

**REPUBLIC OF SIERRA LEONE**



**SIERRA LEONE ROADS AUTHORITY**

# **MANUAL FOR LOW-VOLUME ROADS**

## **PART D: DESIGN OF LOW-VOLUME ROAD SURFACINGS**

## ABBREVIATIONS, ACRONYMS AND INITIALISMS

>	:	Greater than
<	:	Less than
%	:	Percentage

### A

AADT	:	Annual Average Daily Traffic
AADTT	:	Annual Average Daily Truck Traffic
AASHTO	:	American Association of State Highway and Transportation Officials
ALD	:	Average Least Dimension
ASTM	:	American Society for Testing and Materials

### B

BS	:	British Standards
BS EN	:	British Standards European Norm

### C

CBR	:	California Bearing Ratio
CSIR	:	Council for Scientific and Industrial Research

### D

DCP	:	Dynamic Cone Penetrometer
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### E

EF	:	Equivalency Factor
e.g.	:	For example (abbreviation for the Latin phrase <i>exempli gratia</i> )
ESA	:	Equivalent Standard Axles

### F

FACT	:	Fine Aggregate Crushing Test
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### G

g/m <sup>2</sup>	:	Grams per Square Metre
GM	:	Grading Modulus

### H

### I

i.e.	:	That is (abbreviation for the Latin phrase <i>id est</i> )
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### K

### L

LVR	:	Low Volume Road
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### M

mm	:	Millimetre
MC	:	Medium Curing
MPa	:	Megapascal (a unit of pressure equal to 1000 kilopascals (kPa), commonly used in the building industry to measure crushing pressure of bricks)

**N****O**

OMC : Optimum Moisture Content)  
ORN : Overseas Road Note

**P**

Pen. : Penetration  
PJCP : Plain Jointed Concrete Pavements

**R**

RC : Rapid Curing  
ReCAP : The Research for Community Access Partnership  
RS : Road Safety

**S**

SC : Subgrade Class

**T**

TLC: Traffic Load Class

**U**

UTRCP : Ultra-Thin Reinforced Concrete Pavement

**V**

VEF : Vehicle Equivalency Factor

**W**

WC : Wearing Course

## GLOSSARY OF TECHNICAL TERMS

### **Aggregate (for construction)**

A broad category of coarse particulate material including sand, gravel, crushed stone, slag and recycled material that forms a component of composite materials such as concrete and asphalt.

### **Asphalt Concrete**

A mixture of inert mineral matter, such as aggregate, mineral filler (if required) and bituminous binder in predetermined proportions.

### **Atterberg limits**

Basic measures of the nature of fine-grained soils which identify the boundaries between the solid, semi- solid, plastic and liquid states.

### **Binder, Bituminous**

Any bitumen-based material used in road construction to bind together or to seal aggregate or soil particles.

### **Binder, Modified**

Bitumen based material modified by the addition of compounds to enhance performance. Examples of modifiers are polymers, such as PVC, and natural or synthetic rubbers.

### **Bitumen**

A non-crystalline solid or viscous mixture of complex hydrocarbons that possesses characteristic agglomerating properties, softens gradually when heated, is substantially soluble in trichlorethylene and is obtained from crude petroleum by refining processes.

### **Bitumen, Cutback**

A liquid bitumen product obtained by blending penetration grade bitumen with a volatile solvent to produce rapid curing (RC) or medium curing (MC) cutbacks, depending on the volatility of the solvent used. After evaporation of the solvent, the properties of the original penetration grade bitumen become operative.

### **Bitumen, Penetration Grade**

That fraction of the crude petroleum remaining after the refining processes which is solid or near solid at normal air temperature and which has been blended or further processed to products of varying hardness or viscosity.

### **Bitumen emulsion**

An emulsion of bitumen and water with the addition of an emulsifier or emulsifying agent to ensure stability. Conventional bitumen emulsion most commonly used in road works has the bitumen dispersed in the water. An invert bitumen emulsion has the water dispersed in the bitumen. In the former, the bitumen is the dispersed phase and the water is the continuous phase. In the latter, the water is the dispersed phase and the bitumen is the continuous phase. The bitumen is sometimes fluxed to lower its viscosity by the addition of a suitable solvent.

### **Bitumen Emulsion, Anionic**

An emulsion where the emulsifier is an alkaline organic salt. The bitumen globules carry a negative electrostatic charge.

### **Bitumen Emulsion, Cationic**

An emulsion where the emulsifier is an acidic organic salt. The bitumen globules carry a positive electrostatic charge.

## **Bitumen Emulsion Grades**

Premix grade: An emulsion formulated to be more stable than spray grade emulsion and suitable for mixing with medium or coarse graded aggregate with the amount smaller than 0.075mm not exceeding 2%.

Quick setting grade: An emulsion specially formulated for use with fine slurry seal type aggregates, where quick setting of the mixture is desired.

Spray grade: An emulsion formulated for application by mechanical spray equipment in chip seal construction where no mixing with aggregate is required.

Stable mix grade: An emulsion formulated for mixing with very fine aggregates, sand and crusher dust. Mainly used for slow-setting slurry seals and tack coats.

## **Cement (for construction)**

A dry powder which on the addition of water and other additives, hardens and sets independently to bind aggregates together to produce concrete.

## **Chip Seal, Single**

An application of bituminous binder followed by a layer of stone or clean sand. The stone is sometimes covered with a fog spray.

## **Chip Seal, Double**

An application of bituminous binder and stone followed by a second application of binder and stone or sand. A fog spray is sometimes applied on the second layer of aggregate.

## **Concrete**

A construction material composed of cement (commonly Portland cement) as well as other cementitious materials such as fly ash and slag cement, aggregate (generally a coarse aggregate such as gravel or crushed stone plus a fine aggregate such as sand), water, and chemical admixtures.

## **Concrete Block Paving**

A course of interlocking or rectangular concrete blocks placed on a suitable base course and bedded and jointed with sand.

## **Crushed Stone**

A form of construction aggregate, typically produced by mining a suitable rock deposit and breaking the removed rock down to the desired size using crushers.

## **Filler**

Mineral matter composed of particles smaller than 0.075mm.

## **Fog Spray**

A light application of diluted bitumen emulsion to the final layer of stone of a reseal or chip seal or to an existing bituminous surfacing as a maintenance treatment.

## **Gravel**

A naturally-occurring, weathered rock within a specific particle size range. In geology, gravel is any loose rock that is larger than 2mm in its largest dimension and not more than 63mm.

## **Labour Based Construction**

Economically efficient employment of as great a proportion of labour as is technically feasible throughout the construction process to produce the standard of construction as demanded by the specification and allowed by the available funding. Substitution of equipment with labour as the principal means of production.

**Low Volume Road**

Roads carrying up to about 300 vehicles per day and less than about 1 million equivalent standard axles over their design life.

**Otta Seal**

Sprayed bituminous surfacing using graded natural gravel rather than single-sized crushed rock.

**Paved Road**

A road that has a bituminous, concrete or alternative (e.g. segmental blocks) riding surface

**Prime Coat**

A coat of bituminous binder applied to a non-bituminous granular pavement layer as a preliminary treatment before the application of a bituminous base or surfacing. While adhesion between this layer and the bituminous base or surfacing may be promoted, the primary function of the prime coat is to assist in sealing the surface voids and bind the aggregate near the surface of the layer.

**Reseal**

A surface treatment applied to an existing bituminous surface.

**Seal**

A term frequently used instead of “reseal” or “surface treatment”. Also used in the context of “double seal” and “sand seal” where sand is used instead of stone.

**Selected layers**

Pavement layers of selected gravel materials used to bring the subgrade support up to the required structural standard for placing the subbase or base course.

**Site Investigation**

Collection of essential information on the soil and rock characteristics, topography, land use, natural environment, and socio-political environment necessary for the location, design and construction of a road.

**Slurry**

A mix of suitably graded fine aggregate, cement or hydrated lime, bitumen emulsion and water, used for filling the voids in the final layer of stone of a new surface treatment or as a maintenance treatment (also referred to as a slurry seal).

**Subgrade**

The native material underneath a constructed road pavement.

**Surface Treatment**

A general term incorporating chip seals, micro surfacing, fog sprays or tack coats.

**Surfacing**

The layer with which traffic makes direct contact.

**Tack Coat**

A coat of bituminous binder applied to a primed layer or to an existing bituminous surface as a preliminary treatment to promote adhesion between the existing surface and a subsequently applied bituminous layer.

**Ultra-thin Reinforced Concrete Pavement (UTRCP)**

A layer of concrete, 50 mm thick, continuously reinforced with welded wire mesh.

**Unpaved road**

Earth or gravel road.

**Wearing Course**

The upper layer of a road pavement on which the traffic runs and is expected to wear under the action of traffic.

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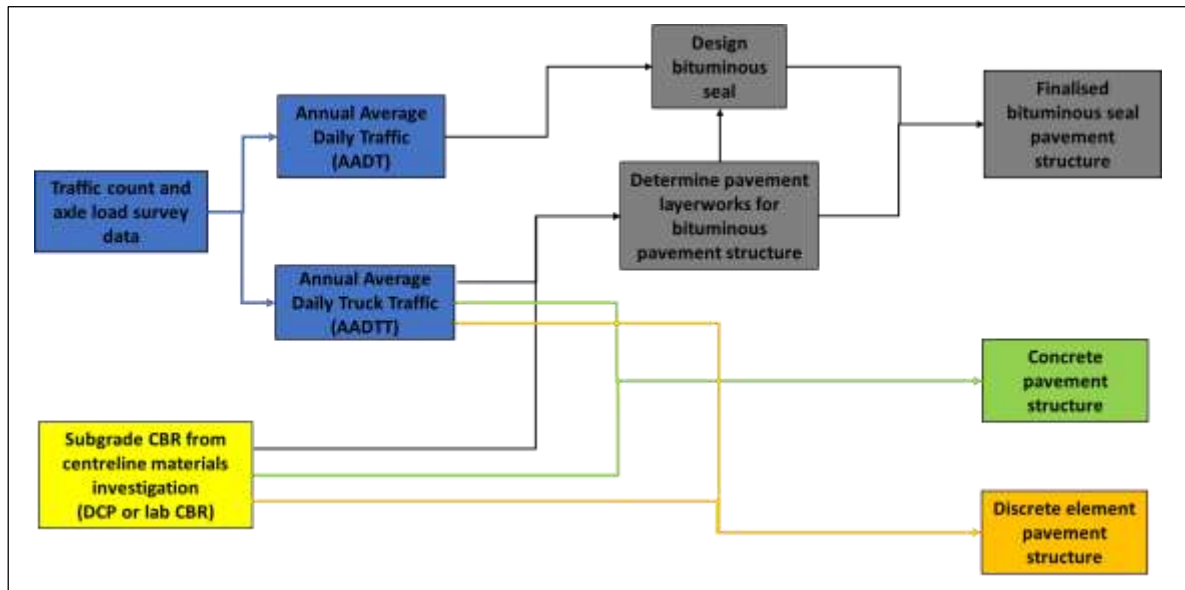
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# 1 INTRODUCTION

An extensive study (Hartman, Calitz, & Pretorius, 2018) was done to investigate alternative methods for the surfacing of low-volume gravel roads in Sierra Leone. Different alternative surfacing types were evaluated in keeping with technical and financial criteria developed during the study. Subsequently, the most appropriate surfacing options for the context of Sierra Leone were identified and listed. In this design specification, only those surfacing options that were listed are discussed. (There are other surfacing types, though, and they can be considered as well, depending on the conditions prevailing on site.)

Importantly, all the surfacing designs that are discussed in this manual will require knowledge of the design traffic and the subgrade conditions indicated in Figure 1.



**Figure 1: Flow diagram of design inputs for various surfacing and pavement types**

In Sections 1.1 and 0 below, the traffic and subgrade classifications described in (Geddes & Goldie-Scot (2018) are summarised, because these components are important in surfacing design. For the design and specification of supporting layerworks, refer to Geddes & Goldie-Scot (2018). Geddes & Goldie-Scot (2018). A summary of the material types used for selected, subbase and base layers is provided in Table 1.

**Table 1: Material properties (Geddes & Goldie-Scot, 2018)**

Material Properties	Material class					
	G7	G15	G30	G40	G60	G80
DCP-DN value (mm/blow) (max)	24.6	13.5	7.84	6.77	4.54	3.62
CBR (%)	7	15	30	40	60	80
CBR Swell (%)	2.0	1.5	1.0	0.5	0.5	0.25
Grading:						
% Passing Sieve Size (mm)						
75					100	100
37.5					80-100	80-100
20					75-100	60-85
10					45-90	45-70
5.0					30-75	30-55
2.0					20-50	20-45
0.425					8-33	8-26
0.075					5-22	5-15
Grading Modulus (max)			2.6	2.5		
Grading Modulus (min)			1.25	1.5	1.95	2.15
Maximum size (mm)	2/3 layer thickness	2/3 layer thickness	2/3 layer thickness	75.0	63.0	53.0
Atterberg Limits:						
Liquid Limit LL (%) (max)			35	30	30	20
Plasticity Index PI (%) (max)	30	25	16	14	12	10
Linear Shrinkage LS (%) (max)			8	7	6	5
Plasticity Modulus PM (max)			250	250	250	200
Notes:						
DCP DN values to be determined on soaked samples.						
All CBR's to be determined at field density specified for the layer in which the material is used, usually 93% of Maximum Dry Density.						
All grading specifications are applicable after placing and compacting. Where applicable, grading curves shall be smooth curves within the specified envelopes and approximately parallel to the envelopes.						
Grading Modulus: $GM = 300 - (P_{0.2} + P_{0.425} + P_{0.075}) \times 100$						
Plasticity Modulus: $PM = PI \times P_{0.425}$						

## 1.1 Traffic

There are several important factors that must be considered when the traffic loading class of a pavement is to be determined, including:

- **Design period.** The design period of a pavement is defined as the time span in years for which the pavement will be in service before it reaches a level of terminal serviceability, after which rehabilitation or reconstruction will be required.
- **Initial traffic volume.** The initial traffic volume is the traffic volume per vehicle class when a new pavement is exposed to traffic for the first time.
- **Traffic growth.** There are various elements that must be considered to determine the traffic growth factor, including current traffic, generated traffic, and diverted traffic. Historical traffic and economic growth predictions should also be taken into account when the expected traffic growth rate is calculated.
- **Equivalent standard axle (ESA) load.** The load equivalency factor (EF) and vehicle equivalency factor (VEF) of a pavement must be considered. It is recommended that

axle load surveys be done. The EF relates an axle load to an equivalent 80kN axle through an exponential relationship, and the VEF is the mean EFs for a specific vehicle class. The equivalent standard axle (ESA) load is taken as 8 tonnes.

- **Daily equivalent standard axles.** Daily equivalent standard axles are the sum of the ESAs for all vehicles traversing a pavement in a single day.
- **ESA over the design period.** The ESA over the design period is the cumulative ESAs calculated from the total traffic prediction over the entire design period, taking the traffic growth and axle load growth into account.
- **Traffic lane distribution.** The ESAs will vary per lane when there is more than one lane in each direction. Heavy vehicles tend to concentrate in the outer, slower moving lanes.
- **Directional distribution.** In some cases, the traffic loading in different directions on the road is not equally distributed. On export corridors, for example, heavy loading in one direction would be greater than in the opposite direction. This should be considered during the design.

For a more detailed explanation of traffic calculation, refer to Section 2 of the manual for low-volume roads published by the Sierra Leone Roads Authority (Geddes & Goldie-Scot, 2018).

Predictions in traffic data may contain large errors, in part because of the uncertainty that accompanies predictions for ten or more years into the future. Because of potential errors, traffic classes are used. Traffic classes represent a standard pavement design that will be able to carry a band of design traffic. Table 2 contains a list of the traffic classes considered appropriate for low-volume roads.

