Manual for Low Volume Roads

Ministry of Public Works
Government of Republic of Liberia

DESIGN OF LOW-VOLUME ROAD SURFACINGS

This standard is subject to revision from time to time.

Users should ensure that they are using the current version for all design projects undertaken on behalf of the Government of Liberia.

Version History

Revision	Revision Date	Details	Authorised	
			Name/Position	Signature

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

E

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

F

FACT	:	Fine Aggregate Crushing Test

G

g/m^2	:	Grams per Square Metre
GM	:	Grading Modulus

H

I

i.e.	:	That is (abbreviation for the Latin phrase *id est*)

K

L

LVR	:	Low Volume Road

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.

Complementary Interventions

Actions that are implemented through a roads project which are targeted toward the communities that lie within the influence corridor of the road and are intended to optimise the benefits brought by the road and to extend the positive, and mitigate the negative, impacts of the project.

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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1 Introduction

An extensive study (Hartman, Calitz, & Pretorius, 2018) was done to investigate alternative methods for the surfacing of low-volume gravel roads in Liberia. 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 Liberia 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 1-1.

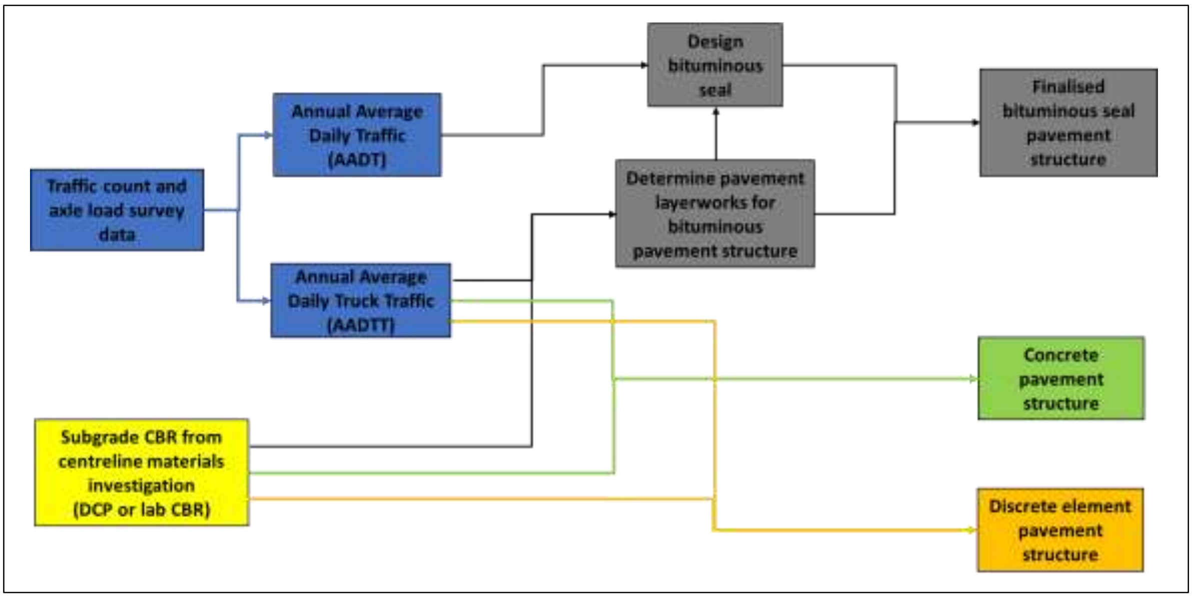


Figure 1-1: Flow diagram of design inputs for various surfacing and pavement types

In Sections 1.1 and 1.2 below, the traffic and subgrade classifications described by 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). A summary of the material types used for selected, subbase and base layers is provided in Table 1-1.

Table 1-1: 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 (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 1-2 contains a list of the traffic classes considered appropriate for low-volume roads.

Table 1-2: Traffic loading classes for pavement design (Geddes & Goldie-Scot, 2018)

Traffic load class (TLC)			
Traffic range (ESA x 10^6)	**TLC 0.01**	**TLC 0.3**	**TLC 1.0**
	< 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, four subgrade classes are indicated. These classes are given in Table 1-3.

Table 1-3: 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.)

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 1-4 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	Strip Roads	Single Seal	Double Seal	Otta Seal	Block Paving
TRAFFIC						
Light	✓	✓	✓	✓	✓	✓
Moderate	✓	✓		✓	✓	✓
Heavy	✓			✓	✓	✓
CONSTRUCTION REGIME						
High labour content	✓	✓				✓
Intermediate machinery	✓	✓				✓
Moderate cost		✓	✓	✓	✓	
High cost	✓					✓
MAINTENANCE REQUREMENTS						
Low	✓	✓				✓
Moderate			✓	✓	✓	
OTHER						
Poor aggregate quality					✓	
Limited supervision	✓	✓			✓	✓

Table 1-4: 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
- 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 pass ability 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 two types of concrete surfacings that can be considered for low volume road application. These include:

- Plain Jointed Concrete Pavements (PJCPs)
- Strip roads

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.

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 2-1, and the grading specification for aggregate relevant to this design specification is indicated in Table **2-2**.

Table 2-1: 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 2-2**: 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 o 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 **2-2**, 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.

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
- Improvethe 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 consistency 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.

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^3.

2.1.7 Reinforcement

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 2-1, and includes the layerworks and concrete thickness designs for PJCP, concrete strip roads, and UTRCP.

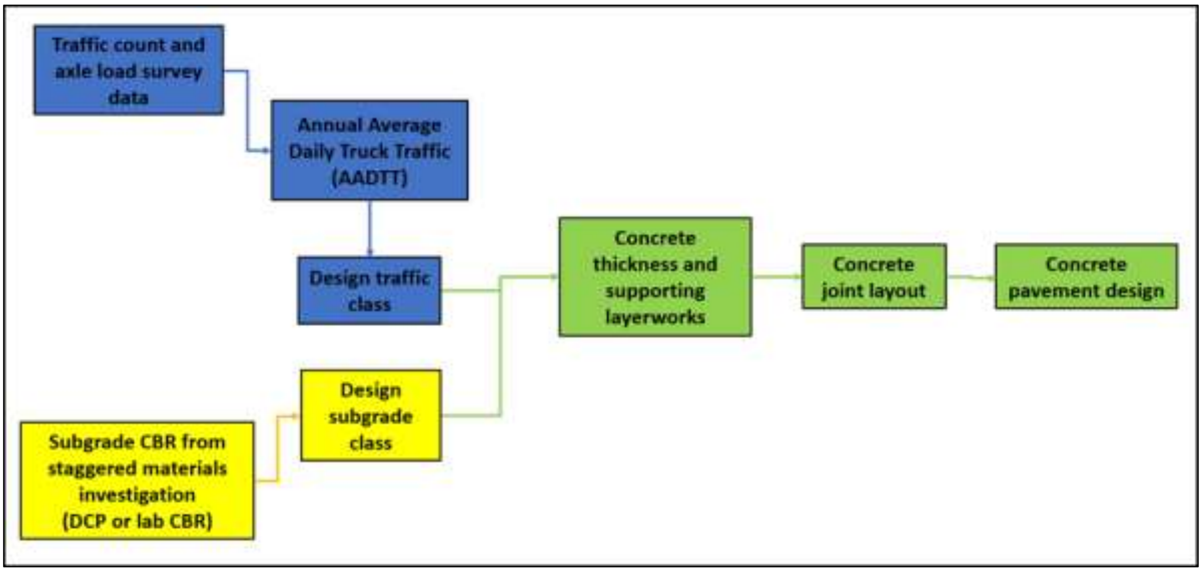


Figure 2-1: Flow diagram of the design procedure for concrete surfacings

In the sections that follow, design requirements for PJCPs and concrete strip roads, 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 2-3 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 2-3.

Table 2-3: 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 1-1** 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 tiebar 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 inlock 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 2-2. 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 2-3. When lanes are cast in separate pours, it is advised that a keyed joint be used, as indicated at the top of Figure 2-3. 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 2-3.

