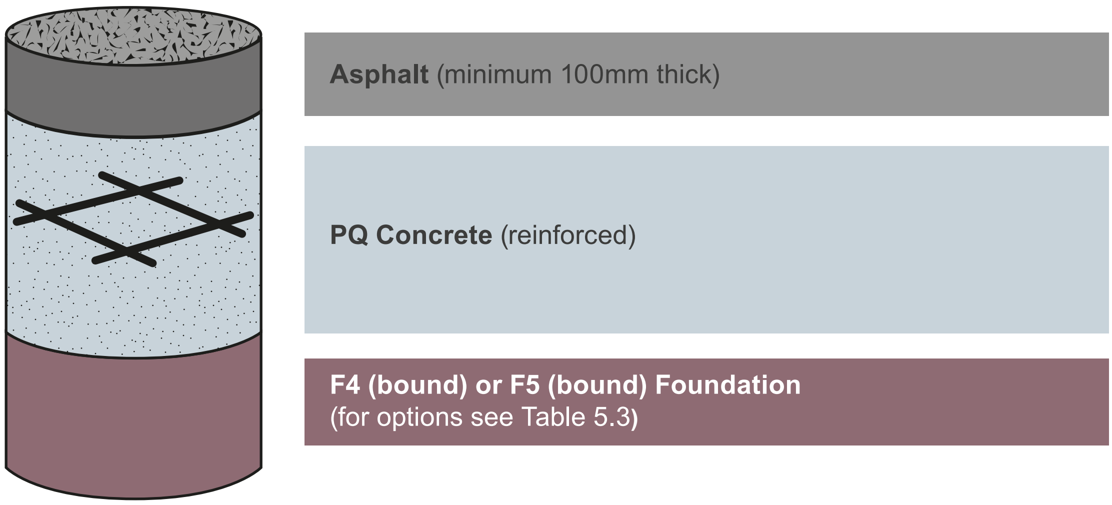
CONTINUOUSLY REINFORCED CONCRETE BASE (CRCB)

(with a Shoulder/Edge Strip and > 100 mm Asphalt)

With Longitudinal Reinforcement R = 0.4 % = Approx. 800 mm²/m

for 200 mm Thick Concrete

for Medium to Very Heavy Traffic Roads (1 – 400 M CESA)



Foundation Class	Concrete Strength f_f (MPa)	**Pavement Quality Concrete Thickness** (mm) — **Design Traffic** (Million CESA)						
		1–17	**17–30**	**30–50**	**50–80**	**80–100**	**100–150**	**>150**
F4 (bound) (SM > 200 MPa)	**4.5**	150	150	150	165	170	190	Calculate thickness for exact traffic (and round up to nearest 5 mm)
	5.0	150	150	150	150	150	170	
	5.5	150	150	150	150	150	150	
	6.0	150	150	150	150	150	150	
F5 (bound) (SM > 400 MPa)	**4.5**	**Not usually used (150)**					185	
	5.0						160	
	5.5						150	
	6.0						150	

SM = Surface Modulus.

Notes:

1: *The design life should be 40 years.*

2: *The design concrete thickness is based on the presence of a (minimum) 1 m wide edge strip or tied lane/shoulder adjacent to the most heavily trafficked lane. If this is NOT present then the design concrete thickness shall be increased by 30 mm.*

3: *All CRCB designs require a minimum 100 mm asphalt.*

4: *A Foundation of F4 (bound) is usually used for design traffic up to 100 M CESA. Above 100 M CESA, either F4 (bound) or F5 (bound) can be used (see Figure 5.3 in Section 5.7).*

5: *The transverse reinforcement for a CRCB is 12 mm diameter deformed steel bars (T12) @ 600 mm spacings.*

6: *The longitudinal reinforcement for a CRCB requires 12 mm diameter deformed steel bars (T12) at R = 0.4 %.*

7: *f_f denotes mean concrete flexural strength (N/mm² or MPa) at 28 days in accordance with BS EN 12390-5 (Testing hardened concrete. Part 5: Flexural strength of test specimens), where f_f = 4.5, 5.0, 5.5 or 6.0 MPa.*

8: *For Foundation options see Table 4.3.*

9: *Maximum Design Traffic = 400 M CESA.*

10: *Crack inducers shall not be used with CRCB designs.*

6.12 Catalogue CHV8: Continuously Reinforced Concrete Pavement (CRCP)

CHV8

Thickness Design Catalogue for:

