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- Spatial Planning
- Structural & Hydraulic Design
- Specification & Detailing
- Construction & Maintenance

DESIGN & CONSTRUCTION OF CONCRETE BLOCK PERMEABLE PAVEMENTS

www.paving.org.uk

Interpave
THE PRECAST CONCRETE PAVING AND KERB ASSOCIATION

CONTENTS

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GLOSSARY

Note that definitions are provided in terms of CBPP.

Angle of repose

The angle of repose, or critical angle of repose, of a granular material is the steepest angle of descent or dip, relative to the horizontal plane to which a material can be piled without slumping. At this angle, the material on the slope face is on the verge of sliding.

Asphalt concrete (AC) (formerly known as dense bitumen macadam DBM)

Asphalt concrete is a composite material pavement layer. It consists of aggregate bound together with asphalt, laid in layers, and compacted.

Attenuation

Reduction of peak flow rate and increased duration of a flow event. This is achieved through the storage and subsequent slow release of run-off.

Attenuation storage

Volume in which runoff is stored when the inflow to the storage is greater than the controlled outflow.

Attenuation tank

Device for the storage of attenuated runoff.

Base

A pavement layer stiffer than the sub-base, that is positioned immediately above the sub-base layer. Base can be either asphalt concrete (AC) or hydraulically bound coarse graded aggregate (HBCGA). This layer is part of a CBPP system and is capable of carrying traffic loads and, if HBCGA is used, the temporary storage of rainwater.

California Bearing Ratio (CBR)

A penetration test for evaluation of the mechanical strength of a subgrade of natural ground or engineered fill beneath new pavement construction.

Capping

Layer of material placed immediately above the subgrade. Depending on the permeable pavement system type, this material may have to be permeable and must not be adversely affected by the infiltration of water.

Channelised traffic

Traffic where the vehicle track width and the traffic lane width are virtually the same.

NOTE: Normal lane widths in a highway do not constitute channelised traffic.

Coarse graded aggregate (CGA)

An aggregate with specific grading and physical characteristics to form a permeable sub-base.

Commercial vehicles

Vehicles defined as those over 3.5 tonnes gross vehicle weight.

Concrete block permeable pavement (CBPP)

A permeable pavement surfaced with concrete paving units, capable of carrying traffic loads with joints, voids or openings that allow water to pass through the pavement construction into an open graded sub-base that is designed for storage or attenuation of storm water.

Conventional pavement

A pavement that does not specifically allow storm water to pass through its layers.

Conveyance

Movement of water from one location to another.

Cored asphalt concrete (CAC)

An impermeable asphalt concrete base, cored or perforated with 75mm diameter holes on a 750mm orthogonal grid to allow water to infiltrate to the underlying layers via the cored or perforated holes.

Cumulative traffic or design traffic

The design traffic is the commercial vehicle loading over the design period, expressed as the number of equivalent standard axles; it is calculated using the commercial vehicle flow, traffic growth and wear factors and is measured in million standard axles (msa).

Design CBR

The lower of the equilibrium (long term) and short term CBR values.

Design thickness

The permeable structural thickness and the hydraulic thickness are compared and the greater thickness is deemed to be the design thickness, measured in mm. Note that this measurement excludes the thickness of the paving units, laying course, capping and any other layer that may be incorporated in the CBPP that does not store water.

Diffuse pollution

Pollution from widespread activities with no one discrete source, e.g. acid rain, pesticides, urban run-off.

Drainage system

Drainage is the collection and transportation of rainwater and sub-surface water from an area.

Dynamic loading

Spectrum of loads normally occurring on highway pavements at vehicle speeds exceeding 30 mph (50 km/h).

Equilibrium CBR

The long term value of CBR that occurs once the pavement is constructed and the moisture content of the subgrade comes into equilibrium with suction forces, e.g. as a result of unloading due to excavation, groundwater levels and wetting as a result of water storage in the sub-base.

Evaporation

Evaporation is the process by which water changes from a liquid to a gas or vapour.

Exceedance design

Designing a system to manage effectively events that exceed (i.e. are bigger and rarer than) the drainage system's required level of service.

Exceedance event

A rainfall event or flow event that exceeds (i.e. is bigger and rarer than) the design event, not to be confused with an extreme event.

Exceedance flows

Flows on the surface that result from:

a) the occurrence of events that exceed the design capacity of the drainage system; or

b) run-off that is unable to enter the drainage system; or

c) blockage and/or structural failure of any part of the drainage system; or

d) flood levels in the receiving water body limiting the capacity of the drainage system.

Exceedance routes

Overland flow routes of exceedance water.

Extreme event

A rainfall or flow event that is relatively rare. Generally considered to be an event with a return period of 30 years or more, not to be confused with an exceedance event.

Fin drains

Fin drains, also known as geocomposite drains, are proprietary products which can be used for pavement drainage purposes. They normally comprise a plastic core and are wrapped in geotextile filter material.

Fines

Small soil particles less than 63 microns in size.

Flow control device

A device used to limit the flow of water through the outlet from a SuDS component (such as CBPP), usually necessary to meet a required discharge rate.

Formation level

Surface of an excavation prepared to support a pavement or other overlying structure.

Frequency of rainfall
The number of times, during a specified period of years, that precipitation of a certain magnitude or greater occurs.

Geo-cellular box system
A proprietary storm water storage system comprising a series of modular plastic units clipped together to form a void for the storage of storm water.

Geocomposite
A form of geosynthetic that is made by creating a single component from two or more elements (e.g. a drainage core and geotextile).

Geogrids
Layers of material reinforcement inserted between construction layers to increase structural performance.

Geotextile
A permeable fabric that can separate, filter, reinforce, protect or drain.

Greenfield runoff
The surface water runoff regime from a site before development.

Greenfield runoff rate
The greenfield runoff measured in l/sec/ha.

Half empty time
The time it takes to reduce the volume of water in a CBPP to half its maximum capacity.

Hoar frost
A deposit of needle-like ice crystals formed on the ground by direct condensation at temperatures below freezing point.

Hydraulically bound coarse graded aggregate (HBCGA)
An aggregate with specific grading, physical characteristics and the inclusion of a cement binder, to form a permeable base. Usually HBCGA is CGA with the addition of cement.

Hydraulic thickness
The total thickness of the sub-base and permeable base (if required), to temporarily store the storm water for the site conditions and storm predictions, measured in mm.

Impermeable geomembrane
An impermeable sheet, typically manufactured from polypropylene, high density polyethylene or other geosynthetic material, used to form an impermeable system, as required for System C CBPP.

Initial compaction
The process of bedding the paving units into the laying course using a vibrating plate compactor.

Initial rainfall loss
The amount of rain that falls on a surface before water begins to flow off the surface.

Interception
The prevention of runoff from a site for the majority of small (frequent) rainfall events (or for the initial depth of rain for larger events).

Joint filling aggregate
An aggregate used to fill the joints or voids between adjacent paving units. Permeability is achieved by specific grading characteristics of the aggregate.

Joint filling compaction
Sometimes referred to as the final compaction. The process of compacting the joint filling aggregate into the joints with a vibrating plate compactor.

Joint space
The distance or gap, measured in mm, between adjacent paver units (recommended by the paving manufacturer).

Laying course
Sometimes referred to as the bedding layer. Layer of aggregate on which paving units are bedded. Permeability is achieved by specific grading characteristics of the aggregate to allow water to infiltrate to the underlying layers.

Lower geotextile
Geotextile positioned between the subgrade and sub-base, or subgrade and capping, for System A or B pavements.

Management train
The sequence of drainage components that collect, convey, store and treat runoff as it drains though the site.

Overland flow route
The route taken by water flowing over the ground surface from a conveyance or storage component once the capacity of that component is exceeded.

Particle size distribution
Particle size distribution, also known as grading, refers to the proportions by dry mass of a soil or aggregate distributed over specified particle size ranges.

Pavement
A pavement is a hard-surfaced structure which is capable of carrying traffic loads and dissipating these applied loads to an acceptable load for the existing subgrade beneath.

Paver or paving unit (permeable)
Sometimes referred to as block paving. Concrete paving units specifically designed for use in CBPPs. These paving units have spacer nibs larger than nibs on conventional pavers, to create larger joints to facilitate the infiltration of storm water between paving units. Alternatively, permeability between adjacent paving units is achieved by voids created by the geometric shape of the paving unit.

Paver surface

A structural surface consisting of paving units laid on a permeable laying course and the joints or voids between adjacent paving units filled with permeable aggregate.

Peak flow rate

The highest flow rate of water from a given rainfall event.

Perforated pipe

A pipe which has small slots or holes through which water can flow.

Permeability

The ability of a material to allow water to pass through it.

Permeable pavement

A pavement that is designed to allow rain water to pass from the surface to the underlying layers.

Pollution

A change in the physical, chemical, radiological or biological quality of a resource (air, water or land) caused by man or man's activities that is injurious to the existing intended or potential use of a resource.

Porosity (of the permeable base or sub-base)

Porosity is the amount of air space or void space between aggregate particles. Infiltration and storage of water occur in these void spaces. The porosity is the ratio of the volume of pore space in a unit of material to the total volume of material, measured as a percentage. (In permeable pavement design, the porosity of the base and sub-base are assumed to be 30% but this should always be confirmed by testing or certification).

Rainfall event

A single occurrence of rainfall before and after which there is a dry period that is sufficient to allow its effect on the drainage system to be defined.

Rainfall intensity

Amount of rainfall occurring in a unit of time generally expressed in mm/h.

Rainwater

Water that has fallen as, or been obtained from, rain.

Return periods

An estimate of the likelihood of a particular event occurring. A 100-year storm refers to the storm that occurs on average once every hundred years. In other words, its annual probability of exceedance is 1% (1:100).

Roof drainage

Rainwater collected from a roof.

Runoff

Water flow over the ground to the drainage system. This occurs if the ground is impermeable, saturated or if the rainfall is particularly intense.

Runoff coefficient
A measure of the amount of rainfall that is converted to runoff.

Runoff route
The mapping of runoff.

Separate spacer
A device inserted between adjacent paving units to achieve the minimum joint space for paving units that do not have cast spacer nibs.

Sewer
A pipe or channel conveying foul and/or surface water from buildings and surrounding areas.

SHW Type 3
An alternative sub-base to Coarse Graded Aggregate (CGA). Type 3 is a permeable aggregate compliant with the Highway Agency's Specification of Highway Works (SHW) Clause 805. (The porosity of Type 3 should be checked for any regional variations.)

Short term CBR
The value of CBR obtained from CBR tests on the subgrade, taken once it is exposed for construction.

Source control
The control of runoff at or near its source, so that it does not enter the drainage system or is delayed and attenuated before it enters the drainage system.

Spacer nibs
Projections cast on the side of paving units to achieve the minimum joint space between adjacent paving units.

Spare hydraulic storage capacity
Spare hydraulic storage capacity is where the structural thickness is greater than the hydraulic thickness. This difference is measured in mm.

Standard axle
A vehicle axle carrying a load of 80kN or 8,200 kg.

Structural thickness
The total thickness of the sub-base and base (if required), to carry the predicted traffic loadings for the site conditions, measured in mm.

Storm
An occurrence of rainfall, snow or hail.

Storm water
Water from a storm.

Sub-base
A permeable aggregate layer positioned immediately above the capping layer or subgrade comprising of either coarse graded aggregate (CGA) or SHW Type 3. This layer is part of a CBPP system and is capable of carrying traffic loads and the temporary storage of storm water.

Subgrade
Upper part of the soil, natural or constructed, that supports the loads transmitted by the overlying pavement.

Subgrade improvement layer
Layer of granular or treated material at the top of the subgrade to provide an improved load bearing capability of the subgrade.

Surface permeability (of a CBPP)
Permeability of the paver surface that comprises the concrete paving units, laying course and jointing aggregate. Measured in mm/h and m/s.

Surface water
Water bodies or flows that appear as a result of rainfall.

Sustainable drainage system (SuDS)
Individual or multiple linked drainage components designed to collect, manage, control and treat surface water runoff and, where possible, to provide amenity, biodiversity and climate resilience benefits.

Swale
A shallow vegetated channel designed to convey, treat and occasionally store surface water, and which may also permit infiltration.

Time of entry
Time taken for runoff from rainfall to reach an inlet into the drainage system.

Total volume
Total volume of runoff from a site.

Upper geotextile
Geotextile positioned between the laying course and HBCGA base or sub-base (CGA or Type 3).

Water abstraction zones
Defined by the Environment Agency as Source Protection Zones (SPZs) for groundwater sources such as wells, boreholes and springs used for public drinking water supply.

Watercourses
A term including all rivers, streams, ditches, drains, cuts, culverts, dykes, sluices and passages through which water flows.

Water harvesting
The collecting of rainwater from surfaces on which rain falls, and subsequently storing this water for later use as non-potable water.

1. INTRODUCTION

This Guide is intended for planners, urban designers, engineers, local authorities and other decision makers to assist them in the design, construction, approval and maintenance of Concrete Block Permeable Paving (CBPP) on developments. Its scope includes the use of CBPP as a key Sustainable Drainage System (SuDS) technique but it covers other types of application as well.

It covers all aspects and stages of design, relevant to the various professions constituting the project design team, from initial master-planning through to detailed design and construction, and finally post-construction. Its primary aims are to ensure that CBPP delivers predictable, robust solutions and to minimise costs, maintenance and adoption issues.

1.1 RELATIONSHIP WITH OTHER GUIDANCE

Figure 1: Example of CBPP at Upton Meadows Primary School, Northampton, in use since 2006.

This Guide assumes a basic understanding of CBPP, SuDS and current national requirements for them, which are covered by Interpave's other guidance document *'Understanding Permeable Paving'*: further information can be found on the website **www.paving.org.uk**. Straightforward design and construction guidance for CBPP on private driveways, patios and other lightly trafficked domestic paving can be found in Interpave's *'Paving for Rain'*.

This Guide follows the recommendations of various other authoritative publications, a full list of which is given in the Reference Section. In particular, it mirrors and shares methodologies with *'The SuDS Manual'* (CIRIA, 2015) – the most up to date reference on SuDS in the UK – and does reiterate some key information from it. It also recognises European and British Standards, and encourages the use of pavement construction materials that are widely available. International experience has also been considered, including the document *'Permeable Interlocking Concrete Pavements'* (Interlocking Concrete Pavement Institute, 2017).

Whilst this Guide offers the latest, definitive design method for CBPP other methods exist which have proved successful over time. It is also important to recognise that members of Interpave manufacture specific CBPP systems that may involve alternative approaches or specifications to those given in this Guide.

Although CBPP is an established technology in use for over 25 years, more recent experience gained from its expanding use has rendered some older guidance from various sources outdated, which should therefore be treated with caution.