**Table 2: Traffic loading classes for pavement design (Geddes & Goldie-Scot, 2018)**

Traffic load class (TLC)			
	TLC 0.01	TLC 0.3	TLC 1.0
Traffic range (ESA x 10 <sup>6</sup> )	< 0.01	0.01–0.3	0.3–1.0
Typical number of heavy vehicles per day	≤ 2	3–20	> 20

## 1.2 Subgrade

The subgrade is classified by using either the standard soaked California Bearing Ratio (CBR) test or the Dynamic Cone Penetrometer (DCP) method. In the manual for low-volume roads that was published by the Sierra Leone Roads Authority, four subgrade classes are indicated. These classes are given in Table 3.

**Table 3: Subgrade classes (Geddes & Goldie-Scot, 2018)**

Parameter	Subgrade class			
Subgrade class	SC1	SC2	SC3	SC4
ORN 31 Subgrade strength class (TRL, 1993)	S1	S2 & S3	S4	S5 & S6
CBR range %	< 3	3–7	8–14	≥ 15

For the SC1 subgrade class, no provision for layerworks design is made in this manual. The subgrade must be improved to a class SC2 before layerwork construction can commence.

(For further information about subgrade classification and design, refer to the manual for low-volume roads that was published by the Sierra Leone Roads Authority.)

### 1.3 Appropriate selection of surface treatments

(Cook, Petts, & Rolt, 2013) suggests an approach for selecting appropriate surface treatments, where unsuitable or high-risk options are eliminated using a series of road environment related screens before considering detail design. The following general process was proposed:

- Obtain all relevant information.
- Divide the road into sections of similar condition and required surfacing.
- Identify suitable surfacing solutions for each section – Table 4 provides some guidance.
- Compare initial and life cycle costs.
- Compare contracting resource in terms of knowledge, skills and available plant.
- Do final selection.

Surfacing Type	Plain Jointed	Ultra-Thin	Strip Roads	Otta Seal	Block Paving	Cobbles
<b>TRAFFIC</b>						
Light	✓	✓	✓	✓	✓	✓
Moderate	✓	✓		✓	✓	✓
Heavy	✓	✓		✓	✓	
<b>CONSTRUCTION REGIME</b>						
High labour content	✓	✓	✓		✓	✓
Intermediate machinery	✓	✓	✓		✓	✓
Moderate cost			✓	✓		
High cost	✓	✓			✓	✓
<b>MAINTENANCE REQUIREMENTS</b>						
Low	✓	✓			✓	
Moderate			✓	✓		✓
<b>OTHER</b>						
Poor aggregate quality				✓		
Limited supervision	✓		✓	✓	✓	

**Table 4: Factors affecting choice of surface treatments**

### 1.4 Content of this manual

In the three chapters that follow, the following three kinds of surfacing are discussed:

- Rigid or concrete surfacings
- Flexible or bituminous surfacings seals
- Semi-rigid or segmented paving surfacings

In each of the chapters, the material requirements and the design procedure for each of the types of surfacing are discussed. Details regarding construction that would affect the design of the surfacings are also discussed.

## 2 RIGID OR CONCRETE SURFACINGS

Concrete is an economical road surfacing for low-volume applications. All-weather passability can be promoted especially on steep sections where roads are prone to erosion. When concrete roads are constructed, the use of labour-intensive construction is possible.

This manual described three types of concrete surfacings that can be considered for low volume road application. These include:

- Plain Jointed Concrete Pavements (PJCPs)
- Strip roads
- Ultra-Thin Reinforced Concrete Pavements (UTRCPs)

The selection of any of these surfacings will depend on the conditions encountered on site. Strip roads are suitable only for very low traffic volumes. The construction of UTRCP requires high levels of supervision and more supporting layerworks.

### 2.1 Materials

In this section, the use of cement, aggregates, water, and admixtures in the mixing of concrete is discussed. Furthermore, the consistency of fresh concrete, the properties of hardened concrete, and the use of reinforcement are considered.

#### 2.1.1 Cement

Cement should comply with the requirements of ASTM C150 for Type 1 or Type 2 cement. Type 1 cement can be defined as general-purpose cement that is used when concrete is not subject to exposures such as sulphate attack. Temperature rise during hydration is relatively higher compared to other cement types. Type 2 cement is used when there is a moderate risk of sulphate attack. The heat generation during hydration is also less than heat generation when Type 1 cement is used.

The important ingredients in cement include (Civil Engineering, 2018):

- **Lime.** The correct amount of lime is important because a deficiency in lime will cause the cement not to reach adequate strength and it will set quickly. Excess lime will make cement unsound and can cause expansion and disintegration of concrete.
- **Silica.** The quantity of silica should be considered in conjunction with the quantities of di-calcium and tri-calcium silicate. Silica is necessary for strength gain in concrete.
- **Magnesia.** The quantity of magnesia should be controlled, as excess magnesia will reduce the strength of cement.
- **Iron oxide.** Iron oxide is important for hardness and strength gain.
- **Alumina.** Alumina is responsible for the quick-setting properties of cement. An excessive quantity of alumina weakens the cement.
- **Sulphur trioxide.** The quantity of sulphur trioxide should be controlled, as quantities of more than 2% could cause cement to be unsound.
- **Calcium sulphate.** Calcium sulphate retards the setting action of cement.
- **Alkaline.** Excess alkaline matter causes efflorescence.

For the specifications regarding the composition of the cement refer to ASTM C150.

Fly ash or natural pozzolans can be used to alter the properties of cement. Three classes of fly ash and natural pozzolans are discussed in ASTM C618:

- Class N: Raw or calcined natural pozzolans

- Class F: Fly ash produced from burning anthracite or bituminous coal
- Class C: Fly ash produced from lignite or subbituminous coal

### 2.1.2 Aggregates

Aggregates should generally comply with the requirements set out in ASTM C33/C33M. The grading specification for sand is given in Table 5, and the grading specification for aggregate relevant to this design specification is indicated in Table 6.

**Table 5: Grading specification for sand (refer to ASTM C33/C33M)**

Sieve size	% Passing	
9.5 mm	100	100
4.75 mm	100	95
2.36 mm	100	80
1.18 mm	85	50
600 µm	60	25
300 µm	30	5
150 µm	10	0

In addition to this specification, fine aggregates should also possess an acid insolubility of at least 40%. This is to promote proper skid resistance. When quartzose sand is used, this requirement should be satisfied. Dolomites and other calcareous sands can be used if blended with at least 40% of a suitable quartzose sand.

The dust content (material passing the 75 µm sieve) must not exceed 5% by mass. The fines modulus must fall within the range of 1.2 to 3.5. The chloride content of fine aggregate, expressed as a percentage by mass, must not exceed 0.08% (Cement and Concrete Institute, 2009).

**Table 6: Grading specification for aggregate (refer to ASTM C33/C33M)**

Code	Nominal size, sieves with square openings	Amounts finer than each laboratory sieve, mass percentage passing							
		37.5 mm	25 mm	19 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm
5	25 to 12.5 mm	100	90 to 100	20 to 55	0 to 10	0 to 5	-	-	-
56	25 to 9.5 mm	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	-	-
57	25 to 4.75 mm	100	95 to 100	-	25 to 60	-	0 to 10	0 to 5	-
6	19 to 9.47 mm	-	100	90 to 100	20 to 55	0 to 15	0 to 5	-	-
6-7	19 to 4.75 mm	-	100	90 to 100	-	20 to 55	0 to 10	0 to 5	-
7	12.5 to 4.75 mm	-	-	100	90 to 100	40 to 70	0 to 15	0 to 5	-
8	9.5 to 2.36 mm	-	-	-	100	85 to 100	10 to 30	0 to 10	0 to 5

Except for the grading requirements in Table 6, coarse aggregate must have a flakiness index of less than 35% (BS 812-105.1). The dry aggregate crushing value must not exceed 29%

(BS 812-110). The 10% Fines Aggregate Crushing Value (FACT) should range between 100 and 300 kN (Cement and Concrete Institute, 2009).

For PJCPs and strip roads, the nominal maximum size of coarse aggregate should be limited to one quarter of the pavement thickness. **For UTRCPs, the recommended nominal stone size is 9 mm.**

### 2.1.3 Water

Water used in concrete preparation should be clean and potable. If there is any uncertainty about the quality of the water, the water should be tested as stipulated in BS EN 1008. When the water is tested, consideration should be given to both the composition of the water and the intended application of the concrete to be produced. Aspects that are important regarding the water used in concrete include (Cement and Concrete Institute, 2009):

- **Chloride content.** The chloride content must not exceed 1 000 mg/l for concrete with reinforcement (such as plain-jointed concrete with tied longitudinal joints) and 4 500 mg/l for concrete without reinforcement.
- **Sulphate content.** The sulphate content of water should not exceed 2 000 mg/l.
- **Alkali content.** When alkali-reactive aggregates are used to produce concrete, the equivalent sodium oxide content of the water must not exceed 1 500 mg/l.
- **Harmful contaminants.** Tests should be conducted to determine the presence of sugar, phosphate, lead, zinc, and nitrates.

### 2.1.4 Admixtures

In this section, the use of chemical admixtures and air-entraining agents to modify concrete is explored.

#### 2.1.4.1 Chemical admixtures

Chemical admixtures can be used to adjust the properties of fresh concrete so as to (Cement and Concrete Institute, 2009):

- Reduce the water content of concrete without reducing its slump
- Increase the slump of concrete without increasing its water content
- Reduce the segregation of the concrete
- Increase the pumpability of concrete
- Adjust the setting time of concrete
- Reduce bleeding of the concrete

In ASTM C494, the following seven chemical admixtures and their properties are discussed:

- Type A - Water-reducing admixtures
- Type B - Retarding admixtures
- Type C - Accelerating admixtures
- Type D - Water-reducing and retarding admixtures
- Type E - Water-reducing and accelerating admixtures
- Type F - Water-reducing, high-range admixtures
- Type G - Water-reducing, high-range, and retarding admixtures



#### **2.1.4.2 Air-entraining agents**

When they are used in concrete, air-entraining agents can:

- Improve the handling properties of concrete
- Improve the compaction of low-workable concrete
- Improve the cohesion of concrete and reduce bleeding

Overdosing of air-entraining admixtures could result in a loss in concrete strength. (Refer to ASTM C494 for the properties of air-entraining agents.)

#### **2.1.5 Consistency of fresh concrete**

The slump test (Test Method BS EN 12350-2) can be used to measure the consistence of concrete. For hand-compacted concrete, a slump of 70 to 120 mm is used, and for vibrated concrete, a slump of 30 to 70 mm is used.

***For ultra-thin reinforced concrete pavements, the recommended slump is 75 mm.***

#### **2.1.6 Properties of hardened concrete**

To ensure a hard, durable, skid-resistant surface, and to accommodate the tensile stresses resulting from warping, shrinkage, and loading, the concrete should possess adequate strength. To meet this requirement, a target flexural strength or modulus of rupture is typically specified during the design. The flexural strength requirement will be met when the concrete has a characteristic 28-day compressive strength of 30 MPa. The 28-day compressive strength can be tested in accordance with the procedures set out in ASTM C192/C192M, ASTM C172 and BS EN 12390-3.

To ensure a durable concrete mixture, the maximum water–cement ratio should be limited to 0:52. The cement content should not be less than 310 kg/m<sup>3</sup>.

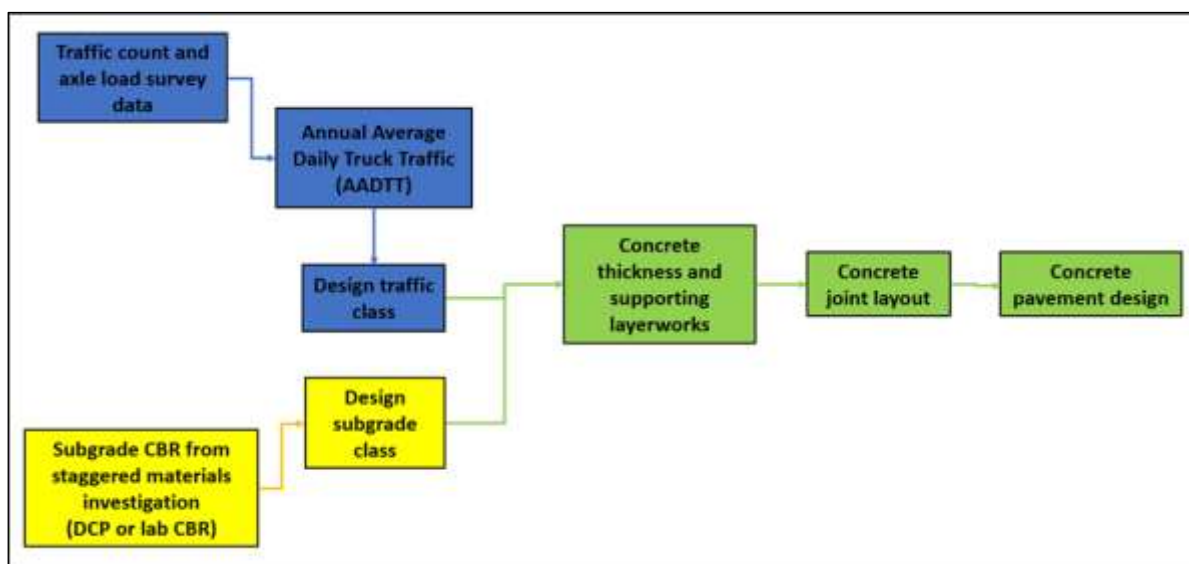
#### **2.1.7 Reinforcement**

Reinforcement used for UTRCP should be welded wire mesh conforming to the requirements indicated in BS EN 10080. The aperture size of the mesh should be 100 x 100 mm, and the diameter of the steel bars should be 4 mm. The mesh should be supplied in sheets of 6 m by 2.4 m. Wired mesh in rolls is not acceptable.

Tiebar reinforcement used for PJCP should be high-tensile steel conforming to the requirements set out in BS EN 10080.

### **2.2 Design**

The design procedure for concrete surfacings is shown in Figure 2, and includes the layerworks and concrete thickness designs for PJCP, concrete strip roads, and UTRCP.



**Figure 2: Flow diagram of the design procedure for concrete surfacings**

In the sections that follow, design requirements for PJCPs, concrete strip roads, and UTRCPs are considered.

### 2.2.1 Plain-jointed concrete pavement surfacings

Thickness design, joints, nominal reinforcement for oddly shaped slabs, steep slopes, and the use of plum concrete must be considered in the design of PJCPs.

#### 2.2.1.1 Thickness design

Table 7 provides a catalogue that can be used to determine the concrete layer thickness for PJCPs. For lower subgrade classes, additional layerworks will be required as indicated in Table 7.

**Table 7: Plain-jointed concrete pavement layerworks and thickness design**

Traffic class	Pavement layer	Subgrade class (CBR %)		
		SC2 (3–7%)	SC3 (8–14%)	SC4 (≥ 15%)
TLC 0.01	Concrete	130 mm	130 mm	130 mm
	Subbase	150 mm G15	150 mm G15	none
	Capping layer	150 mm G7	none	none
TLC 0.3	Concrete	130 mm	130 mm	130 mm
	Subbase	150 mm G15	150 mm G15	none
	Capping layer	150 mm G7	none	none
TLC 1.0	Concrete	165 mm	150 mm	150 mm
	Subbase	150 mm G15*	150 mm G15*	none
	Capping layer	150 mm G7	none	none

\* It is recommended that these subbase layers be stabilised to enhance the long-term performance of these pavements. G7, G15 refer to granular materials as defined in Table 1 and discussed in Geddes & Goldie-Scot (2018)

#### 2.2.1.2 Joints

Joints have three functions in concrete pavements:

- To facilitate construction and level control
- To control cracking and limit stresses
- To accommodate concrete movements such as expansion and contraction due to temperature changes

There are three main types of joints to be considered for PJCPs in a low-volume road application:

- **Tie joints:** Tie joints are usually used in longitudinal joints when two or more traffic lanes need to be held tightly together. A tie joint can be formed with a key or can be wet-formed or saw-cut and includes a tie bar that holds the two slabs together.
- **Contraction joints:** Contraction joints allow horizontal movement between two slabs due to thermal effects and are usually placed in a transverse direction along the pavement. In PJCP, these joints are not reinforced, and are either formed with a key to facilitate load transfer or saw-cut or wet-formed to induce a crack. Load transfer is then realised through aggregate interlock across the crack.
- **Isolation joints:** Isolation joints allow horizontal and vertical movement across abutting elements. Complete separation between the elements is achieved through the use of a compressible, preformed joint filler.