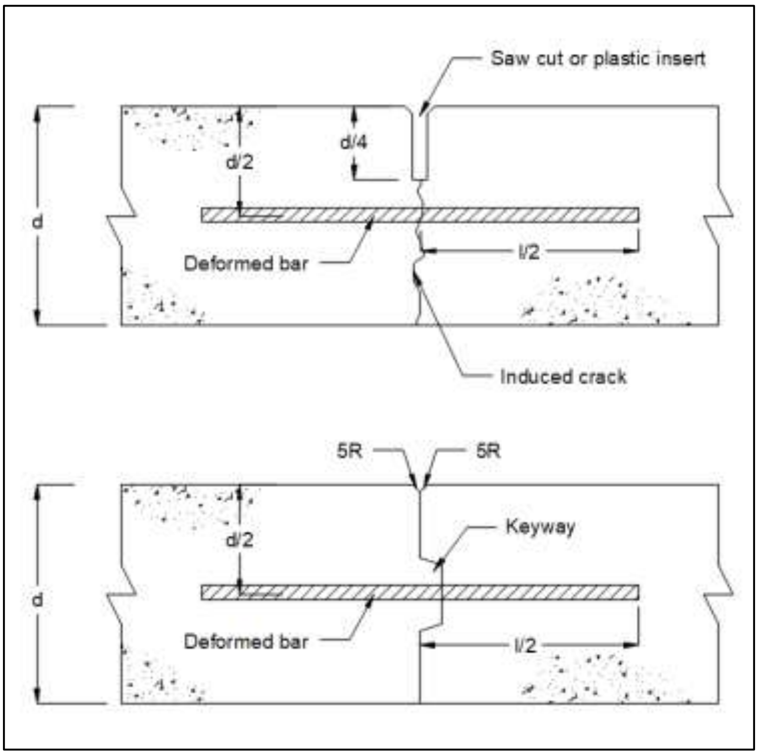


Figure 2-2: Typical detail of tie joints

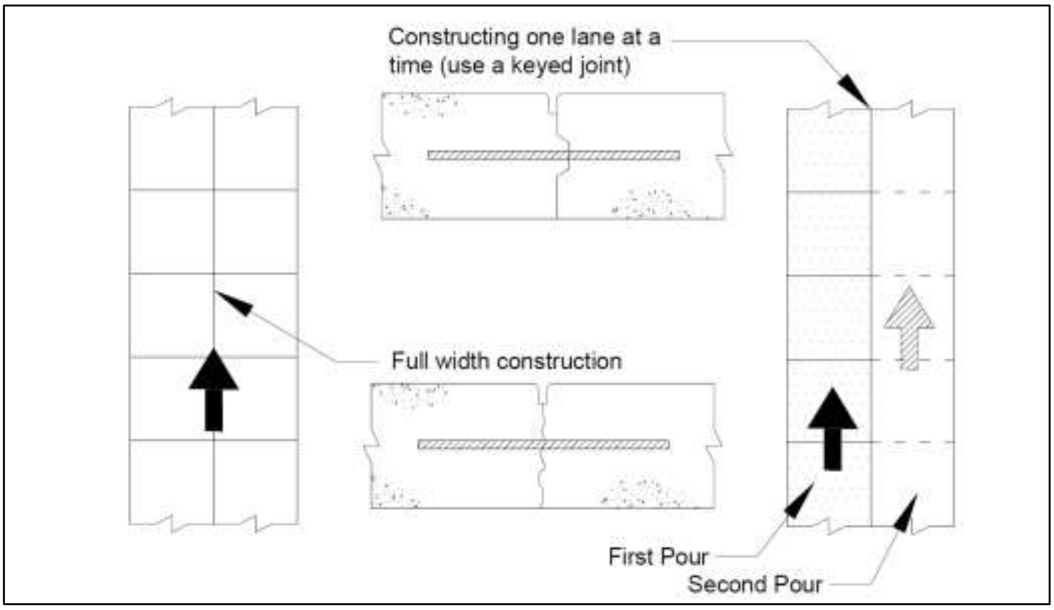
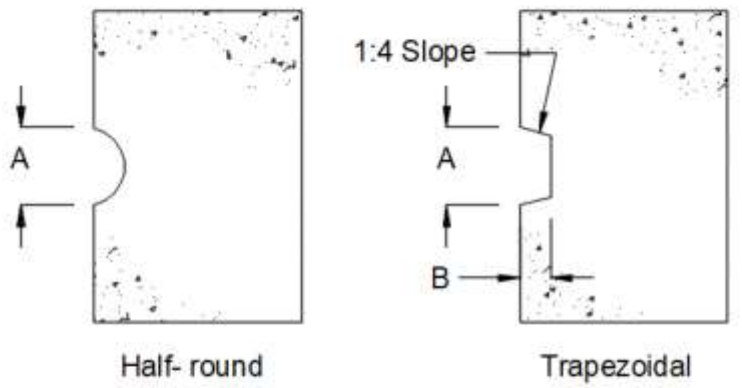


Figure 2-3: Construction of longitudinal joints (Perrie, 2000)

Details on keyed joints are presented in Figure 2-4. The keyway is half-round or trapezoidal.



d (mm)	A (mm)	B (mm)
130	25	15
150	30	15
155	30	18
165	35	18

Figure 2-4: 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 2-5) can be formed with a polyethylene sheet or bituminous felt. The polyethylene sheet should be a 90 g/m^2 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.

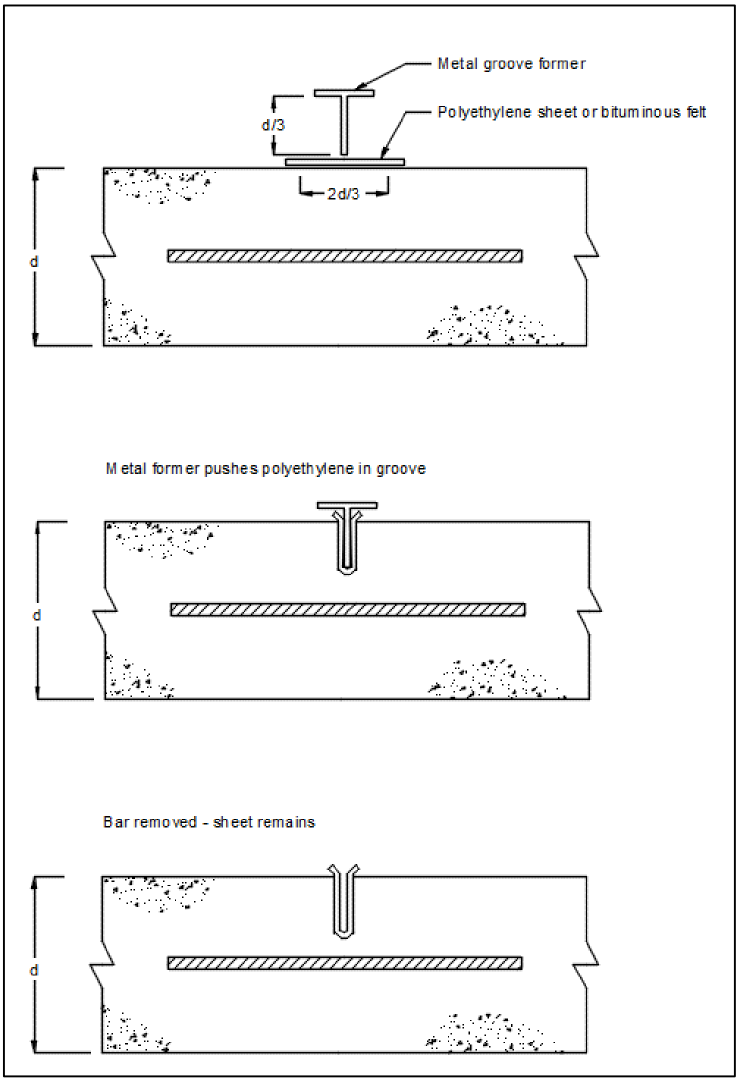


Figure 2-5: Steps in wet-forming of a joint (Perrie, 2000)

Tiebars must be placed at mid depth of the concrete slab. The purpose of the tiebars is to maintain aggregate interlock, structural capacity, and serviceability. The tiebar sizes and spacing for the various slab thicknesses (see Section 2.2.1.1) are indicated in Table 2-4.

Table 2-4: Tiebar 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 2-6. Transverse joints are normally perpendicular to the centreline and the pavement edges. Transverse joints can also be skewed, as indicated in Figure 2-7. 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).

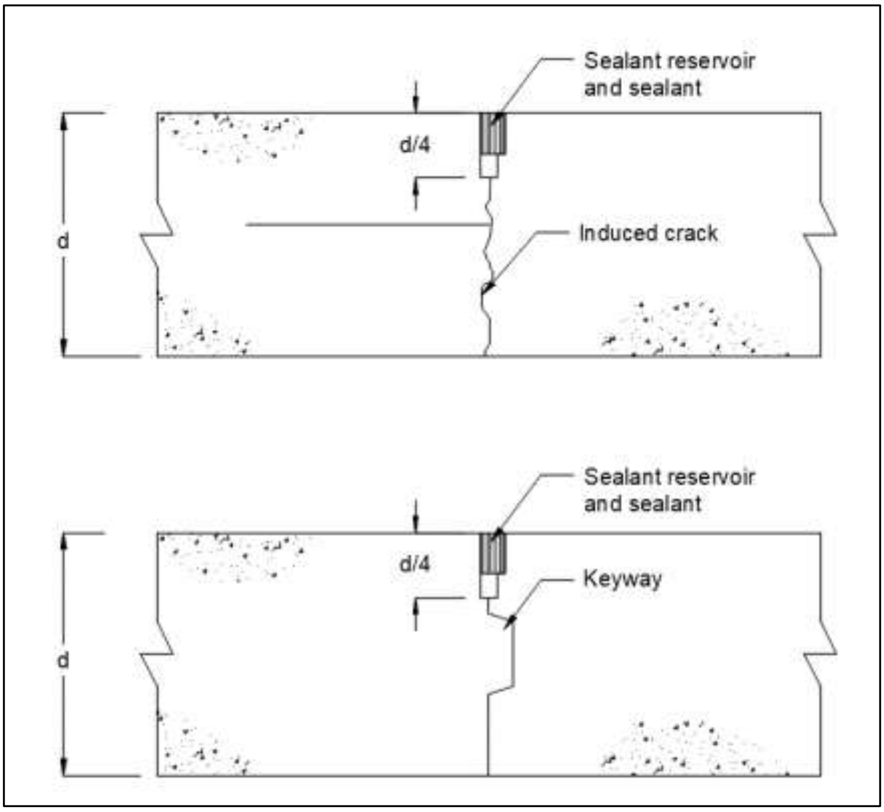


Figure 2-6: Typical detail of contraction joint

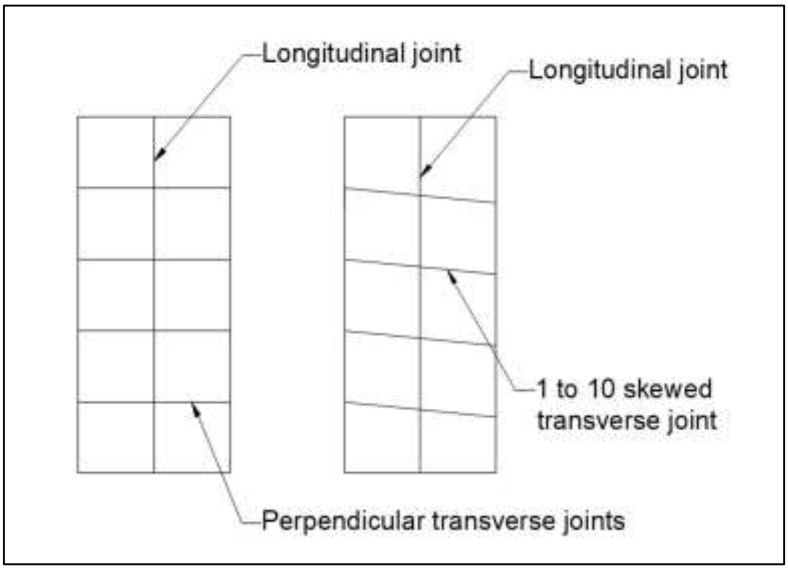


Figure 2-7: Perpendicular and skewed transverse joints

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 2-8.

