

BS 7533-13:2009



# BSI British Standards

## **Pavements constructed with clay, natural stone or concrete pavers**

Part 13: Guide for the design of permeable pavements constructed with concrete paving blocks and flags, natural stone slabs and setts and clay pavers

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ISBN 978 0 580 58077 2

ICS 93.080.20

The following BSI references relate to the work on this standard:

Committee reference B/507

Draft for comment 07/30159351 DC

**Publication history**

First published March 2009

**Amendments issued since publication**

Date	Text affected
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### Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 26, an inside back cover and a back cover.



## Foreword

### Publishing information

This part of BS 7533 is published by BSI and came into effect on 31 March 2009. It was prepared by Technical Committee B/507, *Paving units, kerbs, screeds and in-situ floorings*. A list of organizations represented on this committee can be obtained on request to its secretary.

### Relationship with other publications

BS 7533 consists of the following parts:

- *Part 1: Guide for the structural design of heavy duty pavements constructed of clay pavers or precast concrete paving blocks;*
- *Part 2: Guide for the structural design of lightly trafficked pavements constructed of clay pavers or precast concrete paving blocks;*
- *Part 3: Code of practice for laying precast concrete paving blocks and clay pavers for flexible pavements;*
- *Part 4: Code of practice for the construction of pavements of precast concrete flags or natural stone slabs;*
- *Part 5: Guide for the design of pavements (other than structural aspects);*
- *Part 6: Code of practice for laying natural stone, precast concrete and clay kerb units;*
- *Part 7: Code of practice for the construction of pavements of natural stone setts and cobbles;*
- *Part 8: Guide for the structural design of lightly trafficked pavements of precast concrete flags and natural stone slabs;*
- *Part 9: Code of practice for the construction of rigid pavements of clay pavers;*
- *Part 10: Guide for the structural design of trafficked pavements constructed of natural stone setts;*
- *Part 11: Code of practice for the opening, maintenance and reinstatement of pavements of concrete, clay and natural stone;*
- *Part 12: Guide to the structural design of trafficked pavements constructed on a bound base using concrete paving flags and natural stone slabs;*
- *Part 13: Guide for the design of permeable pavements constructed with concrete paving blocks and flags, natural stone slabs and setts and clay pavers.*

### Use of this document

As a guide, this part of BS 7533 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this part of BS 7533 is expected to be able to justify any course of action that deviates from its recommendations.

### **Presentational conventions**

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

*Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.*

The word "should" is used to express recommendations of this standard. The word "may" is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word "can" is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this standard. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

### **Contractual and legal considerations**

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

**Compliance with a British Standard cannot confer immunity from legal obligations.**

## 1 Scope

This part of BS 7533 gives guidance on the design of permeable pavements surfaced with:

- concrete paving blocks manufactured in accordance with BS EN 1338;
- concrete paving flags manufactured in accordance with BS EN 1339;
- natural stone slabs manufactured in accordance with BS EN 1341;
- natural stone setts manufactured in accordance with BS EN 1342; and
- clay pavers manufactured in accordance with BS EN 1344.

and laid in accordance with BS 7533-3.

It applies to all pavements subjected to the usual road spectrum of axle loads up to 8 000 kg, including both highway pavements and light industrial pavements where the traffic is similar in character to highway vehicles.

It specifically excludes heavy duty pavements with traffic and other applications such as aircraft pavements and those in ports and specialized industrial areas.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 1377-4:1990+A2:2002, *Methods of test for soils for civil engineering purposes – Part 4: Compaction-related tests*

BS 1377-9, *Methods for test for soils for civil engineering purposes – Part 9: In-situ tests*

BS 6100-3, *Building and civil engineering – Vocabulary – Part 3: Civil engineering – General*

BS 7533-1:2001, *Pavements constructed with clay, natural stone or concrete pavers – Part 1: Guide for the structural design of heavy duty pavements constructed of clay pavers or precast concrete paving blocks*

BS 7533-3, *Pavements constructed with clay, natural stone or concrete pavers – Part 3: Code of practice for laying precast concrete paving blocks and clay pavers for flexible pavements*

BS EN 752, *Drain and sewer systems outside buildings*

BS EN 993-1, *Methods of test for dense shaped refractory products – Part 1: Determination of bulk density, apparent porosity and true porosity*

BS EN 1097-6:2000+A1:2005, *Tests for mechanical and physical properties of aggregates – Part 6: Determination of particle density and water absorption*

BS EN 1338, *Concrete paving blocks – Requirements and test methods*

BS EN 1339, *Concrete paving flags – Requirements and test methods*

BS EN 1341, *Slabs of natural stone for external paving – Requirements and test methods*

BS EN 1342, *Setts of natural stone for external paving – Requirements and test methods*

BS EN 1344, *Clay pavers – Requirements and test methods*

BS EN 12457-3, *Characterisation of waste – Leaching – Compliance test for leaching of granular waste materials and sludges – Part 3: Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with a high solid content and with a particle size below 4 mm (without or with size reduction)*

BS EN 12620, *Aggregates for concrete*

BS EN 13242:2002+A1:2007, *Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction*

HIGHWAYS AGENCY. *Manual of Contract Documents for Highway Works, Volume 1: Specification for Highway Works*. London: The Stationery Office.

### 3 Terms and definitions

For the purposes of this part of BS 7533, the terms and definitions given in BS EN 1339, BS 6100-3 and the following apply.

- 3.1 paving unit**  
either a concrete paving block or flag, natural stone slab or sett or clay paver designed to allow water ingress into the pavement sub-layers
- 3.2 laying course**  
layer of material on which paving units are bedded
- 3.3 subgrade**  
upper part of the soil, natural or constructed, that supports the loads transmitted by the overlying pavement
- 3.4 sub-base**  
one or more layers of open graded material placed immediately above the subgrade
- 3.5 standard axle**  
axle carrying a load of 8 200 kg
- 3.6 permeable pavement**  
pavement consisting of a surface course of paving units laid with wide joints, voids or openings that allows water to pass through the pavement construction into an open graded sub-base that is designed for storage or attenuation of storm water
- 3.7 geo-cellular box system**  
storm water storage system comprising a series of modular plastic boxes clipped together to form a void either for the storage or attenuation of storm water
- 3.8 jointing material**  
material applied to fill the joints between paving units

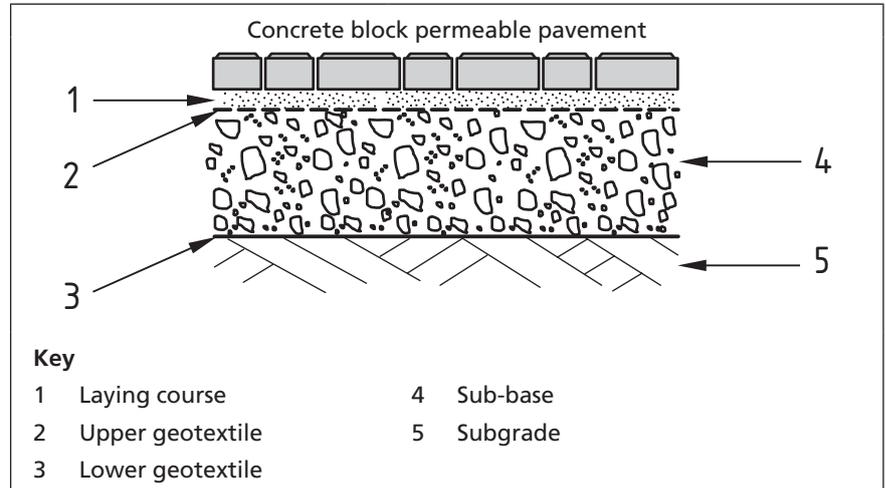
*NOTE* See Annex B for gradings for jointing material.