In the sections that follow, the different kinds of joints required in a PJCP are discussed in detail. Moreover, construction joints, joint layout, and joint sealing are also considered.

#### 2.2.1.2.1 Tie or longitudinal joints

A typical detail of a tie joint is shown in Figure 3. The purpose of longitudinal joints is to control cracking. The spacing of longitudinal joints should not exceed 4 m. Longitudinal joints can be constructed in one of two ways, as shown in Figure 4. When lanes are cast in separate pours, it is advised that a keyed joint be used, as indicated at the top of Figure 4. For the construction of more than one lane at a time, a sawn or wet-formed joint can be used, as shown at the bottom of Figure 4.

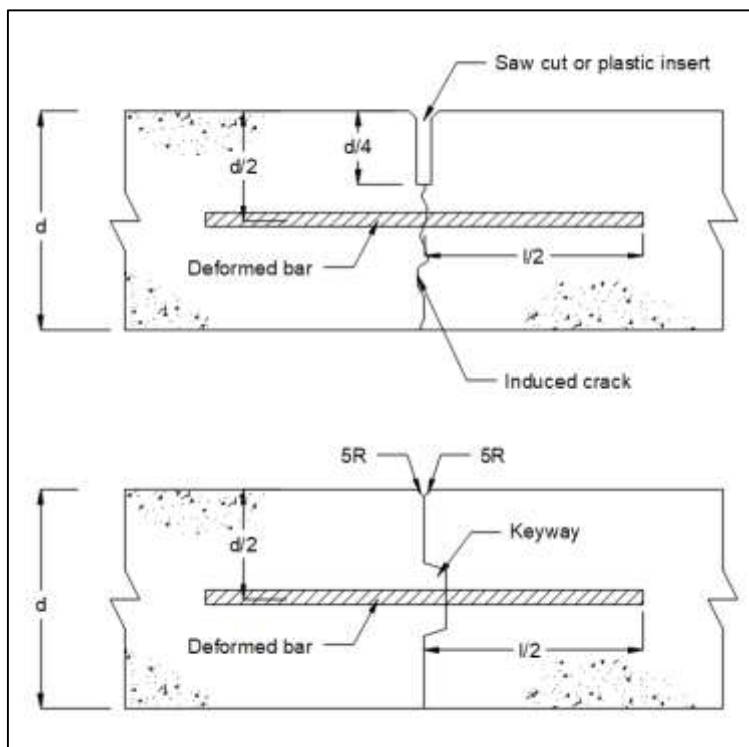


Figure 3: Typical detail of tie joints

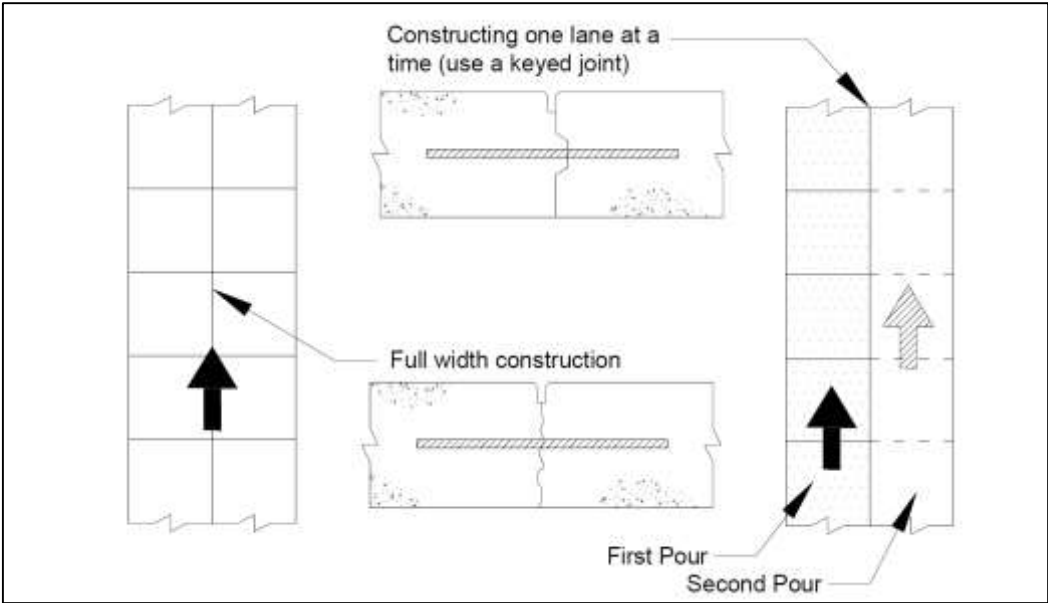


Figure 4: Construction of longitudinal joints (Perrie, 2000)

Details on keyed joints are presented in Figure 5. The keyway is half-round or trapezoidal.

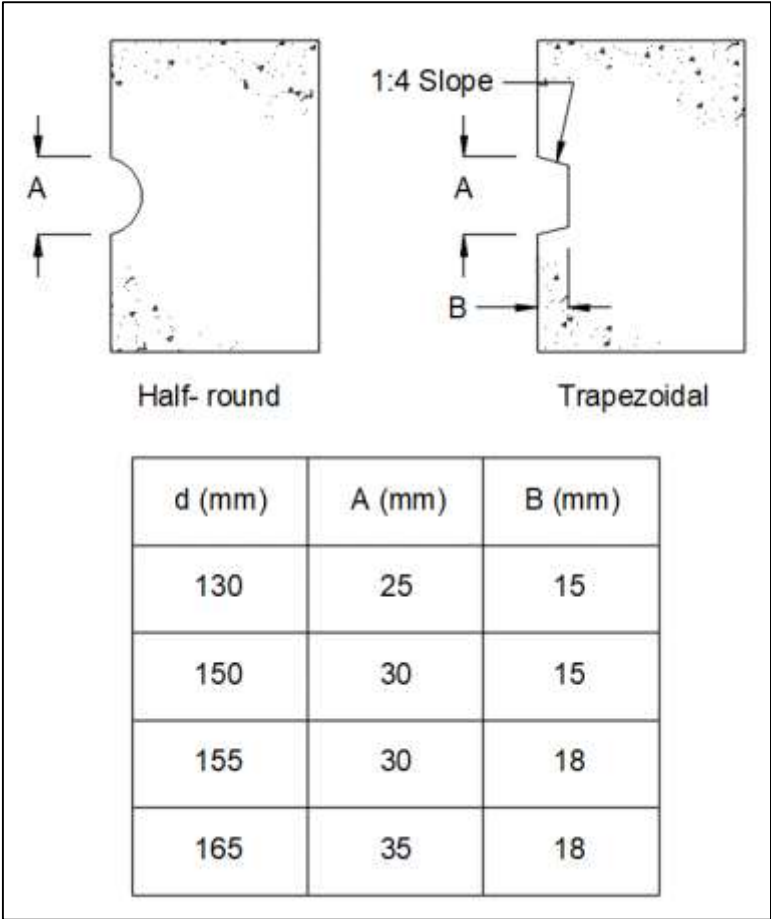


Figure 5: Standard keyway dimensions (Perrie, 2000)

Before a second pour is done next to an existing pavement section, it is important that a bond breaker be applied to the surface of the concrete face. Products suitable for this purpose include bitumen emulsion and lime-wash.

When lanes are cast simultaneously, sawn or wet-formed joints can be used. Sawing of the joint should commence as soon as the concrete has hardened, which can take 4 to 24 hours. Joints should be sawn before uncontrolled cracking occurs. Sawn joints should not be more than 3 mm wide. Where sealing of the joints is required, the top portion of the groove should be reamed out to the required width and depth not earlier than 7 days after sawing the joint. As soon as the sawing operation is complete, the joint should be washed out with a jet of clean water to remove all fines. The joint must then be sealed temporarily with paper rope or fibre cord.

Wet-formed joints (indicated in Figure 6) can be formed with a polyethylene sheet or bituminous felt. The polyethylene sheet should be a 90 g/m<sup>2</sup> sheet with a thickness of about 0.1 mm. The sheet should be placed on the concrete, and a metal bar of 6 mm should be pushed into the concrete. It is customary to allow the sheet to be about 20 mm wider than twice the depth of the joint to facilitate inspection of joints. The polyethylene strip or bituminous felt is left in the concrete.

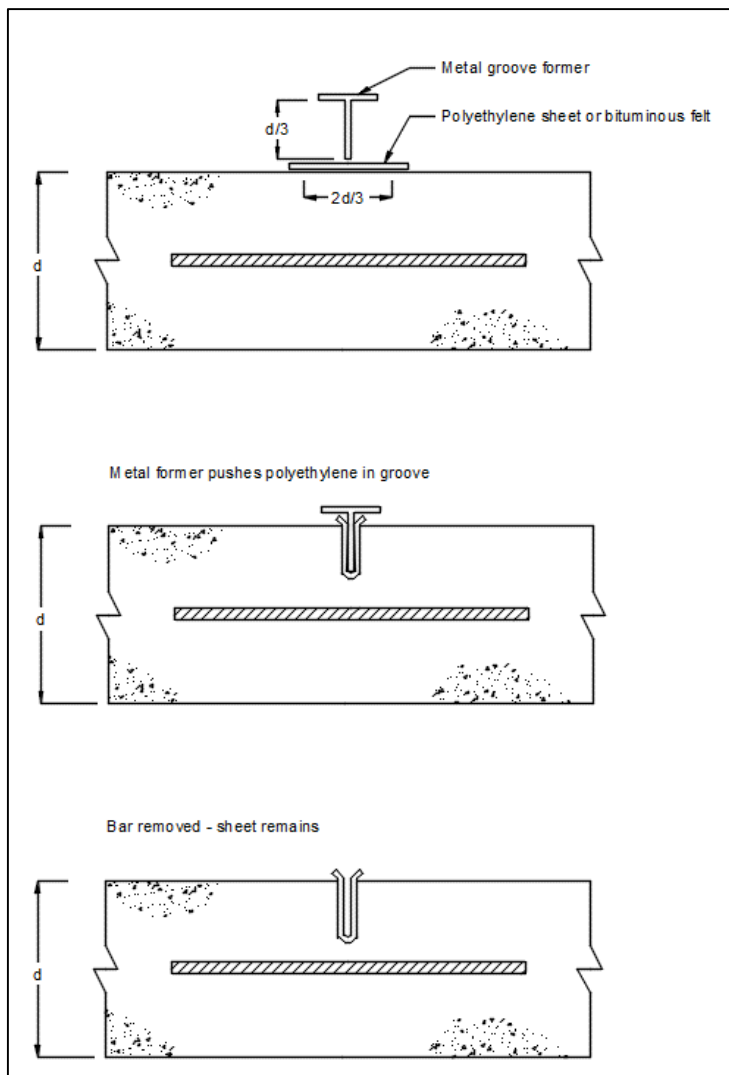


Figure 6: Steps in wet-forming of a joint (Perrie, 2000)

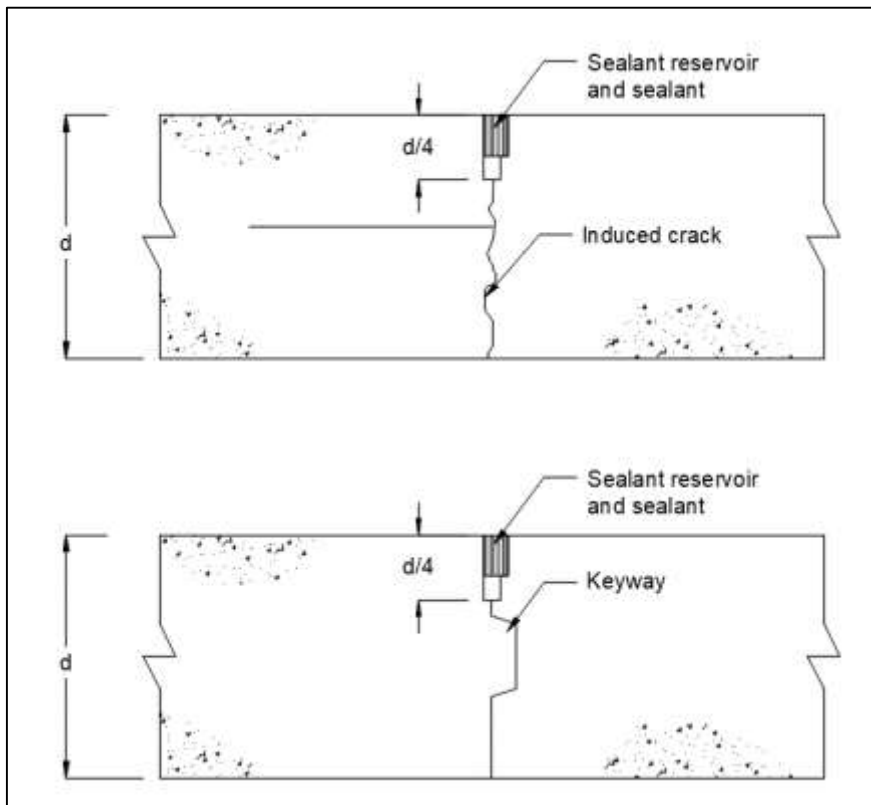
Tie bars must be placed at mid depth of the concrete slab. The purpose of the tie bars is to maintain aggregate interlock, structural capacity, and serviceability. The tie bar sizes and spacing for the various slab thicknesses (see Section 2.2.1.1) are indicated in Table 8.

**Table 8: Tie bar sizes and spacing for slab thicknesses**

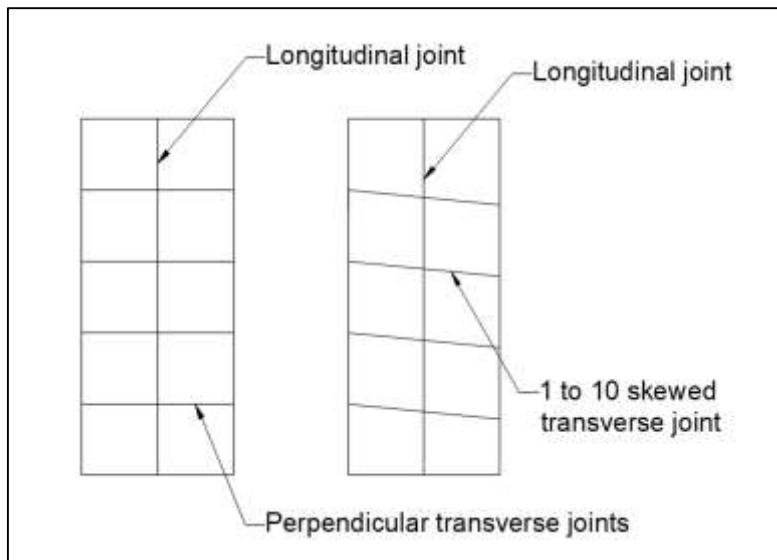
Slab thickness (mm)	Bar diameter (mm)	Spacing (mm)
130	10	750
150	12	750
165	12	750

**2.2.1.2.2 Contraction or transverse joints**

A typical detail of a contraction joint is shown in Figure 7. Transverse joints are normally perpendicular to the centreline and the pavement edges. Transverse joints can also be skewed, as indicated in Figure 8. The purpose of skewed joints is to reduce the dynamic loading across joints by preventing the simultaneous crossing of wheels on an axle over a specific joint. The angle of the joint should be limited to 1 to 10 to prevent excessive corner breaks (Pavement Interactive, 2018).