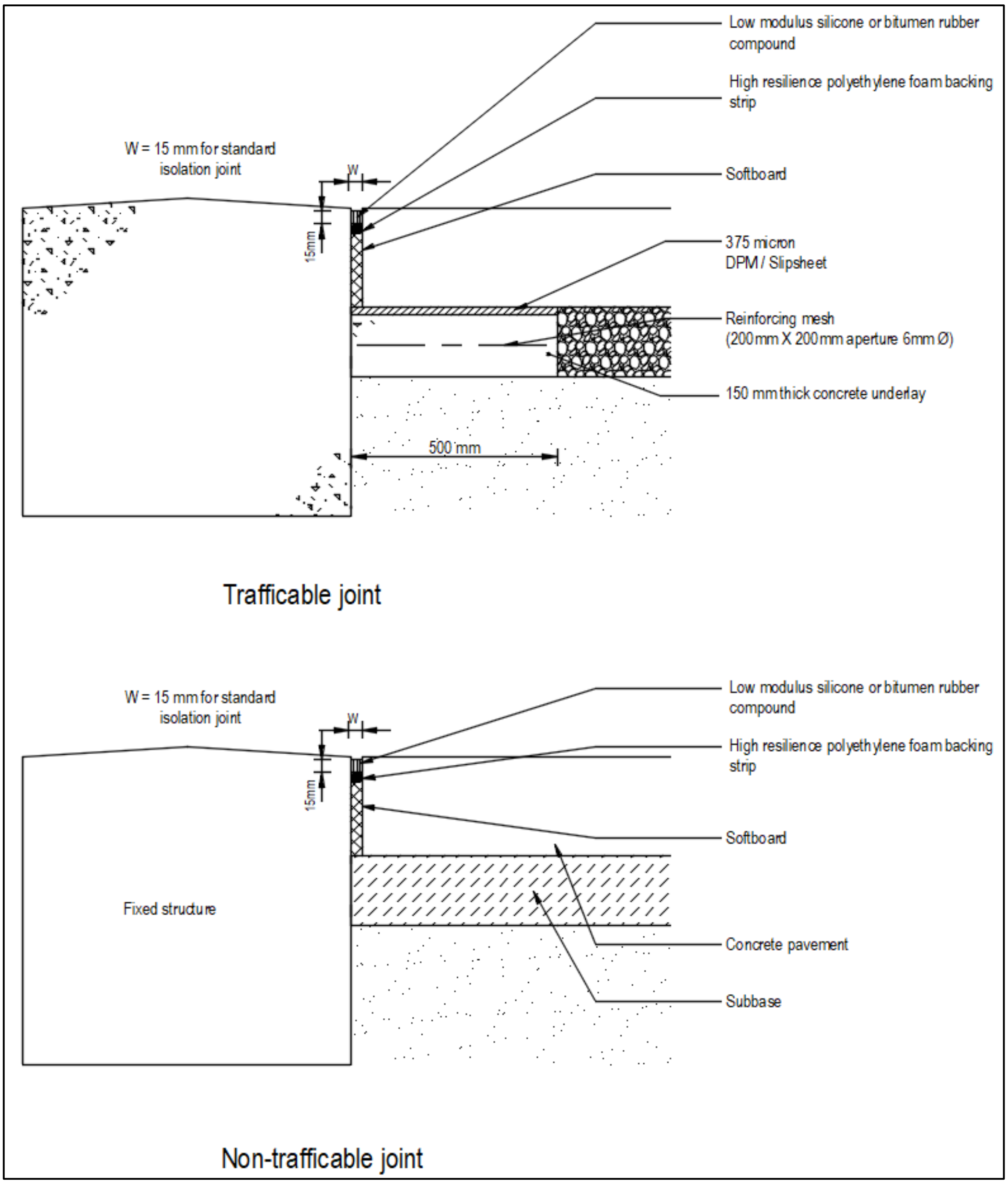


Figure 2-8: Typical isolation joint detail

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 2-4.

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 2-9.

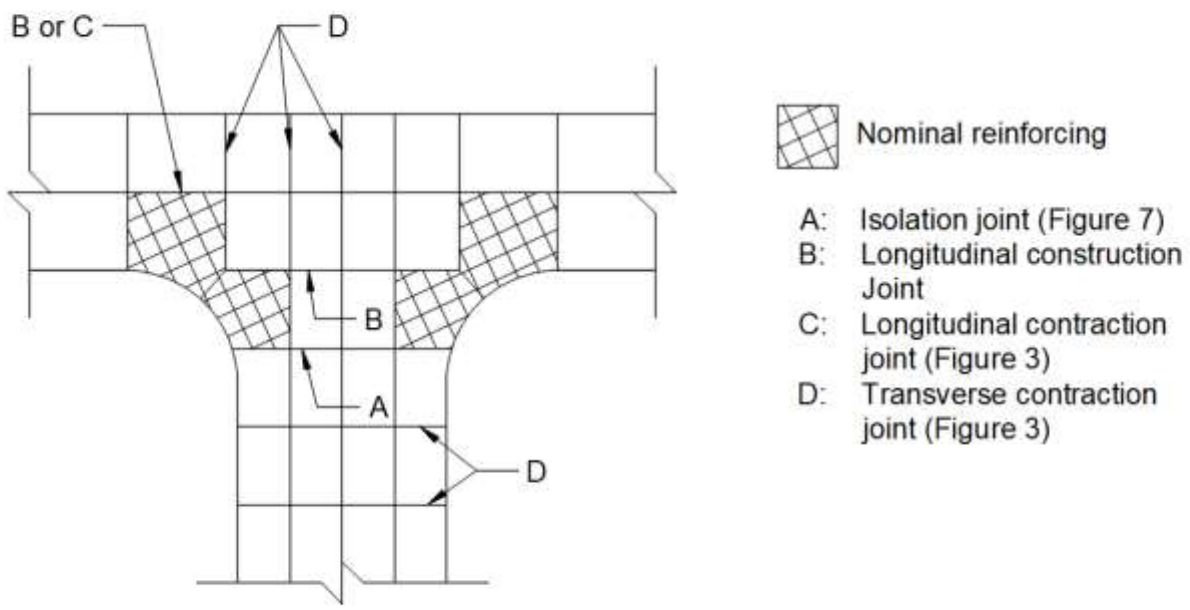


Figure 2-9: Joint layout and details for odd shapes and intersections (Perrie, 2000)

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 2-10.

Table 2-5: 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

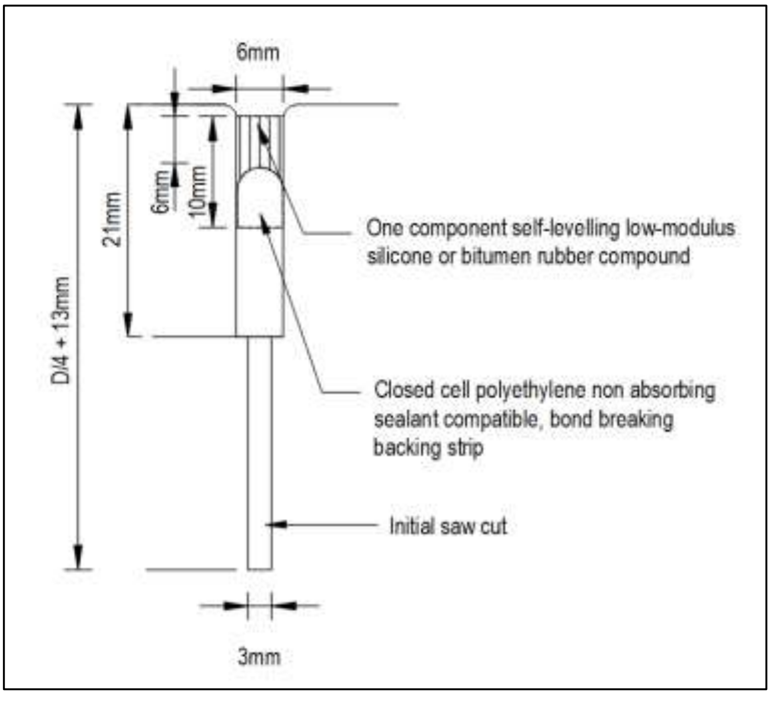


Figure 2-10:Joint sealing detail

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 1:30to 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 2-6.

Table 2-6: 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 2-11 and Figure 2-12.