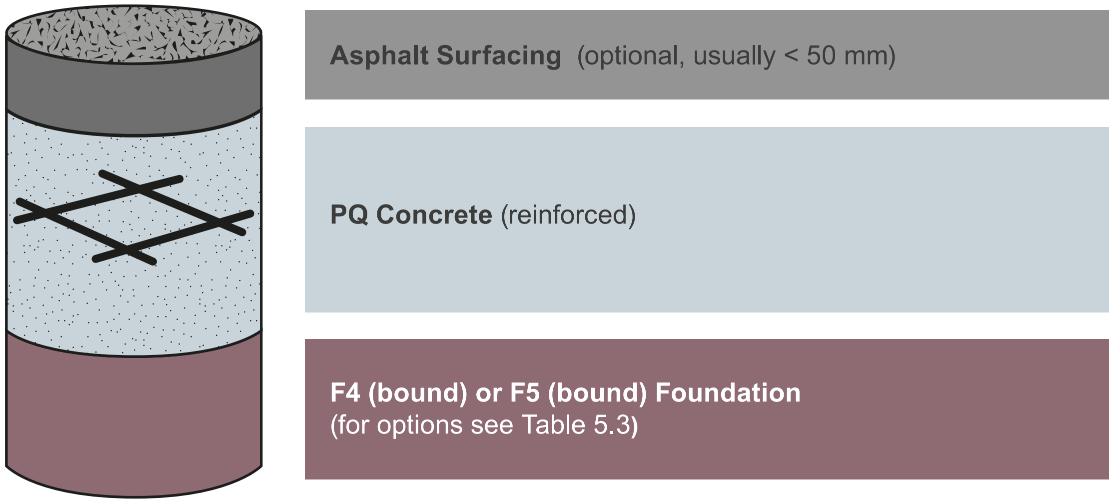
CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (CRCP)

(with a Shoulder/Edge Strip and Optional Asphalt Surfacing)

Longitudinal Reinforcement R = 0.6 % = Approx. 1206 mm²/m

for 200 mm Thick Concrete

for Medium to Very Heavy Traffic Roads (1 – 400 M CESA)



Foundation Class	Concrete Strength f_f (MPa)	Pavement Quality Concrete Thickness (mm)				
		Design Traffic (Million CESA)				
		1–50	50–80	80–100	100–150	>150
F4 (bound) (SM > 200 MPa	4.5	200	200	200	215	Calculate thickness for exact traffic (and round up to nearest 5 mm)
	5.0	200	200	200	200	
	5.5	200	200	200	200	
	6.0	200	200	200	200	
F5 (bound) (SM > 400 MPa)	4.5				210	
	5.0				200	
	5.5				200	
	6.0				200	

SM = Surface Modulus.

Notes:

1: *The design life should be 40 years.*

2: *The design concrete thickness is based on the presence of a (minimum) 1 m wide edge strip or tied lane/shoulder adjacent to the most heavily trafficked lane. If this is NOT present then the design concrete thickness shall be increased by 30 mm.*

3: *Concrete thicknesses have been rounded up to the nearest 5 mm.*

4: *A Foundation of F4 (bound) is usually used for design traffic up to 100 M CESA. Above 100 M CESA, either F4 (bound) or F5 (bound) can be used (see Figure 5.3 in Section 5.7).*

5: *The transverse reinforcement for a CRCP is 12 mm diameter deformed steel bars (T12) @ 600 mm spacings.*

6: *The longitudinal reinforcement for a CRCP requires 16 mm diameter deformed steel bars (T16) at R = 0.6%.*

7: *f_f denotes mean concrete flexural strength (N/mm² or MPa) at 28 days measured in accordance with BS EN 12390-5 (Testing hardened concrete. Part 5: Flexural strength of test specimens). Where f_f = 4.5, 5.0, 5.5 or 6.0 MPa.*

8: *Where a CRCP is designed with an asphalt surfacing, no binder course is required. A minimum asphalt surfacing thickness of 30 mm is recommended.*

9: *For Foundation options see Table 4.3.*

10: *Maximum Design Traffic = 400 M CESA.*

11: *Crack inducers shall not be used with CRCP designs.*

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Appendices

Appendix A: List of Standards

A.1 Introduction

This Appendix lists the Kenyan Standards (KS), East African Standards (EAS), Eurocode (EN), International Standardisation Organisation (ISO) and British (BS) Standards mentioned in the text of this part of the manual. This list to assist the designer, but it should be noted that the list may not be complete, and the designer should check if other relevant standards are available.

The standards are listed in subject groups and within each group the standards are ordered in terms of KS or KS EAS or KS ISO, then ISO, then BS EN, EN, BS ISO and BS, each in number order. Please note that dates have been removed, so that this document does not become out of date as soon as a standard is updated. The latest version of a standard should always be used, except where stated.