**Figure 7: Typical detail of contraction joint**



**Figure 8: Perpendicular and skewed transverse joints**

The purpose of transverse joints is to:

- Relieve curling stresses caused by moisture and temperature gradients in slabs
- Relieve stresses that occur when slabs contract

There are several ways to form a transverse joint (refer to Section 2.2.1.2.1 for more details). Joints can be constructed by either:

- Sawing the joint after the concrete has set or
- Inserting a preformed strip into the plastic concrete

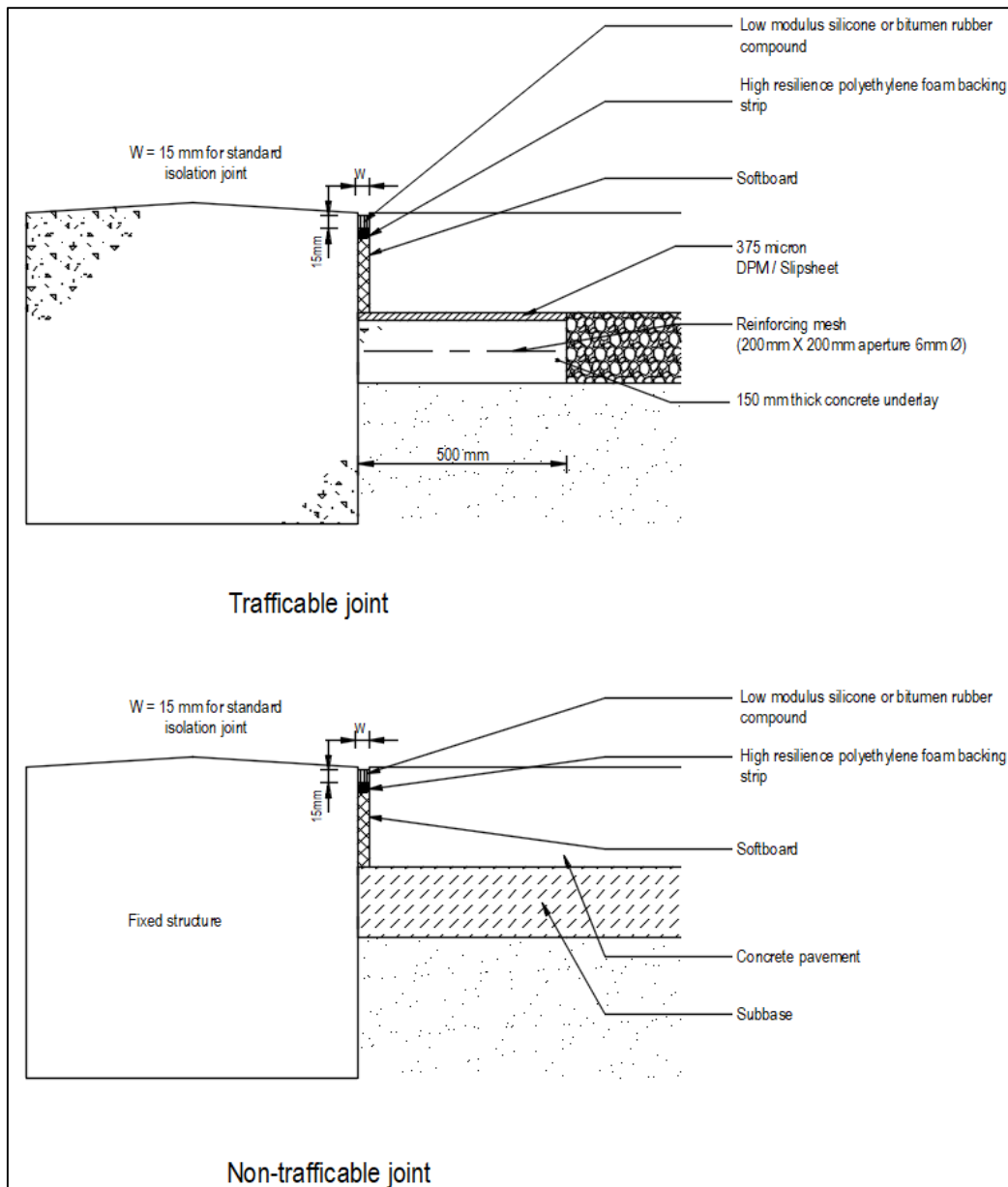
It is important that the following be taken into consideration when a joint forming method is selected:

- Aggregate characteristics
- Weather during construction
- The economics of the operation and results achieved

The joint depth should be one quarter of the pavement thickness. When the concrete surfacing is constructed on a stabilised subbase, the thickness should be increased to one third of the pavement depth.

### **2.2.1.2.3 Isolation joints**

An isolation joint is formed to isolate the pavement from an immovable object, a structure, or another pavement area (e.g. at a bridge or culvert structure). The joint should provide a complete separation from adjacent slabs. A joint filler can be used to prevent water ingress. Generally, a concrete underlay is added when the joint is traversed by traffic. A typical detail for an isolation joint is presented in Figure 9.



**Figure 9: Typical isolation joint detail**

#### **2.2.1.2.4 Construction joints**

Construction joints are inserted at planned intervals, e.g. when construction ends at the end of a day. Construction joints can also be placed as an emergency measure, e.g. when it starts to rain. The last reason for making construction joints is when alternate panel construction is used. The joint is usually key formed as indicated in Figure 5.

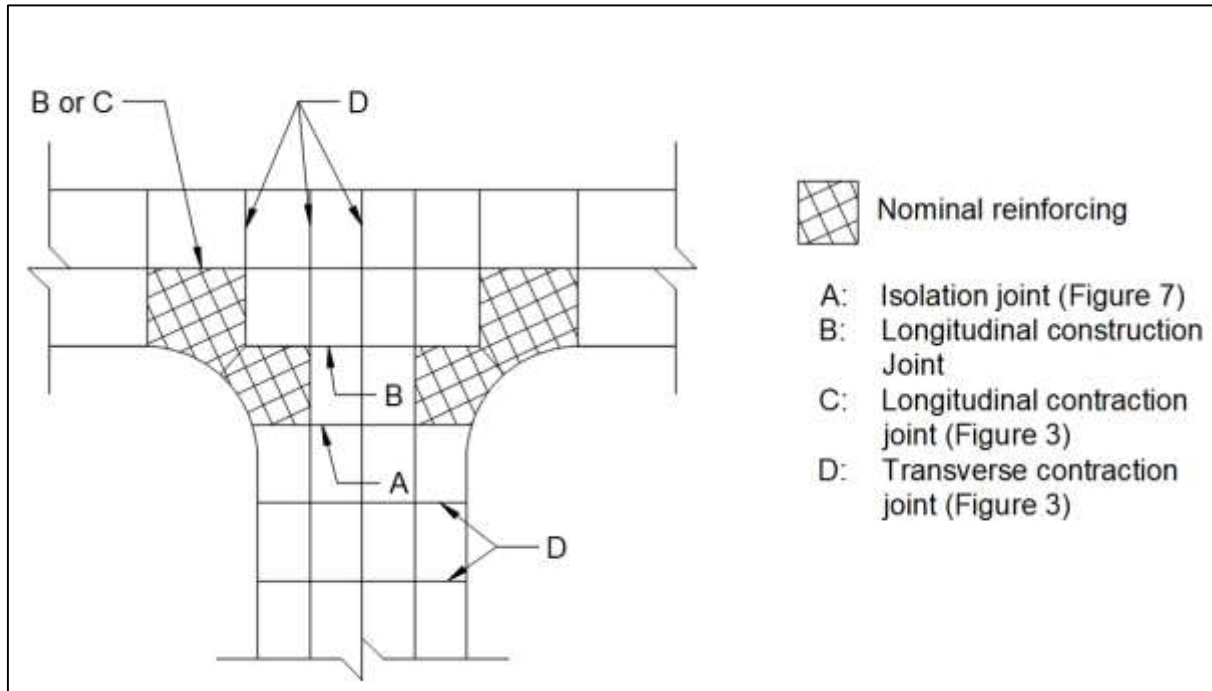
#### **2.2.1.2.5 Joint layout**

Critical guidelines when planning joint layouts include the following:

- The maximum spacing of longitudinal joints is 3.8 m.
- The maximum spacing for transverse joints is 25 times the pavement thickness, subject to a maximum of 4.5 m.
- Panels should be kept as square as possible. The length to width ratio should not exceed 1:25. Oddly shaped panels should be avoided as far as possible.



A typical joint layout for an intersection is presented in Figure 10.



**Figure 10: Joint layout and details for odd shapes and intersections (Perrie, 2000)**

#### 2.2.1.2.6 Joint sealing

The sealing of joints is important because it prevents incompressibles from entering the joint, and water from entering the supporting pavement layerworks. Incompressibles cause point-bearing pressures that may lead to joint spalling and even blow-up failures. Water ingress could result in the erosion of the subbase, the pumping of fines, the faulting of the concrete slabs, and ultimately the cracking of the slabs.

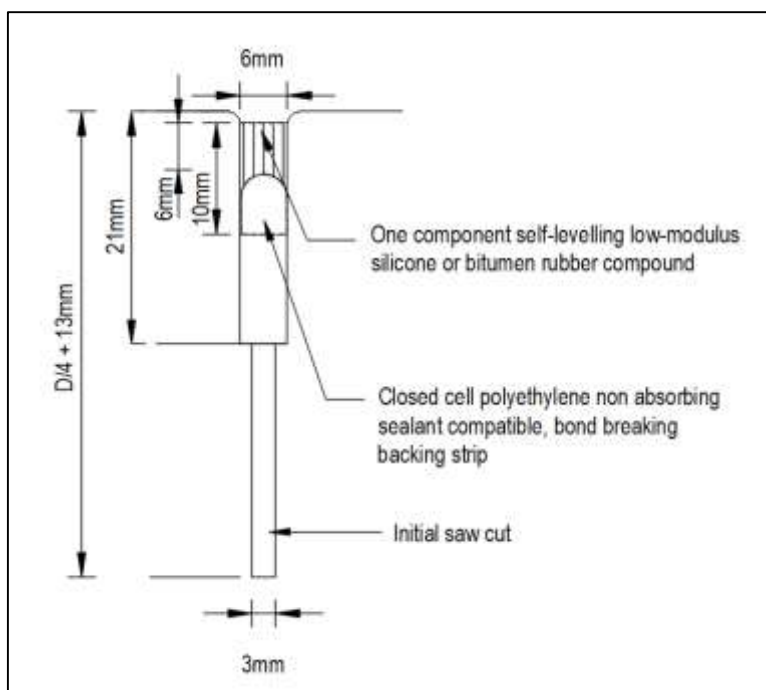
Joints should be sealed with a one-component self-levelling low-modulus silicone or with a bitumen rubber compound that is made up of the following:

- Polymer-modified anionic emulsion (6 parts)
- Granulated rubber crumbs (10 parts)
- Cement (0.2 parts)

The granulated rubber crumbs must have a natural rubber hydro-carbon content of at least 60% by mass, and the crumb sizes must comply with the requirements stated in (CSIR, 2008). A detail for sealing joints is presented in Figure 11.

**Table 9: Particle size distribution for rubber crumbs**

Particle size (mm)	Percentage by mass (%)
Passing 1.18	100
Passing 0.6	50–70
Passing 0.075	0–5



**Figure 11: Joint sealing detail**

### 2.2.1.3 Nominal reinforcement for oddly shaped slabs

Slabs that are shaped irregularly (length to width ratio greater than 1:2) should be reinforced with REF 311 steel mesh (200 x 200 x 7.1 mm high-yield reinforcement steel) placed 50 mm from the top concrete surface.

### 2.2.1.4 Steep slopes

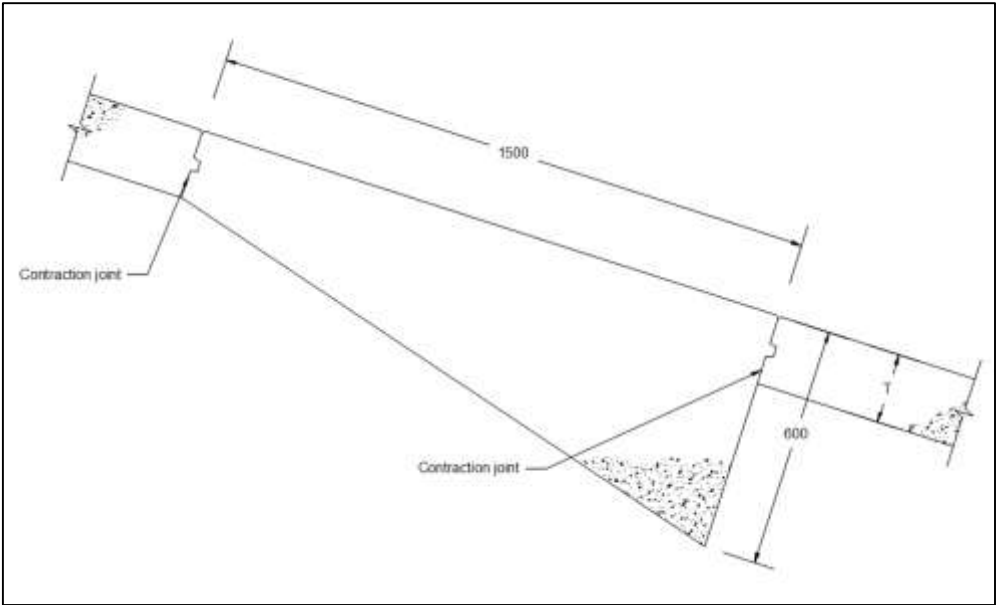
The material requirements for steep slope construction are somewhat different from those for flat surface construction. A stiffer mix is required to prevent concrete from flowing downhill. A vibrating screed board should be considered for compaction. As an alternative to this, a poker vibrator can be used. If vibrating equipment is not available, more effort will be required from labour.

Anchor panels and anchor blocks must be included where panels are constructed on slopes steeper than 1:30 to prevent the downhill creep of panels. There should be a minimum of one anchor block at the bottom of each steep slope, along with anchor panels as specified in Table 10.

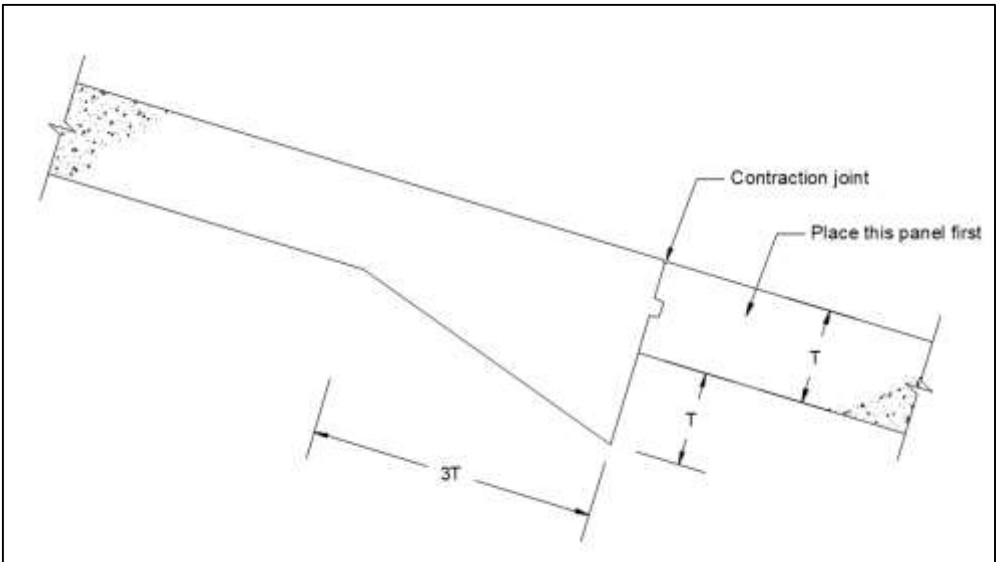
**Table 10: Provision of anchor blocks and panel anchors for steep sections**

Slope of roadway	Anchor block	Panel block
Flatter than 1:30	None	None
Between 1:30 and 1:15	At bottom end of slope	Each third panel
Between 1:15 and 1:10	At bottom end of slope	Each second panel
Steeper than 1:10	At bottom end of slope and at intervals of 30 m thereafter	Each panel except where an anchor block is required.