**3.9 geotextile**

permeable textile, mesh, net or grid that allows water to flow through and prevents migration of particulates between construction layers

*NOTE* Can be used in the upper layer or lower layer position of the construction (see Figure 1).

Figure 1 Typical location of geotextile

**3.10 coarse graded aggregate**

main structural and hydraulic functional layer with particle within the range 20 mm to 4 mm

**3.11 hydraulically bound coarse graded aggregate**

layer to strengthen and stiffen the pavement

**3.12 capping layer**

subgrade improvement layer

layer of granular or treated material at the top of the subgrade to improve foundation for the pavement

**3.13 impermeable membrane**

membrane which contains all the water entering the pavement and being detained within the structure

**4 General design criteria****4.1 Basis of design**

A permeable pavement is an effective means of providing a structural pavement suitable for pedestrians and vehicular traffic whilst allowing water to pass straight through the surface into the pavement construction for temporary storage, storm attenuation and dispersal to the ground or collection.

A permeable pavement needs to be able to capture the specified amount of water to be retained and then discharge it in a controlled manner through the subgrade or drainage system. At the same time, the pavement has to be able to withstand the loadings imposed by vehicles. The design of the pavement is approached by considering the sub-base thickness required to meet both the hydraulic factors and the loading factors. The greater sub-base thickness identified for either of these factors is adopted.

## 4.2 Design considerations

### 4.2.1 General

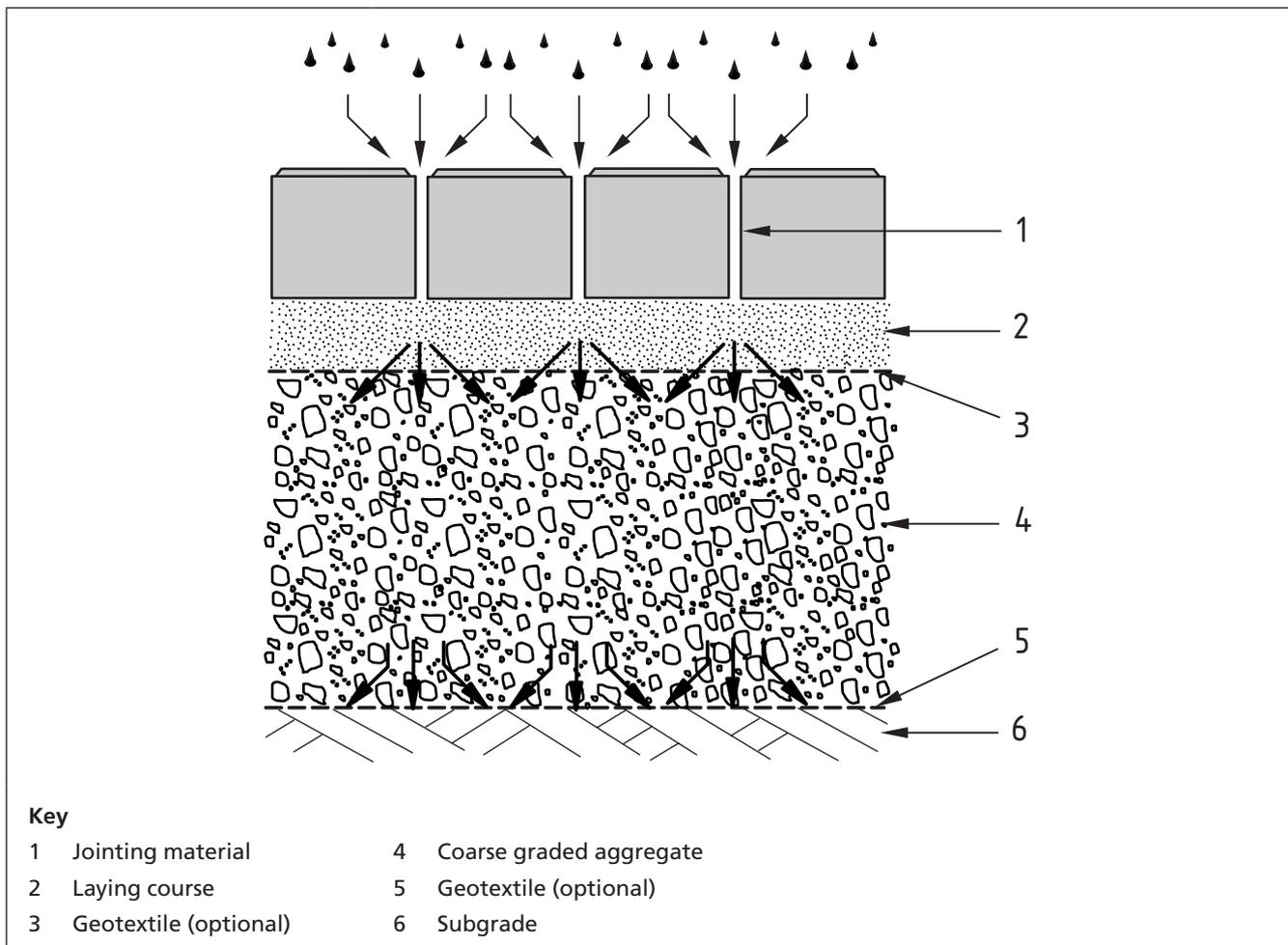
Design for pavements is in two parts, support the traffic load and manage the surface water effectively, which are considered separately.

There are three types of permeable pavement systems as given in 4.2.2, 4.2.3 and 4.2.4.

### 4.2.2 System A – total infiltration

System A (see Figure 2) allows all water falling onto the pavement to infiltrate down through the joints or voids between the paving units passing through the constructed layers below and eventually into the subgrade. Some retention of the water will occur temporarily in the sub-base layer allowing for initial storage before it eventually passes through. System A offers a solution with zero discharge, i.e. no additional water is discharged eliminating the need for associated traditional drainage systems such as gulleys and associated pipe work. In some situations, overflows might be needed to provide support drainage in storm conditions.