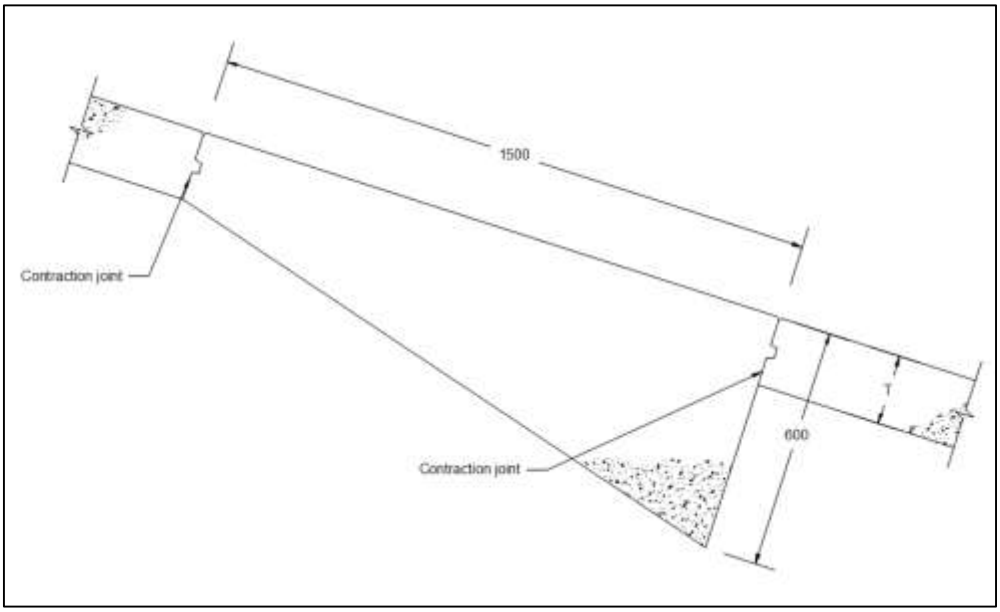


Figure 2-11: Anchor block

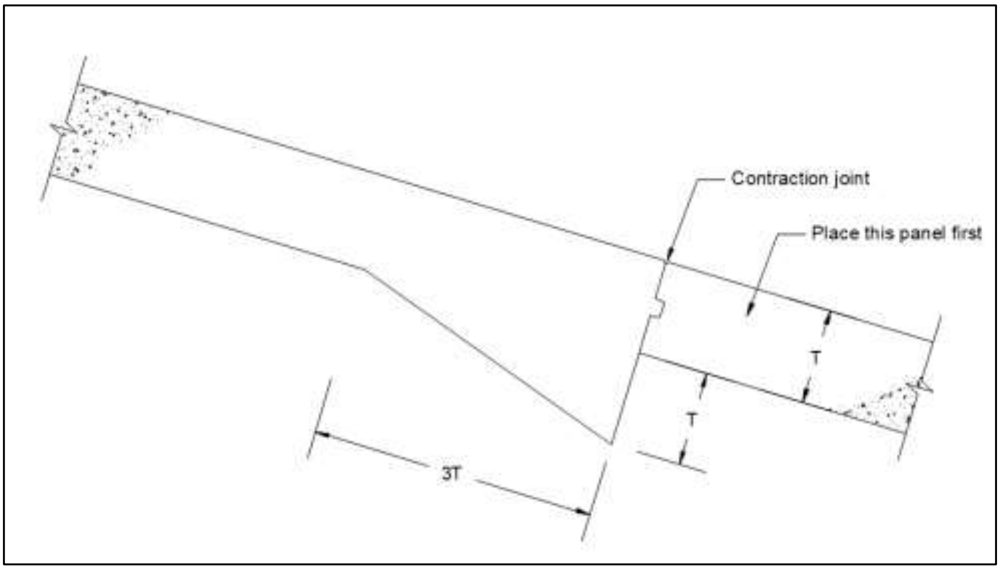


Figure 2-12: Panel anchor

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 2-13 to prevent traffic damage, unless an anchor block is placed at the end.

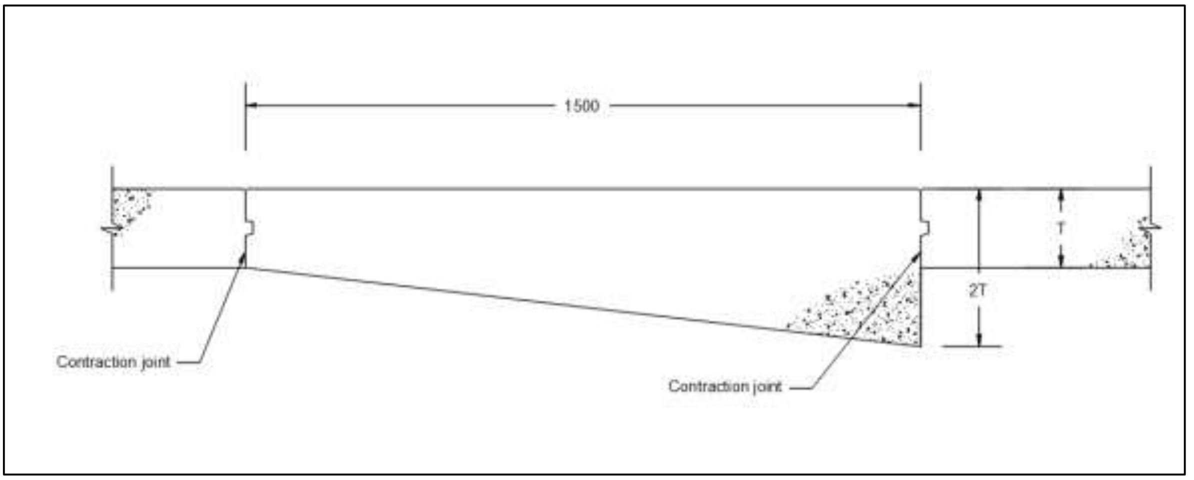


Figure 2-13: Panel at end of PJCP road

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 plume concrete is shown Figure 2-14.

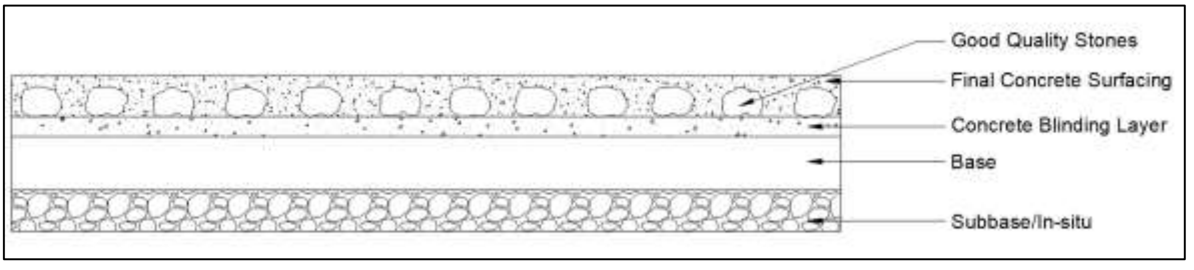


Figure 2-14: Construction of plume concrete

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 2-15. 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 2-16 for roads where a high percentage of three-wheel vehicles is expected.

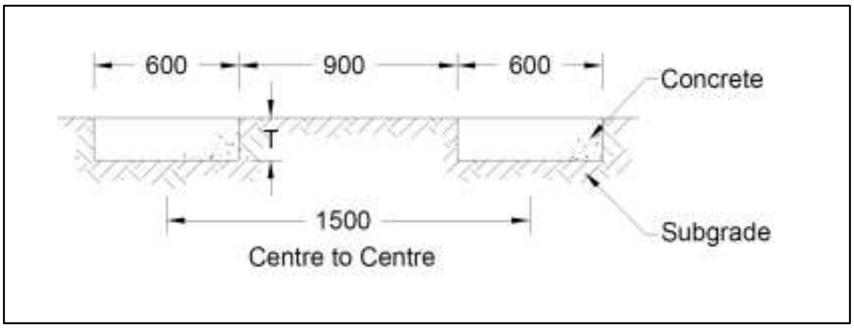


Figure 2-15:Typical cross-section of concrete strip roads

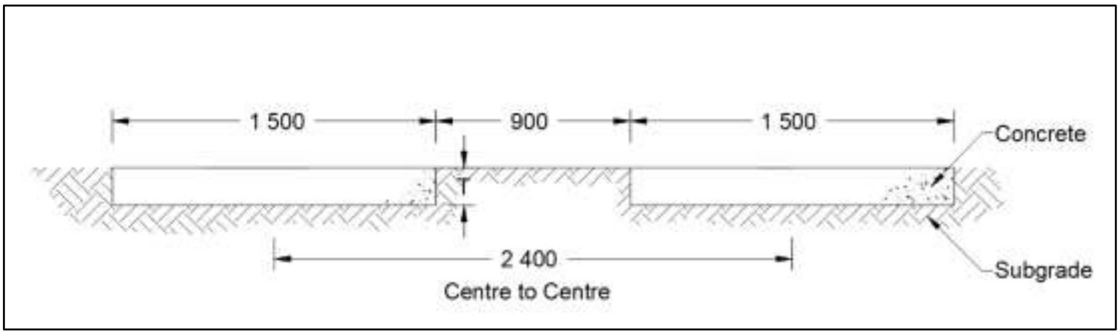


Figure 2-16:Typical cross-section of concrete strip road where three-wheeled vehicles are expected

The minimum thickness of the concrete strips and the required layerworks are indicated in Table 2-7 and based on an article published by the Concrete Institute of South Africa (The Concrete Institute, 2016).

Table 2-7: 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 2-17) or keyed (Figure 2-18) 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.

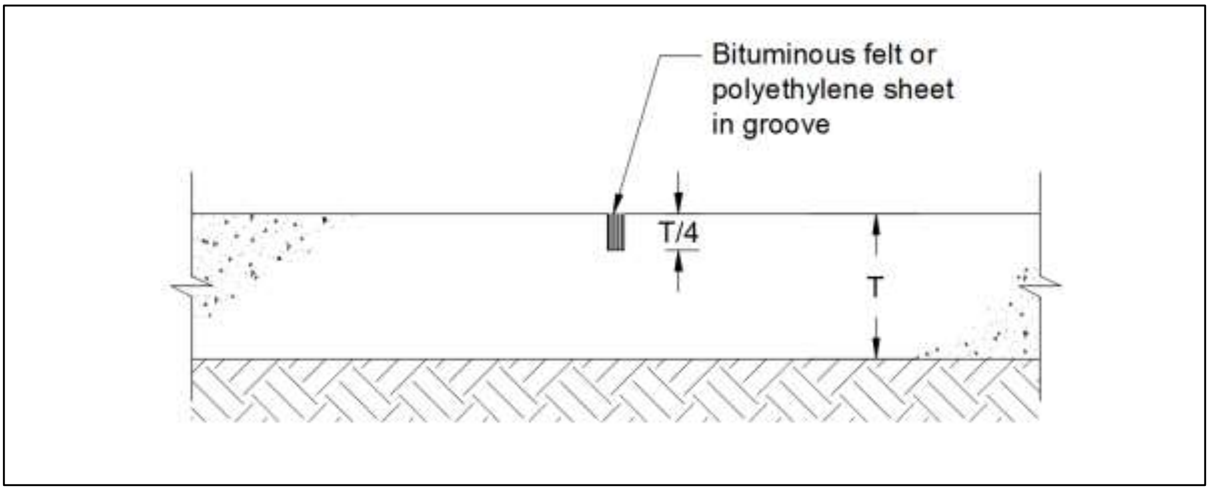


Figure 2-17:Grooved joint

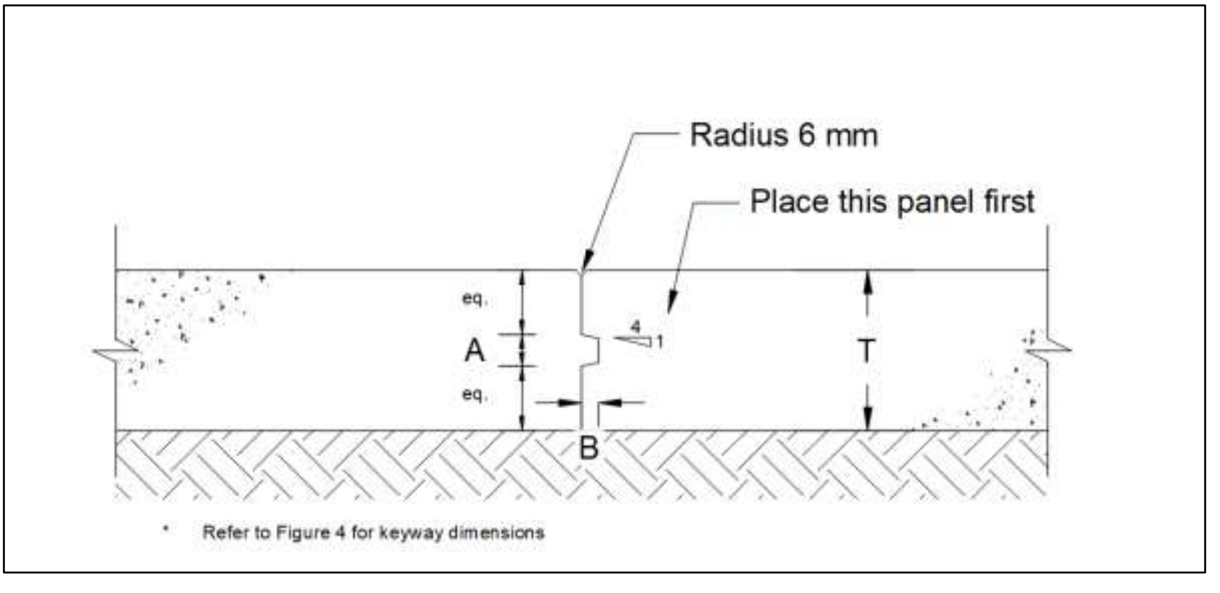


Figure 2-18:Strip roads keyed joint

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.