Details for the construction of anchor blocks and panel anchors are shown in Figure 12 and Figure 13.



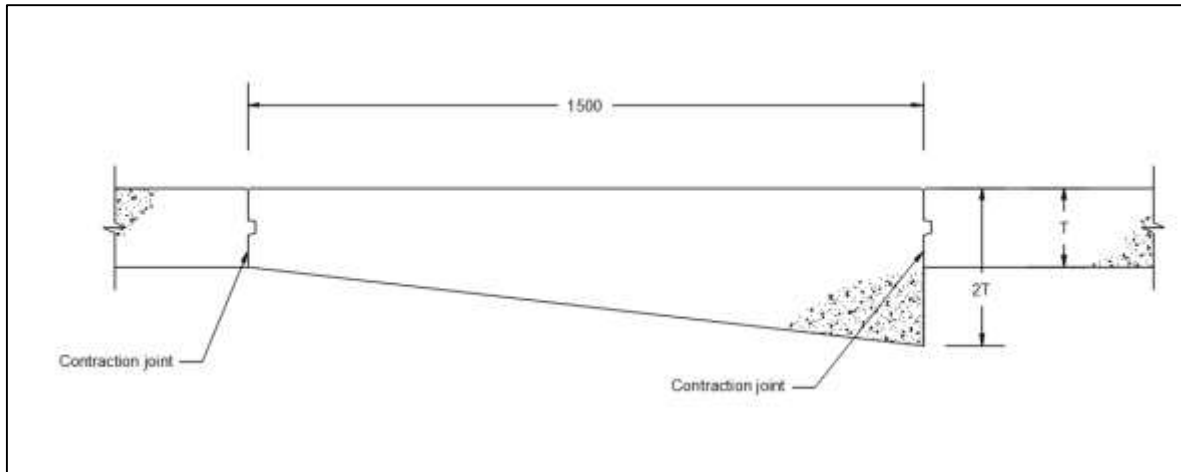
**Figure 12: Anchor block**



**Figure 13: Panel anchor**

Anchor blocks and panel anchors must be as wide as the roadway. The recesses that should form the panel anchors should be excavated shortly before the concrete is cast.

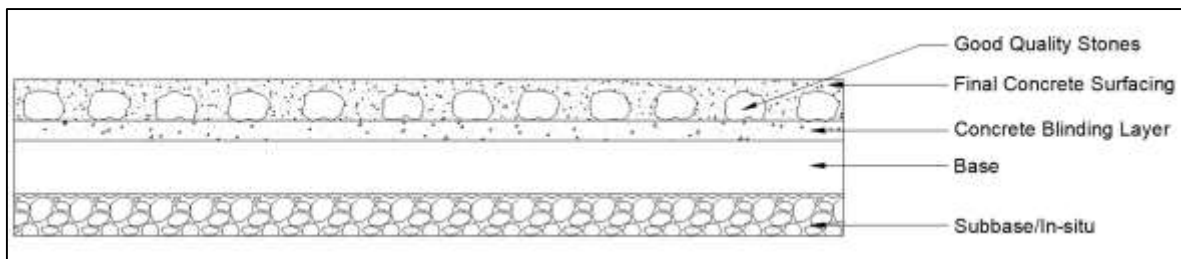
Where the road ends and is joined by another surfacing, a thickened panel should be cast as shown in Figure 14 to prevent traffic damage, unless an anchor block is placed at the end.



**Figure 14: Panel at end of PJCP road**

### **2.2.1.5 Plum concrete**

Plum concrete is a cost-saving alternative in areas where good quality stone is available close to the site. A plum concrete pavement has between 30 and 40% of the volume of concrete replaced by the placing of large stones on the subbase before the concrete is placed. The plums or large stones of 7 to 10 cm in size reduce the volume of concrete and thus the cost of the surfacing. The construction of the plum concrete pavement usually starts with a concrete blinding layer of 5 cm thick. On top of this layer, the stones are placed. The stones should be placed about 5 cm apart. Concrete is then poured over the stones to ensure a cover of at least 2 cm (Don Bosco Foundation, 2015). A schematic representation of plum concrete is shown Figure 15.



**Figure 15: Construction of plum concrete**

## **2.2.2 Concrete strip roads**

In this section, the thickness and the cross-section of concrete strip roads, and joints, steep slopes, and other design requirements relating to concrete strip roads are discussed.

### **2.2.2.1 Thickness and cross-section**

A typical cross-section for concrete strip roads is presented in Figure 16. Strips should be 600 mm wide and 900 mm apart. On long curves, the strips should be widened by 100 mm on the inside of bends and by 150 mm on sharp bends. An alternative cross-section is presented in Figure 17 for roads where a high percentage of three-wheel vehicles is expected.

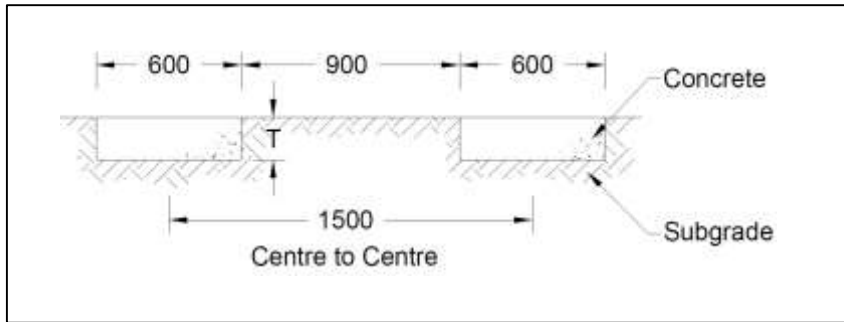


Figure 16: Typical cross-section of concrete strip roads

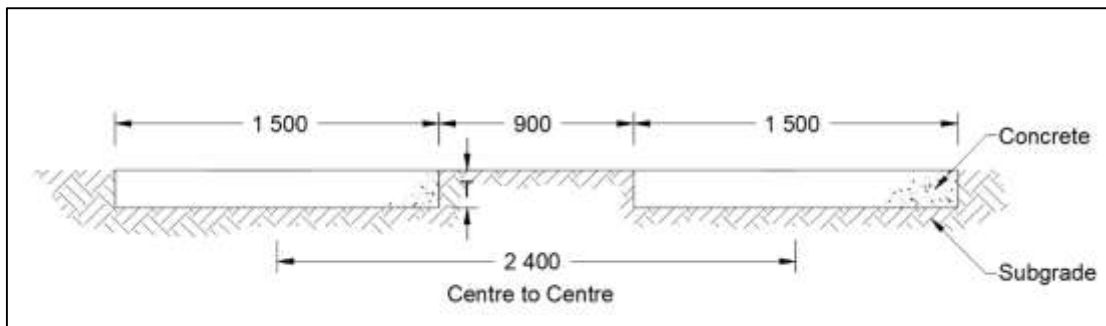


Figure 17: Typical cross-section of concrete strip road where three-wheeled vehicles are expected

The minimum thickness of the concrete strips and the required layerworks are indicated in Table 11 and based on an article published by the Concrete Institute of South Africa (The Concrete Institute, 2016).

Table 11: Concrete strip roads pavement layerworks and thickness design

Subgrade class (CBR %)		SC2 (3–7%)	SC3 (8–14%)	SC4 (≥15%)
TLC 0.01	Concrete	130 mm	130 mm	130 mm
	Subbase	100 mm cemented	none	none
TLC 0.3	Concrete	155 mm	155 mm	155 mm
	Subbase	100 mm cemented	none	none
TLC 1.0	Concrete	Not suitable for this traffic class		
	Subbase			

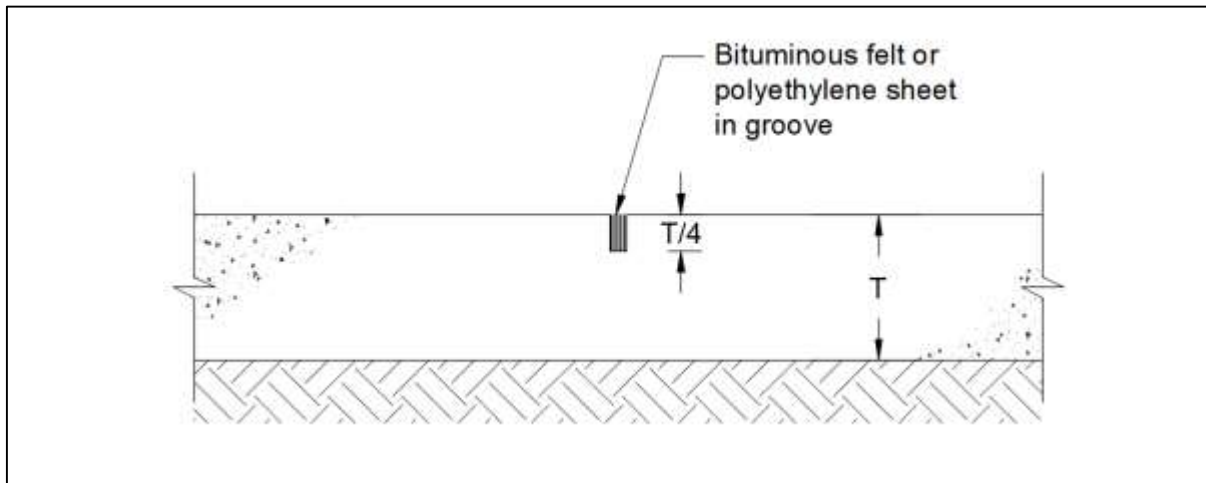
No reinforcement is required in the concrete strips.

### 2.2.2.2 Joints

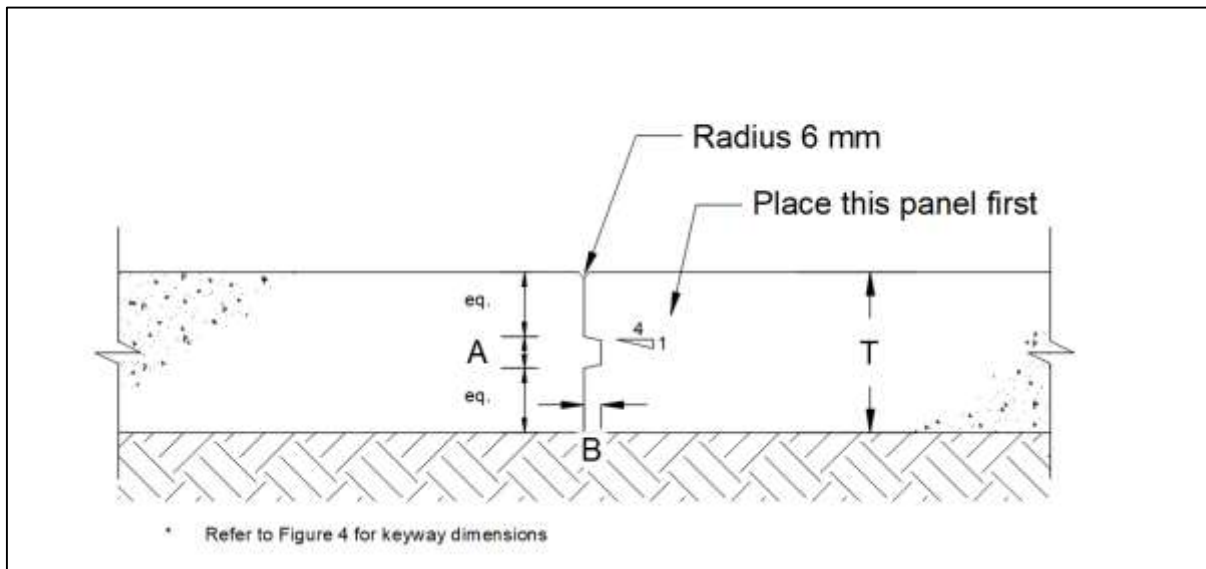
Each of the concrete strips must be divided into panels by either grooved (Figure 18) or keyed (Figure 19) joints.

Joint spacing must be at a maximum of 1.5 m for strips that are 0.6m wide, and a maximum of 2.0 m for strips that are 1.5 m wide. Grooved joints are used when strips are placed in continuous operations yielding panels of more than 1.5 m at a time. When alternate-panel construction is done (e.g. when the first, third, and fifth panels are constructed on Day 1, and

the second, fourth, and sixth panels are constructed on Day 2), keyed joints are used. A keyed joint must be made when continuous construction is interrupted for more than an hour.



**Figure 18: Grooved joint**



**Figure 19: Strip roads keyed joint**

### 2.2.2.3 Steep slopes

The same requirements for PJCP apply for concrete strip roads on steep slopes (refer to Section 2.2.1.4).

Where concrete strip roads are to be constructed on steep sections, it is recommended that these roads have erosion protection and longitudinal edge drains. Several erosion protection options exist, including (but not only):

- Groundcover vegetation to prevent soil from eroding
- Stone pitching (surfacing must be smooth enough to allow motorbikes to cross between strips)
- Stabilisation of the gravel between and next to the strips

### 2.2.2.4 Other design considerations

Aspects that should be considered before the construction of strip roads include:

- Erosion on the sides of the pavement causing dangerous edge drops
- Erosion or possible overgrown vegetation between the strips

Strip roads should be built with a minimum longitudinal slope of 1:100 to ensure that storm water will be drained off the road.

### 2.2.3 Ultra-thin reinforced concrete pavement (UTRCP)

This section is based on the CSIR manual for ultra-thin concrete pavements (CSIR, 2008). The placing of welded wire mesh, and joints for UTRCP are considered in the CSIR thickness design.

#### 2.2.3.1 Thickness design

The minimum thickness of the UTRCP and the required supporting layerworks are presented in Table 12.

The CSIR manual (CSIR, 2008) suggests a concrete thickness of 50 mm. Because of difficulties with the tolerances on the base level and its influence on the thickness of the UTRCP and the cover of the concrete over the reinforcement, it is recommended that a concrete layer of at least 60 mm thick be constructed.