Figure 2 Typical section of total infiltration construction (System A)

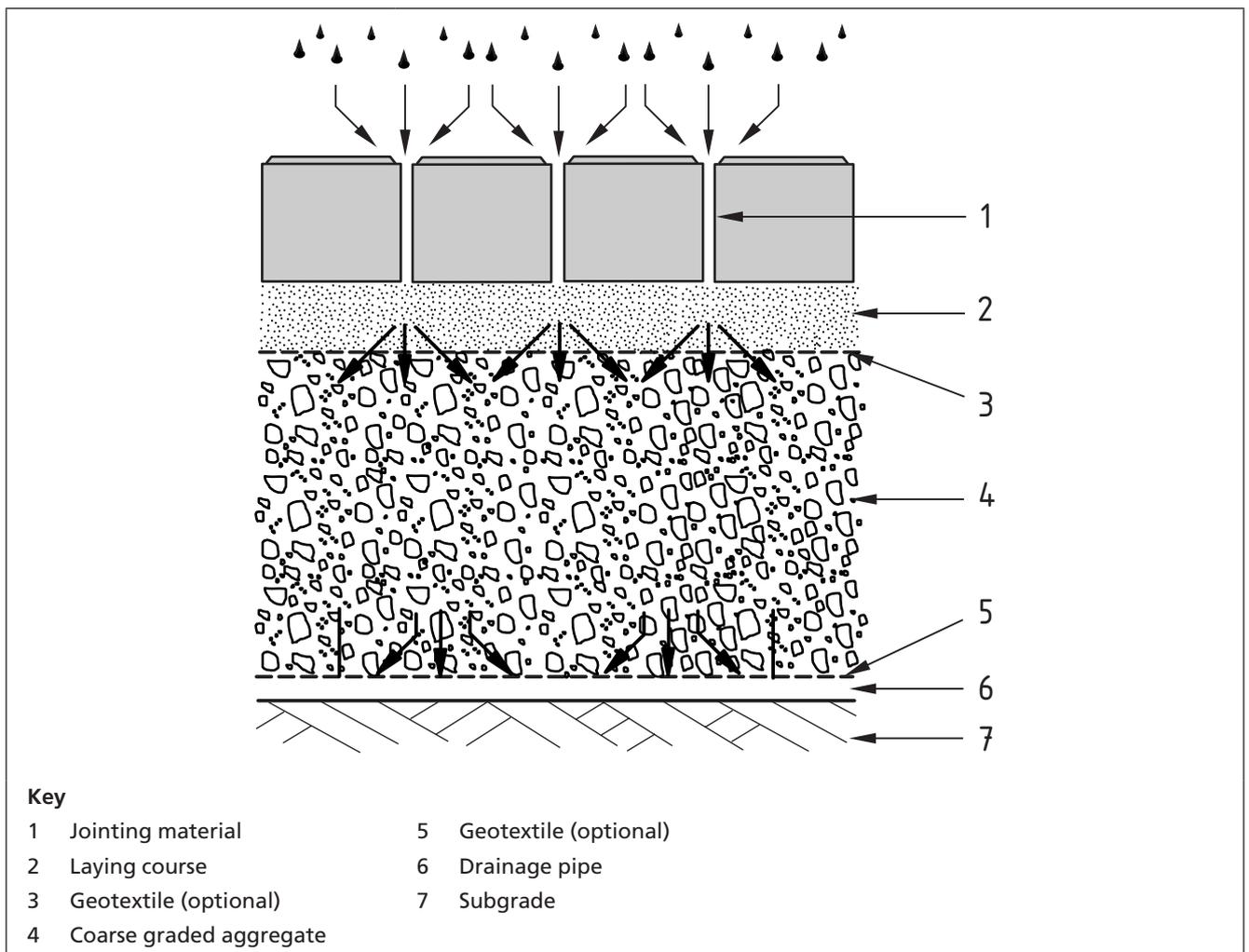


**4.2.3 System B – partial infiltration**

System B (see Figure 3) allows all water falling onto the pavement to infiltrate down through the joints or voids between units passing through into the sub-base. A series of perforated pipes or fin-drains are normally laid at or near the top of subgrade to collect and to allow excess water to be drained to suitable sustainable drainage systems, e.g. sewers, swales or watercourses or a drainage system if permitted.

*NOTE System B can be used in situations where the existing subgrade might not be capable of absorbing all the water. This system can, therefore, prevent the existing soil from losing its stability.*

Figure 3 Typical section of partial infiltration (System B)



**4.2.4 System C – no infiltration**

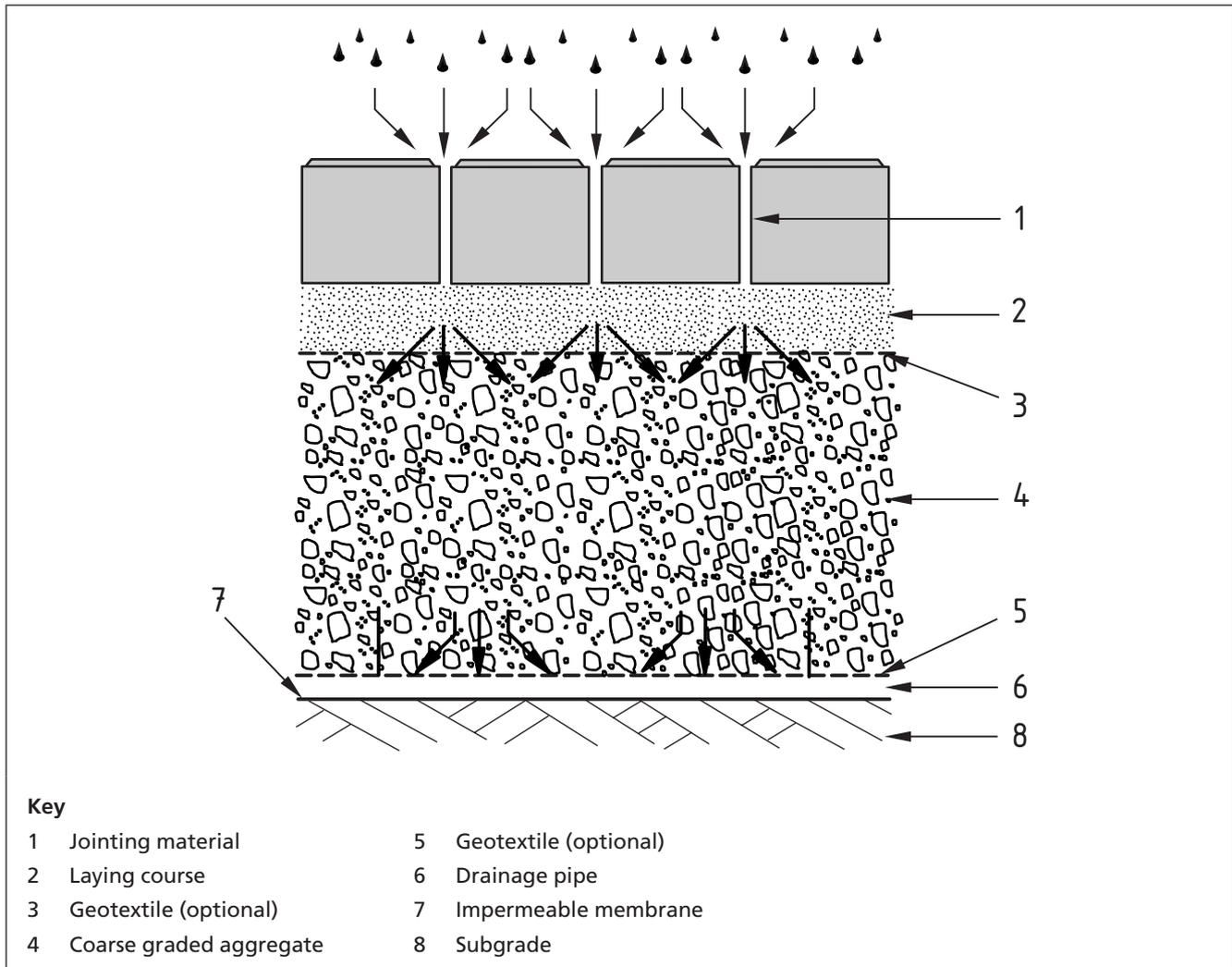
System C (see Figure 4) allows for the complete capture of the water using an impermeable, flexible membrane placed on top of the formation level and to the sides of the sub-base to effectively form a storage tank. A series of perforated pipes or fin-drains are placed on top of the impermeable membrane to transmit the water to sewers, watercourses or treatment systems.