2. PERMEABLE PAVEMENT PRINCIPLES

Photo: Warren Smith

In conventional pavements, rainwater simply runs across the surface to gulleys that collect and direct it into pipes, removing it as quickly as possible. This means that water and the pollutants contained in it are rapidly conveyed into overloaded drains, streams and rivers, leading to floods in extreme conditions.

In contrast to conventional sealed pavements, CBPP temporarily stores water during rainfall, releasing it gradually over time. It also cleans the water and addresses flooding, pollution and water quality issues, unlike attenuation tanks which only deal with flooding. It serves a dual purpose, acting as the drainage system as well as a hard surface supporting traffic loads. In fact, CBPP goes further in satisfying a diversity of requirements and providing multi-functional SuDS in line with the Code of Practice BS 8582 (BSI, 2013a).

Figure 2: Principles of CBPP. As water passes through the pavement silt and other pollutants are also removed, which reduces downstream pollution.

2.1 HOW IT WORKS

CBPP allows water to pass through the surface – between the paving units (Figure 2) – and the permeable laying course, into the underlying permeable construction where it is stored and, dependent on the system type, released slowly into the ground, to the next SuDS management stage or to a drainage system. At the same time, many pollutants are substantially removed from the water and treated within the CBPP itself, before water infiltrates to the subgrade or passes into the next stage of the management train.

Increasingly, CBPP is used at the head of the management train for surface water collection and as a 'source control'. It can provide a controlled source of clean water for downstream, open SuDS features and also for harvesting, irrigation and amenity, forming an integral and multi-functional part of landscape design.

Figure 3: CBPP in a high density development.

Unlike conventional road constructions, the CBPP materials are specifically designed to accommodate water.

The multi-functionality of CBPP makes it very efficient in terms of space. A study by H. R. Wallingford (Kellagher and Laughlan 2003) confirmed that CBPP is one of the most space-efficient SUDS components available, as they do not require any additional land take (Figure 3), unlike other SuDS methods such as swales, attenuation tanks, etc.

2.2 SURFACE MANAGEMENT OF RAINWATER

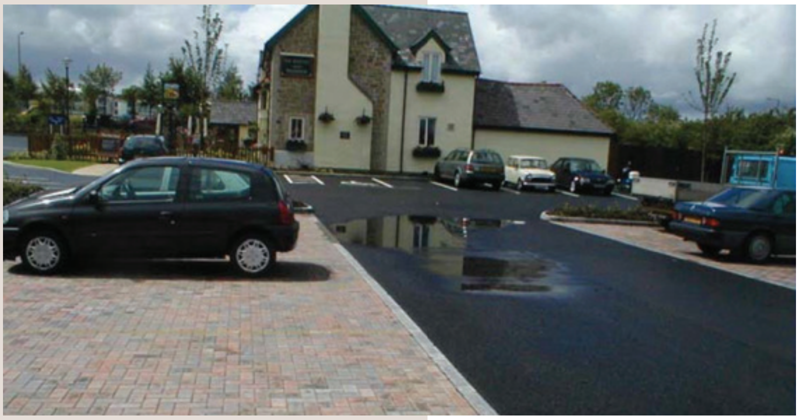


Figure 4: a demonstration of 'ponding' on impermeable asphalt paving, absent from adjacent CBPP under the same rain conditions.

CBPP behaves differently to normal hard surfaces when it rains.

On conventional hard surfaces, the falling water first wets the surface then, as the rainfall increases, water may pond in surface depressions until these have filled. The surface water then moves towards drainage points or discharges into watercourses. This moving water becomes the surface water runoff, whilst the water remaining in puddles will be absorbed or will evaporate. The amount of time taken for the water to move from the farthest point where rain hits the ground to entering the drainage system is known as the 'time of entry'.

In the case of traditional impermeable surfaces the distance from the farthest point to a gulley inlet may be some 20 to 30m. In contrast, with CBPP, the falling water runs into the joints or voids between adjacent paving units (typically a maximum of 100mm). As this time is so short, standing water on the pavement and surface ponding are virtually eliminated. This is clearly demonstrated in practice when comparing CBPP and impermeable surfaces under similar conditions (Figure 4). Importantly, this also means that localised clogging of the surface has little impact because water simply finds an alternative way into the CBPP nearby.

Unlike conventional, impermeable pavements, CBPP can be laid level with no fall, while still retaining excellent surface drainage, up to a maximum surface gradient of about 5% (1 in 20). For steeper gradients, consideration of the management of the water passing through the sub-base is required (see section 4.2).

2.3 BENEFITS OF CONCRETE BLOCK PERMEABLE PAVEMENTS

The main benefits of CBPP can be summarised as follows:

- providing a structural pavement while allowing rainwater to infiltrate into the pavement construction for temporary storage
- playing an important part in removing a wide range of pollutants from water passing through
- allowing treated water to infiltrate to the ground, be harvested for re-use or released to a watercourse, the next SuDS management stage or other drainage system
- suitable for a wide variety of residential, commercial and industrial applications
- optimising land use by combining two functions in one construction: structural paving combined with the storage and attenuation of surface water
- handling rainwater from roof drainage and impervious pavements as well as the CBPP itself.

3. TYPES OF SYSTEM

There are three principal systems for managing water in the construction of CBPP, known as Systems A, B and C (the following drawings are indicative only). It is important to determine the appropriate system for specific applications and conditions (see Section 7 – System Selection). CBPP provides an attractive, durable and well-drained surface to collect and initially treat water for other types of construction, including sub-base replacement systems.

3.1 SYSTEM A – TOTAL INFILTRATION

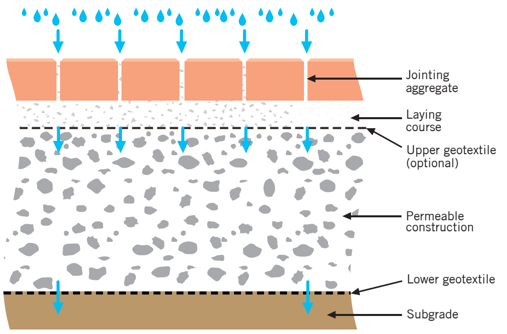


Figure 5: System A - total infiltration

System A can be used in situations where it is possible and allowable to discharge all the collected water into the subgrade. This system (Figure 5) 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 may occur temporarily in the underlying permeable construction allowing for initial storage before it eventually passes through.

System A is sometimes known as 'Zero Discharge', as no water from the CBPP is discharged into the next stage of the management train or the sewer system, eliminating the need for pipes and gulleys, resulting in cost savings.

3.2 SYSTEM B – PARTIAL INFILTRATION

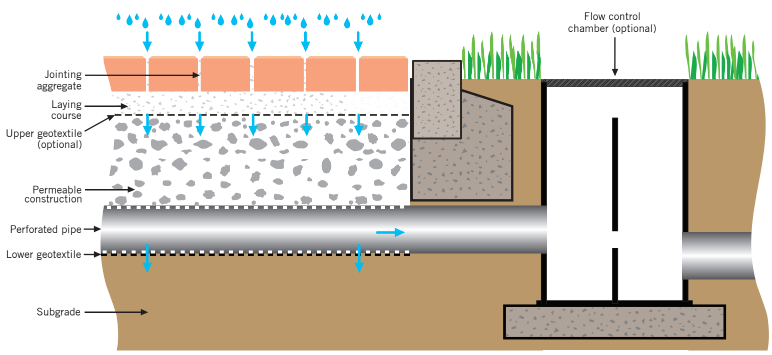


Figure 6: System B - partial infiltration

System B can be used in situations where the existing subgrade may only be capable of absorbing some but not all the water and/or where interception is required. In System B (Figure 6) outlet pipes within the CBPP collect the excess water and drain it to another part of the SuDS management train or drainage system (such as sewers or watercourses). Alternatives to pipes include fin-drains, proprietary CBPP drainage systems or geocomposite blankets at the bottom of the pavement or placed vertically around the edges to collect the water.

For smaller storm events, typically the water entering the pavement can infiltrate into the existing ground. However, for more extreme events, the infiltration aspect is complemented by additional drainage features within the pavement. The excess is collected (using techniques discussed in 12.5) and eventually discharged into sewers or watercourses, with a maximum allowable discharge rate that is agreed with the environmental regulators. This is one way of achieving the requirement for reducing the volume and frequency of runoff by interception and will most likely remove the need for any other long-term storage. The pipes ensure that water does not sit on the surface of the subgrade for long periods and the risk of soil softening is negligible. Importantly, the outlet pipes are connected to a chamber with a flow control device to restrict flow so that water is temporarily stored within the pavement and discharge slowed.

3.3 SYSTEM C – NO INFILTRATION

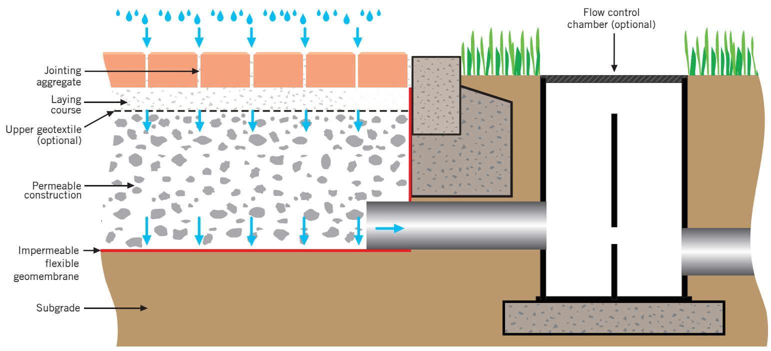


Figure 7: System C - no infiltration

This system (Figure 7) allows for the complete capture of the water within the pavement using an impermeable, flexible geomembrane placed on top of the subgrade and up the sides of the permeable construction, in effect to form a storage tank. It can be 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 prevent water soaking into the ground in sensitive locations such as water abstraction zones or where the water table is very close to the bottom of the sub-base.

Water is collected (using techniques discussed in 12.5) and is discharged via pipes constructed through the impermeable geomembrane at suitable locations to transmit the water to another part of the SuDS management train or drainage system (such as sewers or watercourses). Importantly, the outlet pipes are connected to a chamber with a flow control device to restrict flow so that water is temporarily stored within the pavement and discharge slowed.

System C is particularly suitable for contaminated sites, as it prevents pollutants from being washed further down into the subgrade where they may eventually infiltrate the groundwater. In addition to offering much shallower invert levels when compared to alternative SuDS methods for accommodating high volumes of water, it can also act as an underground retention/detention zone and, in some instances, the stored or captured water can be collected, cleansed, stored and re-used for other purposes, such as flushing toilets (i.e. 'rainwater harvesting') or for irrigation (see Section 5.2).

3.4 SUB-BASE REPLACEMENT SYSTEMS

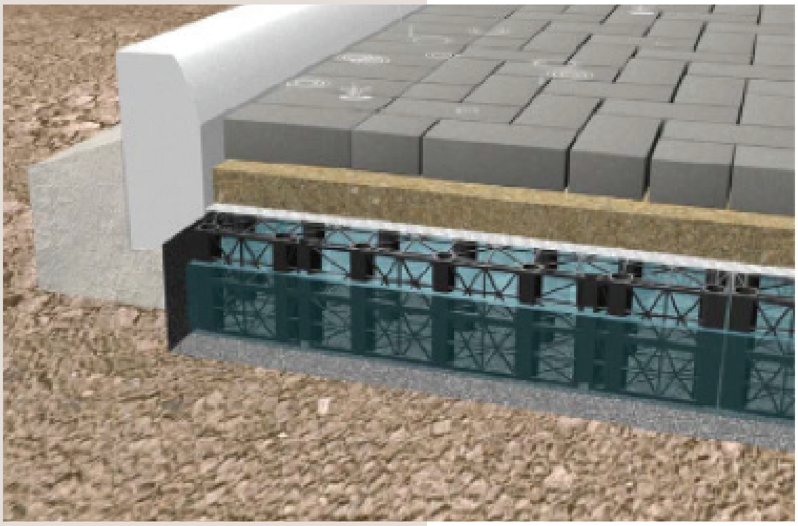


Figure 8: CBPP with geocellular sub-base replacement system below

In some cases, the CBPP aggregate pavement construction can be replaced with geocellular systems (Figure 8). They provide a higher storage capacity (with > 90% porosity), useful for water harvesting, and/or reduced pavement thickness. Particular care is needed with design of these systems, especially in handling the high loads encountered and to ensure adequate water treatment. Advice should be sought from the suppliers/manufacturers or found in the SuDS Manual (CIRIA, 2015).

3.5 OTHER APPLICATIONS

Figure 9: CBPP retrofitted over an existing road structure collects water and discharges it through slot drains into adjacent rain-gardens.

CBPP can be used as a permeable surface in various situations, such as on roofs, balconies and podium decks. It can also be used as an overlay comprising only the paving units and laying course, if necessary with a thin drainage medium below, installed over an existing road construction. The overlay CBPP collects the water and provides limited attenuation and cleaning before discharging near the surface. Discharge may be into other shallow SuDS features, such as rain-gardens (Figure 9), or to existing road gulleys below. The latter may be particularly useful when traditional stepped kerb streets are transformed into shared-surface areas.

The structural design of the CBPP overlay should take account of the condition of the existing road surface. If it is in poor condition and water is stored over it, the water could soak into cracks and reduce the strength of the underlying pavement. The existing surface should be sealed or a geomembrane used if water is to be stored over it. This may not be necessary where water is only being conveyed over the top of the old surface.

4. SPATIAL PLANNING

CBPP is a particularly adaptable technology, combining drainage and hard surfaces for a wide range of applications, including areas that are trafficked by HGVs, on all types of projects, whether new or retrofit. While CBPP is popular as part of a management train comprising various SuDS techniques it can equally be used in isolation or as a stand-alone technique to improve conventional drainage systems.

At the same time, as part of the landscape design it will help to define the character of a development. To make the most of its potential multi-functional benefits, a holistic approach to project design and consideration of CBPP from the very start – from the master-planning stage – are essential: refer to Interpave's guidance document *'Understanding Permeable Paving'*. The following particular situations should also be borne in mind.

4.1 EXCEEDANCE ROUTES

As with any drainage system, flood conveyance routes to cater for extreme events should be planned within the overall project layout. Design of CBPPs must also take into account the overland flow routes of water when the design capacity is exceeded. Although exceedance will result in flooding of some areas, the flows should be routed to prevent flooding of buildings for events that are well in excess of the capacity of the system. Further guidance is provided in CIRIA Report C635 (CIRIA, 2006).

4.2 SLOPING SITES

Constructing CBPPs on sloping sites is permissible. The maximum gradient of the paver surface should be about 5% (1 in 20) to avoid water running over the surface and failing to enter the pavement.

When designing for sloping sites, the relationship between pavement surface and subgrade levels is key. Without design measures, the water within the permeable construction could simply run to and collect at the lowest point, reducing the available storage.