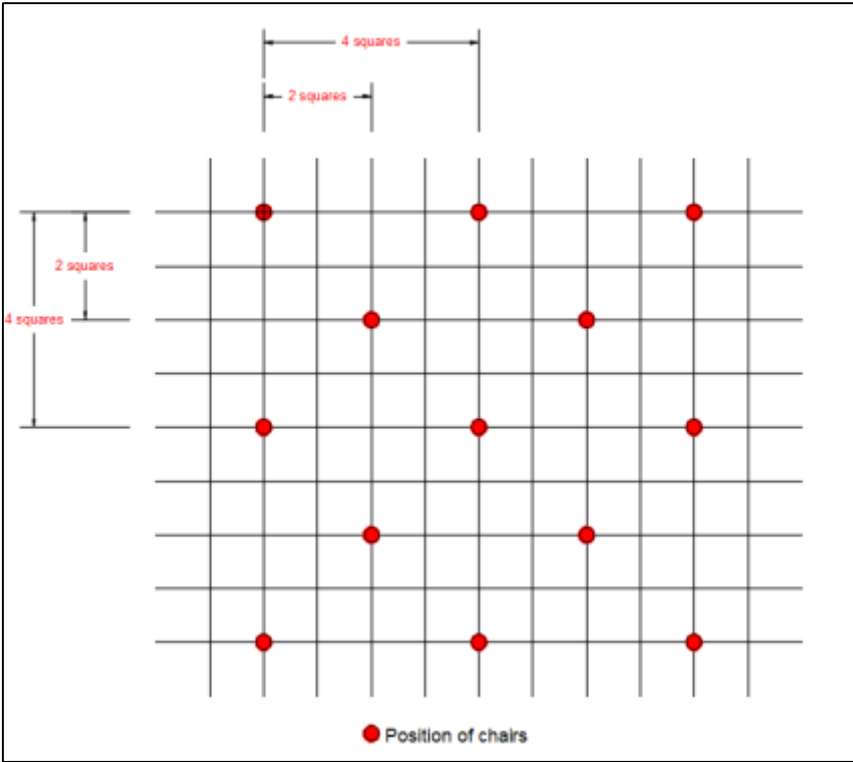
**Table 12: Ultra-thin continuously reinforced concrete pavement layerworks and thickness design**

Subgrade class (CBR%)		SC2 (3–7%)	SC3 (8–14%)	SC4 (≥ 15%)
TLC 0.01	Concrete	60 mm	60 mm	60 mm
	Subbase	150 mm G80	150 mm G80	100 mm G80
	Capping layer	200 mm G30	none	none
TLC 0.3	Concrete	60 mm	60 mm	60 mm
	Subbase	150 mm G80	150 mm G80	125 mm G80
	Capping layer	250 mm G30	100 mm G30	none
TLC 1.0	Concrete	60 mm	60 mm	60 mm
	Subbase	150 mm G80	150 mm G80	150 mm G80
	Capping layer	350 mm G30	150 mm G30	none

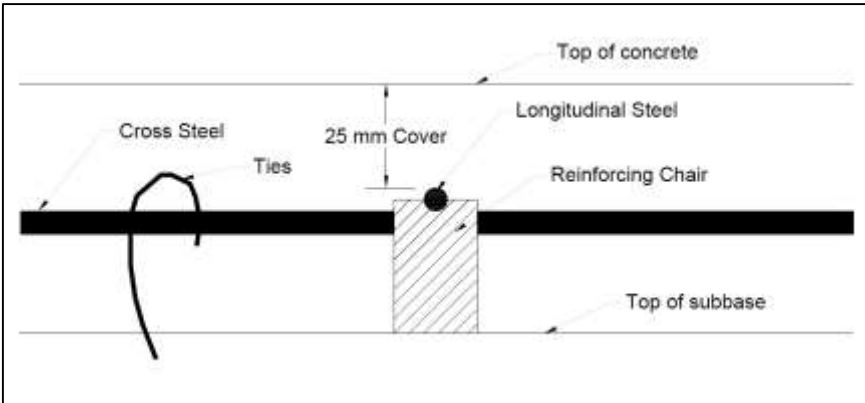
Note: G30, G80 refer to granular materials as defined in Table 1 and discussed in Geddes & Goldie-Scot (2018)

#### 2.2.3.2 Placing of welded wire mesh

The welded reinforcement mesh is relatively flexible, and care should be taken when the mesh is placed. It is important that the proper location of the mesh within the concrete layer be maintained before and while the concrete is placed. Suitably sized reinforcing chairs (i.e. chairs that can keep the mesh in place to provide a cover of at least 25 mm from the final surface finish) should be used. The position and placement of reinforcing chairs are indicated in Figure 20 and Figure 21.



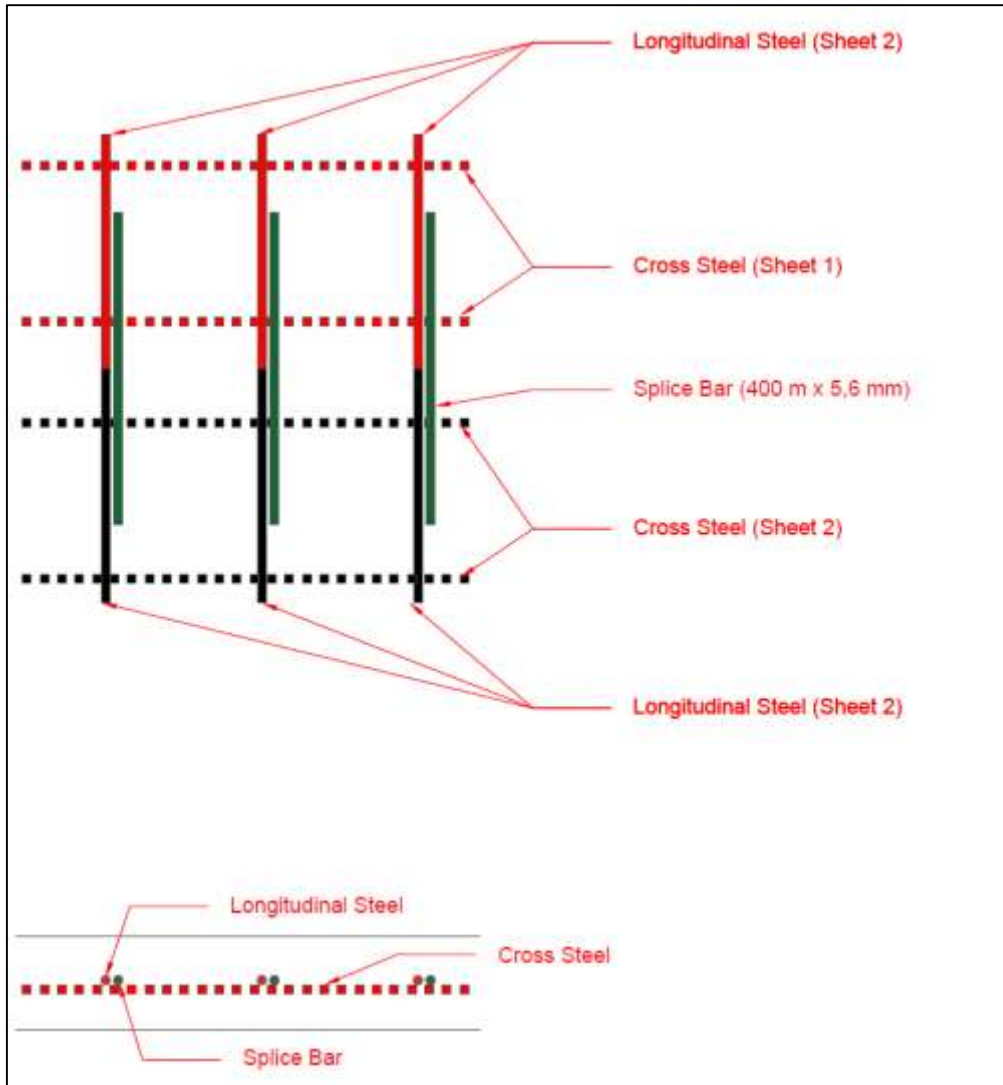
**Figure 20: Spacing of chairs to support reinforcement**



**Figure 21: Placing of reinforcement chairs and ties**

At the position where two reinforcement-mesh sheets are joined, a splice bar should be added as shown in Figure 22. Although Figure 22 shows only longitudinal steel splicing, a splice bar should be used to join cross steel as well.





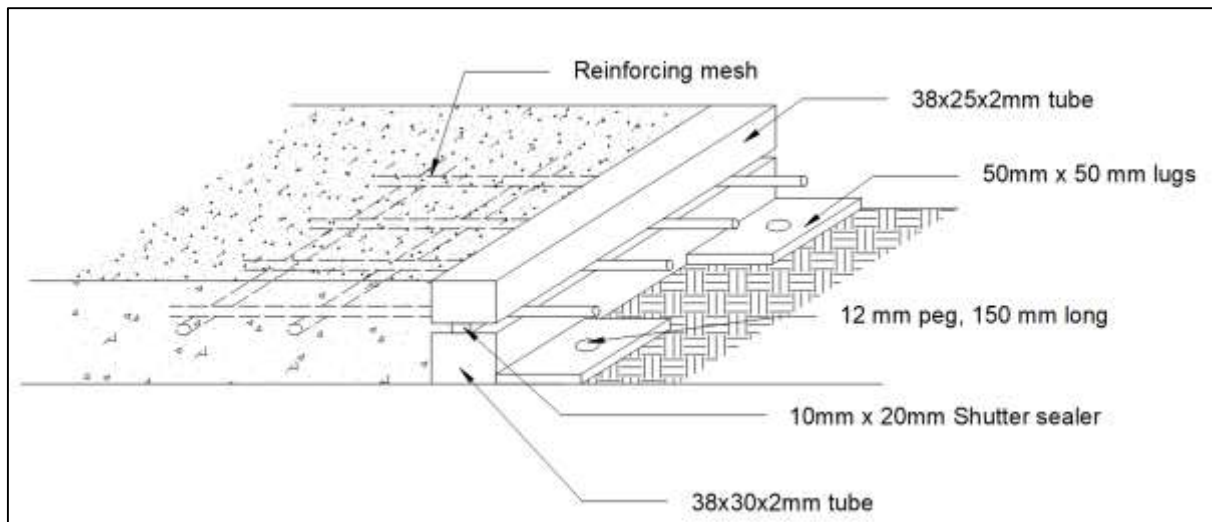
**Figure 22: Position and length of splice bars**

### **2.2.3.3 Joints**

Construction joints, longitudinal joints, joint sealing, and starter and end beams for UTRCP are discussed in this section.

#### **2.2.3.3.1 Construction joints**

A construction joint should be used only to provide a neat joint at the end of each day's work or where concrete placing is interrupted due to unforeseen circumstances. Because the reinforcement should be continuous, careful consideration is necessary when this joint is constructed. An example of the formwork required to make a neat construction joint is shown in Figure 23.



**Figure 23: Construction joint formwork**

A self-adhesive polyurethane shutter sealing strip should be applied to the full length of the lower shutter to prevent the concrete from seeping through the joint around the reinforcement. The foam strips should be removed as soon as the concrete has set to prevent spalling.

Before casting starts the next day, the concrete should be cleaned, lightly roughened, and treated with cement slurry. Before the shutters are reused, the formwork must be cleaned and oiled.

#### **2.2.3.3.2 Longitudinal joints**

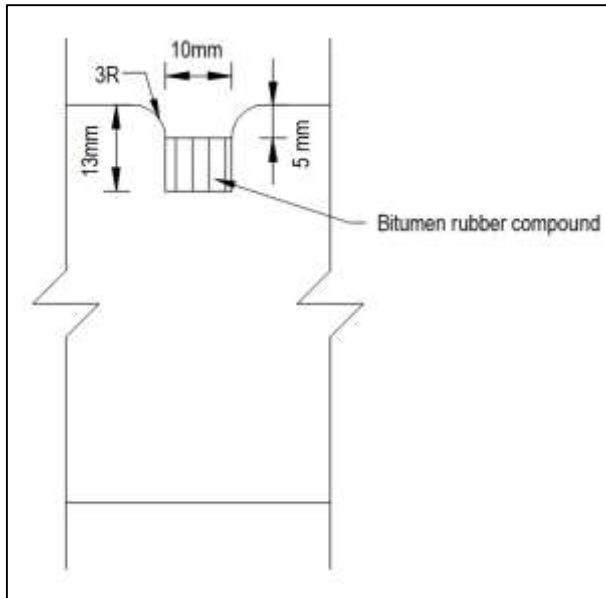
A longitudinal joint should be formed:

- Along the centreline of the road
- Between adjacent longitudinal sections
- Along a kerb

There are two ways in which this joint can be formed: either by casting the second section against the first, or by sawing and sealing the joint with a cold-poured bitumen rubber sealant. As with construction joints, the face of the first section must be cleaned before the casting of the second section can continue.

#### **2.2.3.3.3 Joint sealing**

Both the construction and longitudinal joints must be sawn 10 mm wide to a depth of 13 mm. Joints must be sealed with a bitumen rubber compound (refer to Section 2.2.1.2.6). A detail for sealing joints is presented in Figure 24.

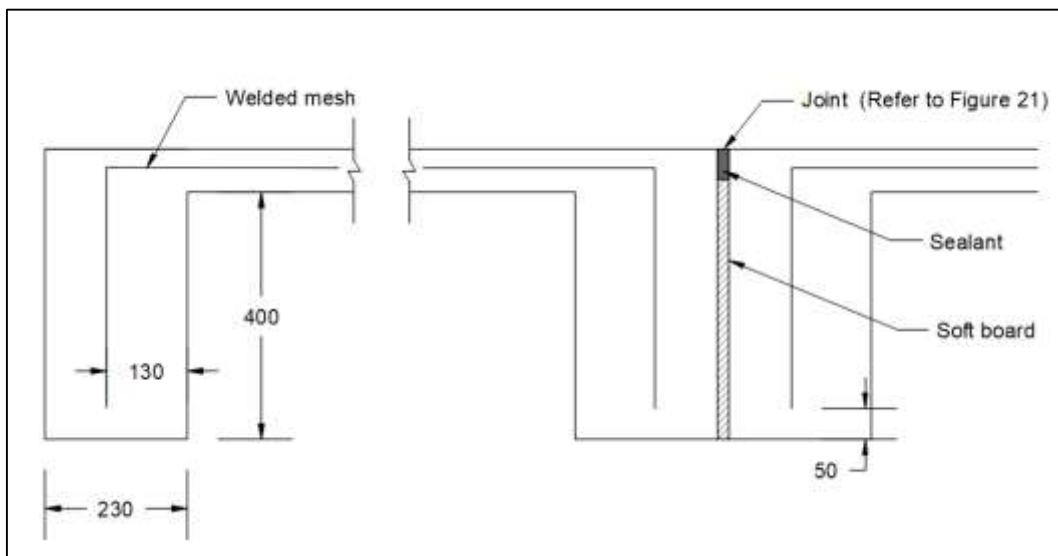


**Figure 24** Joint sealing detail for UTRCP

**2.2.3.4 Starter and end beams**

As indicated in Figure 25, beams must be constructed where the UTRCP begins and ends. Where there are changes in vertical and horizontal alignment, end and starter beams must be provided.

The reinforcement mesh must be folded down into the beams as shown in Figure 25.



**Figure 25:** Starter and end beams for UTRCP

### 3 FLEXIBLE OR BITUMINOUS SURFACINGS OR SEALS

Bituminous surfacings generally comprise an admixture of different proportions of aggregates of sand and bitumen. Thin bituminous surfacings do not add any significant structural strength to pavement and therefore largely fulfil functional requirements, e.g. skid resistance and the sealing of underlying pavement layers to prevent water ingress.

The design of the required supporting layerworks (base, subbase, and selected or capping layers) is provided in (Geddes & Goldie-Scot, 2018), and this section thus covers only the design of the surfacing. The surfacings covered in this section is the Otta seal. The selection of this surfacing will depend on the site conditions encountered.

#### 3.1 Otta seal

An Otta seal essentially consists of a bituminous surfacing of 16 to 32 mm thick. A thick film of soft binder is applied to the base. Subsequently, graded aggregate is placed on top of the base. The rolling and trafficking of the surface allow the binder to work its way up through the aggregate. As discussed below, a sand seal is sometimes placed as final cover. The aggregate relies on the interlocking of the binder and aggregate to achieve its final strength.

After the construction and rolling of the surface, it is essential that the road be opened to traffic. The soft binder allows the surfacing to settle as traffic is channelled over it.