According to the Standards ACT CAP 496, it is a legal requirement to meet the Kenya standards. Thus, where a Kenya standard exists then it must be met. For information about Kenya standards, consult the Kenya Bureau of Standards (KEBS) website: www.kebs.org. Other standards should only be used in cases where no Kenya standards exists.

It should be noted that Kenya has adopted Eurocode Standards (EN) and by January 2021, all British Standards (BS) should have been replaced by EN. Some BS are still listed as they may still be useful to the reader.

The East African Standards (EAS) comprise the following countries: Tanzania, Kenya, Uganda, Rwanda, Burundi, and Somali.

For further information about testing of concrete and associated materials, see **RDM Volume 3 Part.2: Materials - Field and Laboratory Testing**.

A.2 Concrete (General)

KS 95	Specification for natural aggregates for use in concrete
KS 594	Specification for concrete.
KS EAS 18-1	Cement - Part 1: Composition, spec'n & conformity criteria for common cements.
KS EAS 131-1	Concrete - Part 1: Specification, performance, production, and conformity.
KS EAS 981	Hydraulic road binders – Specification.
BS EN 206 +A2	Concrete - Specification, Performance, Production & Conformity.
BS EN 450-1	Fly ash for concrete Pt1: Definition, specifications & conformity criteria.
BS EN 450-2	Fly ash for concrete Pt2: Conformity evaluation.
BS EN 13286-4	Unbound and hydraulically bound mixtures. Test methods for laboratory reference density and water content. Vibrating hammer.
BS EN 13877-1	Concrete Pavements Part 1: Materials.
BS EN 13877-2	Concrete Pavements Part 2: Functional requirements for concrete pavements.
BS EN 13877-3	Concrete Pavements Part 3: Specifications for dowels in concrete pavements.
BS 8500-1+A2	Concrete Part 1: Method of specifying & guidance for the specifier. (Complementary to BS EN 206).
BS 8500-2+A2	Concrete Part 2: Specification for constituent materials and concrete. (Complementary to BS EN 206).
BS 9227	Hydraulically bound materials for Civil Engineering purposes. Specification for production and installation in pavements. (Includes Annex E: Guidance on constituents & mix design for RCC).

A.3 Testing Fresh and Hardened Concrete

KS ISO 1920	Testing of concrete-Parts 1-7.
BS EN 12350	Testing Fresh Concrete – Parts 1-4.
BS EN 12390	Testing Hardened Concrete - Parts 1-5.
BS EN 12504-1	Testing concrete in structures. Cored samples. Pt 1: Taking, examining & compression testing.

A.4 Steel Reinforcement, Dowel Bars, Tie Bars, Fibres, etc

KS 22	Hot-rolled mild steel bars for reinforcement of concrete – Specification.
KS 101	Methods of detailing reinforced concrete.
KS 105	Specification for hard drawn steel wire for reinforcement of concrete.
KS 106	Specification for bending & scheduling of bars for concrete reinforcement.
KS EAS 134	Cold rolled steel sections - Specification.
KS EAS 412-1	Steel for the reinforcement of concrete-Part 1: Plain bars.
KS EAS 412-2	Steel for the reinforcement of concrete-Part 2: Ribbed bars.
KS EAS 412 -3	Steel for the reinforcement of concrete-Part 3: Welded fabric.
BS EN 10080	Steel for Reinforcement of Concrete Weldable reinforcing steel.
BS EN 13877-1	Concrete pavements Part 1: Materials.
BS EN 13877-2	Concrete Pavements Part 2: Functional requirements for concrete pavements.
BS EN 13877-3	Concrete Pavements - Specifications for dowels in Concrete Pavements.
BS EN 14889-1	Fibres for concrete. Steel fibres. Definitions, specifications and conformity.
BS EN 14889-2	Fibres for concrete. Polymer fibres. Definitions, specifications & conformity.

A.5 Joint Sealants

KS 1744	Specification for cold-applied joint sealants for concrete pavements (polymer based with a curing agent).
KS 1759	Specification for hot-applied joint sealants for concrete pavements.
BS EN 14188-1	Joint fillers & sealants Pt 1: Specifications for hot applied sealant.
BS EN 14188-2	Joint fillers & sealants Pt 2: Specifications for cold applied sealant.
BS EN 14188-3	Joint fillers & sealants Pt3: Specifications for preformed joint sealant.

A.6 Surface Characteristics

BS EN 13036-1	Road and airfield surface characteristics. Test methods. Part 1: Measurement of pavement surface macrotexture depth using a volumetric patch technique.

A.7 Concrete Block Paving

KS 827	Specification for precast concrete paving blocks (2nd Edition).
BS EN 1338	Concrete paving blocks - Requirements and test methods.

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