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 underlaying 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 include:

- Single seals
- Double seals
- Otta seals

The selection of any of these surfacings will depend on the site conditions encountered. It is recommended that a single seal should not be constructed on a new base layer, and that a single seal should be considered only for resealing purposes due to its vulnerability to the harsh environmental conditions experienced in Liberia.

3.1 SINGLE AND DOUBLE SEALS

The structure of a surface seal usually comprises a thin film of bitumen that is sprayed onto the road surface and then covered with a layer of stone chippings. For the double seal, a second bitumen coat is applied, and followed by a second layer of stone chippings. The size of the chippings in the second layer is, in most cases, smaller than the first layer of chippings. An example of a double seal is shown in Figure 3-1.

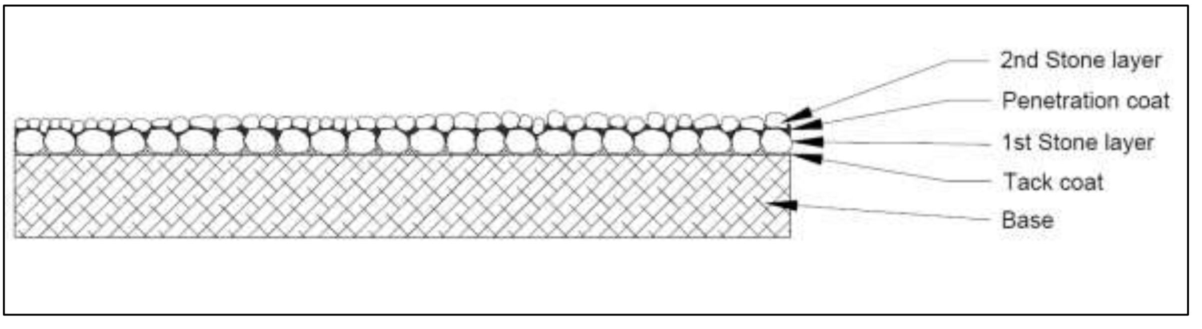


Figure 3-1: Double seal

The function of the binder is to act as a waterproofing seal to prevent water ingress into the base and subbase layers. The stone chippings provide a durable surfacing to prevent traffic movement from damaging the bituminous waterproofing seal. It also provides a skid-resistant travelling surface that is dust-free. The binder keeps the stones intact and together they form a durable surfacing.

The success of a surfacing seal is dependent on the adhesion of the chipping to the road surface. The road surface, as well as the chippings, should be dust-free to ensure maximum adhesion.

When a double seal is constructed, there will be a noticeable increase in surfacing quality when the first dressing is trafficked for two to three weeks before the second dressing is applied. Trafficking the first dressing will allow the chips to settle into a stable interlocking firm foundation for the second dressing. The downside of traffic on the unfinished pavement is that contamination of the surfacing can occur. This could cause an adhesion problem when the next layer is applied.

3.1.1 Materials

Aggregates and the type of binder to be used must be considered in the construction of single or double seals.

3.1.1.1 Aggregates

The ideal shape of chippings used for seals is cubical and single-sized. Other important features of chipping include strength, durability, and resistance to polishing under traffic loading.

Chippings should be tested for grading, flakiness, aggregate crushing value, polished stone value, and aggregate abrasion value. Table 3-1 provides typical requirements for aggregates to be used in surfacing seals.

Table 3-1: Aggregate requirements for surface dressings

Grading limits	Nominal size of aggregates (mm)			
	20	**14**	**10**	**6.3**
28	100	–	–	–
20	85–100	100	–	–
14	0–40	85–100	100	–
10	0–7	0–40	85–100	100
6.3	–	0–7	0–35	85–100
5.0	–	–	0–10	–
3.35	–	–	–	0–35
2.36	0–3	0–3	0–3	0–10
0.600	0–2	0–2	0–2	0–2
0.075	–	–	–	–
Flakiness index	35 maximum	35 maximum	35 maximum	–
Aggregate crushing value	20–35	20–35	20–35	20–35

The most critical time for a surfacing is immediately after construction. Dusty chippings can inhibit adhesion, resulting in greater stripping potential. Aggregates have an affinity for water rather than bitumen. When heavy rains occur after construction, adhesion may not develop fully, and there may be weak patches.

3.1.1.1.1 Precoating materials or adhesion agents

To ensure good adhesion between the aggregate and the binder, either the seal chippings are precoated or adhesion agents are added to the binder. Precoating is not used when emulsion binders are used.

If aggregates are dusty, the adhesion agent will be ineffective, and precoating only can be considered.

3.1.1.1.2 Method for precoating

The untreated stockpile of aggregate should be thoroughly sprayed with water, and then be allowed to drain off. The damp aggregate should then be loaded into the bucket of a front-end loader (1 m^3) and 12 litres of an approved precoating fluid sprayed evenly over the aggregate by means of a watering can. The wetting agent should be added to the precoating fluid typically at a rate of 0.5% of the volume of the precoating fluid.

The mixture of aggregate and precoating fluid should then be dumped on a carefully prepared site that is free of grass, dirt, and other deleterious materials. This process is to be repeated until a stockpile of approximately 15 to 20 m^3 of aggregate has been built up. This stockpile should then be turned over with the front-end loader until the aggregate is uniformly coated with the precoating fluid. Three complete turnings of the stockpile will probably be required.

3.1.1.2 Prime coat

Where a surface dressing will be applied for the first time, it is essential that the road surface be dry, clean, and free from dust. A prime coat can ensure these favourable conditions. The function of a prime coat includes the following:

- It promotes adhesion between the base and the surfacing seal.
- It reduces the amount of binder absorbed by the base layer because it seals the surface pores.
- It binds the finer particles at the top of the road base, and thereby strengthens the base near the surface.
- It provides temporary protection against rainfall and light traffic until the surfacing is constructed.

The prime should penetrate the base between 3 and 10 mm. The spray rate should be such that the base is dry within a few hours. The type of prime is also dependent on the type of base material. For stabilised surfaces, a low-viscosity cutback bitumen can be used. For untreated surfaces, a higher viscosity cutback bitumen is recommended. Emulsions are not suitable for use as a prime. Recommended primes include MC30 and MC70 cutback bitumen, and typical application rates are provided in Table 3-2.

Table 3-2: Typical prime application rates

Pavement surface	Prime	
	Grade	Rate of application (l/m^2)
Tight bonded (light primer)	MC30	0.7–0.8
Medium porosity (medium primer)	MC30/MC70	0.8–0.9
Porous (heavy primer)	MC30/MC70	0.9–1.1

Priming should not be carried out when the surface temperature is below 10°C, when there is strong wind, or when rain threatens. Priming should be done when the base has dried to approximately 50% of the optimum moisture content.

3.1.1.3 Bituminous binders

Bitumen's that are often used for surface dressing in tropical conditions include the following:

- Penetration-grade bitumen
- Emulsion bitumen
- Cutback bitumen
- Modified binders

The maximum gradients at which the different binders can be applied are shown in Table 3-3.

Table 3-3: Recommended maximum gradients for different binder types

Binder type		Maximum gradient*
Bitumen grade	80/100 penetration grade	12%
	150/200 penetration grade	10%
	300 penetration grade	6%
Cutback bitumen	MC3000	8%
	MC800	6%
Emulsion	60%	6%
	65%	8%

*Note: The maximum gradient refers to the maximum gradient resulting from the vertical alignment and camber of the road, and not to the vertical alignment only.

3.1.2 Design

The design of a suitable surface dressing is dependent on the daily volumes of commercial vehicles using each lane of the road, the size of the aggregate, as well as the hardness and roughness of the existing pavement surface. When traffic levels are high, and when the underlying surface is soft, the embedment of chippings occurs more rapidly, and a reseal might be required. Larger chippings are therefore required on soft surfaces or when traffic is heavy.

The process for designing a surfacing seal is presented in the flow diagram provided in Figure 3-2, and is discussed in more detail below.