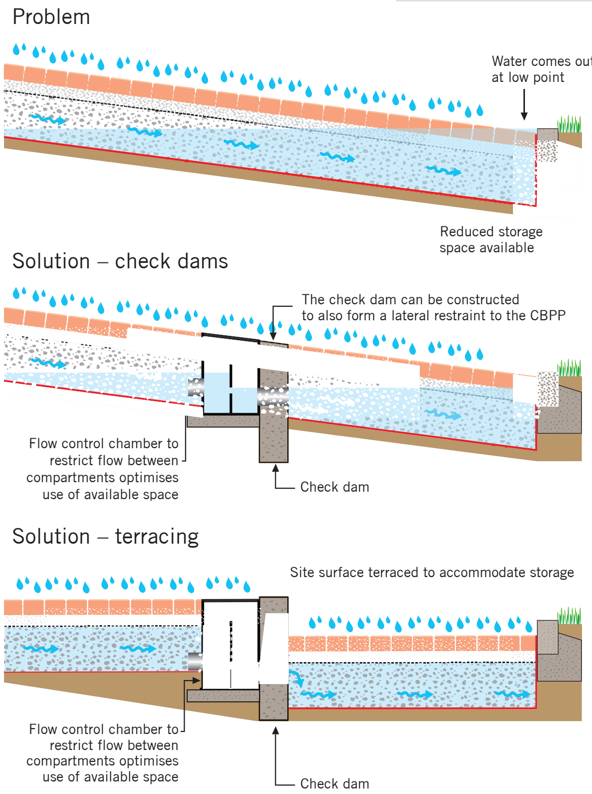


Figure 10: Managing CBPPs on sloping sites.

There are various potential solutions to this issue for all types of CBPP, including:

1. Install dams within the underlying permeable construction to create separate compartments with flow control devices to ensure that water does not flow uncontrolled to the lowest level and discharge through the surface. There are various ways of achieving this including bunds formed in concrete, masonry blocks or proprietary CBPP drainage systems (Figure 10). A low-cost solution is to form a dam with the impermeable geomembranes of adjoining compartments lifted up and folded back.

2. Terrace the site with dams to give relatively level areas of CBPP that have separated compartments of underlying permeable construction with flow control devices as above (Figure 10).

3. Use high capacity geocellular storage (plastic boxes) at the lower end of the site to increase storage capacity.

4. The underlying permeable construction thickness can be increased to allow for the reduced storage capacity in the CBPP at the top of the slope.

Guidance on checking the available hydraulic storage on a slope is given in section 9.10.

These precautions are required wherever the underlying permeable construction is used for water storage on sloping sites (including any infiltration systems – i.e. Systems A or B). In all cases careful analysis and detailing is required to ensure that the water flows within the pavement are as predicted and that unexpected 'spring lines' do not occur in the pavement. The exact design will depend on the site area, discharge limits, gradient, etc.

4.3 DRAINING IMPERMEABLE ONTO PERMEABLE AREAS

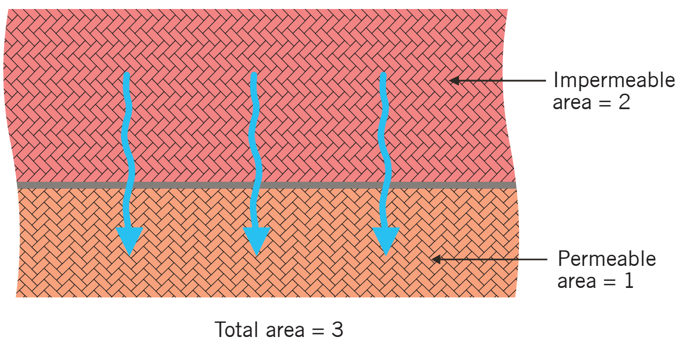


Figure 11: Ratio of impermeable to permeable

One of the strengths of CBPP is a capability to handle runoff from adjacent impermeable areas of paving and roofs. For example, car parking bays are often constructed using CBPP with access ways of impermeable construction. Where runoff flows from an impermeable surface onto an adjacent permeable surface it is normal practice to limit the ratio of impermeable area to permeable pavement to about 2:1, as a rule of thumb and depending on site parameters (Figure 11). The main reason for this is that silt loads onto the CBPP become excessive at greater ratios and the risk of the surface clogging increases. As an example, if a site has a total area to be drained of 1500m^2 then 1000m^2 can be impermeable draining into 500m^2 of CBPP.

Where conventional block paving abuts CBPP, stabilisation of the joints in the former may be considered to avoid migration of jointing sand onto the CBPP.

Where roof water is brought directly **into** the permeable construction by a suitable catchpit to remove silt (see Section 12.4), the 2:1 rule need not apply (unless the roof water is being infiltrated within 5m of a building or other structure, in which case it should still be applied). The design process requires the determination of both the structural thickness and the hydraulic thickness. If the structural thickness is greater than the hydraulic thickness this means that there is spare hydraulic storage capacity that can be utilised to accommodate runoff from adjacent areas. If there is no spare hydraulic capacity and it is required to accommodate runoff from adjacent areas then the hydraulic thickness will need to be increased accordingly.

4.4 ACCOMMODATING STATUTORY SERVICES

Whenever possible avoid locating services within CBPP to minimise the need of having to excavate and reinstate the CBPP to repair or replace any services. Design the layout of the roads and parking bays with a combination of CBPP and conventional impermeable pavements and restrict the services to the conventional pavements only.

If this is unavoidable, then create delineated service trenches within the CBPP that can be excavated and reinstated with the minimum disturbance to the permeable pavement layers. The service trench should be constructed using conventional pavement materials. Figure 13 illustrates a typical example of how to achieve this.

Both these approaches can also form a key part of the overall layout design both visually and technically, as shown in Figures 12 and 13.

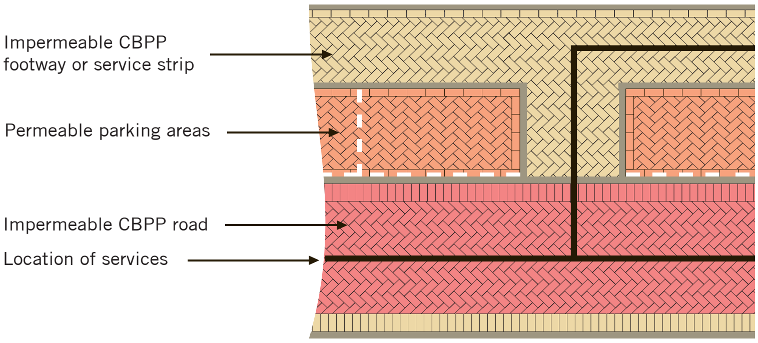
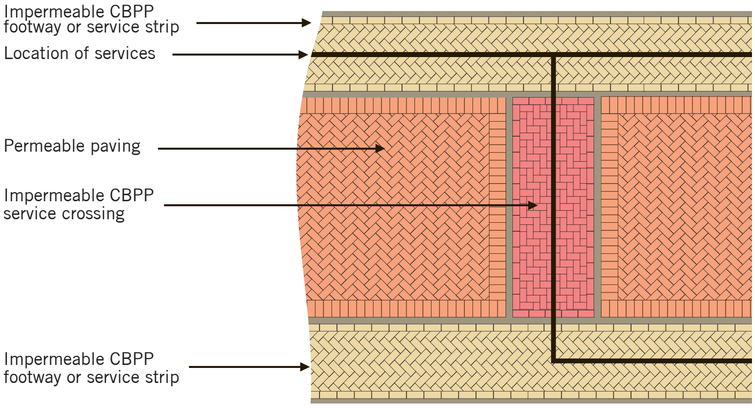


Figure 12: Plan of a layout with services in road and footway.



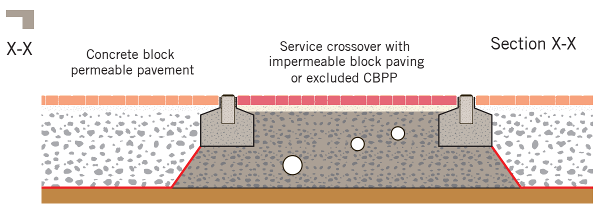


Figure 13: Plan and cross section of a typical service crossing.

4.5 TREES AND PLANTING

CBPPs (irrigating directly via Systems A and B, or via slot drains from System C: see Section 3.5) are also particularly useful where a hard surface is required in close proximity to trees and other planting (whether established or new), as water flow to roots can be maintained without special measures. CBPPs are an excellent form of construction near trees, because they allow air and water to enter the soil, which is beneficial to tree growth. Depending on species, if tree roots have sufficient water and air in the soil, they are much less likely to interfere with CBPPs. However, depending on the site and any other restrictions, some form of tree-root protection system may be prudent.

4.6 NON-DRAINAGE APPLICATIONS

In addition to water drainage applications, CBPPs have also been used to vent and prevent the build-up of gases below ground, for example with development over landfill sites for dispersal of methane.

4.7 INAPPROPRIATE APPLICATIONS

There are a few situations where CBPP may be inappropriate. For example, do not use CBPPs where there will be very heavy silt loads from the proposed use (e.g. stockpiling sawdust or recycling centres), or heavy contamination (e.g. scrap or chemical disposal facilities).

5. GENERAL DESIGN CONSIDERATIONS

There are a number of considerations to take into account when embarking on the design of CBPP, in addition to structural and hydraulic requirements.

5.1 COMPARTMENTATION AND FLOW CONTROL

There are several advantages in considering areas of CBPP as distinct compartments within a sub-catchment, particularly when flow control devices – with access for adjustment – are fitted to the pavement outlet pipes. As discussed earlier, this technique is useful for containing flows through CBPP on sloping sites. It also optimises the time that water remains in the pavement to maximise infiltration potential (in System B) and for removal of pollutants, fulfilling a major benefit of CBPP: a controlled flow of clean water within the landscape.

Importantly, CBPP compartments with flow control devices provide demonstrable volume storage deployed around a site, requiring no additional land take (see 9.3). CBPP is therefore not just a collection and conveyance mechanism – it does provide storage that can be used and will reduce (or completely negate) the need to provide other storage on a development.

5.2 RAINWATER HARVESTING

Irrespective of ground conditions, System C CBPPs can be designed to collect, treat and store rainwater for re-use for non-potable purposes such as irrigation, washing vehicles or toilet flushing (Figure 14 and Beecham et al, 2010). For rainwater harvesting design purposes, a runoff coefficient of 40% is recommended due to the greater evaporation than with an impermeable surface. Rainwater harvesting systems are not normally used to provide potable water as this would require specialised treatment and monitoring to manage the contamination risks. See Chapter 11 of the SuDS Manual (CIRIA, 2015) for more information on harvesting.

Extensive research summarised in CIRIA C609 (CIRIA, 2004) has demonstrated that CBPPs will significantly reduce pollution but there may also be a need to treat the water further before use in some cases. In the majority of situations, this is not normally required for toilet flushing and irrigation.

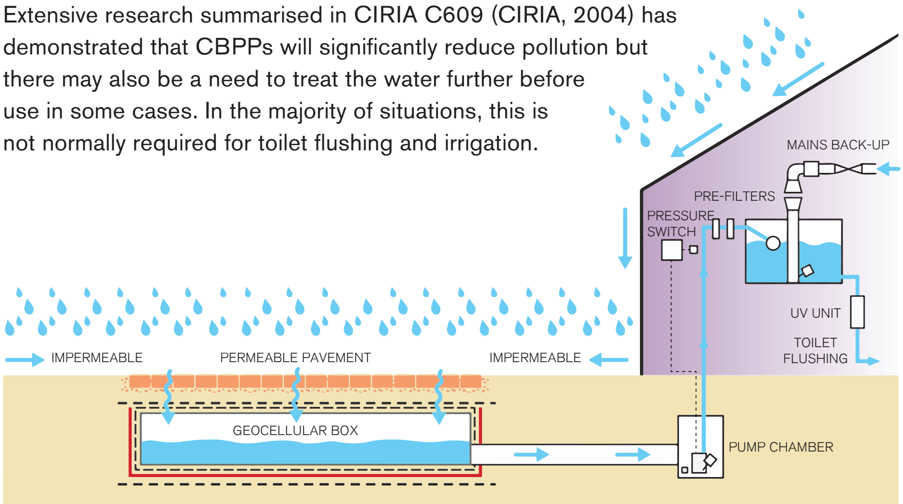


Figure 14: Example of a rainwater harvesting system

5.3 ROOF DRAINAGE

As discussed earlier, CBPP can generally accept runoff from roofs. For domestic roofs and smaller capacities, downpipes can discharge directly onto the CBPP surface or flag paving incorporated into the CBPP for localised diffusion. The maximum ratio of 2:1 should still apply. The additional volume of water entering the CBPP needs to be taken into account when determining the hydraulic thickness. See Section 9.11 for details of how to calculate the additional hydraulic thickness.

For larger outlets and roofs, rainwater can be discharged into the CBPP via filter chambers (accessible for maintenance) leading to diffusers within the permeable base or sub-base. Here, the 2:1 rule need not apply (unless the roof water is being infiltrated within 5m of a building or other structure). It is important to consider the velocity and volume of water entering the pavement when designing the filter chambers and diffusers to avoid excessive 'point loading'. Roof drainage can direct large volumes of water into the pavement very quickly, especially where syphonic drainage is being considered. See Section 12.4 for details.

5.4 PROXIMITY TO BUILDINGS

System C non-infiltrating CBPP can be constructed up against buildings but infiltrating Systems A and B may also be used close to buildings as they allow dispersed infiltration similar to natural vegetation. Therefore, the minimum 5m requirement cited in Building Regulation guidance for soakaways (which, in contrast, provide a single concentrated point discharge) need not apply, as has been specifically clarified by the Government (DTLR Response, April 2002).

However, if a concentrated outflow (such as a roof drainage terminal) is used within the pavement, this should be at a sufficient distance to ensure that the stability of the building is not affected. On many sites, even when the flow from roofs is included, the ratio of area drained to the area of infiltration for a CBPP is much less than that from a traditional soakaway (between 3:1 and 6:1 for a CBPP, compared to 30:1 and 300:1 for a traditional soakaway). Thus, water flows from the base of CBPPs are much less concentrated and, even with the additional roof water, it may be possible to allow infiltration within 5m of a building. Additional information can be found in Susdrain Factsheet 12 (Susdrain 2012).