*NOTE 1 System C is used in situations where the existing subgrade has a low permeability or low strength and would therefore be damaged by the introduction of additional water. It can also be used for water-harvesting or to protect sensitive existing conditions such as water extraction zones.*

**NOTE 2** It is particularly suitable for contaminated sites, as it prevents pollutants from being washed further down into the subgrade, where they might eventually be washed into existing natural water systems. Stored water can eventually be released into existing systems at times of low-flow by mechanical means, preventing overloading at times of heavy rainfall.

**NOTE 3** It also acts as an underground retention zone and, in some instances, the stored or captured water can be collected, cleansed and re-used for other purposes, such as flushing toilets (i.e. "grey water") or for irrigation.

Figure 4 Typical section of no infiltration construction (System C)



### 4.3 Loading design factors

The following design factors should be considered.

- The subgrade soaked California Bearing Ratio (CBR) value (see Table 1).
- Load categories (see Table 8).

#### 4.4 Subgrade assessment

The design CBR should be obtained either by testing or by measurement of the plasticity index of the subgrade material. In the case of CBR testing, the method described in BS 1377-4:1990+A2:2002, Clause 7 should be used.

The sample should be taken at subgrade level and tested at estimated long-term moisture content. In situations where it is possible that the subgrade will become saturated during part or all of the life of the pavement, the method employing the soaking procedure should be used. Alternatively, equilibrium suction index CBR values should be used. In the case of fine grained soils, the equilibrium suction index CBR can be determined from a knowledge of the plasticity index as shown in BS 7533-1:2001, Table 1.

As effective subgrade drainage can have a significant effect on long-term CBR values, it should be considered during the design procedure.

On sites where the CBR varies from place to place, the lowest recorded values should be used or appropriate designs should be provided for different parts of the site using the lowest CBR recorded in each part.

*NOTE It might be possible to remove soft spots and therefore ignore those low CBR values that relate to the removed material.*

Consideration should be given to using portable CBR measuring apparatus, some of which have been found to give sufficiently accurate results on fine grained soils when carried out at appropriate depths and moisture contents. It is often the case that a large number of CBR measurements undertaken with this type of apparatus is preferable to a relatively few measurements undertaken with the full scale in situ CBR measuring apparatus.

Care should be exercised in the interpretation of site investigation data as the strength of soils is a function of their moisture content, the in-service strength might be much lower in soils than the recorded values in the site investigation. Care should also be exercised in using CBR values measured in summer as artificially high figures might be obtained due to the dryness of the soil.

Particular care should be exercised with soils having CBRs of 3% or less. It should be recognized that BS 1377-9 requires that CBRs are quoted to the nearest whole figure, so that for very low CBRs the recorded value will be an approximation.

The surface of the subgrade material should be prepared according to the Highways Agency's *Specification for Highway Works*, Clause 616. In the case of silty clays, as the use of a vibrating roller might fluidize the material rather than compact it, a deadweight roller should be used.

Detailed preparation of the subgrade should be in accordance with the recommendations in BS 7533-3.

#### 4.5 Selection of pavement system

Table 1 recommends appropriate pavement systems for a range of subgrade conditions, while Table 2 gives guidance on soil classification.

Table 1 Guidance on selection of a pavement system

		System A – total infiltration	System B – partial infiltration	System C – no infiltration
Permeability of subgrade defined by coefficient of permeability, $k$ (m/s)	$10^{-6}$ to $10^{-3}$	✓	✓	✓
	$10^{-8}$ to $10^{-6}$	✗	✓	✓
	$10^{-10}$ to $10^{-8}$	✗	✗	✓
Highest recorded water table within 1 000 mm of formation level		✗	✗	✓
Pollutants present in subgrade		✗	✗	✓

Table 2 Soil classification guide

Soil classification	Typical range for coefficient of permeability, $k$ m/s	Typical range of CBR values when read in conjunction with Table 1	Plasticity index
Heavy clay	$10^{-10}$ to $10^{-8}$	2 to 5	40 to 70
Silty clay	$10^{-9}$ to $10^{-8}$	3 to 6	30
Sandy clay	$10^{-9}$ to $10^{-6}$	5 to 20	10 to 20
Poorly graded sand	$5 \times 10^{-7}$ to $5 \times 10^{-6}$	10 to 40	—
Well graded sand	$5 \times 10^{-6}$ to $10^{-4}$	10 to 40	—
Well graded sandy gravel	$10^{-5}$ to $10^{-3}$	30 to 80	—

For System A and System B, the highest recorded groundwater level should be greater than 1 000 mm below the bottom of the sub-base. This is to allow filtration of pollutants in the soil below the pavement and also to prevent groundwater rising and reducing the available storage in the sub-base.

#### 4.6 Spacing of outflow pipes for system C

The maximum surface run-off rate,  $q$  (in m/s), that can be removed by a flat permeable sub-base is estimated by:

$$q = k(h/b)^2$$

where

$k$  = coefficient of permeability of sub-base (m/s);

$h$  = thickness of sub-base above impermeable base (m);

$b$  = half the distance between drains (m).

For sloping subgrades and non-symmetrical pipe layouts, the flow in the sub-base,  $Q$  (in m<sup>3</sup>/s), can be estimated using Darcy's law:

$$Q = Aki$$

where

$A$  = cross sectional flow area (m<sup>2</sup>);

$k$  = coefficient of permeability of sub-base (m/s);

$i$  = hydraulic gradient (assumed to be the slope of the subgrade – generally a conservative assumption).

## 5 Design

*NOTE* A design example is given in Annex D.

### 5.1 General

The simplest approach is to consider the permeable pavement as an infiltration or storage device, taking into account the following factors.

- Storage volume in the sub-base.
- Rate of infiltration or restricted outflow rate.

*NOTE* The rate of infiltration can be determined using the approach described in CIRIA report R156 [1].

For larger sites, those that are terraced or ones that are very flat, the use of modelling software is recommended to ensure that the whole system will operate as anticipated and that use of the available storage is optimized.

Another approach is to consider the permeable pavement as a sub-catchment that provides a hydrograph to be applied to the network model. Simple bulk mass balance and simplified flow equations can be used to model the movement of water into and out of the sub-base. Other factors that can be taken into account include the following.

- Evaporation.
- Initial run-off losses.
- Run-off routing.