Otta seals can generally be divided into one of two categories:

- Single Otta seals (see Figure 26)
  - Open/medium/dense grade with either a sand seal or no sand seal cover
- Double Otta seals (see Figure 27)
  - Open/medium/dense grade with either a sand seal or no sand seal cover

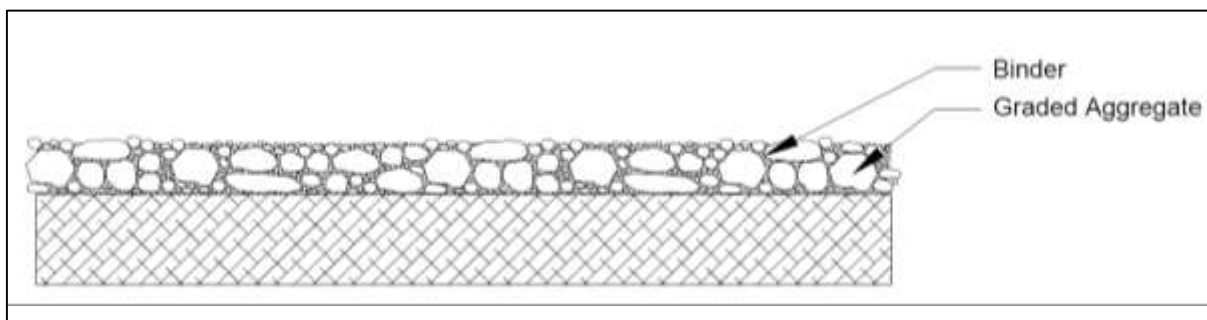


Figure 26: Single Otta seal

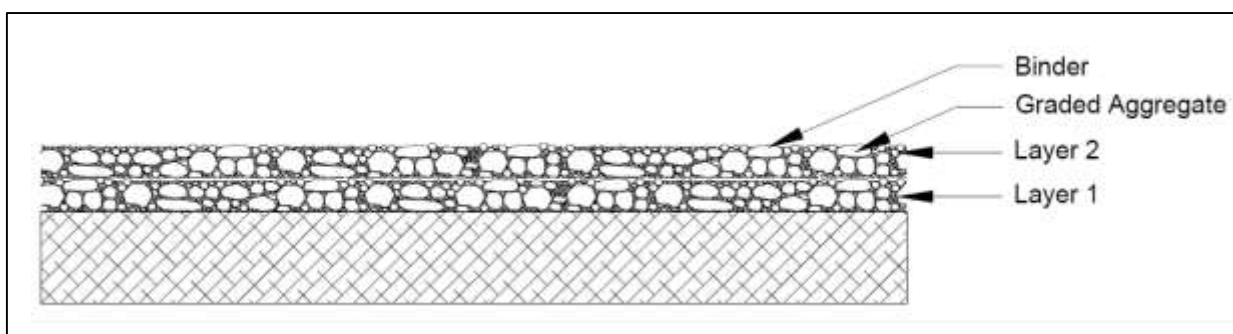


Figure 27: Double Otta seal

### **3.1.1 Materials**

In this section, the requirements for aggregates and binders for use in Otta seals are discussed.

#### **3.1.1.1 Aggregates**

The Otta seal has reduced requirements regarding:

- Strength
- Grading
- Particle shape
- Binder adhesion
- Dust control

This allows for the maximum usage of locally available natural gravel or crushed materials.

In the sections that follow, aggregate sources, screened natural gravel, crushed aggregate, aggregate requirements, aggregate strength, and aggregate grading are considered.

##### **3.1.1.1.1 Aggregate sources**

A large variety of material sources can be used to acquire graded aggregate for Otta seal construction, including:

- Screened natural gravel from weathered rock or river gravels and sands (typically laterites)
- Crushed and screened gravel from a variety of rock types

##### **3.1.1.1.2 Screened natural gravel**

Natural gravels should be screened to remove excessive fines and oversized particles. The screening of aggregate can be done either by using a power screen or by applying labour-based methods. The material should preferably have a low moisture content at the time of sieving, because the finer sieves could get clogged otherwise. If the sieving of moist material is unavoidable, the sieve mesh size should be increased. Fines may be present in the screened material if the required adjustments are made to the binder viscosity, the application rates, and the construction methodology.

##### **3.1.1.1.3 Crushed aggregate**

When compared to other seals, a higher percentage of crushed materials can be used for Otta seals due to the wider grading envelope requirements. In this regard, the Otta seal is more economical than other chip seals because there is less wastage of materials. Either crushed rock or crushed gravel can be used to construct the seal.

##### **3.1.1.1.4 Aggregate requirements**

Aggregate grading is dependent on the traffic volume at the time of construction as well as during the two months after construction is completed. In the sections that follow, maximum particle size, fines content, and flakiness index requirements are discussed.

###### **3.1.1.1.4.1 Maximum particle size**

The maximum particle size is 16 mm, although aggregate of between 16 and 19 mm is acceptable for use in the first layer when a double Otta seal is constructed. Particles larger than 16 mm tend to dislodge during operation, and skid resistance is thus decreased.

### 3.1.1.1.4.2 Fines content

Binder tends to coat first the finer particles first and then the larger ones. A lack of binder on larger particles could lead to a less durable surface. Where possible, the amount of fines (< 0.075 mm) should not exceed 10%.

### 3.1.1.1.4.3 Flakiness index

There are no requirements specified for the flakiness index for natural gravel or a mixture of natural gravel and crushed material for use in Otta seals. When crushed rock is used on its own, the flakiness index is used. The flakiness index should not exceed 30. This is an index calculated on the following fractions:

9.5–13.2 mm; 6.7–9.5 mm; 4.75–6.7 mm

### 3.1.1.1.5 Aggregate strength

Compared to the aggregates used for conventional chip seals, the strength requirements for Otta seals are lower. The strength requirements for Otta seal aggregates are set out in Table 13.

**Table 13: Aggregate strength requirements for Otta seals**

Aggregate strength requirements	Vehicles per day at the time of construction	
	< 100	> 100
Minimum Dry 10% FACT	90 kN	110 kN
Minimum Wet/Dry strength ratio	0.60	0.75

Lower strengths are acceptable in Ota seals because the wider grading envelope and the inclusion of smaller particles result in reduced internal pressure caused by stone-on-stone contact.

### 3.1.1.1.6 Aggregate grading

Grading requirements for Otta seals are relaxed and allow for a wider grading envelope. It is still a requirement that the aggregate grading fall within the envelope and be as smooth and parallel as possible to the envelope. Three grading envelopes can be used based on the traffic volumes. The binder spray rate and viscosity should be adjusted accordingly. Grading requirements for Otta seals are indicated in Table 14.

**Table 14: Grading requirements for Otta seals**

Sieve sizes (mm)	Open grading (> 100 AADT)	Medium grading (100–1000 AADT)	Dense grading (> 1000 AADT)
	(% passing)	(% passing)	(% passing)
19	100	100	100
16	80–100	84–100	93–100
13.2	52–82	68–94	84–100
9.5	38–58	44–73	70–98
6.7	20–40	29–54	54–80
4.75	10–30	19–42	44–70
2	0–8	3–18	20–48
1.18	0–5	1–14	15–38
0.425	0–2	0–6	7–25

Sieve sizes (mm)	Open grading (> 100 AADT)	Medium grading (100–1000 AADT)	Dense grading (> 1000 AADT)
	(% passing)	(% passing)	(% passing)
0.075	0–1	0–2	3–10

### 3.1.1.2 **Binder**

For good performance of the Otta seal, it is critical that the correct binder and application rate be selected. The type of binder will depend on the aggregate properties, traffic volumes, and temperature conditions.

In general, the binder properties desirable in Otta seals include the following:

- The binder must be soft enough to initially coat the fines in the aggregate.
- The binder must be soft enough to move up through the aggregate matrix during rolling and trafficking. This could take four to eight weeks.
- It must be possible for large enough quantities of binder to be applied during a single spray operation.

#### 3.1.1.2.1 **Penetration-grade bitumen**

Penetration-grade bitumen such as 80/100 is not suitable for use in Otta seal construction. The hardest type of bitumen that can be used successfully is 150/200 penetration grade. When construction takes place during colder months, it is recommended that the 150/200 penetration-grade bitumen be cut back with about 5% power paraffin.

#### 3.1.1.2.2 **Cutback bitumen**

MC3000 and MC800 cutback bitumen have been used with success in Otta seal construction. MC800 is a cutback bitumen, and MC3000 is a medium viscous cutback bitumen.

To produce a cutback bitumen, volatile oils are added to a bitumen binder to temporarily reduce the viscosity of the binder. Cutter volatility will determine whether a rapid-curing, medium-curing or slow-curing cutback bitumen is produced. Cutters used to produce medium-curing bitumen include:

- Power paraffin
- Illuminating paraffin
- JetA1 aviation turbine fuel

Medium-curing cutback bitumen is the only cutback bitumen suitable for use in Otta seals. Volatiles will evaporate within eight to twelve weeks.

The viscosity of medium-curing cut-back bitumen is not determined by the type but by the amount of cutter added.

The type of cutter determines the time required for the volatiles to evaporate.

### 3.1.1.2.3 Blending proportions

Blending proportions to produce medium-curing cutback bitumen are set out in Table 15.

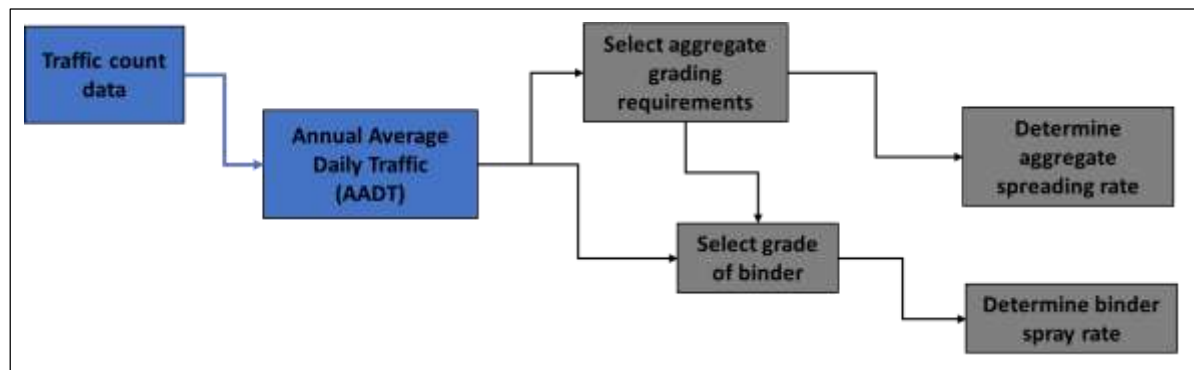
**Table 15: Blending proportions to produce medium-curing cutback bitumen**

Required product	Cutter (power paraffin) in percentage of total mixture	
	80/100 base bitumen	150/200 base bitumen
150/200	3–5% (use flux oil)	
MC800	18–20%*	15–18%
MC3000	8–10%*	5–8%

\* Binder durability can be improved by replacing 3% of cutter with flux oil.

### 3.1.2 Otta seal design

The process for the design of an Otta seal is indicated in Figure 28.



**Figure 28: Flow diagram of the design procedure for Otta seals**

In the sections that follow, pavement layerworks, aggregate application rate, choice of binder, and binder spray rate are discussed.



### 3.1.2.1.1 Pavement layerworks

The manual for low-volume roads indicates that the layerworks listed in Table 16 can be used for bituminous pavements.

**Table 16: Layerworks for bituminous pavements**

Subgrade CBR	Layer	Traffic loading class		
		TLC 0.01	TLC 0.3	TLC 1.0
<b>SC1 (&lt; 3%)</b>		Special subgrade treatment required		
<b>SC2 (3–7%)</b>	Base	150 G60	125 G60	150 G80
	Subbase	175 G40	150 G30	150 G40
	Selected	n/a	200 G15	200 G15
<b>SC3 (8–14%)</b>	Base	100 G40	125 G60	150 G80
	Subbase	125 G30	125 G30	150 G40
	Selected	n/a	125 G15	125 G15
<b>SC4 (≥ 15%)</b>	Base	125 G40	175 G80	150 G80
	Subbase	N/A	N/A	150 G40

Note: G15, G30, G40, G60, G80 refer to granular materials as defined in **Table 1** and discussed in **Geddes & Goldie-Scot (2018)**

### 3.1.2.1.2 Aggregate application rate

Sufficient amounts of aggregate need to be applied to the surfacing during construction to ensure that there is surplus material during rolling and through the initial curing period. When crushed aggregate is used, embedment within the binder will take about two weeks, after which excess material can be swept off the surface. The curing period will be longer if natural aggregate is used. The aggregate application rate is shown in Table 17.

**Table 17: Aggregate application rate**

Seal type	Open grading (< 100 AADT)	Medium grading (100–1000 AADT)	Dense grading (> 1000 AADT)
Otta seal	0.013–0.016 m <sup>3</sup> /m <sup>2</sup>	0.013–0.016 m <sup>3</sup> /m <sup>2</sup>	0.013–0.020 m <sup>3</sup> /m <sup>2</sup>
Sand covered seal	0.010–0.012 m <sup>3</sup> /m <sup>2</sup>	0.010–0.012 m <sup>3</sup> /m <sup>2</sup>	0.010–0.012 m <sup>3</sup> /m <sup>2</sup>

### 3.1.2.1.3 Choice of binder

The choice of binder depends on the annual average daily traffic as well as the aggregate grading. A suggestion of binder choice is given in Table 18.

**Table 18: Choice of bitumen in relation to traffic and grading**

AADT at the time of construction	Type of bitumen		
	Open grading	Medium grading	Dense grading
> 1000	N/A	N/A	MC3000 and MC800 in cold weather
100–1000	N/A	150/200 penetration grade in cold weather	MC3000 and MC800 in cold weather
< 100	150/200 penetration grade	MC3000	MC800

### 3.1.2.1.4 Binder spray rate

The spray rate requirements for Otta seals vary according to the following parameters (Botswana Roads Department, 1999):

- Aggregate grading
- Daily traffic
- Absorbency of aggregate particles
- Whether the base is primed (priming is not a requirement for Otta seal construction)

**Table 19: Bitumen spray rates (l/m<sup>2</sup>)**

Type of Otta seal		Open grading	Medium grading	Dense grading	
				AADT < 100	AADT > 100
Double	First layer	1.60	1.70	1.80	1.70
	Second layer*	1.50	1.60	2.00	1.90
Single, with a sand covered seal	Fine sand	0.70	0.70		0.60
	Crusher dust or coarse river sand	0.90	0.80		0.70
	First layer*	1.60	1.70	2.00	1.90
Single*		1.70	1.80	2.00	1.90
Maintenance reseal (single)		1.50	1.60	1.80	1.70

\* On a primed base course, the spray rate can be reduced by 0.2 l/m<sup>2</sup> in the first layer.

Notes:

- The bitumen spray rate must be increased by 0.3 l/m<sup>2</sup> where the aggregate has a water absorbency of more than 2%.
- For sand-covered seals, MC3000 must be used for crusher dust and coarse river sand. MC800 must be used for fine sand.

## 4 SEMI-RIGID OR SEGMENTED PAVING SURFACINGS

Well-designed, well-constructed discrete element pavement can last for years even without being maintained. Concrete blocks and cobbles not only provide a durable wearing surface but also serve as structural components in that they contribute to the strength of the pavement and reduce the stresses in the lower layers.

There are seven key elements that must be considered in the design of a discrete element surfacing:

- In situ subgrade and its characteristics
- Subbase
- A thin layer of bedding sand that matches the required grading characteristics
- Concrete blocks which double as a surface course and a wearing course
- Jointing sand that fills the gaps between blocks
- Edge restraints that prevent the concrete blocks from moving
- Drainage to prevent water build-up in pavement layers

### 4.1 Materials

In the next section the bedding sand and jointing sand requirements are discussed.

#### 4.1.1 Bedding sand

The function of bedding sand is to provide an even surface on which blocks can be laid. Bedding sand should not be used to level out an uneven subbase, as this will lead to the subsequent settlement of the blocks, and an uneven riding surface.

Cleaned river sand should be adequate for use as bedding material, but sand can be sourced from commercial crushers. The grading of bedding sand should fit within the envelope shown in Figure 29. The envelope parameters are given in Table 20.