5.5 MANAGING POLLUTION

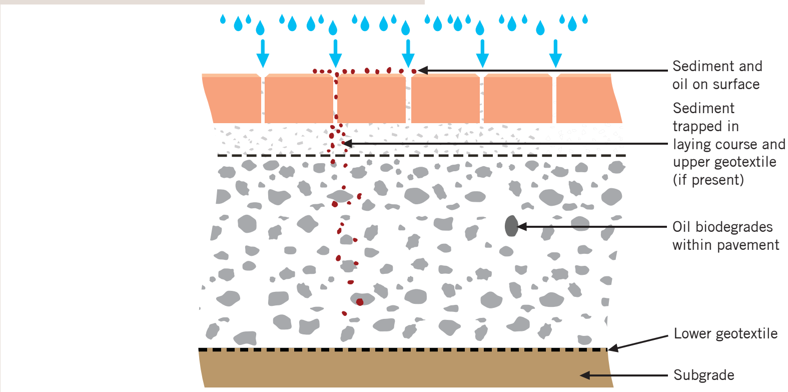


Figure 15: Management of pollutants in CBPP.

Pollution is present on road and car park surfaces as a result of oil and fuel leaks, and drips, tyre wear, dust from the atmosphere, etc. This type of pollution arises from a wide variety of sources, is spread throughout urban areas and is known as diffuse pollution. Rainfall washes the pollutants off the surface. Conventional drainage systems, as well as attenuation tanks, effectively concentrate pollutants, which are flushed directly into the drainage system during rainfall and then into watercourses or groundwater. The impact of this is to reduce the environmental quality of watercourses.

The 'Water Framework Directive' (European legislation) requires that surface water discharges are managed so that their impact on the receiving environment is mitigated. The objective is to protect the aquatic environment and to control pollution from diffuse sources such as urban drainage. This will be a key aspect that will effectively preclude the use of the traditional piped approach to drainage in future.

There is a wealth of research information available from around the world showing that CBPPs are very effective at removing the main pollutants of concern, i.e. total suspended solids, hydrocarbons and metals. The pollutants may either remain on the surface (particularly with zero gradients) or may be flushed into the underlying pavement layers where many are filtered and trapped, such as metals and total suspended solids (TSS), or degrade over time, such as hydrocarbons (see Figure 15).

It is well-established that oil separators are not required when CBPPs are used. Indeed CBPPs are more effective at removing a wider range of pollutants from runoff than oil separators (CIRIA, 2004). If additional treatment is required for higher risk areas, it is normally more effective to use green SuDS methods such as swales or wetlands, as these also treat a wider range of pollutants.

5.6 DESIGNING FOR WATER QUALITY

Design of SuDS to achieve water quality requirements is explained in the SuDS Manual (CIRIA, 2015). Sites are assigned 'Pollution Hazard Indices' for TSS, metals and hydrocarbons, depending on the likely risk of pollution being present. SuDS components are assigned a 'Pollution Mitigation Index', which depends on how effective the component is at removing each of the pollutant categories.

To deliver adequate treatment, the selected SuDS components should have a total Pollution Mitigation Index (for each contaminant type) that exceeds the Pollution Hazard Index (for each contaminant type) i.e.:

Total SuDS Pollution Mitigation Index (for each contaminant type)	**≥**	**Pollution Hazard Index (for each contaminant type)**

There are different sets of mitigation indices that depend on the destination of the water discharging from the sub-base of the CBPP and also in which region of the UK the site is located.

<table>
<tr><th>Principal destination of the runoff</th><th>England</th><th>Wales</th><th>Scotland</th><th>NI</th></tr>
<tr><td>Surface water i.e. there is no infiltration from the SuDS to groundwater</td><td colspan="4">Use 'surface water' mitigation indices</td></tr>
<tr><td>Surface water, but small amounts of infiltration may occur from un-lined components (Interception)</td><td colspan="2">Use 'surface water' mitigation indices for main discharge and 'groundwater' mitigation indices for minor infiltration</td><td colspan="2">Use 'surface water' mitigation indices</td></tr>
<tr><td>Groundwater, but discharges to surface waters may occur once the infiltration capacity is exceeded</td><td colspan="4">Use 'groundwater' mitigation indices</td></tr>
</table>

The SuDS Manual (CIRIA, 2015) recognises the effectiveness of CBPP in removing pollution and for areas with a low to medium pollution hazard level CBPPs are more than sufficient on their own to provide an adequate pollution mitigation index (see Table 1). For higher risk sites, the CBPP could discharge to another SuDS feature such as a basin or a pond.

Table 1: Extract from Tables 26.2, 26.3 and 26.4 of the SuDS Manual (CIRIA, 2015) showing pollution hazard indices for low risk areas and mitigation indices provided by CBPP

Land use	Pollution Hazard Level	Total suspended solids (TSS)	Metals	Hydro-carbons
Pollution hazard				
Individual property driveways, residential car parks, low traffic roads (e.g. cul de sacs, homezones and general access roads) and non-residential car parking with infrequent change (e.g. schools, offices) i.e. < 300 traffic movements/day	Low	0.5	0.4	0.4
Commercial yard and delivery areas, non-residential car parking with frequent change (e.g. hospitals, retail), all roads except low traffic roads and trunk roads/ motorways [1]	Medium	0.7	0.6	0.7
SuDS Mitigation				
Mitigation indices for CBPP discharge to surface waters [1]		0.7	0.6	0.7
Mitigation indices for CBPP discharge to groundwaters (where a suitable filtration layer is included that provides treatment and including a geotextile at the base separating the foundation from the sub-grade) [1, 2]		0.7	0.6	0.7

Note:
1. CBPPs will only deliver these indices if they follow design guidance with respect to hydraulics and treatment set out in the relevant technical component chapters of the SuDS Manual (CIRIA, 2015).
2. Designs should generally include a minimum of 1m unsaturated depth of aquifer material between the infiltration surface and the maximum likely groundwater level. In the case of localised and discontinuous perched water tables, the 1m minimum separation might be reduced. This will require the designer to assess the risk to groundwater from pollution in surface runoff.

5.7 CONSTRUCTION TRAFFIC

Often there is a need to use the partially completed or completed CBPPs as access roads or storage areas during the construction of a project. If the sub-base (CGA or Type 3) is trafficked, the unbound surface will rut and become clogged. If the HBCGA base or paver surface is trafficked it will become clogged. Options to overcome these issues are:

1. Design the layout of the roads and parking bays with a combination of CBPP and conventional impermeable pavements and restrict construction traffic and storage of materials to the conventional pavements only.
2. For System C CBPP use a designed capping layer to allow site trafficking during construction. (For CBPPs with a low CBR a capping layer or subgrade improvement layer is required.) Then complete the construction of the CBPP at the end of the project construction. It may be necessary to construct a capping layer thicker than the original design thickness, to cope with the construction traffic loads. It may also be necessary to repair and trim the capping to return it to the design profile before proceeding with completion of the pavement.
3. Complete the CBPP and overlay with a sacrificial layer to protect the surface and prevent clogging of the joints. Overlaying the paver surface with geotextile or some other protective means may be required to protect the surface of the paving units from damage, scuffing and clogging of the joints.
4. For Traffic Category 5 or greater, a base is required. This base can be HBCGA or impermeable AC. If AC is selected this can be used as a temporary impermeable surface and just prior to the installation of the paving units, the AC is cored or perforated to form CAC. For Traffic Category 4 or lower, the AC can be incorporated as an additional layer. In both cases it will be necessary to assess the volume of construction traffic and, if required, increase the thickness of the AC to allow for the predicted construction traffic - see Section 8.9. Consideration must be given to dealing with the surface water as it will not be able to infiltrate into the lower pavement layers prior to coring or perforating the AC.

6. ENGINEERING DESIGN OVERVIEW

The design stages discussed here follow the Spatial Planning design of the project and are applied to each area/compartment of CBPP. From an engineering perspective, a CBPP must be designed to achieve two aims:

- Support the traffic loads over its design life (structural design).
- Manage surface water effectively (hydraulic design)

The design process requires the determination of both the structural thickness and the hydraulic thickness. The structural and hydraulic thicknesses are compared and the greater thickness selected as the design thickness.

If the permeable structural thickness is greater than the hydraulic thickness, then this means that there exists spare hydraulic storage capacity that can be utilised to accommodate runoff from adjacent areas. If there is no spare hydraulic capacity and there is a requirement to accommodate runoff from adjacent areas, then the hydraulic thickness will need to be increased accordingly. If necessary the sub-base and/or capping layer thickness can be increased to provide additional storage. Finally, the 'half-empty' time is determined and ancillary aspects, such as flow conveyance through the sub-base, outlet spacing and flow control devices, are designed.

The design procedure is summarised in Figure 16. Straightforward design guidance for CBPP on private driveways, patios and other lightly trafficked paving can be found in Interpave's *'Paving for Rain'.*

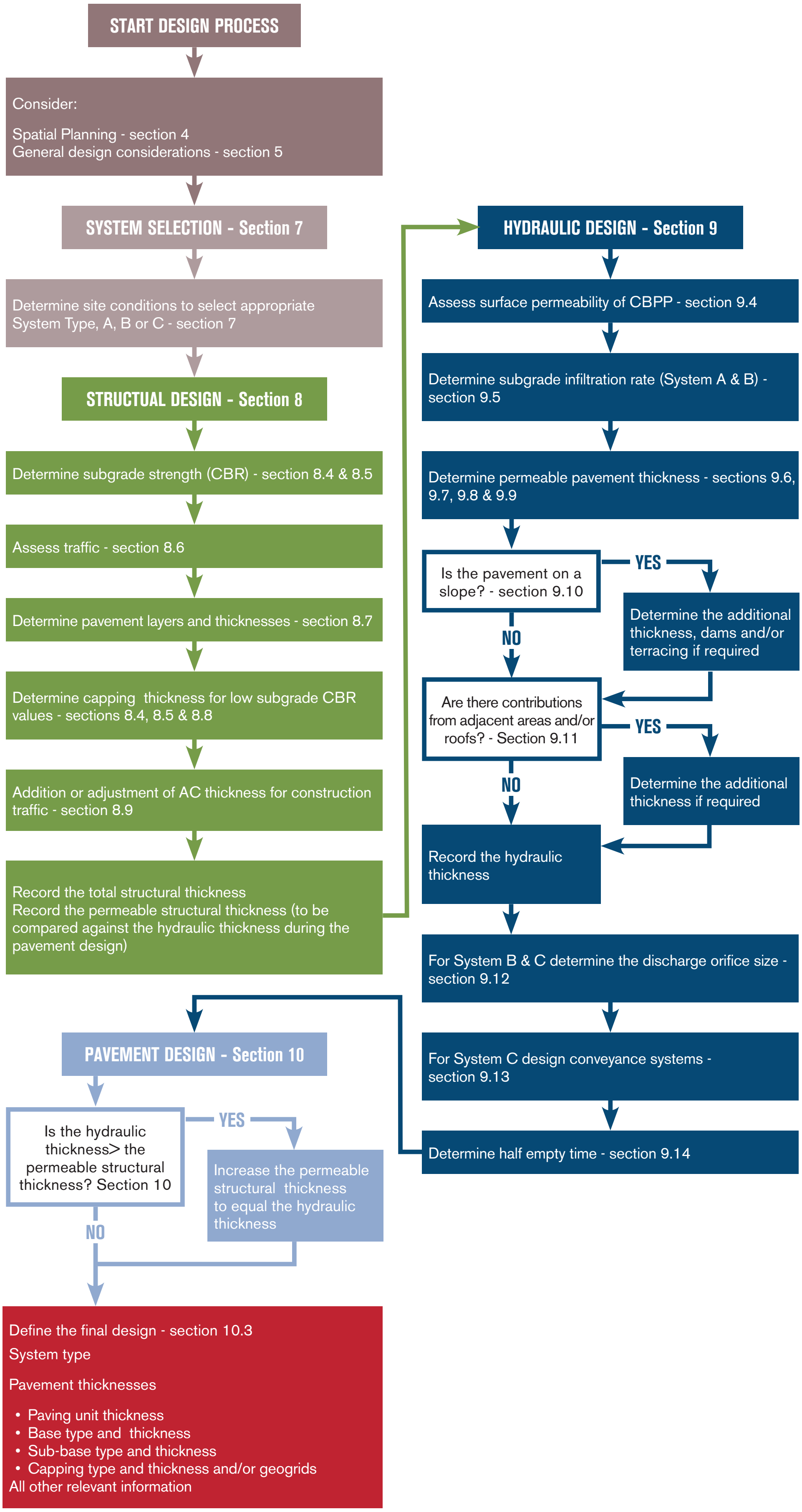


Figure 16: Engineering design procedure for CBPP

7. SYSTEM SELECTION

The three types of CBPP construction – Systems A, B and C – are described in Section 3. While sharing the same surface appearance, structural performance and water treatment capabilities, the three systems have very different hydraulic characteristics and applications. System A simply allows all the water to infiltrate to the subgrade after temporary storage, while System C contains all the water and System B in effect provides a combination of both.

Wherever the overall project design includes containment of the water for harvesting (see 5.2), use within the landscape or other purposes, System C or B CBPP should be used. Otherwise, the following criteria will determine the appropriate system selection.

7.1 SUBGRADE PERMEABILITY

Subgrade permeability is the key selection criterion, derived from infiltration tests on site (similar to those for traditional soakaways). However, CBPPs infiltrate water into the ground at much shallower depths than traditional soakaways and tests should be carried out close to the final formation level of the pavement. Generally, this will be less than 1m depth and with a lower head of water, replicating the CBPP behaviour. Guidance on appropriate pavement systems for a range of subgrade and site conditions, including permeability derived from infiltration tests, can be found in Figure 17 and Table 2.

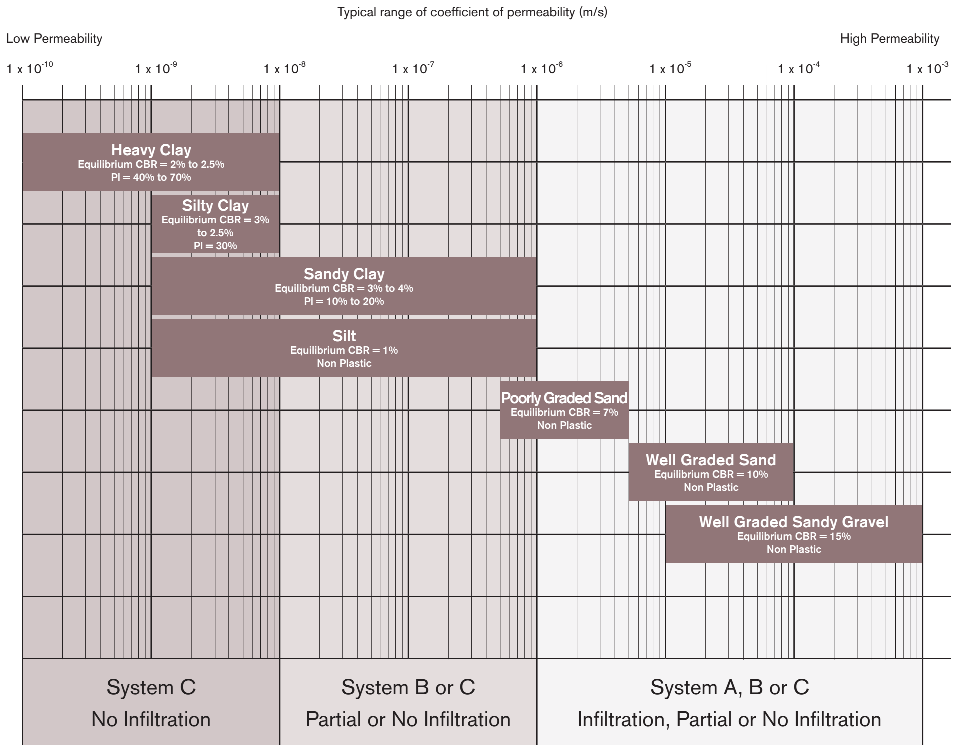


Figure 17: Soil classification guide

Note: A significant proportion of clay and silt (>15% of particles less than 63μm) will reduce the permeability and CBR values of sand and of gravels.