### 5.2 Hydraulic design factors

#### COMMENTARY ON 5.2

*For most situations it is not feasible to provide a structure which will withstand the greatest rainfall that has ever occurred. It is often more economical to tolerate a periodic failure than to design for every intense storm. For these purposes, data providing return periods of storms of various intensities and durations are essential. This return period is defined as a period within which the depth of rainfall for a given duration will be equalled or exceeded once on average.*

The amount of water that can pass through a concrete block permeable pavement is dependent on the infiltration rates of joint filling, laying course and sub-base materials, not the proportion of open area in relation to concrete surface. Geotextiles in the upper layers can also affect the infiltration rate. The percolation through joints will vary with the materials used but a typical value for newly laid block paving is 4 000 mm/h. The sub-base aggregates, as described in A.1, will have a percolation rate many times this, at least 40 000 mm/h.

Regardless of the high percolation rate of the aggregates used in the openings and base, a key consideration is the lifetime design infiltration of the entire pavement cross-section including the subgrade.

*NOTE 1* A conservative approach should always be taken when establishing the design infiltration rate of a pavement system.

The infiltration rate will decrease but stabilize with age, due to the build-up of detritus in the jointing aggregate.

*NOTE 2* Experience recommends that the design infiltration rate should be 10% of the initial rate, to take into account the effect of clogging over a 20-year design life.

Even after allowing for clogging, studies have shown that the long-term infiltration capability of permeable pavements will normally substantially exceed UK hydrological requirements. Therefore permeable pavements can be designed to handle both prolonged rainfall and short duration storms.

In any event, the risk of potential flooding should be assessed for each project and this will depend upon the type of project and its location. In general, the level of risk attributed to the consequences of a failure of the pavement will decide the return period of the design storm. For example, occasional flooding of an infrequently used overspill parking area in a country park might be more acceptable than to a hospital car park or a housing estate road. BS EN 752 differentiates (with increasing caution) between the following locations in terms of design flooding frequency.

- Rural areas.
- Residential areas.
- City centres, commercial and industrial.
- Underground areas (such as underpasses).

### 5.3 Sloping sites

In System B and System C the base can have a gradient of approximately 0.5% towards the drainage outlets. For sloping sites where the subgrade gradient exceeds 5%, terraced areas of paving are separated below the surface by compartmental walls.

*NOTE The flow rate between compartments can be controlled enabling optimal treatment of water for maximum pollutant removal within the pavement. Terraces of interconnecting permeable pavements can be used in isolation or with just a final SUDS stage such as a pond.*

### 5.4 Sub-base thickness for water storage (hydraulic factors)

Table 3 and Table 4 are based on the following assumptions.

- Storage provided for development design rainfall events of 1 in 30 year, 1 in 100 year and 1 in 100 year plus 20% for climate change.
- Greenfield run-off to be 7 l/s/ha.
- 100% run-off from a permeable paving.

The thickness of the sub-base required to provide sufficient water storage capacity can be obtained using Table 3 for System A and Table 4 for System C.

Table 3 Sub-base thickness for System A

Rainfall data	r <sup>A)</sup>	Required sub-base thickness mm		
		1 in 30 year event	1 in 100 year event	1 in 100 year event plus 20% climate change
M60 <sup>B)</sup> = 20 mm	0.4	120	160	210
	0.3	140	190	240
	0.2	180	250	310
M60 = 17 mm	0.4	100	140	180
	0.3	110	160	210
	0.2	150	210	270
M60 = 14 mm	0.4	—	—	—
	0.3	90	130	170
	0.2	110	170	220

A) Ratio of a 60-minute storm rainfall depth to the depth of the 2-day maximum rainfall depth.

B) 60-minute storm recurring every 5 years.

Table 4 Sub-base thickness for System C

Rainfall data	r <sup>A)</sup>	Required sub-base thickness mm		
		1 in 30 year event	1 in 100 year event	1 in 100 year event plus 20% climate change
M60 <sup>B)</sup> = 20 mm	0.4	120	160	210
	0.3	140	190	240
	0.2	180	250	310
M60 = 17 mm	0.4	100	140	190
	0.3	120	160	210
	0.2	150	210	270
M60 = 14 mm	0.4	—	—	—
	0.3	90	130	170
	0.2	120	160	220

A) Ratio of a 60-minute storm rainfall depth to the depth of the 2-day maximum rainfall depth.

B) 60-minute storm recurring every 5 years.

### 5.5 Draining impermeable areas onto permeable areas

If permeable paving is required to handle run-off from impermeable areas including roofs, the thickness of the permeable paving sub-base should be increased in the ratio of:

$$\frac{\text{total of impermeable and permeable areas}}{\text{area of permeable paving}}$$

The pavement thickness calculated using this procedure assumes that there is no outflow of water through the subgrade or any other drainage during the period of the storm (the worst case scenario).

Therefore, the design capacity for System A or System B will generally exceed the required capacity.

For System C, Table 5 can be used to determine the sub-base thickness.

Table 5 Sub-base thickness for System C collecting impermeable area

Rainfall data	$r^A$	Required sub-base thickness mm		
		1 in 30 year event	1 in 100 year event	1 in 100 year event plus 20% climate change
$M_{5-60} = 20$ mm	0.4	230	340	450
	0.3	240	390	480
	0.2	260	400	530
$M_{5-60} = 17$ mm	0.4	190	270	360
	0.3	190	280	380
	0.2	200	320	440
$M_{5-60} = 14$ mm	0.4	—	—	—
	0.3	140	210	290
	0.2	140	230	330

*NOTE* Thickness assumes sub-base has a voids ratio of 30%.

*Infiltration rate greater than  $1 \times 10^{-5}$  m/s.*

*Maximum ratio of impermeable to permeable is 2:1.*

<sup>A)</sup> Ratio of a 60-minute storm rainfall depth to the depth of the 2-day maximum rainfall depth.

In most cases it is preferable that permeable pavements be designed to have a zero gradient but they can also be constructed on sloping sites. Consideration should be given to how water will flow and accumulate on a sloping site as flooding can occur at the lowest point. Where standing water will soften the subgrade in an infiltration system, a nominal fall should be provided to the outfall. This is not required with System C.

*NOTE* Care should be taken to avoid run-off from areas adjacent to the permeable pavement causing discharge of silt or other debris, as this will cause clogging of the permeable area and affect performance.

## 5.6 Sub-base thickness for loading

### 5.6.1 Selection of loading category

Traffic loading needs to be assessed so that the pavement can be placed into one of the load categories shown in Table 6.

This is based on 25 years of trafficking.

For load categories C, D and F (see Table 6) the DBM layer can substitute some or all the hydraulically bound coarse graded aggregate course layer. But the minimum thickness of the remaining hydraulically bound coarse grade aggregate course layer should not be less than 125 mm.