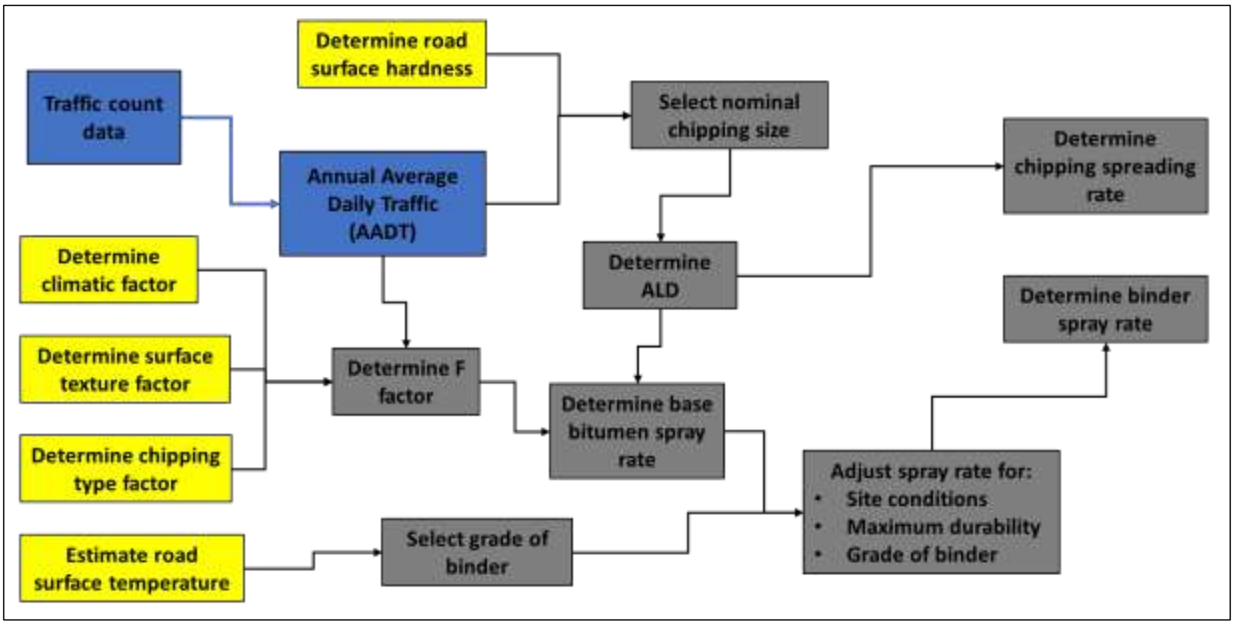


Figure 3-2: Flow diagram of design procedure for seals

In the sections that follow, pavement layerworks, the selection of stone size and of binder, the bitumen spray rate, and spray rate adjustments are discussed.

3.1.2.1 Pavement layerworks

The manual for low-volume roads indicates that the layerworks listed in Table 3-4 can be used for bituminous pavements.

Table 3-4: Layerworks for bituminous pavements

Subgrade CBR	Layer	Traffic loading class		
		TLC 0.01	TLC 0.3	TLC 1.0
SC1 (< 3%)		Special subgrade treatment required		
SC2 (3–7%)	Base	150 G60	125 G60	150 G80
	Subbase	175 G40	150 G30	150 G40
	Selected	none	200 G15	200 G15
SC3 (8–14%)	Base	100 G40	125 G60	150 G80
	Subbase	125 G30	125 G30	150 G40
	Selected	none	125 G15	125 G15
SC4 (≥ 15%)	Base	125 G40	175 G80	150 G80
	Subbase	none	none	150 G40

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

3.1.2.2 Selection of stone size

There are four important components to consider in the selection of stone size: the surface hardness, the traffic in the design lane, the average least dimension of the chippings and the spread rate of the chippings.

3.1.2.2.1 Road surface hardness

Road surface hardness can be estimated by means of the information presented in Table 3-5. A modified soil assessment cone penetrometer test can be performed to determine the penetration at 30°C. The standard cone is replaced with a probe rod with a diameter of 4 mm and a hemispherical tip made of hardened steel. A load of 35 kg (343 kN) is applied to the rod for 10 seconds. The depth of penetration is measured by a spring-loaded collar that slides up the rod. The penetration is then corrected to an equivalent value at a standard temperature of 30°C.

Table 3-5: Categories of road surface hardness

Category penetration of surface at 30°C (mm)		Definition
Very hard	0–2	Concrete or very lean bituminous structures with dry stony surfaces. There would be negligible penetration of chippings under the heaviest traffic.
Hard	2–5	Likely to be an asphalt surfacing that has aged for several years and is showing some cracking. Chippings will penetrate only slightly under heavy traffic.
Normal	5–8	Typically, an existing surface dressing that has aged but that retains a dark and slightly bitumen-rich appearance. Chippings will penetrate moderately under medium and heavy traffic.
Soft	8–12	New asphalt surfacings or surface dressings that look bitumen-rich and have only slight surface texture. Surfaces into which chippings will penetrate considerably under medium and heavy traffic.
Very soft	> 12	Surfaces, usually a surface dressing that is very rich in binder and that has virtually no surface texture. Even large chippings will be submerged under heavy traffic.

3.1.2.2.2 Selection of chipping size

The required sizes of chippings are indicated in Table 3-6.

Table 3-6: Recommended nominal size of chippings (mm)

Type of surface	Approximate number of commercial vehicles with an unladen weight greater than 1.5 tonnes currently carried per day in the design lane				
	2000–4000	1000–2000	200–1000	20–200	< 200
Very hard	10	10	6	6	6
Hard	14	14	10	6	6
Normal	20*	14	10	10	6
Soft	#	20*	14	14	10
Very soft	#	#	20*	14	10

The size of chipping specified is related to the mid-point of each lane traffic category. Lighter traffic conditions may make the next smaller size of stone more appropriate.

* Very particular care should be taken when using 20 mm chippings to ensure that no loose chippings remain on the surface when the road is opened to unrestricted traffic, as there is a high risk that the chippings may break vehicles' windscreens.

These sizes are unsuitable for surface dressing.

When selecting chipping sizes for the double seal, the chipping size should be selected based on the hardness of the existing surface as well as the traffic category (Table 3-6). The second layer of chippings should be selected based on the Average Least Dimension (ALD). For the sake of good interlocking, the ALD of the second layer should not be more than half the ALD of the first. If the base was constructed using stabilised material, it is recommended that an inverted double seal first be built where the small chippings are to be applied, and that a second layer of larger chippings then be applied.

3.1.2.2.3 Average least dimension (ALD) of chippings

There are two factors required to determine the ALD:

- A grading analysis should be performed in accordance with the procedures outlined in British Standard 812:1985.
- The flakiness index should be determined in accordance with the method specified in British Standard 812:1985.

The ALD is determined using the information given in Figure 3-3. The median sieve size (the sieve size through which 50% of the chippings pass – Line A) is joined to the flakiness index (Line C), with a straight line. The ALD is read off from Line B.

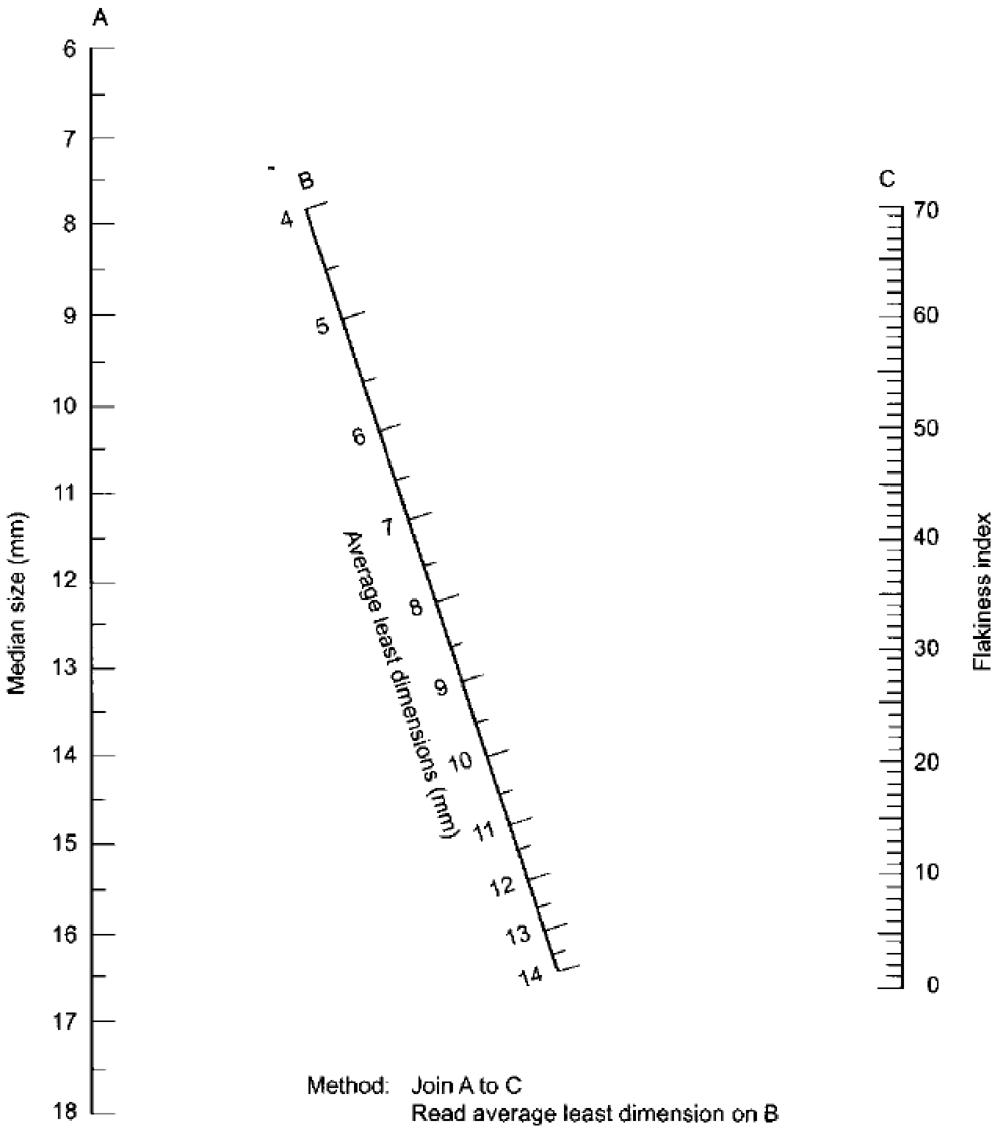


Figure 3-3: Determination of the average least dimension

3.1.2.2.4 Spread rate of chippings

The spread rate of chippings can be determined as follows:

$$\text{Application rate } \left(kg/m^2\right) = 1.364 \times ALD$$

3.1.2.3 Selection of binder

Binder selection is based firstly on the materials available from a local supplier. Other factors that should then be considered include the temperature of the road surface at the time of construction, the binder handling and spraying equipment, the nature of the chippings, and the characteristics of the roadside.

3.1.2.3.1 Temperature of road surface at time of construction

Cutback and penetration-grade binders should have a viscosity of between 1x 104 and 7x 105 centistokes at the road surface temperature. In tropical areas, daytime road temperatures vary between 25 and 50°C. In most cases, the temperatures rise towards the upper end of the range, unless heavy rainfall occurs. For higher road temperatures, penetration-grade bitumen is more suitable. At lower temperatures, cutback bitumen is more appropriate.