Ground Characteristics		Type A: Total Infiltration	Type B: Partial Infiltration	Type C: No Infiltration
Permeability of subgrade defined by coefficient of permeability k (m/s)	1×10^{-6} to 1×10^{-3}	✓	✓	✓
	1×10^{-8} to 1×10^{-6}	✗	✓	✓
	1×10^{-10} to 1×10^{-8}	✗	✗ (1)	✓
Highest expected water level within 1000mm of formation level		✗	✗	✓
Pollutants present in subgrade		✗	✗	✓
Ground conditions such that infiltration of water is not recommended (solution features, old mine working, etc.)		✗	✗	✓

Note: Partial infiltration systems may be used in soils with permeability less than 10^{-8}m/s but the infiltration of water is not allowed for in the storage design. This helps with the provision of interception.

Table 2: Guidance on selection of a pavement system type

7.2 GROUNDWATER LEVEL

For Systems A and B, the highest recorded groundwater level must be greater than 1000mm below the bottom of the permeable construction. 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 permeable sub-base.

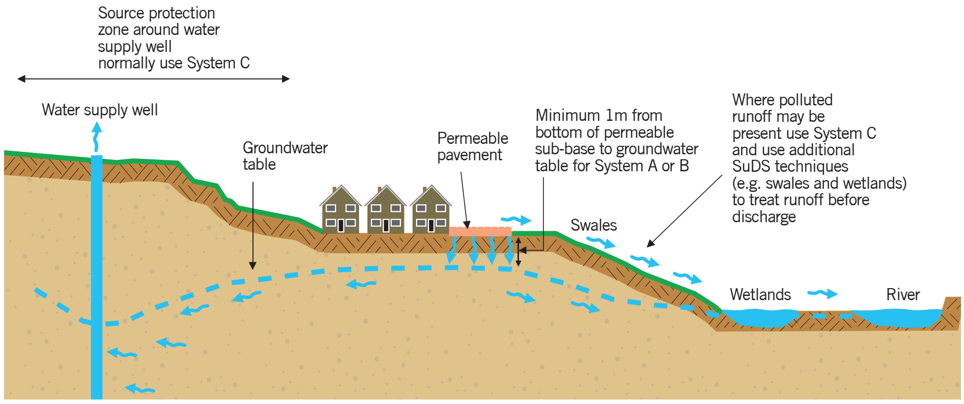


Figure 18: Pollution prevention considerations

7.3 POLLUTION PREVENTION

There are defined areas around water supply boreholes known as 'source protection zones' (Figure 18). In these areas the use of System A or B CBPPs may not be appropriate and System C may be necessary. The use of CBPPs in these locations should follow the advice provided by the Regulator (e.g. in England, Environment Agency (2017)).

Detailed groundwater risk analysis following normal good practice can be undertaken to confirm whether CBPP will be acceptable on its own or if additional treatment stages are required. In one example, the use of CBPP within a source protection zone was shown to pose a lower risk to the water supply borehole than the use of a large soakaway outside the zone. This was because the CBPP treated the runoff to remove pollution and dispersed the flows over a wide area at a low intensity when compared with a traditional soakaway.

System A and B infiltrating pavements should not be used on brownfield sites unless it can be demonstrated that the risk posed by leaching of contaminants is at acceptable levels. If any site is classified as a 'high pollution risk' and there is any risk that stormwater can infiltrate the groundwater, infiltrating CBPPs on their own are not recommended and either System C should be used or additional treatment stages provided, such as ponds, basins or wetlands (see Figure 18, Table 2 and Environment Agency, 2017). Such applications include: vehicle scrap yards, recycling facilities, petrol stations, service and maintenance facilities, and other locations that handle potentially polluting substances.

7.4 ENVIRONMENTAL LICENCES AND PERMITS

Drainage discharges from some high pollution hazard sites either to the ground or to surface watercourses may require an environmental licence or permit. Low to medium hazard sites are not likely to require such permission.

A summary of the UK regulations for discharges to groundwaters is provided below and details of the water quality design and permit requirements can be found in the SuDS Manual (CIRIA, 2015).

- The regulators in England and Wales should be consulted if a discharge meets the definition of a 'groundwater activity' under the Environmental Permitting (England and Wales) Regulations 2016 and does not meet an appropriate exemption.

- In Northern Ireland, other local regulations apply.

- In Scotland, an authorisation under the Controlled Activity Regulations (CAR) or a pollution prevention and control (PPC) permit may be required. In Scotland, certain discharges to surface waters are automatically authorised by 'general binding rules' (GBR). In such cases, it is not necessary to apply for authorisation from SEPA, but the design and discharge must comply with the conditions of the GBR.

8. STRUCTURAL DESIGN

In this section, Interpave's structural design method is described and the thicknesses and properties of all of the materials within the structure of the pavement can be selected and specified. It supersedes the structural design method found in BS 7533-13:2009, *Guide for the design of permeable pavements constructed with concrete paving blocks and flags, natural stone slabs and setts and clay pavers* (BSI, 2009a). It is based on the most recent research and design methods and is consistent with the approach in the SuDS Manual (CIRIA, 2015). In due course BS 7533-13: 2009 will be re-written so as to be consistent with the SuDS Manual (CIRIA, 2015) and this document.

8.1 PERMEABLE PAVEMENT COMPONENTS

Typical components of a concrete block permeable pavement are:

PAVING BLOCKS

The surfacing comprises paving units specifically manufactured for CBPPs. They permit water to enter and infiltrate into the pavement from its surface either by the use of oversize spacer nibs or by special shapes that create a space between adjacent paving units.

It is also possible to use conventional concrete blocks or paving units, without spacer nibs, or flag paving. These paving units can be laid, with or without separate spacers, to achieve suitable joint spaces. They are only suitable for pedestrian and light traffic applications. Advice on suitability of products and applications should be sought from the paving manufacturer.

JOINTING AGGREGATE

The joint spaces or voids between the paving units are filled with aggregate, of a specific grading and physical properties, that allows the infiltration of water into the laying course. Joint filling sand is not permissible.

LAYING COURSE

Paving units are installed over a laying course of aggregate, of a specific grading and physical properties, that allows the infiltration of water into the underlying layer. Conventional block laying course sand is not permissible.

For the determination of the hydraulic design thickness, the jointing and laying course aggregates are considered to have no hydraulic storage capacity.

BASE

For areas subject to Traffic Category 5 or greater (see Table 5) a base is required over the sub-base. The base is a stronger and stiffer layer of pavement material than the sub-base. The thickness of this base is a function of the Traffic Category - refer to Table 5 to determine the base thickness and material type. The base is either permeable hydraulically bound coarse graded aggregate (HBCGA) or impermeable asphalt concrete (AC). HBCGA is CGA with the addition of a cement binder.

For Traffic Category 4 or lower, the AC can be incorporated as an additional layer. In both cases it may be necessary to increase the thickness of the AC to allow for the predicted construction traffic - refer to Section 8.9 for details.

NOTE: Before the installation of the paving units the AC is cleaned, if required, to remove mud and detritus, then cored or perforated with 75mm diameter holes on a 750mm orthogonal grid to form CAC, so as to allow the infiltration of water into the pavement layers below. The holes are filled with CGA, Type 3 or laying course aggregate.

For the determination of the hydraulic design thickness, CAC is considered to have no hydraulic storage capacity and HBCGA a porosity of 30% (see Table 10).

SUB-BASE

For Traffic Categories 0 to 8, a permeable sub-base is required. The thickness of the sub-base is a function of the Traffic Category - refer to Table 5 to determine the sub-base thickness. CGA is specifically manufactured for permeable pavements and comprises crushed angular aggregate of a particular grading and physical properties, to provide a structural layer but with at least 30% porosity for the temporary storage of water.

For the determination of the hydraulic design thickness, CGA is considered to have a porosity of 30% (see Table 10).

Alternatively Type 3 sub-base can be used in lieu of CGA but the physical characteristics need to be determined and compared with CGA and, if necessary, the thickness increased to allow for lesser stiffness characteristics than CGA.

NOTE: The porosity of HBCGA, CGA and Type 3 needs to be confirmed by testing or certification from the aggregate supplier. The hydraulic design thicknesses given in Table 10 are based upon a porosity of 30%. Therefore, if the proposed aggregate differs from 30%, then adjustments to the hydraulic thicknesses will have to be made.

CAPPING

For pavements where the subgrade CBR value is below 5%, a subgrade improvement and/or a capping layer will be required. For System A and B pavements that allow water to infiltrate into the subgrade the capping must have an infiltration rate equal to or greater than the subgrade and be unaffected by the infiltration of water.

IMPERMEABLE GEOMEMBRANE

System C pavements include an impermeable geomembrane which holds all of the water entering the pavement and being detained within it.

GEOTEXTILES

Lower Geotextile - This geotextile is required as a separation layer between the subgrade and capping.

Upper Geotextile - This may be required between the laying course and the underlying pavement layer.

SPECIFICATIONS AND MATERIALS

Refer to Section 11 for details of all the materials and components within a CBPP.

8.2 STRUCTURAL DESIGN PRINCIPLES

The main principle behind road pavement design is the distribution of concentrated loads from vehicle wheels down through the pavement to the weaker subgrade below so that it can support the loads without excessive deformation or failure. The strongest pavement materials are used at the top, where the wheel pressure is highest, reducing in strength further down the pavement. The layers of a typical CBPP road pavement are shown in Figure 19.

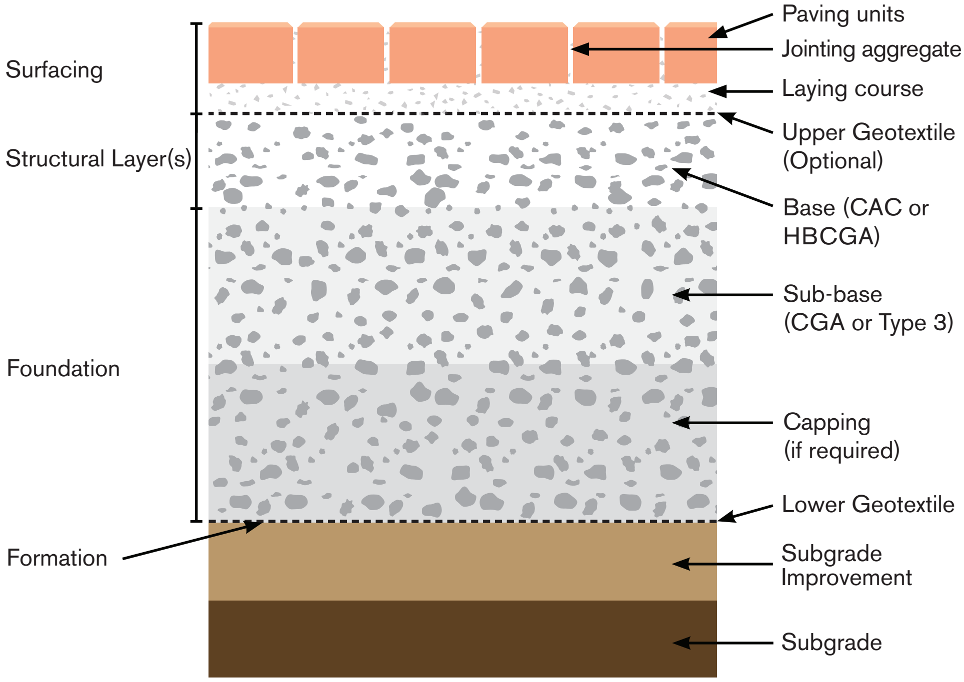


Figure 19: A typical CBPP road pavement

The surfacing comprises concrete paving units with permeable jointing aggregate and laying course, and should resist excessive deformation when trafficked. The structural layers, usually comprising either HBCGA or CAC, are particularly important where regular HGV traffic is anticipated. The foundation layer provides the base and construction platform for the layers above, spreading loads across the formation layer.

8.3 THE STRUCTURAL DESIGN PROCESS

The structural design process comprises the following stages:

Stage 1 – Subgrade assessment
Use Table 3 to determine the equilibrium CBR value of the subgrade.

Stage 2 – Traffic assessment
Use Table 4 to select the Traffic Category, from 1 to 10.

Stage 3 – Pavement layer thicknesses
Use Table 5 to determine the pavement layer thicknesses.

Stage 4 – Adjustment for low CBR
Adjust the thicknesses from Table 5 for pavements installed over subgrades of CBR less than 5% using Table 7.

Stage 5 – Construction traffic
Consider the need for site access. CBPP pavement layers must be kept clean during the construction phase. This can be inconvenient when the construction method requires that the roads be installed early and can be used for site access. Various methods can be used to resolve this issue: see Section 13.7.

8.4 SUBGRADE ASSESSMENT

The first stage of the design is to assess the CBR value of the subgrade. CBR varies inversely with moisture content (as the latter increases the CBR value decreases). The equilibrium CBR value is the long term value that occurs once the pavement is constructed and the moisture content of the subgrade comes into equilibrium with suction forces (e.g. as a result of unloading due to excavation, groundwater levels and wetting as a result of water storage in the sub-base). It may be possible to use higher CBR values for System C where waterproofing is robust.

This can be determined by carrying out laboratory CBR tests in accordance with BS1377-4 (BSI, 1990a) at the equilibrium moisture content as described in LR1132 (Powell et al., 1984). For System A and B pavements the CBR should be tested after saturation. The Interlocking Concrete Pavement Institute (2017) recommends 96 hours saturation period. Alternatively, the value should be estimated based on the type of soil (plasticity index and grading) following the guidance in LR1132, as provided in Table 3.