Table 6 Loading categories

Category/ application	No. of standard axles	Traffic guide	Application
A/domestic	0	No large HGV	<ul style="list-style-type: none"> <li>• Patio</li> <li>• Private drives</li> <li>• Decorative features</li> <li>• Enclosed playgrounds</li> <li>• Footways with zero overrun</li> </ul>
B/car parking	100	Emergency vehicles only	<ul style="list-style-type: none"> <li>• Car parking bays and aisles</li> <li>• Railway station platforms</li> <li>• External car showrooms</li> <li>• Sports stadium pedestrian routes</li> <li>• Footways with occasion overrun</li> <li>• Private drives</li> <li>• Footway crossover</li> </ul>
C/pedestrian	0.015 msa	1 large HGV/ week	<ul style="list-style-type: none"> <li>• Town/city pedestrian street</li> <li>• Nursery access</li> <li>• Parking areas to residential development</li> <li>• Motel parking</li> <li>• Garden centre external displays</li> <li>• Cemetery/crematorium</li> <li>• Airport car park (no bus pick-up)</li> <li>• Sports centre</li> </ul>
D/shopping	0.15 msa	10 large HGV/ week	<ul style="list-style-type: none"> <li>• Retail development delivery access route</li> <li>• School/college access route</li> <li>• Office block delivery route</li> <li>• Garden Centre delivery route</li> <li>• Deliveries to small residential development</li> <li>• Fire station yard</li> <li>• Airport car park with bus to terminal</li> <li>• Sports stadium access route/forecourt</li> </ul>
E/commercial	1.5 msa	100 large HGV/ week	<ul style="list-style-type: none"> <li>• Industrial premises</li> <li>• Lightly trafficked public roads</li> <li>• Light industrial development</li> <li>• Mixed retail/industrial development</li> <li>• Town square</li> <li>• Footway with regular overrun</li> <li>• Airport landside</li> </ul>
F/heavy traffic	15 msa	1000 large HGV/week	<ul style="list-style-type: none"> <li>• Main road</li> <li>• Distribution centre</li> <li>• Bus station (bus every 5 minutes)</li> <li>• Roundabout</li> <li>• Bus lane</li> </ul>

### 5.6.2 Selection of pavement course material and thickness

For System A and B select the pavement course thickness and material type from Table 7.

*NOTE* Table 7 is suitable for subgrades with  $CBR \geq 15\%$ .

For System C select the pavement course thickness and material type from Table 8.

*NOTE 1* Table 8 is suitable for subgrades with  $CBR \geq 15\%$ .

The impermeable membrane is installed at the interface of the coarse graded aggregate and the sub-base. The impermeable membrane is brought to just below the surface of the pavement at its perimeter to maximize the detention volume of the pavement.

Table 7 System A and B – selection of pavement course material and thickness

Category/application	Block/laying course mm	Hydraulically bound base mm	Course graded material mm
A/domestic	80/50	—	250
B/car parking	80/50	—	350
C/pedestrian	80/50	125	150
D/shopping	80/50	150	150
E/commercial	80/50	200	150
F/heavy traffic	80/50	300	150

Table 8 System C – selection of pavement course material and thickness

Category/application	Block/laying course mm	Hydraulically bound base mm	Course graded material mm	Capping layer mm
A/domestic	80/50	—	250	150
B/car parking	80/50	—	350	150
C/pedestrian	80/50	125	150	150
D/shopping	80/50	150	150	150
E/commercial	80/50	200	150	150
F/heavy traffic	80/50	300	150	150

*NOTE* Originally 80 mm blocks were used for all types of concrete permeable pavements, but thinner concrete blocks are now available, suitable for specific loadings. It is recommended that advice is sought from the manufacturer on recommendation for suitable block thickness.

### 5.6.3 Adjustment to pavement design for low CBR subgrade

The additional thickness to be provided in the case of low CBR can be taken from Table 9 for System A and System B and Table 10 for System C.

Table 9 Additional thickness of coarse graded material for System A and System B

CBR of subgrade %	Adjustment of coarse graded material mm
1	300 <sup>A) B)</sup>
2	175 <sup>B)</sup>
3	125 <sup>B)</sup>
4	100 <sup>B)</sup>
5	Use Table 10 for thickness
8	Use Table 10 for thickness
10	Use Table 10 for thickness
15	Use Table 10 for thickness

<sup>A)</sup> Expert guidance should be sought.

<sup>B)</sup> Subgrades of CBR less than 55 are often too fine to permit sufficient infiltration.

Table 10 Total thickness of capping material for System C

CBR of subgrade %	Adjustment of capping layer mm
1	600 <sup>A)</sup>
2	350
3	250
4	200
5	Use Table 8 for thickness
8	Use Table 8 for thickness
10	Use Table 8 for thickness
15	Use Table 8 for thickness

<sup>A)</sup> Expert guidance should be sought.

#### 5.6.4 Base thickness for site traffic

A permeable pavement can be protected from site traffic by installing a dense bitumen macadam (DBM) over the unbound coarse graded aggregate with holes punched through this layer with 75 mm holes on an orthogonal grid of 750 mm.

*NOTE 1 This layer remains in situ throughout the service life of the pavement.*

*NOTE 2 For load categories C, D, E and F (see Table 6) the DBM replaces the hydraulically bound aggregate course.*

*NOTE 3 For load categories A and B (see Table 6) the DBM is additional to the unbound coarse graded aggregate.*

The thickness of the DBM depends on the number of standard axles which will be applied by site traffic and in-service traffic.

The number of standard axles that will use the base as a service road is shown in Table 11 (taken from BS 7533-1:2001, Figure 2).

Table 11 Determination of standard axles using the base as a service road

Site traffic	No. of standard axles
20 dwellings	200
50 dwellings or 5 000 m <sup>2</sup>	500
80 dwellings or 8 000 m <sup>2</sup>	1 000
Large development	5 000

The thickness of the DBM required is taken from BS 7533-1:2001, Figure 3 and is reproduced in Table 12.

Table 12 Determination of DBM thickness for total number of standard axles

Total traffic	DBM thickness
	mm
Up to 1.5 msa	130
1.5 to 4.0 msa	145
4.0 to 8.0 msa	170
8.0 to 12.0 msa	185

## 6 Selection of pavement components

### 6.1 General

The components of the pavement are as illustrated in Figure 1, Figure 2 and Figure 3, depending on the type of pavement required.

### 6.2 Base for water storage

Typical gradings and physical properties for materials are specified in **A.1**. In a permeable pavement system, there is a requirement for stiffness but the base aggregate also needs to be permeable to allow water to flow through it and to have sufficient void space for water storage.

*NOTE 1 Conventional DTp Type 1 (see Highways Agency's Specification for Highway Works) sub-base is not recommended.*

The choice of base material is a compromise between stiffness, permeability and storage capacity.

The requirement for low fines content means that the load in the base will be carried essentially by point-to-point contact between aggregate particles. In order to maximize the friction between particles and thus increase strength, the particles should be rough and angular to give good interlock. Crushed rock (e.g. granite, basalt, gabbro, etc.) or concrete with greater than 90% fracture faces or blast furnace slag is required to achieve this.

*NOTE 2 Sand and gravel with rounded particles should not be used in permeable pavement sub-base construction.*

As the base material will be in contact with water for a large part of the time, the strength and durability of the aggregate particles when saturated and subjected to wetting and drying should be

assessed. The materials should also not crush or degrade either during construction or in service.

Blast furnace slag should conform to BS EN 12620 and BS EN 13242. The presence of contaminants within the slag and all materials, which can leach out before and into the percolating rainwater, should be considered and leaching tests should be undertaken to confirm that this will not occur at significant rates. Leaching tests should be carried out in accordance with BS EN 12457-3.

*NOTE 3 Guidance on leaching limits and waste acceptance criteria for inert waste is given in the Environment Agency's Guidance for waste destined for disposal in landfills [2].*

The material specification should be based on BS EN 13242 or **A.1**.