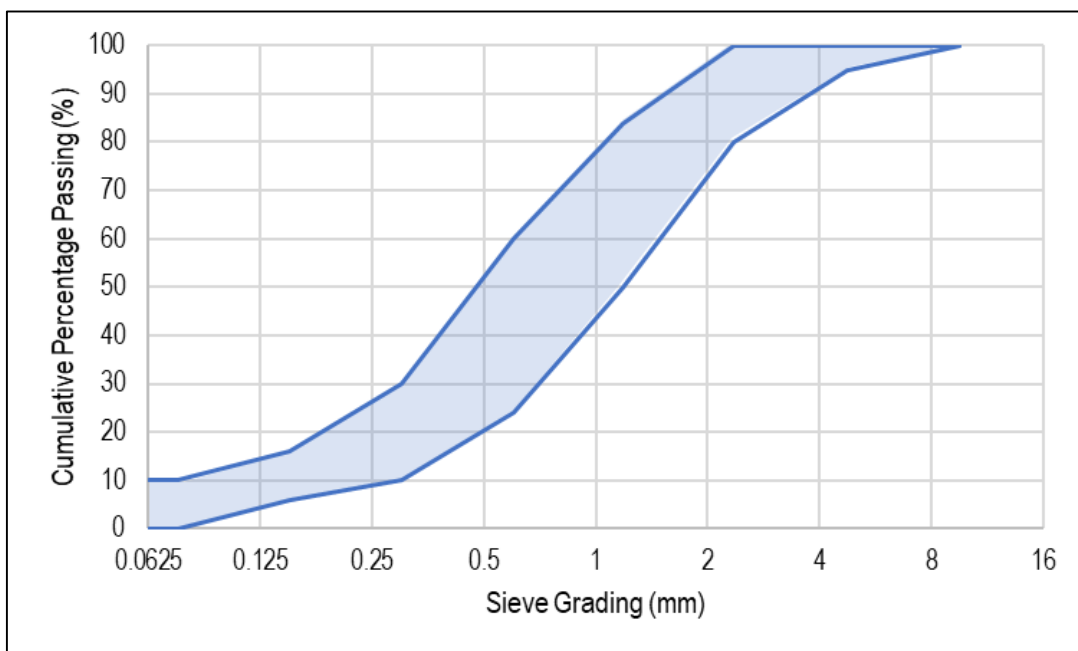


Figure 29: Grading envelope for bedding sand

**Table 20: Grading envelope for bedding sand**

Sieve grading (mm)	Percentage passing (%)
9.5	100
4.75	95–100
2.36	80–100
1.18	50–84
0.6	24–60
0.3	10–30
0.15	6–16
0.075	0–10
0.0625	0–10

Bedding sand must be spread evenly over the subbase. Ideally, the compacted thickness for the bedding sand should be 25 mm. During spreading, the moisture content should be about 6%, with a maximum variation of 2%.

The depth of the bedding sand should be adjusted according to the amount of compaction. To determine the correct bedding sand thickness, a test area of paving should be laid on 30 mm of loose sand and compacted with three passes of the same plate vibrator to be used to compact the final surfacing. Settlement should be noted, and the sand thickness before compaction can be adjusted accordingly.

It is important that the levels of the surfacing be checked at regular intervals. If the moisture content of the bedding sand changes, the blocks might have to be lifted and the bedding sand raked and rescreeded to new levels before the blocks can be laid.

#### 4.1.2 Jointing sand

Once the compaction of the blocks is complete, jointing sand is swept into the joints. The grading requirements for jointing sand are very different from the requirements for bedding sand, as jointing sand is much finer. The grading envelope for jointing sand is shown in Figure 30. The envelope parameters are specified in Table 21. Ideally, jointing sand should contain a small amount of clay or silt, as this helps to prevent water ingress.

**Table 21: Grading envelope for jointing sand**

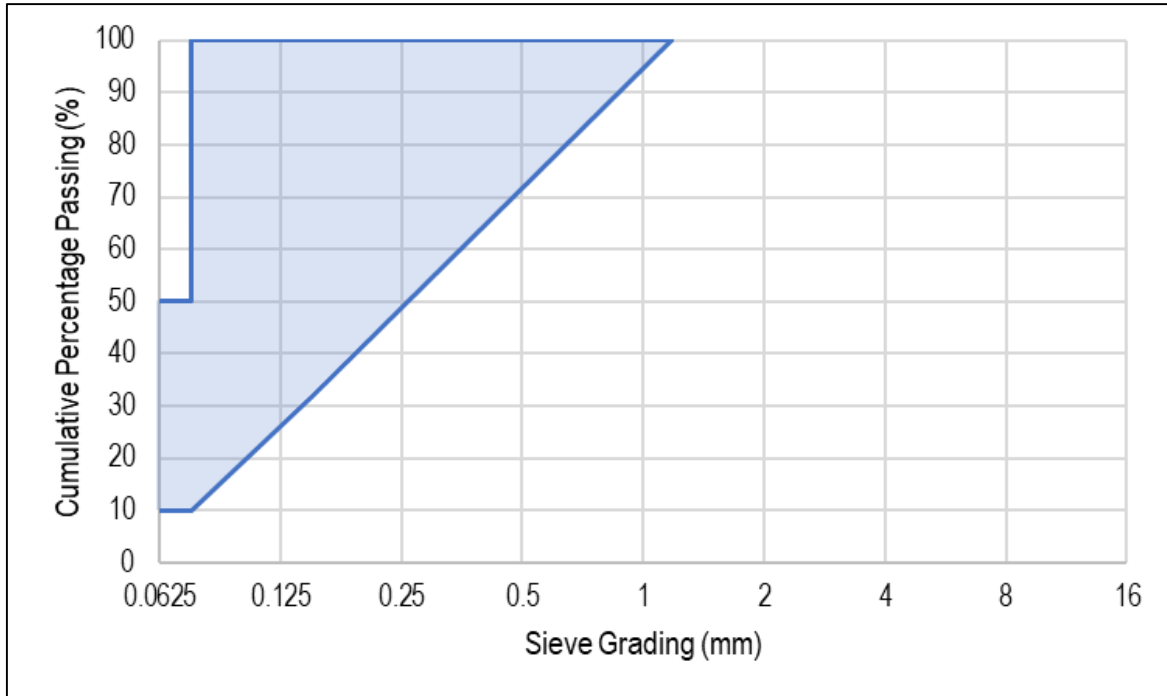
Sieve grading (mm)	Percentage passing (%)
1.18	100
0.15	32–100
0.075	10–100
0.0625	10–50

It is recommended that cement not be mixed into the jointing sand, as it creates a rigid layer that keeps the pavement from accommodating thermal or flexural movement stresses without distress. Any movement would cause crack formation, leading to water ingress.

Joint filling should commence only after all the necessary adjustments have been made to ensure that the blocks are on the correct levels, and two compaction passes have been completed. Sand complying with the requirements set out in Section 4.1.2 must be broomed

into the joints until they are sufficiently filled up. A plate compactor must be used to settle the joint filling. The process should be repeated until the joints remain full after compaction.

During the spreading of the joint sand, the sand and the surfacing should be as dry as possible to prevent clogging. It is essential that joints be completely filled to ensure structural performance. All excess sand must be broomed off the surfacing once compaction has been completed.



**Figure 30: Grading envelope for jointing sand**

## 4.2 Design

A road is classified according to its traffic volume and subgrade strength. Once the road has been classified, the catalogue in Table 22 can be used to select the appropriate pavement design. The data provided in Table 22 can be used to determine the layerworks requirements for discrete element pavements.

In the sections that follow, the design of concrete paving blocks and cobblestones surfacings are discussed.

### 4.2.1 Concrete paving blocks

When a concrete paving block surfacing is being designed, there are a number of aspects that should be taken into account, including the strength, shape, laying pattern and slope of the surfacing.

#### 4.2.1.1 Strength

The average compressive strength of segmented block paving is 25 MPa. Concrete paving blocks have a much greater strength than clay bricks (7 MPa). Therefore, they can withstand higher levels of traffic loading and abrasion than clay bricks, and are more suitable for use as roadbuilding materials. The thickness of concrete pavers ranges between 60 and 80 mm. The larger 80 mm blocks are recommended for heavy vehicle routes and industrial use, while the smaller 60 mm blocks are used for light vehicle traffic conditions.

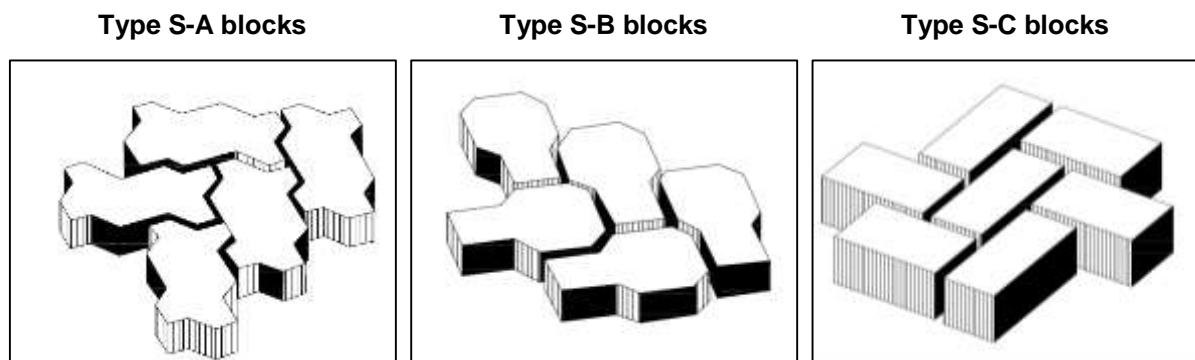
**Table 22: Layerworks for discrete element pavements**

SG CBR	Layer	TLC 0.01	TLC 0.3	TLC 1.0
		< 0.01	0.01–0.3	0.3–1.0
SC2 (3–7%)	Surfacing	Paving blocks or cobbles	Paving blocks or cobbles	Paving blocks or cobbles
	Bedding sand	25 mm	25 mm	25 mm
	Base	125 mm G80	125 mm G80	150 mm G80
	Subbase	100 mm G30	125 mm G30	175 mm G30
	Capping layer	none	150 mm G15	175 mm G15
SC3 (8–14%)	Surfacing	Paving blocks or cobbles	Paving blocks or cobbles	Paving blocks or cobbles
	Bedding sand	25 mm	25 mm	25 mm
	Base	150 mm G80	150 mm G80	175 mm G80
	Subbase	none	200 mm G30	225 mm G30
SC4 (≥ 15%)	Surfacing	Paving blocks or cobbles	Paving blocks or cobbles	Paving blocks or cobbles
	Bedding sand	25 mm	25 mm	25 mm
	Base	125 mm G80	150 mm G80	150 mm G80
	Subbase	none	125 mm G30	150 mm G30

Note: G15, G30, and G80 refer to granular materials as defined in Table 1 and discussed in Geddes & Goldie-Scot (2018)

**4.2.1.2 Shape**

There are three general shape types available for paving blocks as indicated in Figure 31. S-A blocks are most commonly used for roads with heavy vehicle loading, because they develop the best resistance to vertical and horizontal creep, as all their faces allow for geometrical interlocking. Type S-B and Type S-C blocks allow for either geometric interlocking on some of their faces, or no interlocking at all, and are therefore used for aesthetic purposes where only slow, light vehicle traffic is expected.



**Figure 31: General paving block shapes**

#### 4.2.1.3 Laying patterns

Three of the most common laying patterns for concrete paving blocks are shown in Figure 32. Other patterns are also possible. The herringbone pattern ensures the best resistance to horizontal and vertical deformation and is generally used for road and industrial pavements. The other patterns are usually used for pedestrian walkways.

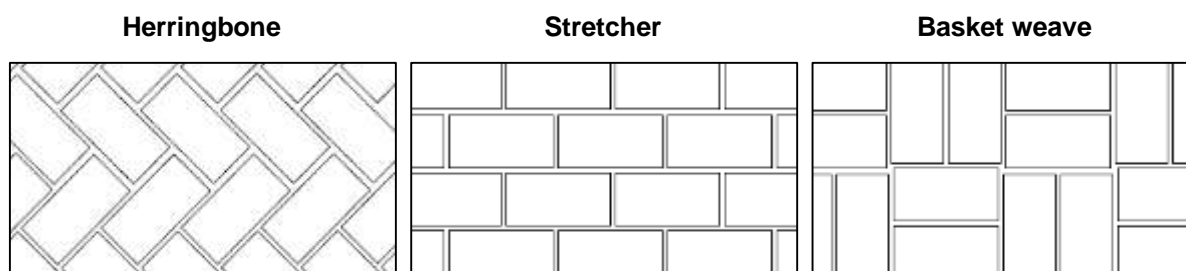


Figure 32: Concrete paving block laying patterns

The laying pattern of the blocks should be specified in the project specifications or indicated on the construction drawings. If no guidelines are given, blocks should be laid in herringbone pattern. If the shape of the blocks makes it impossible for the blocks to be laid in a herringbone pattern, the blocks should be arranged so that their long sides are perpendicular to the line of traffic.

To control the alignment of the units, lines for placing the blocks should be set up at right angles. It is essential that some space be left between blocks so that sand can be vibrated in between the blocks to facilitate bonding. After vibration, the blocks are settled into the bedding sand.

#### 4.2.1.4 Steep slopes

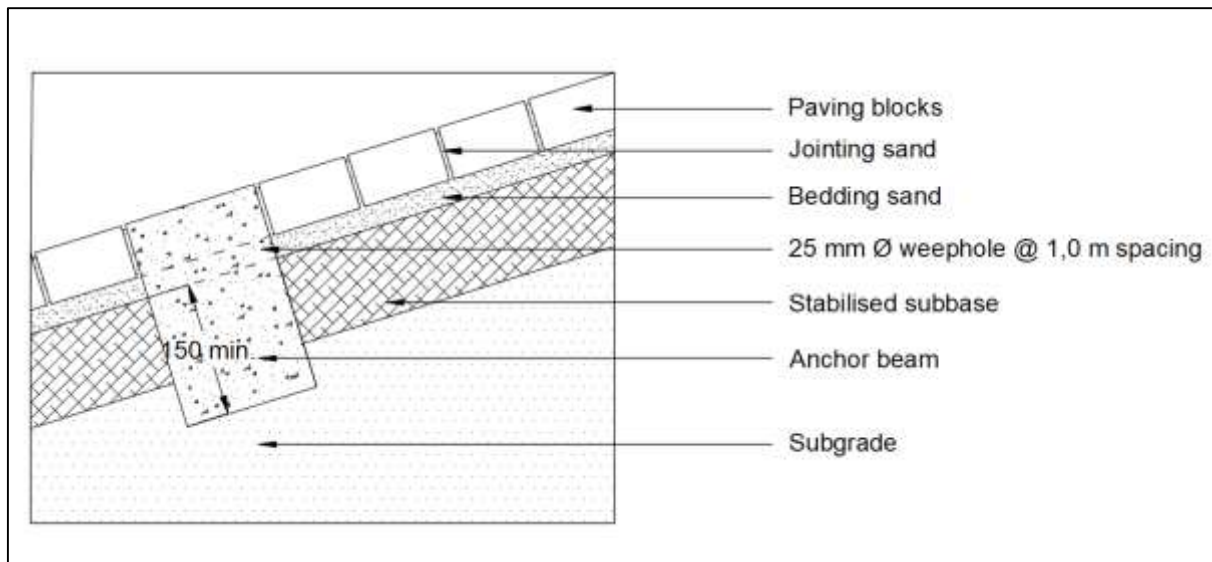
When a paving block surfacing must be constructed on steep slopes, anchor beams must be provided at the intervals indicated in Table 23.

Table 23: Spacing of anchor beams on steep slopes

Slope	Anchor beam spacing
12%	30 m
15%	20 m
20%	15 m

When anchor beams are constructed, the blocks are laid first. Afterwards, two rows of blocks are removed at the position of the beam, and the subbase is excavated to the required depth and width. The beam is then cast with the top roughly 10 mm lower than the surrounding blockwork. This allows for the settlement of the blocks and creates an even riding surface.

A typical anchor beam is shown in Figure 33.



**Figure 33: Construction of anchor beam**

## **4.2.2 Cobblestones**

When a cobblestone surfacing is being designed, there are a number of aspects that should be considered, including the strength, shape, and slope at which the blocks are laid.

### **4.2.2.1 Strength**

Strong durable stones can be broken into shapes that are almost cubic. The strength of the stones must have an unconfined compressive strength of > 75 MPa.

### **4.2.2.2 Shape**

It is recommended that stones be fairly cubic.

### **4.2.2.3 Steep slopes**

Refer to Section 4.2.1.4.



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