Table 3: Equilibrium Subgrade CBR Estimation for CBPP

Soil Type	Plasticity Index	Guideline equilibrium CBR Value for CBPP design [1, 3] (%)
Heavy Clay	70	2
	60	2
	50	2
	40	2.5
Silty Clay	30	3
Sandy Clay	20	4
	10	3
Silt [2]	--	1
Sand (Poorly Graded)	--	7
Sand (Well Graded)	--	10
Sandy Gravel (Well Graded)	--	15

Notes:
1) Assumes thin construction. If pavement thickness (from surface to subgrade) is greater than 1200mm refer to Interim Advice Note 73/06 Rev 1 (Highways Agency, 2009) to obtain equilibrium CBR values for clay and silt only.
2) Estimated assuming some probability of material saturating.
3) These CBR values assume a high water table and that the subgrade may be wetted during the life of the pavement. If a suitable impermeable membrane is used higher values may be appropriate.

The highest values of Plasticity Index measured on a site should be used (to give the lowest CBR value) for the design, unless there are a substantial number of results available to allow the mean or other statistical value to be used with confidence (note that if the mean is used there will be an increased risk of pavement failure in some areas). It may be possible to remove soft spots and therefore ignore those low CBR values which relate to the removed material.

On sites where the CBR varies from place to place, appropriate designs may be provided for different parts of the site using the lowest CBR recorded in each part. Once the subgrade is exposed during construction the CBR value of the soil should be confirmed by laboratory testing of CBR samples (BS1377-4 (BSI, 1990a) or using insitu methods (BS1377-9 (BSI, 1990b)). This is the short term CBR value at the time of construction. If the short term CBR is found to be less than the equilibrium CBR, the subgrade must either be improved to achieve the equilibrium CBR or the pavement thickness redesigned. The reason for this is because construction during very wet periods of weather can adversely affect the soil strength and lead to lower CBR values.

In summary the final Design CBR value should be the lower of:

1. The equilibrium CBR value obtained from CBR tests at equilibrium moisture content (saturated for 96 hours for System A and B) or based on plasticity and grading results using the correlations above; or

2. The short term CBR value obtained from CBR tests on the subgrade, taken once it is exposed for construction.

Where the CBPP is to be constructed on a subgrade of engineered fill the equilibrium CBR value of the engineered fill should be obtained from CBR tests where the fill material is first compacted into the test mould at optimum moisture content prior to testing. Alternatively, the equilibrium CBR value of the engineered fill may be obtained based on plasticity and grading results using the correlations above.

8.5 SUBGRADE WITH LOW CBR (CBR < 3.0%)

The minimum permitted Design CBR is 3.0% for normal pavements and this also applies to CBPPs. Subgrades with a lower Design CBR are considered unsuitable to support a pavement. In these cases a subgrade improvement layer should be provided to permanently improve the load bearing capacity of the subgrade. This can be achieved by removing the weak material to sufficient depth and replacing it with suitable fill material. The thickness removed may typically be between 0.5 and 1.0m. Although the new material may be of better quality, the new Design CBR should be assumed to be equivalent to 3.0%, in order to allow for effects of any softer underlying material and the potential reduction in the strength of the replacement material to its long-term CBR value.

The existing subgrade materials may also be improved by the addition of lime and/or cement to give an acceptable long term CBR value if the areas with a low CBR are extensive. This will only be possible with System C pavements (no infiltration) as the permeability of System A and B pavements may be reduced. The impact of water on the stabilised materials should be carefully considered.

The incorporation of a geosynthetic material or geogrid into the foundation design may also overcome the issue of a weak subgrade. Specialist advice should be sought to adopt an alternative design CBR value that may be necessary, based on testing or previous experience with the specific geosynthetic and the materials being used to construct the pavement.

8.6 TRAFFIC ASSESSMENT

Table 4 shows the Traffic Categories for the design of CBPPs. It also shows the maximum number of standard 80kN axles for each category based upon the assumption that pavements are designed to achieve a life of 25 years' trafficking. Using knowledge of either the number of standard 8000kg axles or the number of commercial vehicles per day, or the end use of the pavement, select one of the Categories 1 to 10. Note that designs for Categories 9 to 11 are not covered by this guidance. Also, there is a significant difference between pavements designed for Traffic Categories 4 and 5.

Table 4: Traffic Categories for CBPP design.

Traffic category	Standard axles per day	msa	NRSWA[1] Road Type	Typical application
11	Areas with axle loads greater than permitted by the Construction and Use Regulations are not included in this document.			
10	≤8 000	≤60	0	Adopted highways and commercial/ industrial developments used by a high number of commercial vehicles Ports and airport landside Bus stops and bus lanes
9	≤4 000	≤30	1	
8	≤1 500	≤10	2	
7	≤350	≤2.5	3	
6	≤70	≤0.5	4	Adopted highways and other roads used by a moderate number of commercial vehicles Pedestrian areas subjected to regular overrun of commercial vehicles. Industrial premises Petrol station forecourts
5	≤7	≤0.05		Pedestrian areas subjected to occasional overrun of commercial vehicles Car parks receiving occasional commercial vehicular traffic Railway platforms excluding edge
4	1	N/A		Urban footways with no planned vehicular overrun Pedestrian areas used by light commercial vehicles, emergency vehicles and maintenance vehicles
3	0			Small car parks subject to car, light van and motorcycle access
2	0			Pedestrian and cycle areas, domestic driveways
1	0			Pedestrian-only areas, including domestic applications
0	0			No requirement (decoration)

Notes:
1) New Roads and Streetworks Act 2010

8.7 SELECTION OF PAVEMENT LAYER THICKNESSES

Use Table 5 to select pavement layer thickness and material types according to Traffic Category. Note that the resulting pavement will be suitable for subgrades of CBR 5% or greater.

Table 5: Typical construction thickness over subgrade with 5% CBR or greater.

Traffic category	Concrete paving units – minimum thickness	Laying course – nominal thickness	Base – HBCGA or AC	Sub-base – CGA or Type 3	Design basis
11		Areas with axle loads greater than permitted by the Road Vehicles (Construction and Use) Regulations (1986) as amended are not included in this document			
10		Site specific using Interpave guide for heavy duty pavements (Knapton, 2008)			Knapton (2008)
9		Site specific using Interpave guide for heavy duty pavements (Knapton, 2008)			Knapton (2008)
8	80 mm	50 mm	300 mm HBCGA or 220 mm AC32	150 mm	ICPI Permeable Design Pro
7	80 mm	50 mm	200 mm HBCGA or 130 mm AC32	150 mm	
6	80 mm	50 mm	125 mm HBCGA or 90 mm AC32	150 mm	
5	80 mm	50 mm	100 mm HBCGA or 70 mm AC32	150 mm	
4	80 mm	50 mm	--	300 mm	Knapton et al (2012) and ICPI Permeable Design Pro
3	60 mm	50 mm	--	225 mm	
2	60 mm	50 mm	--	150 mm	
1	60 mm	50 mm	--	100 mm	
0	60 mm	50 mm		Sufficient to provide suitable construction base	

Notes:

1) For Traffic Category 5 and above, CBPP should only be laid in a herringbone pattern.
2) Some types of paving unit can be machine laid. Advice should be sought from the manufacturer on colours, paving types, paving thickness and suitable laying patterns for particular applications.
3) For traffic categories 0 and 1, it is possible to use traditional paving units (e.g. conventional concrete blocks, flags) provided suitable joint spacers are used to create a suitably wide joint for long-term performance. Advice on suitability of products and applications should be sought from the paving manufacturer.
4) HBCGA refers to hydraulically bound coarse graded aggregate (conforming to BS EN 14227-1 (BSI, 2013b), minimum cement content 3%, strength class C5/6 as defined in BSI (2013b) and minimum permeability 20,000 mm/hr).
5) AC refers to asphalt concrete (AC 32 dense 40/60 designed in accordance with BS EN 13108-1 (BSI, 2016)). This AC is impermeable and is often incorporated to provide temporary access for construction traffic. Prior to the installation of the paving units the AC is cleaned, if required, to remove mud and detritus, cored or perforated with 75mm diameter holes on a 750mm orthogonal grid to form CAC. The holes are filled with CGA, Type 3 or laying course aggregate.
6) Pavements sustaining Traffic Categories 5 to 8 include HBCGA or AC32, whereas pavements sustaining Traffic Categories 1 to 4 only require CGA or Type 3. Therefore, if there is any doubt about the level of likely HGV traffic, it is safer to select category 5 or above. Particular care should be taken in the design of shared surfaces where adjacent areas should be protected from HGV overrun or designed for regular overrun.

System A and System B infiltrating pavements include a geotextile material at the interface between the coarse graded aggregate and the subgrade. This geotextile is not brought to the surface at the perimeter of the pavement. System C pavements include a geomembrane below the CGA or Type 3 storage layer that is brought up the sides to provide water storage.

It is possible to refine site-specific designs using analytical pavement design or software such as Permeable Design Pro published by the ICPI in the USA. The program has been used to help assess the design thicknesses in the preceding table. The properties assumed for the materials in the designs above are summarised in Table 6.

Material	Elastic modulus (MPa)	Structural layer coefficient for use in ICPI Permeable Design	Poisson's ratio
Concrete paving units (for CBPP) on a 50 mm laying course that meets requirements of BS7533-13 (BSI, 2009a)	1000 (based on work by Shackel, 2000). Note, evidence from Knapton and Meletiou (1996) and Knapton (2008) is that the modulus of the surface layer has very little effect on the predicted stress on the subgrade and performance of the pavement. Increasing elastic modulus values of the surface layer to justify a reduction in pavement thickness is not normally recommended, as it requires extremely high construction quality, and there is no guarantee that all the joints will be completely full of jointing aggregate for the life of the pavement to maintain an elevated elastic modulus.	0.3	0.40
Base - AC32	6000	0.3–0.44	0.30
Base - HBCGA that meets requirements of CBGM B – Cement Bound Granular Mixture Type B with strength class C5/6 in accordance with Series 800 Specification for Highway Works (Highways Agency et al, 2016a)	4000	0.24	0.25
Sub-base – CGA in accordance with BS7533-13 (BSI, 2009a) or Type 3 in accordance with Series 800 Specification for Highway Works (Highways Agency et al, 2016a)	1000 (note that the main factor that affects stiffness is not the Los Angeles test value but the grading and angular nature of the particles)	0.09	0.35
5% CBR subgrade	50	N/A	0.45

Table 6: Properties assumed in generic CBPP design in Table 5.

8.8 ADJUSTMENT FOR LOW CBR

The thicknesses in Table 5 apply in the case of subgrade CBR ≥ 5%. In the case of lower CBR values, a subgrade improvement and/or capping layer is required (from Knapton et al, 2012):

Table 7: Subgrade improvement and/or capping layer requirements for CBR < 5%

CBR (%)	Requirement
1.0	Subgrade improvement
2.0	Subgrade improvement layer (may be incorporated into capping layer to provide a total layer thickness of 350 mm)
3.0	225mm capping
4.0	150mm capping

The capping layer design can also incorporate geogrid(s) which can provide a reduced thickness of this layer.

Note: for infiltration System A, the capping layer should be sufficiently permeable to allow water to percolate through it, without it losing strength. It should also have an infiltration rate that is greater than the material below it. It should also be sufficiently durable and wear-resistant. Alternatively, an increased thickness of coarse graded aggregate can be used. The grading for 6F2 capping (Specification for Highway Works – Highways Agency et al, 2016b) can be modified to reduce the amount of fines and make it more permeable (i.e. less than 5% passing the 63 microns sieve and 0–25% by mass passing the 600 microns sieve). This has been used successfully below infiltrating pavements.

The additional capping thicknesses to be provided in the case of low CBR subgrades can only be determined approximately during the design process because the condition of the subgrade will depend upon site drainage conditions, level(s) of water table(s) and recent weather patterns. The aim is to provide sufficient additional material to ensure that the overlying layers can be compacted successfully. The above values have been found to achieve this but the actual thickness must be determined by site trials undertaken by experienced ground workers.

8.9 ALLOWANCE FOR CONSTRUCTION TRAFFIC USING AN ASPHALT CONCRETE LAYER

As discussed in Section 5.7 (Construction Traffic) there is often a need to use the partially completed CBPP as an access road during the construction of a project. However, if the sub-base (CGA or Type 3) is trafficked, the unbound surface will rut and become clogged. Section 5.7 therefore outlines several options to address construction traffic and protection of the CBPP, with Option 4 being the use of an AC layer over the sub-base (CGA or Type 3). The AC is first used as a temporary impermeable surface and then, just prior to the installation of the laying course and paving units, the AC is cored or perforated to form CAC. If this option is used, then consideration must be given to dealing with the surface water as it will not be able to infiltrate into the lower pavement layers prior to coring or perforation of the AC.

For Traffic Categories 0 to 5, the sub-base (CGA or Type 3) is overlaid with 80mm of AC. For traffic categories 3 and 4 the sub-base (CGA or Type 3) thickness can then be reduced to 150mm. For Traffic Categories 6 and above, the thickness of the AC layer is as per Table 5 or 100mm, whichever is the greater. As the AC has no water storage capability it will be necessary to check that the underlying permeable layer has sufficient water storage capacity.

The required thicknesses of the AC and underlying sub-base (CGA or Type 3) are related to Table 5 and the rules stated above, and are shown in Table 8 below.

Traffic category	Thickness of AC (mm)	Thickness of CGA or Type 3 (mm)
11	Areas with axle loads greater than permitted by the Road Vehicles (Construction and Use) Regulations (1986) as amended are not included in this document	
10	Site specific using Interpave guide for heavy duty pavements (Knapton, 2008)	
9	Site specific using Interpave guide for heavy duty pavements (Knapton, 2008)	
8	220	150
7	130	150
6	100	150
5	80	150
4	80	150
3	80	150
2	80	150
1	80	100
0	80	Sufficient to provide suitable construction base

Table 8: Thicknesses of AC and sub-base (CGA or Type 3) for CBPPs to be used by construction site traffic

9. HYDRAULIC DESIGN

9.1 BASIC REQUIREMENTS

The most up to date guidance on the hydraulic design of sustainable drainage systems is provided in 'The SuDS Manual' (CIRIA, 2015) and BS 8533 (BSI, 2017a), both of which recommend a number of design criteria for the hydraulic performance of SuDS that are intended to reduce the frequency, peak flow rate and total volume of runoff from a site, as well as to remove pollution from the runoff.

This goes beyond previous requirements that have mainly concentrated on reducing the peak rate of runoff. The latest requirements are intended to provide drainage systems with outflow characteristics closer to those of a natural site. They extend the basic compliance criteria included in the Non-statutory Standards for Sustainable Drainage Systems published by DEFRA and will provide far more effective and robust systems than those that just meet the basic criteria.

The main requirements in the SuDS Manual (CIRIA, 2015) are:

- Ensure that people and property on the site are protected from flooding
- Ensure that the impact of the development does not exacerbate flood risk at any other point in the catchment of the receiving watercourse.
- Manage overland flow to ensure buildings are not flooded.