3.1.2.3.2 Binder handling and spraying equipment

An appropriate temperature and spray rate should be maintained throughout the operation.

3.1.2.3.3 Nature of chippings

Dusty chippings should be pre-treated. The acidity of certain chippings should be verified before an emulsion is used.

3.1.2.3.4 Roadside characteristics

Certain binders are not suitable for steep slopes.

3.1.2.4 Determination of the overall weighting factor

The basic spray rate is determined using the ALD and the overall weighting F factor as indicated in Table 3-7. The following four aspects are considered when determining the F factor:

- Traffic level
- Existing road surface condition
- Climatic conditions
- Type of chipping

Determine the weighting F factor by selecting the most fitting description in the various categories and adding the weighting factors.

3.1.2.5 Determination of the bitumen spray rate

Use the ALD and the F factor in the formula below to determine the spray rate.

$$R=0.625+(F\times 0.023)+[0.0375+(F\times 0.0011)]ALD$$

Where:

F = Overall weighting factor

ALD = the average least dimension of the chippings (mm)

R = basic rate of spread of bitumen (kg.m2)

The spray rate (R) in the equation is calculated for MC3000 binder. The relative density of the MC3000 can be assumed to be 1.0. The spread rate can then be expressed in l/m^2.

3.1.2.6 Spray rate adjustments

The spray rate must be adjusted in the following cases:

- For climbing lanes steeper than 3% with slow traffic, the spray rate should be decreased by 10%.

- For downgrades steeper than 3% with fast-moving traffic, the spray rate should be increased by 10%.
- When using binders other than MC3000, the spray rate must also be adjusted. The following recommendations are made:
  - For penetration-grade binders, decrease the spray rate by 10%.
  - For emulsions, multiply the spray rate by 90, and divide it by bitumen content of the emulsion.

A summary of the adjustment of the spray rate is shown in Table 3-8.

Table 3-7: Components for determination of weighting factor

Description		Factor
Total traffic (all classes)		
	Vehicles/lane/day	
Very light	0–50	+3
Light	50–250	+1
Medium	250–500	0
Medium-heavy	500–1500	-1
Heavy	1500–3000	-3
Very heavy	3000+	-5
Existing surface		
Untreated or primed base		+6
Very lean bituminous		+4
Lean bituminous		0
Average bituminous		-1
Very rich bituminous		-3
Climatic conditions		
Wet & cold		+2
Tropical (wet and hot)		+1
Temperate		0
Semi-arid (hot and dry)		-1
Arid (very dry and very hot)		-2
Type of chipping		
Round/dusty		+2
Cubical		0
Flaky		-2
Pre-coated		-2

Table 3-8: Adjustment of binder spray rate

Binder grade	Basic spray rate	Flat terrain, moderate traveling speed	Downhill grades > 3%, high travelling speed	Uphill grades > 3%, low travelling speed
MC3000	X	X	X*1.1	X*0.9
300 penetration grade	X	X*0.95	X*1.05	X*0.86
80/100 penetration grade	X	X*0.9	X*0.99	X*0.81
Emulsion	X	X*(90/% bitumen in the emulsion)	X*(99/% bitumen in the emulsion)	X*(81/% bitumen in the emulsion)

The spray rate of binder for low-volume roads must also be adjusted in accordance with the ALD of the chippings. Table 3-9 gives a guideline of how to adjust the spray rate.

Table 3-9: Spray rate increase for low-volume roads

ADL of chippings (mm)	3		6		> 6	
Vehicles/lane/day	< 20	20–100	< 20	20–100	< 20	20–100
Increase in bitumen spray rate (%)	15	10	20	15	30	20

3.2 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 3-4)
  - Open/medium/dense grade with either a sand seal or no sand seal cover
- Double Otta seals (see Figure 3-5)
  - Open/medium/dense grade with either a sand seal or no sand seal cover

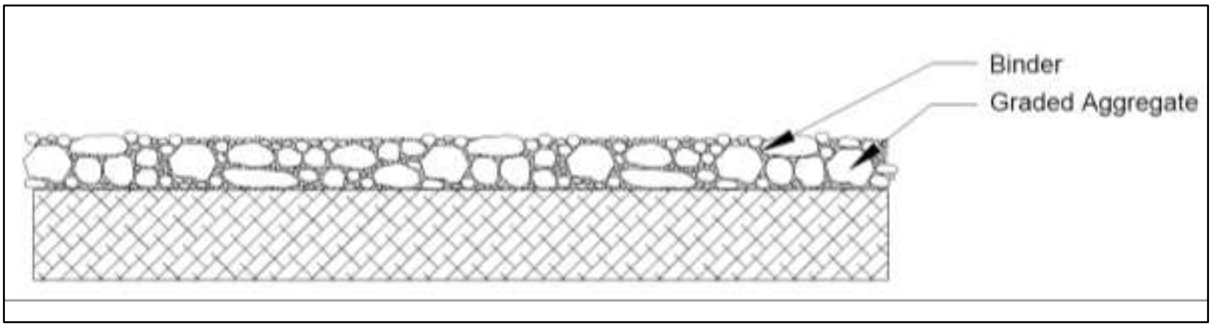


Figure 3-4: Single Otta seal

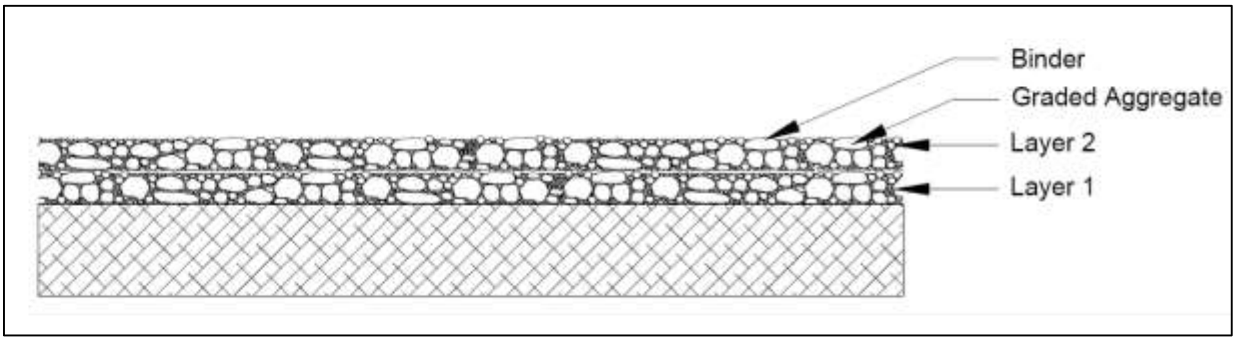


Figure 3-5: Double Otta seal

3.2.1 Materials

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

3.2.1.1 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.

3.2.1.1.1 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

3.2.1.1.2 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.

3.2.1.1.3 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.

3.2.1.1.4 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.

3.2.1.1.4.1 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.

3.2.1.1.4.2 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%.

3.2.1.1.4.3 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

3.2.1.1.4.4 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 3-10.

Table 3-10: 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.

3.2.1.1.4.5 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 3-11.

Table 3-11: Grading requirements for Otta seals

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

3.2.1.2 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 duringa single spray operation.

3.2.1.2.1 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.

3.2.1.2.2 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-cuing 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.

3.2.1.2.3 Blending proportions

Blending proportions to produce medium-curing cutback bitumen are set out in Table 3-12.

Table 3-12: 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.

3.2.2 Otta seal design

The process for the design of an Otta seal is indicated in Figure 3-6.

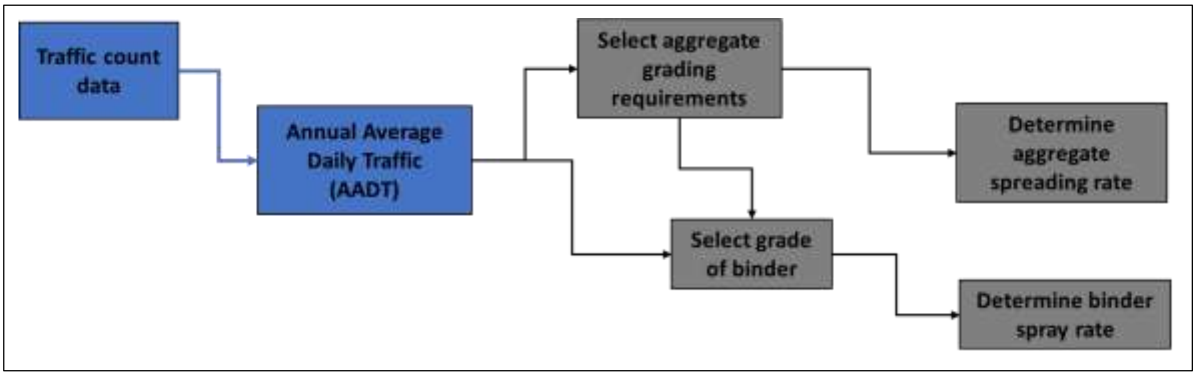


Figure 3-6: Flow diagram of the design procedure for Otta seals

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

3.2.2.1.1 Pavement layerworks

Refer to Section 3.1.2.1.

3.2.2.1.2 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 3-13.

Table 3-13: 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^3/m^2	0.013–0.016 m^3/m^2	0.013–0.020 m^3/m^2
Sand covered seal	0.010–0.012 m^3/m^2	0.010–0.012 m^3/m^2	0.010–0.012 m^3/m^2

3.2.2.1.3 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 3-14.

Table 3-14: 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	NA	MC3000 and MC800 in cold weather
100–1000	NA	150/200 penetration grade in cold weather	MC3000 and MC800 in cold weather
< 100	150/200 penetration grade	MC3000	MC800

3.2.2.1.4 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 3-15: Bitumen spray rates (l/m^2)

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/m² in the first layer.

Notes:

- The bitumen spray rate must be increased by 0.3 l/m² 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 4-1. The envelope parameters are given in Table 4-1.