### 6.3 Hydraulically bound course grade aggregate

Open graded sub-bases can be stabilized with cement to increase the structural capacity or to reduce the sub-base thickness required. The use of cement will reduce the water storage capacity of the sub-base. To maintain high void space, only enough cement to coat the aggregate should be used, taking care not to fill the voids with excessive paste. The amount of cement to achieve this is typically 170 kg/m<sup>3</sup>.

### 6.4 Sub-base replacement systems (geo-cellular box systems)

There are a number of sub-base replacement systems on the market that can be incorporated into permeable pavements. They usually consist of a series of lattice plastic, cellular units, connected together to form a raft structure that replaces some or all of the sub-base, depending upon the anticipated traffic loading. They can be manufactured using recycled plastic.

*NOTE Typical physical properties are given in Annex B.*

The water storage capacity is higher than with conventional granular systems and, consequently, approximately 30% to 40% of the depth of a granular sub-base pavement is needed for the hydraulic design of the pavement. This can lead to a shallower excavation and reduced material disposal to landfill which, in turn, makes them particularly economical for brownfield and contaminated sites. The design of these systems is more specialized than conventional permeable pavements and advice should be sought from the suppliers/manufacturers of these systems.

Consideration should be given to the means of preventing silting and maintenance of these systems.

### 6.5 Impermeable membrane

An impermeable membrane is required for System C only, where effectively a tank is formed from various impermeable membranes or liners. These are available typically manufactured from HDPE, polypropylene or EPDM. They should be:

- a) manufactured from a durable, robust material which can withstand the additional loads applied during construction and throughout the full design life of the pavement;
- b) resistant to puncture, multi-axial stresses and strains associated with movement and environmental stress cracking;

- c) unaffected by potential pollutants such as alkaline or acidic ground water;
- d) installed with fully watertight joints and discharge outlets.

It is recommended that welded joints are tested to ensure the integrity of the system and provide a more robust jointing method.

The two overriding factors that affect the water-tightness of a membrane are the ability to withstand the rigours of the construction process and the integrity of any seams.

The membrane should be able to resist the punching stresses caused by loading on sharp points of contact of the aggregate. It should also have sufficient strength to resist the imposed tensile forces from traffic or other loading. A suitable value of static puncture resistance together with the tensile strength of the membrane and the seams and joints should be specified to ensure these performance criteria are met.

Consideration should also be given to protecting membranes with geotextile fleeces where leakage could have particularly severe consequences.

## 6.6 Geosynthetic filter

Where used, this membrane acts as a filter which should allow free flow of water. It should be manufactured from polyethylene, polypropylene or other suitable mono-filament that can withstand the additional loads applied during construction and for the full design life of the pavement. It should not be adversely affected by pollutants and alkaline or acidic ground water.

It is recommended that specialist advice be sought from the manufacturer or supplier of the material.

*NOTE* See Annex C for a typical specification.

## 6.7 Laying course

The grading of the laying material is specified in **A.2**.

Where a geotextile is not provided between the laying course and sub-base, the two layers should meet conventional soil filter criteria to prevent migration of the finer laying course into the sub-base.

The aggregates should meet the following criteria:

- $D_{15}$  sub-base/ $D_{85}$  laying course  $\leq 5$ ; and
- $D_{50}$  sub-base/ $D_{50}$  laying course  $> 2$ .

where

D is the particle size at which x percent of the particles are finer. For example  $D_{15}$  is the particle size of an aggregate for which 15% of the particles are smaller than D and 85% are coarser.

It is advisable to check that the laying course particles will not fit into the voids of the sub-base material.

A material meeting the average of the laying course and sub-base grading limits recommended in **A.1** should meet these requirements. However, a check should always be made on the actual materials proposed for use on a site to make sure they are compatible with each other.

### 6.8 Jointing/voids material

Typically, materials are similar to those for the laying course. Joints or voids are subsequently filled with a suitable joint filling material. The joint filling material size and specification is specific to each product and manufacturers should be consulted for further advice.

*NOTE* Conventional jointing sand is not suitable as a medium for surface water to pass down through the pavement.

### 6.9 Concrete block paving types

Various types of concrete block paving have been designed specifically for use in permeable pavements; full details are available from manufacturers. These designs incorporate enlarged joints created by larger than conventional spacer nibs on the sides of each paving block or voids generated by geometric block shapes. Joints or voids are subsequently filled with a suitable joint filling material.

## Annex A (normative) Grading recommendations for base, laying course and joint filling material

### A.1 Grading recommendations for sub-base material

Aggregates should conform to Table A.1.

Table A.1 Sub-base grading

Sieve size mm	Percentage passing	
	Coarse aggregate, 4/40	Coarse aggregate, 4/20
80	100	—
63	98–100	—
40	90–99	100
31.5	—	98–100
20	25–70	90–99
10	—	25–70
4	0–15	0–15
2	0–5	0–5
1	—	—

*NOTE* The gradings for 4/20 are typical and advice should be sought from the block manufacturer on specific gradings suitable for their product/system.

### A.2 Grading for laying and jointing material

Aggregates for laying and jointing material should conform to Table A.2.

Table A.2 Laying course and jointing material grading

BS sieve size (BS EN 993-1) mm	Percentage passing
14	100
10	98–100
6.3	80–99
2.0	0–20
1.0	0–5

*NOTE* These gradings are typical, advice should be sought from the block manufacturer on specific gradings suitable for their product/system.

Where  $D_x$  is the particle size at which  $x$  percent of the particles are finer, for example  $D_{15}$  is the particle size of the aggregate for which 15% of the particles are smaller than  $D$  and 85% are coarser. Using the graph in Figure A.1, 15% are smaller therefore  $D_{15} = 9$  mm.