CBPPs are an ideal solution for achieving all the requirements listed above. The role of CBPP in the SuDS Management Train is discussed in '*Understanding Permeable Paving*': further information can be found on the website **www.paving.org.uk**

One of the most common mistakes made when designing CBPPs is use of incorrect units. This is because the common parameters are quoted in different units and require conversion when carrying out calculations. The common units and conversions are provided in Table 9.

Table 9: Units and conversions.

	Units				
Parameter	**mm/h**	**m/h**	**m/s**	**l/s**	
Rainfall	20	0.02	5.6×10^{-6}	0.0056	(note these are all/m^2 which is rarely stated)
Infiltration rate of soil	3.6	0.0036	1×10^{-6}	0.001	
Flow rate into paver surface (through joints) when new	4500	4.5	0.0013	1.31	

The SI unit for reporting soil permeability is m/s. Therefore soil infiltration rates are usually also reported in m/s. The infiltration rate of rainwater into the top surface of CBPP is often compared to rainfall intensity. Rainfall intensity is reported in mm/h and therefore the infiltration of water into the pervious surface is reported in these units.

9.2 ASSESSMENT OF INTERCEPTION PERFORMANCE

Studies have shown that the frequency of runoff from CBPPs is significantly reduced when compared to normal drainage systems. The studies show that typically this does not occur from CBPPs for rainfall events up to 5mm. This is known as interception. Kellagher (2013) found that very high levels of compliance with interception criteria are achievable through the use of CBPPs, providing there is a nominal level of infiltration available. This is because during small rainfall events the water soaks into the paving units, laying course and underlying permeable base and sub-base and is then released by evaporation after the rainfall has stopped. Obviously the extent of this depends on the antecedent conditions (i.e. what the weather has been like beforehand). Even with System C pavements some interception still occurs. The use of rainwater harvesting (using the CBPP as the storage) can also help to achieve interception.

Design of a drainage system for interception should achieve zero runoff for the first 5mm rainfall for 80% of events during the summer and 50% in winter. The SuDS Manual (CIRIA, 2015) explains the conditions in which it can be assumed that CBPPs provide interception.

Where CBPP is only draining rainfall that falls directly on it (i.e. no additional areas such as roofs or adjacent asphalt areas drain onto or into it) then the CBPP can be assumed to provided 5mm interception. The rainfall up to this depth will be absorbed by the pavement and evaporates. There is a limit to how much rainwater a pavement can absorb and evaporate. Therefore, if the pavement is draining adjacent areas the following criteria must be complied with if it is to provide 5mm interception:

- It must be a Type A or B system (i.e. no waterproof geomembrane);
- The impermeable area draining to the CBPP must not be greater than the area of the CBPP.

Where the infiltration capacity of the ground below the CBPP is greater than 1×10^{-6} m/s, up to 5 times the CBPP area can be added as additional contributing area and interception will still be achieved. Note that the maximum additional area could only be achieved if the water was roof water entering directly into the permeable construction and not being discharged onto the surface of the CBPP. If the water is being discharged onto the surface of the CBPP the 2:1 rules in Section 4.3 would still apply, limiting the size of impermeable area for which interception could be achieved.

Where the CBPP also drains an adjacent impermeable area and is lined (System C), compliance cannot be deemed to have been achieved and additional downstream interception components will be required.

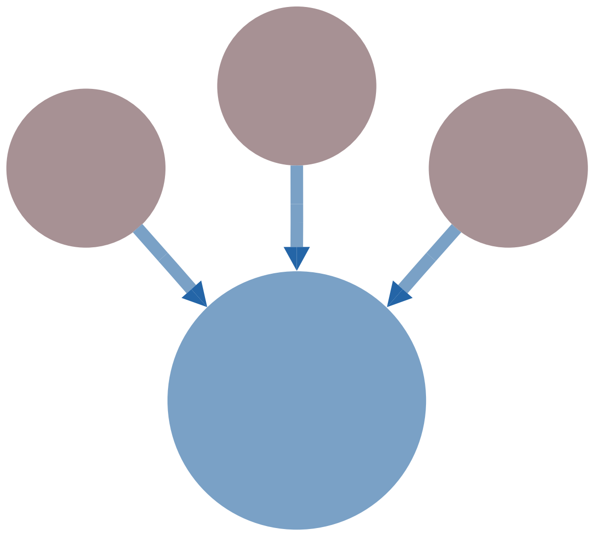
9.3 LONG TERM STORAGE (VOLUME CONTROL)

CBPPs reduce the volume of rainfall that flows out from them significantly and the time it takes for the water to flow out is much longer than for conventional drainage systems. Studies reported in CIRIA report C582 (CIRIA, 2001) have shown that some 11% to 45% of rainfall flows out from the pavement during a rainfall event. Subsequently over the 2 to 4 days after an event, more water flows out to give a total outfall of between 55% and 100%. Thus the CBPP should achieve the aims of long term storage, as it will reduce the volume of runoff at critical periods.

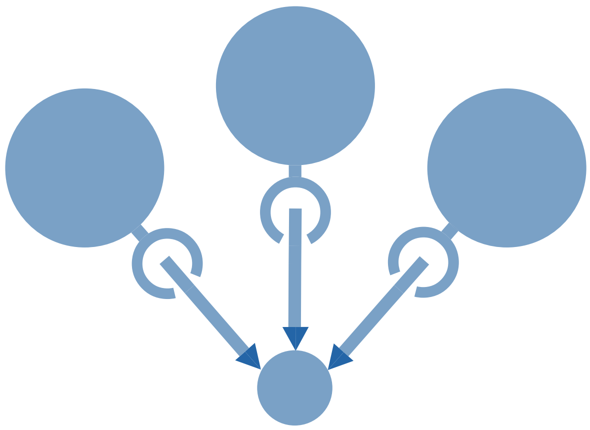
For most relatively small schemes the CBPP should not require any specific long term storage provision, especially if it is not collecting runoff from impermeable areas. This should be agreed with the regulators during the preliminary design process.

However, there are several advantages in considering areas of CBPP deployed around a site as distinct storage compartments, requiring no additional land take. Flow control devices on outfalls of the CBPP can then be used to optimise localised storage and demonstrate compliance with run-off rate requirements for the local authority LLFA.

Flow control devices should be robust, simple to maintain and accessible for inspection or adjustment, but do not need protection from blockages, as the water passing from the CBPP will be free of debris. They should be specifically designed for the relatively shallow construction thicknesses and outfall levels typical of CBPPs. See Section 12.6.



Conveying collected rainwater directly from hard surfaces results in large storage components elsewhere on site.



Storing water in CBPP around the site with flow control devices minimises or eliminates the need for further storage components.

9.4 ASSESS SURFACE PERMEABILITY OF CBPP

The CBPP must have a surface permeability (or surface infiltration rate) that is sufficient to allow the design rainfall to pass through into the underlying permeable construction without causing ponding on the surface. The SuDS Manual (CIRIA, 2015) considers a minimum value of 2500 mm/h (for new pavements) reasonable for a pavement surface to be considered pervious in respect of surface water management. The infiltration capacity of the surface materials is normally stated by the supplier or manufacturer. There is no standard UK or European test procedure for measuring the surface infiltration rate of pervious surfaces. However, ASTM C1781-15 has been developed for CBPP (ASTM International, 2015). The SuDS Manual (CIRIA, 2015) recommends that manufacturers should provide surface infiltration rates measured using this test method and that it should be adopted as a standard method in the UK with the following amendments:

1. The results should be stated in both mm/h and m/s.
2. Sealing the infiltration ring to the surface to be tested should be achieved using mastic sealant, rapid set mortar or other suitable sealant material.

The amount of water that can pass through a CBPP is dependent on the infiltration rates of joint aggregate, laying course, base 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 aggregate used but a typical value for newly laid permeable paving is 4,000 mm/h which is well in excess of the 2,500mm/h requirement. The sub-base aggregates 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.

A conservative approach should always be taken when establishing the design infiltration rate of a pavement system. The surface infiltration rate will decrease but stabilise with age, due to the build-up of detritus in the jointing aggregate. This effect is summarised in Figure 20 and it can be seen that long service lives can be expected from CBPPs, which is borne out by experience of older pavements. To ensure a long service life, it is essential that care is taken to protect the pavement during construction and from landscape runoff.

American and German experience recommends that the design surface infiltration rate should be 10% of the initial rate, to take into account the effect of clogging over a 20-year design life without maintenance.

Even after allowing for clogging, studies have shown that the long-term infiltration capability of CBPPs will normally substantially exceed UK hydrological requirements (for example, an extreme storm of 100mm/hour is shown blue in Figure 20). Therefore CBPPs can be designed to handle both prolonged rainfall and short duration storms. CIRIA Report C582 (CIRIA, 2001) gives further information on measured infiltration rates.

The above does not apply to the infiltration rate of water into the ground below the pavement foundation which is a different parameter to the surface infiltration rate of the paving units.

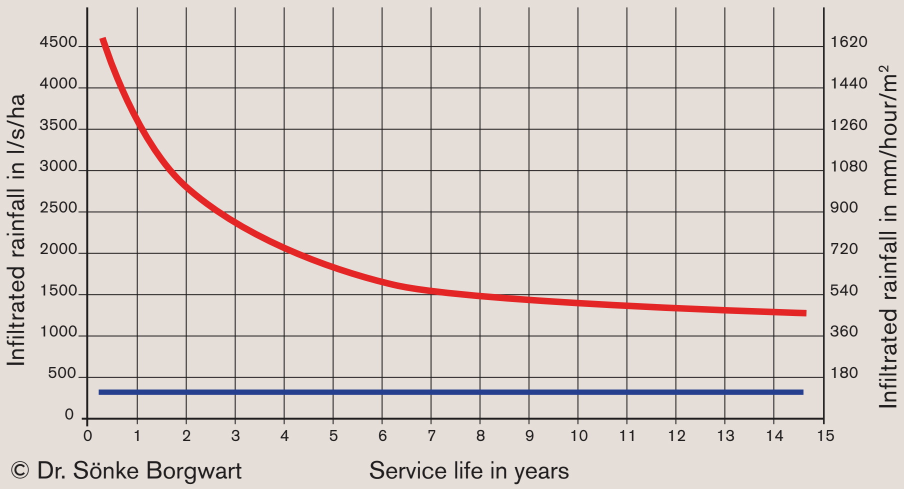


Figure 20: Typical reduction of surface infiltration rate over time.

9.5 DETERMINATION OF SUBGRADE INFILTRATION RATE (Systems A and B)

The infiltration rate or coefficient is a measure of how quickly water soaks into the subgrade below the bottom of the CBPP. Infiltration tests should always be undertaken in order to determine infiltration coefficients for design purposes: see Appendix 1. Any testing should be as extensive as possible and supported by evidence of wider soil characteristics, in order to avoid misrepresentation of relevant soil properties. Testing may be carried out as part of the site investigation report.

9.6 DETERMINATION OF RAINFALL CHARACTERISTICS AND ALLOWANCE FOR CLIMATE CHANGE

There are a number of methods that can be used for estimating rainfall and runoff from developed sites, which are discussed fully in the SuDS Manual (CIRIA, 2015).

It is accepted that the earth's climate is changing. The most recent studies have predicted that:

- Winters will become milder and wetter with more intense rainfall events.
- Summers will be hotter and drier.
- Heavy rainfall events will become more frequent.

The 'Foresight Flooding Future Report' (Evans et al 2004) concluded that effective land management (including drainage) must be put into place to protect urban areas from flooding in the future. To allow for climate change the rainfall intensity should be increased by an appropriate amount. Typical values of 30% increase on the 1 in 100 year rainfall intensity is commonly required by the regulators but is site specific.

The CBPP limits the peak rate of runoff from a site (usually to the greenfield runoff rate). The calculations are completed for a range of return periods and durations and the maximum storage from the calculations is the design storage requirement.

9.7 DETERMINATION OF REQUIRED SUB SURFACE STORAGE CAPACITY

The volume of permeable construction required for attenuation storage is typically calculated using common drainage design software. For smaller sites, simple software such as that found at www.uksudstools.com or the design table in this document may be used.

For the majority of systems the volume of water that enters the CBPP during a storm is greater than the volume of water that flows out. Therefore the excess water (defined below) must be stored within the underlying permeable construction to prevent surface flooding (Figure 21).

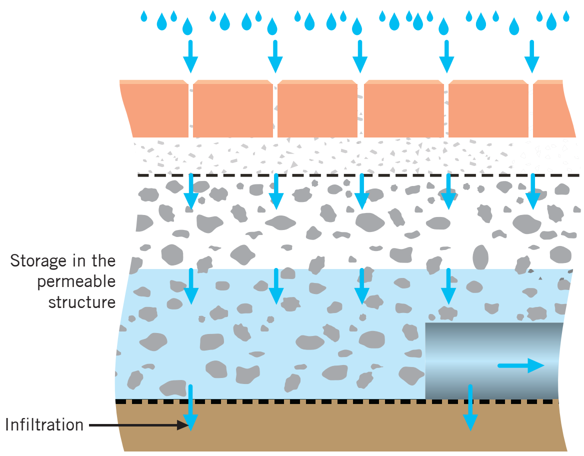


Figure 21: Attenuation and infiltration storage volume.

Excess volume of water requiring storage = volume of rainfall – volume of outflow

9.8 DESIGNS USING SOFTWARE

Drainage design software can be used to design drainage systems that include CBPPs. This allows the performance of the whole drainage system and the impact of the CBPP to be modelled and tested to satisfy all the required design criteria. The simplest approach is to consider the CBPP as an infiltration or storage device, taking into account the following factors:

- Storage volume in the underlying permeable construction
- Rate of infiltration or restricted outflow rate.

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 optimised.

Another approach is to consider the CBPP 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 underlying permeable construction. Other factors that can be taken into account include:

- Evaporation
- Initial rainfall loss
- Runoff routing.

Once the required storage in the CBPP is estimated from the model the thickness of underlying permeable construction can be determined.

The available storage in the base/sub-base layer is determined by the volume of the permeable construction, the effect of any slopes that will decrease the available storage and the usable voids (i.e. voids that are freely draining) within the aggregate. A commonly used value of porosity is 30% for the aggregates that meet the requirements for coarse graded aggregates in BS7533-13 (BSI, 2009a). Care should be taken, if using values higher than this, that all the voids in a material are free draining (e.g. clay soils may have a porosity but the voids are very small and not suitable for storing water).

NOTE: The porosity of HBCGA, CGA and Type 3 needs to be confirmed by testing or certification from the aggregate supplier. The hydraulic design thicknesses given in Table 10 are based upon a porosity of 30% for pavements with zero slopes. Therefore, if the proposed aggregate differs from 30%, then adjustments to the hydraulic thicknesses will have to be made.