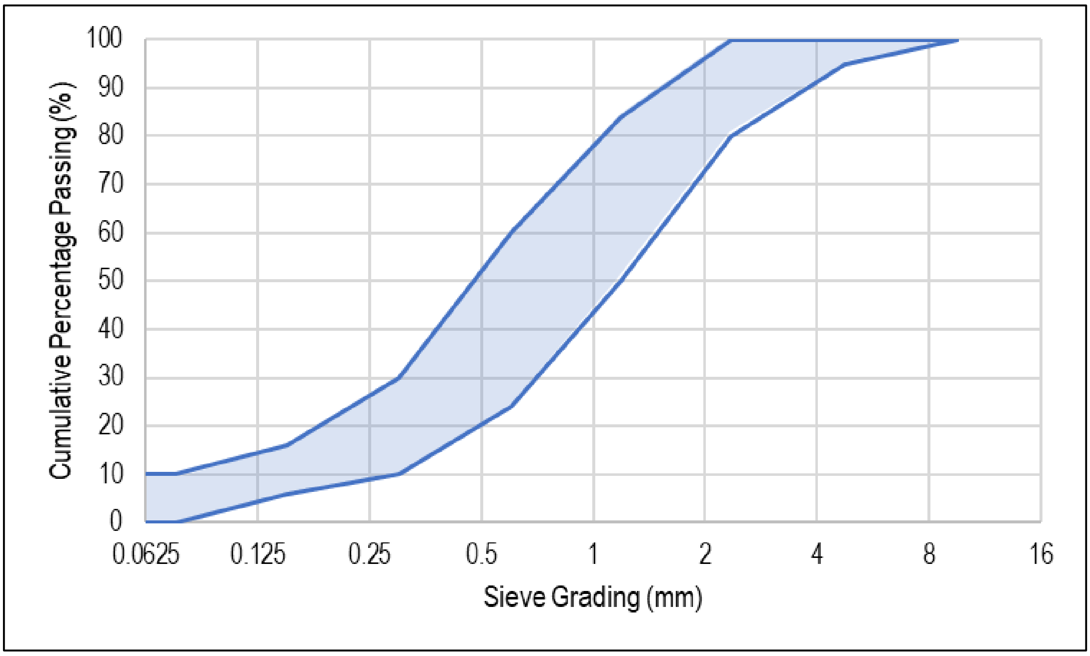


Figure 4-1: Grading envelope for bedding sand

Table 4-1: 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 re-screeded 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 4-2. The envelope parameters are specified in Table 4-2. Ideally, jointing sand should contain a small amount of clay or silt, as this helps to prevent water ingress.

Table 4-2: 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 joining 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 4.1.2must 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.

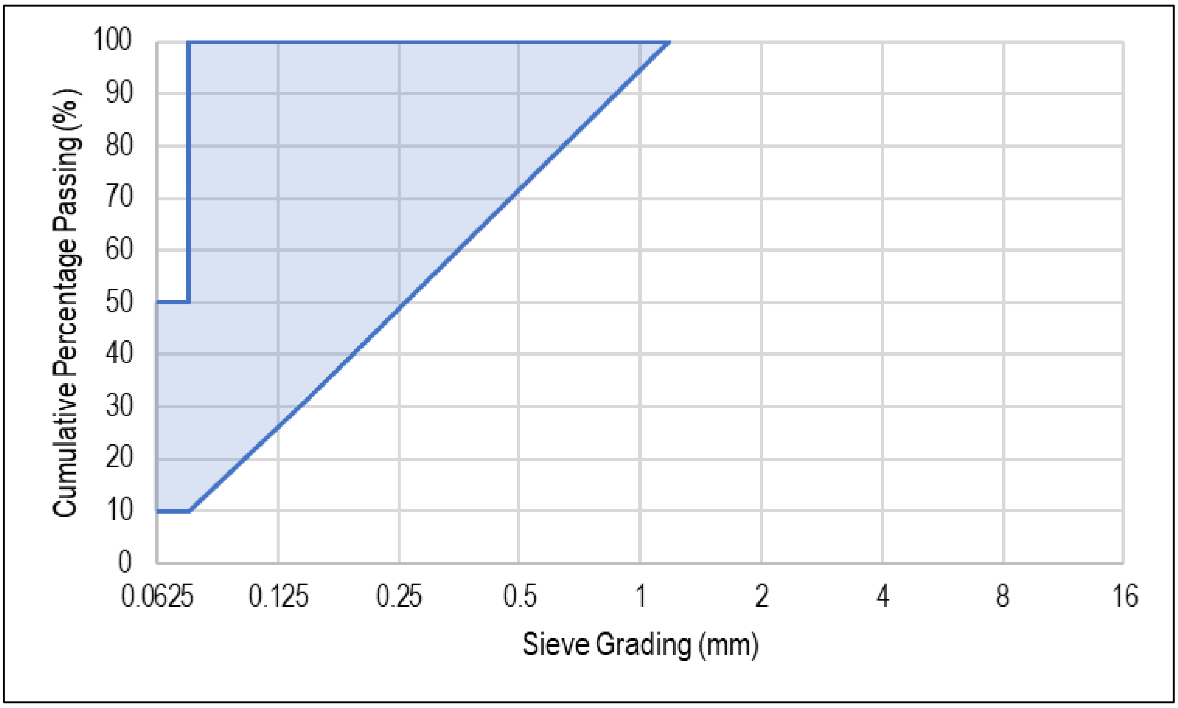


Figure 4-2: Grading envelope for jointing sand

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 4-3can be used to select the appropriate pavement design. The data provided inTable 4-3 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 4-3: 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	Paving blocks	Paving blocks
	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	Paving blocks	Paving blocks
	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	Paving blocks	Paving blocks
	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 1-1** 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 4-3. 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.

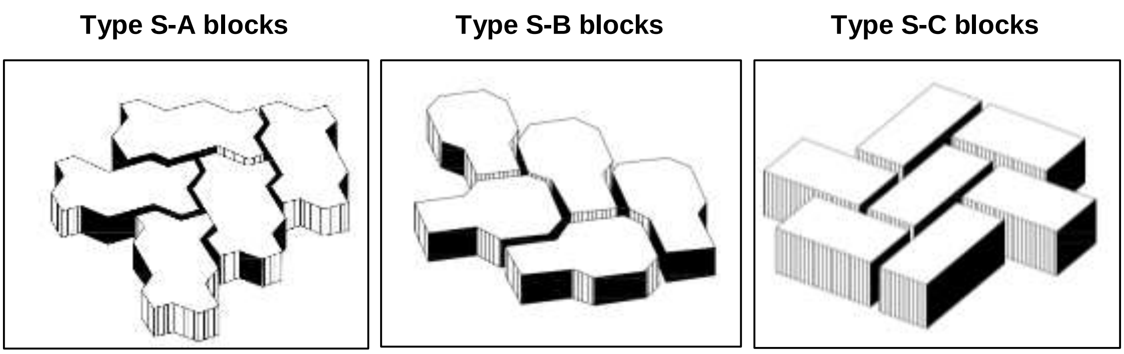


Figure 4-3: General paving block shapes

4.2.1.3 Laying patterns

Three of the most common laying patterns for concrete paving blocks are shown inFigure 4-4. 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.

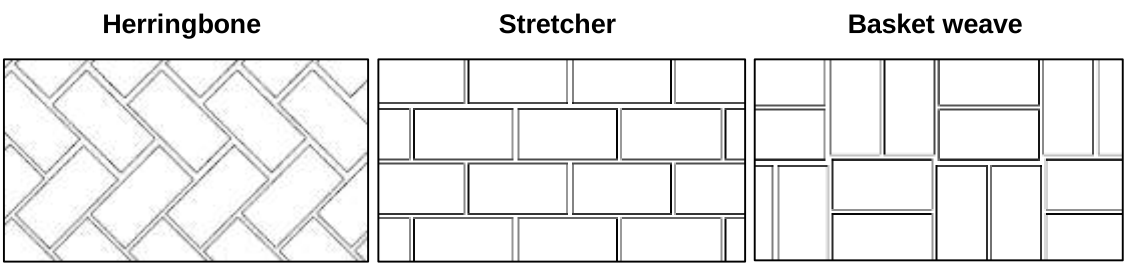


Figure 4-4: Concrete paving block laying patterns

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 inTable 4-4

Table 4-4: 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 4-5.

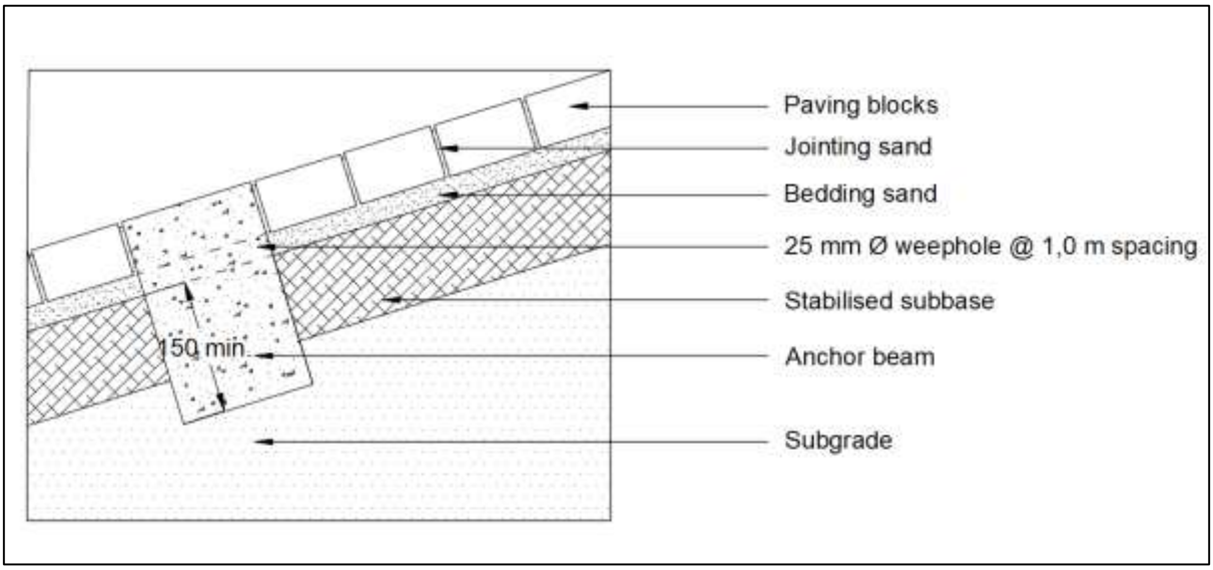


Figure 4-5: Construction of anchor beam

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