Figure A.1 Grading curve example

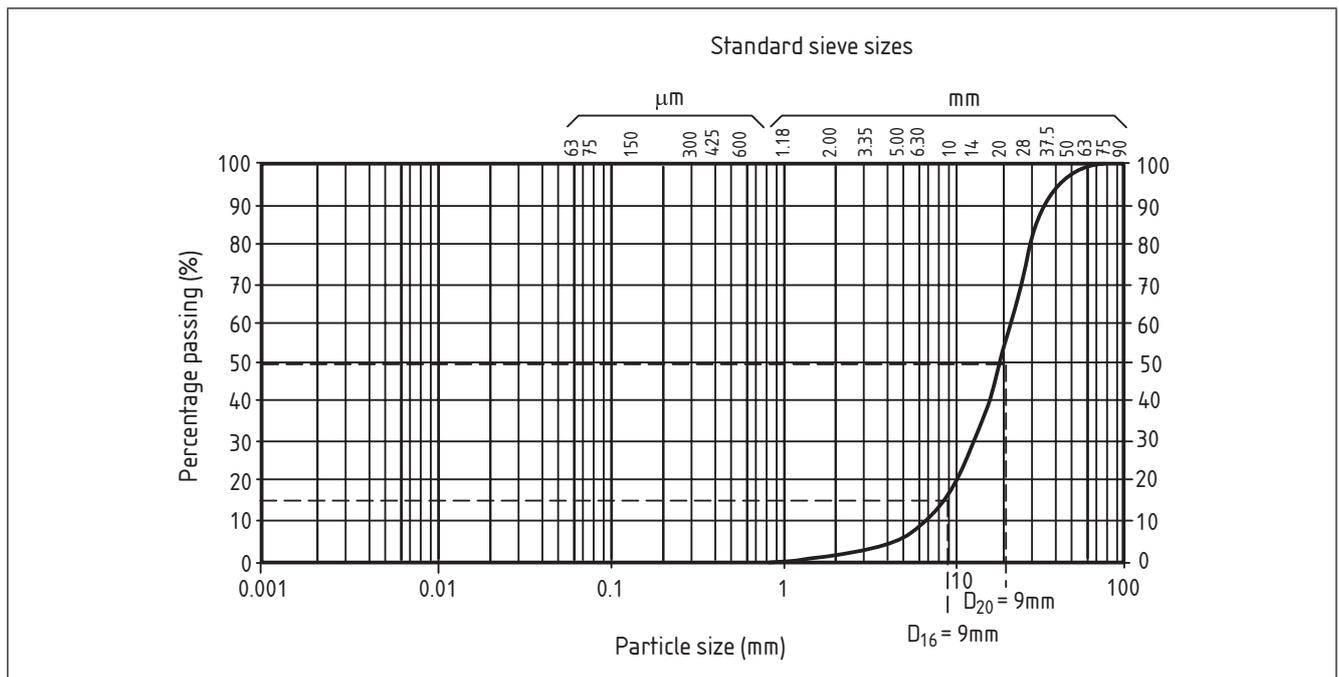


Table A.3 Physical property recommendation for CGA

Properties	Category to BS EN 13242 or BS 12620
Grading	4/20 (preferred) or 4/40, $G_c$ 85–15, $GT_c$ 20/17.5
Fines content	$f_4$
Shape	$Fl_{20}$
Resistance to fragmentation	$LA_{30}$
Durability:	
– Water absorption to BS EN 1097-6:2000 +A1:2005, Clause 7 – for $WA > 2\%$	$WA_{242}$
– Magnesium sulfate soundness	$MS_{18}$
Resistance to wear	$M_{DE20}$
Acid-soluble sulfate content:	
– aggregates other than air-cooled blast-furnace slag and	$AS_{0.2}$
– air-cooled blast-furnace slag	$AS_{1.0}$
Total sulfur:	
– aggregates other than air-cooled blast-furnace slag	$\leq 1\%$ by mass
– air-cooled blast-furnace slag	$\leq 2\%$ by mass
Volume stability of blast-furnace and steel slags: air-cooled blast-furnace slag	Free from dicalcium silicate and iron disintegration in accordance with BS EN 13242:2002+A1:2007, 6.4.2.2.
– steel slag	$V_5$
Leaching of contaminants	Blast-furnace slag and other recycled materials should meet the requirements of the Environment Agency "Waste Acceptance Criteria" <sup>A)</sup> for inert waste when tested in accordance with BS EN 12457-3.

<sup>A)</sup> Guidance on waste acceptance criteria for inert waste is given in the Environment Agency's *Guidance for waste destined for disposal in landfills* [2].

Annex B (informative) **Typical physical properties of replacement systems (geo-cellular) units**

Table B.1 Typical physical properties

Element	Value
Compressive strength	
• Vertical	700 kN/m <sup>2</sup>
• Lateral	150 kN/m <sup>2</sup>
Deflection	
• Vertical	1 mm per 126 kN/m <sup>2</sup>
• Lateral	1 mm per 15 kN/m <sup>2</sup>
Ultimate tensile strength of a single joint	2.25 kN
Tensile strength of a single joint at 1% secant modulus	1 kN
Bending resistance of unit	0.7 kNm
Bending resistance of single joint	0.16 kNm
Minimum void ratio	95%

Annex C (informative) **Typical filter fabric specification used in the upper layer**

Table C.1 Filter fabric specification

Characteristics	Standard	Woven filter	Non-woven filter
Weight	BS EN 965	$\geq 200 \text{ g/m}^2$	$\geq 400 \text{ g/m}^2$
Ultimate tensile strength	BS EN ISO 10319	$\geq 30 \text{ kN/m}$	$\geq 15 \text{ kN/m}$
<ul style="list-style-type: none"> <li>• Longitudinal</li> <li>• Transverse</li> </ul>		$\geq 30 \text{ kN/m}$	$\geq 15 \text{ kN/m}$
Strain at norm tensile strength	BS EN ISO 10319	$\leq 25\%$	—
<ul style="list-style-type: none"> <li>• Longitudinal</li> <li>• Transverse</li> </ul>		$\leq 25\%$	$\geq 70\%$
CBR puncture	BS EN ISO 12236	$\geq 2\,000 \text{ N}$	$\geq 3\,000 \text{ N}$
Opening size	BS EN ISO 12956	$\geq 0.2 \text{ mm}$	$\geq 0.1 \text{ mm}$
Water permeability	BS EN ISO 11058	$\geq 200 \times 10^{-3} \text{ m/s}$	$\geq 6 \times 10 \text{ m/s}$

*NOTE* Advice should be sought from the block manufacturer on recommendation for suitable geotextile requirements

## Annex D (informative) **A structural design example**

### D.1 **General**

A car parking area is to be constructed using concrete block permeable paving in a retail development. The parking bays will only be trafficked by light vehicles and one of the aisles will be used as a delivery access route. Part of the area will be used as a site access road but not the delivery aisle.

### D.2 **Design parameters**

- Subgrade: 5% CBR.
- Assumed 5 000 standard axles during construction.
- System C.

The low CBR value means that the subgrade is unsuitable for direct infiltration of water and System C is therefore the most appropriate.

### D.3 **Loading selection**

From Table 6 select the loading category.

- Parking bays: Category B, 100 cumulative standard axles.
- Delivery route: Category D, 150 000 cumulative standard axles.

### D.4 **Base thickness required for vehicle loadings**

From Table 7, for car park (Category B).

- 80 mm paving units.
- 50 mm laying course material.
- 350 mm coarse graded aggregate.
- Impermeable membrane.

From Table 8, for delivery route (Category D).

- 80 mm paving units.
- 50 mm laying course material.
- 150 mm hydraulically bound coarse graded aggregate.
- 150 mm unbound coarse graded aggregate.
- Impermeable membrane.
- 150 mm capping layer.

### D.5 **Adjustment for CBR**

From Table 9, using 5% CBR value for car park (Category B).

- No change to thickness due to CBR 5%.

From Table 9, using 5% CBR value for delivery route (Category D).

- 80 mm paving units.
- 50 mm laying course material.
- 150 mm hydraulically bound coarse graded aggregate.

- 150 mm unbound coarse graded aggregate.
- Impermeable membrane.
- 150 mm capping material.

#### D.6 Access route

The cumulative number of standard axles during construction phase is 5 000 and in-service phase is 100, therefore total standard axles is 5 100.

The design for this area from Table 12.

- 80 mm paving units.
- 50 mm laying course material.
- 130 mm DBM with holes punch.
- 350 mm coarse graded aggregate.
- Impermeable membrane.
- 150 mm Type 1 sub-base material.
- 350 mm capping material.

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<sup>1)</sup> Available from <http://www.environment-agency.gov.uk/subjects/waste/1019330/1055009/1068705/>.



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