The available storage volume is provided by the void space in the permeable construction:

Available attenuation storage in the permeable construction = Volume of permeable construction × porosity in the soil/aggregate/geocellular layers designed to be the storage volume

9.9 SIMPLE DESIGNS USING TABLES

For simple designs on small areas less than 3000m² Table 10 can be used to size the thickness of permeable construction below a CBPP. The tables are based on the hydrological rainfall regions shown on the map in Figure 22.

The rainfall for a site can be calculated using these two parameters together with the tables and graphs in the Wallingford Procedure for Europe. These calculations have been completed for the various zones and for different return periods. The results have been used to determine the thickness of coarse graded aggregate required to store water (Table 10).

This map, developed by HR Wallingford (Kellagher and Laughlan, 2003), defines eight hydrological zones for the UK using two parameters:

- M5 – 60 is the 1 in 5 year, 60 minute duration rainfall
- “r” is the rainfall ratio (Ratio of 60 minute to 2 day rainfall for a 5 year return period).

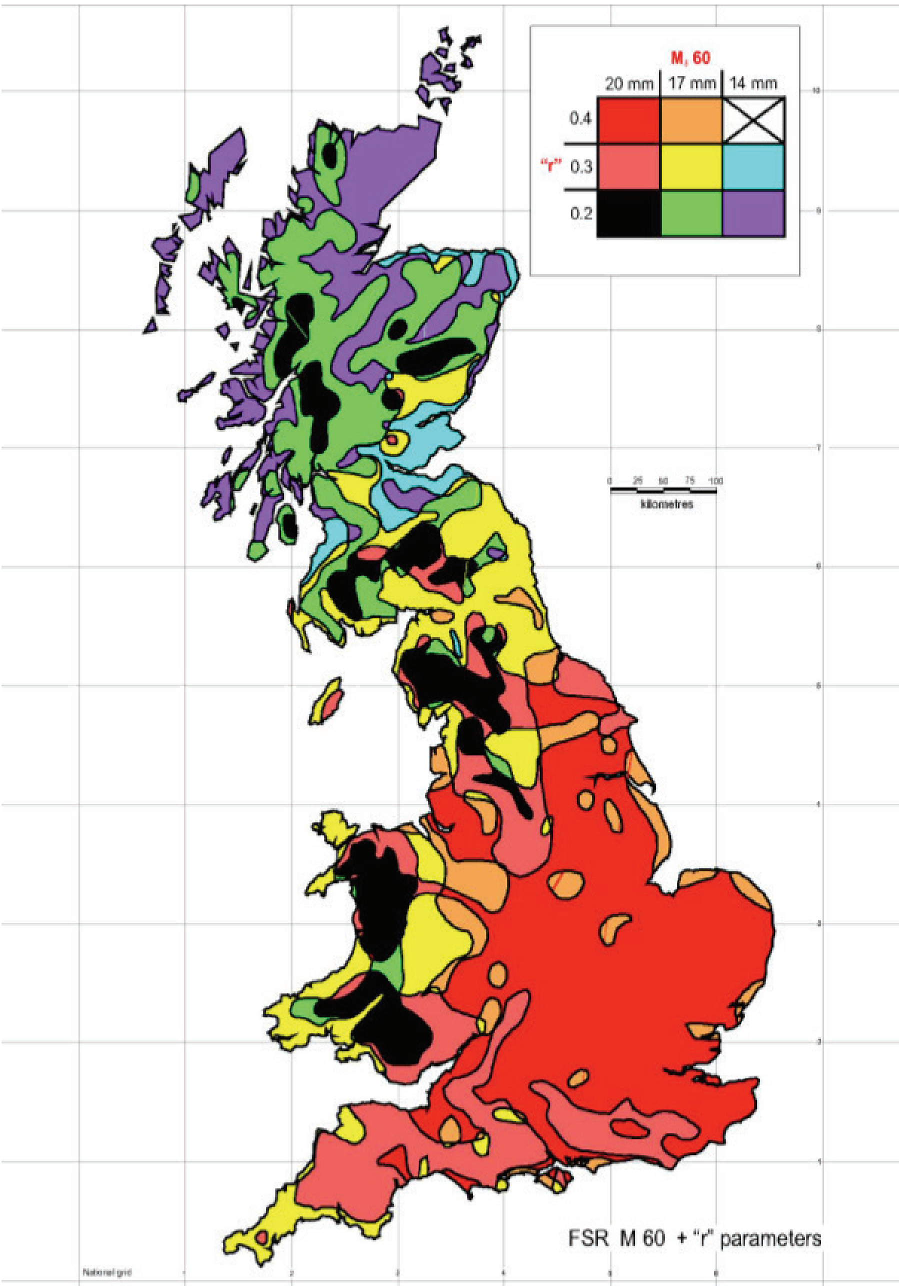


Figure 22:
- M5 – 60 is the 1 in 5 year, 60 minute duration rainfall
- “r” is the rainfall ratio (Ratio of 60 minute to 2 day rainfall for a 5 year return period)

Reproduced with permission from H.R. Wallingford

System A

Infiltration rate = 1 x 10^{-7}m/s

		1 in 10	1 in 30	1 in 100	1 in 100 + 20%	1 in 100 + 30%
M5-60	**r**	**10**	**3.33**	**1**	**0.5**	**0.25**
20	0.4	90	120	160	210	225
	0.3	100	140	190	240	270
	0.2	135	180	250	310	370
17	0.4	70	100	140	180	190
	0.3	80	110	160	210	225
	0.2	105	150	210	270	305
14	0.4					
	0.3	60	90	130	170	180
	0.2	75	110	160	220	245

Infiltration rate = 1 x 10^{-6}m/s

		1 in 10	1 in 30	1 in 100	1 in 100 + 20%	1 in 100 + 30%
M5-60	**r**	**10**	**3.33**	**1**	**0.5**	**0.25**
20	0.4	50	70	95	125	140
	0.3	50	70	100	130	145
	0.2	50	70	105	140	160
17	0.4	50	50	75	100	110
	0.3	50	50	75	100	115
	0.2	50	50	80	110	125
14	0.4					
	0.3	50	50	60	80	85
	0.2	50	50	55	75	90

infiltration rate = 1 x 10^{-5}m/s

		1 in 10	1 in 30	1 in 100	1 in 100 + 20%	1 in 100 + 30%
M5-60	**r**	**10**	**3.33**	**1**	**0.5**	**0.25**
20	0.4	50	50	70	90	105
	0.3	50	50	65	85	100
	0.2	50	50	60	85	95
17	0.4	50	50	55	70	80
	0.3	50	50	50	65	75
	0.2	50	50	50	60	70
14	0.4					
	0.3	50	50	50	50	50
	0.2	50	50	50	50	50

System C

Maximum allowable discharge rate = 3l/s/ha

		1 in 10	1 in 30	1 in 100	1 in 100 + 20%	1 in 100 + 30%
M5-60	**r**	**10**	**3.33**	**1**	**0.5**	**0.25**
20	20/0.4	110	145	200	250	275
	20/0.3	140	190	250	315	350
	20/0.2/3	225	285	365	475	530
17	0.4	90	120	170	210	235
	0.3	110	150	210	270	300
	0.2	175	230	305	395	445
14	0.4					
	0.3	90	120	170	214	240
	0.2	130	180	245	320	360

Maximum allowable discharge rate = 5l/s/ha

		1 in 10	1 in 30	1 in 100	1 in 100 + 20%	1 in 100 + 30%
M5-60	**r**	**10**	**3.33**	**1**	**0.5**	**0.25**
20	20/0.4	95	125	175	220	240
	20/0.3	110	150	210	270	300
	20/0.2/5	160	215	285	375	420
17	0.4	75	110	150	185	210
	0.3	90	125	175	225	250
	0.2	125	175	240	315	350
14	0.4					
	0.3	70	95	140	180	200
	0.2	90	130	190	250	285

Maximum allowable discharge rate = 7l/s/ha

		1 in 10	1 in 30	1 in 100	1 in 100 + 20%	1 in 100 + 30%
M5-60	**M5-60/r**	**10**	**3.33**	**1**	**0.5**	**0.25**
20	20/0.4	85	120	160	210	220
	20/0.3	100	140	190	240	265
	20/0.2/7	135	180	250	310	360
17	17/0.4	70	100	140	180	190
	17/0.3	85	110	160	210	220
	17/0.2	100	150	210	270	300
14	14/0.4					
	14/0.3	60	90	130	170	175
	14/0.2	85	110	160	220	240

Half-empty time exceeds 24 hours

Table 10: Permeable construction thickness for attenuation storage (Systems A and C).

Notes:
1. Site is assumed to be level.
2. Permeable construction is assumed to have a porosity of 30%.
3. Minimum practical layer thickness for some aggregates used in permeable construction is 75mm or greater.
4. Thickness of permeable construction needs to be sufficient to meet structural design requirements.
5. For System A an iniltration rate greater than the stated value is required.
6. Factor of safety on infiltration rate for System A is 1.5.
7. Factor of safety on outflow for System C is 1.0.

The tables are based on the following generally conservative assumptions:

- Storage is provided for development design rainfall events of 1 in 30 yr, 1 in 100 yr and 1 in 100 yr plus 20% and 30% increase for climate change but the greenfield runoff rates of 3, 5 and 7 l/s/ha are around a 1 in 2 year event.
- 100% runoff from the CBPP is assumed.

The calculations have been carried out for a range of rainfall durations up to 24 hours and the maximum thickness is provided in the tables (i.e. the thickness at the critical duration). The tables also assume that there is no impermeable area draining onto or into the CBPP.

System B (partial infiltration) can be designed in two ways:

1. Ignore the infiltration capacity in the design for water storage and use Table 10 to design the permeable construction thickness.
2. Carry out site-specific design calculations allowing for the infiltration that occurs as water is stored. This is quite complex and is best carried out using one of the proprietary drainage design/analysis packages such as Micro Drainage or Info Works.

Table 10 assumes that the permeable construction is level. If this is not the case water will run to the low point and the available storage capacity is reduced. It will then be necessary to check and, if necessary, adjust the pavement thickness accordingly.

9.10 IMPACT OF SLOPE ON AVAILABLE STORAGE

On slopes the water will run to the low end of the pavement construction and the volume available for storage will be reduced (Figure 23). It will then be necessary to check that there is sufficient hydraulic storage and, if required, the pavement thickness increased and/or dams or terracing introduced. Alternatively, software can be used to assess and adjust the pavement thickness. Various solutions to sloping sites are discussed in section 4.2

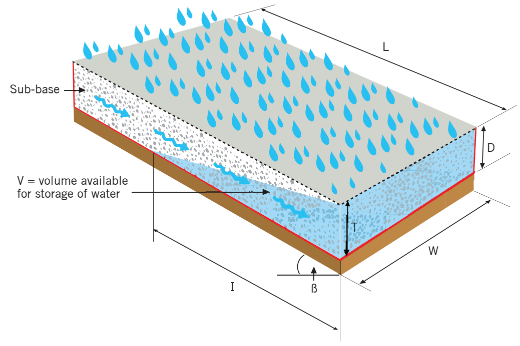


Figure 23: Calculation of available storage for water on sloping sites.

The volume of sub-base available for storage on a level site is given by:

$V_L = W \times L \times D$

Where:

V_L = volume of sub-base providing storage in permeable construction on a level site

W = width of pavement

L = length of pavement

D = thickness of permeable construction perpendicular to slope

For a sloping site the volume of sub-base providing storage is given by:

$V_S = 0.5 \times I \times T \times W$

Where:

I = length of permeable construction where water can be stored = T / tan ß

T = thickness of permeable construction measured vertically (on most shallow sloping sites this can be taken as being equal to D)

ß = slope angle

9.11 DRAINING IMPERMEABLE AREAS ONTO PERMEABLE AREAS

It is quite common to design areas where the CBPP is required to handle runoff from adjacent impermeable areas including roofs. It is normal practice to limit the ratio of impermeable area to permeable pavement to about 2:1, as discussed in section 4.3.

To allow for the extra rainfall being collected, the permeable construction thickness may have to be increased if there is no spare hydraulic storage capacity, to give a larger storage volume. If the thickness of pavement needs to be increased, the following equation can be used.

$T = t\,(A_I + A_P)/A_P$

Where:

T = Thickness of permeable construction to store water from impermeable and permeable contributing areas

t = Thickness of permeable construction to store water from permeable area only (from Table 10)

A_I = Area of impermeable surfacing draining onto the permeable area

A_P = Area of CBPP.

9.12 FLOW CONTROL DEVICES

In order for the permeable construction to act as a storage layer the flow of water out of it must be restricted using a flow control device. The restricted flow rates will either be the greenfield runoff rate or some other value agreed with the regulators. When the flow is restricted at the outlet water backs up into the permeable construction where it is stored temporarily. The permeability of the permeable construction is relatively high and it will not on its own restrict flow to the low levels required, except for very large areas of pavement. Therefore a specific flow control device will normally be required.

There are a wide variety of flow control devices available, but the simplest and most cost effective for CBPPs is an orifice plate located in a shallow inspection chamber. There is rarely a need for more complex or expensive controls. There are also benefits to be gained from using this type of control. An orifice is designed to mimic natural runoff and produces a progressive discharge that increases with head of water. In short return period storms discharge is minimised and more of the available storage is used to reduce runoff. As the size of the storm increases flows through the control increase as a greater head of water occurs. This better simulates the behaviour of greenfield systems.

An orifice is a circular or rectangular opening of specified shape and size that allows a controlled rate of flow when it is submerged. The flow rate depends on the height of the water above the opening, the size of it and the nature of the edge of the opening. CBPP is particularly effective at filtering out silt and other material, delivering clean water, but as a precautionary measure protection against blockage is advisable as illustrated in Figure 25. Flow control devices can incorporate overflows where necessary. (See the SuDS Manual (CIRIA, 2015) for further advice).

For a simple orifice constructed in a weir wall within a chamber the equation below may be used assuming a free outfall, i.e., the orifice is not submerged on the downstream side. The head of water is the maximum head that occurs behind the orifice within the permeable construction.

$$Q = C_d A_o \sqrt{2gh}$$

Where:

Q = orifice discharge rate (m^3/s)

C_d = coefficient of discharge (0.6 if material is thinner than orifice diameter; 0.8 if material is thicker than orifice diameter; 0.92 if edges or orifice are rounded)

A_o = area of orifice (m^2)

h = hydraulic head (m)

g = 9.81 m/s^2

When the orifice is discharging as a free outfall, the effective head is measured from the centre of the orifice to the upstream (headwater) surface elevation. If the orifice is submerged, then the effective head is the difference in elevation of the headwater and tailwater surfaces, as shown in Figure 24.

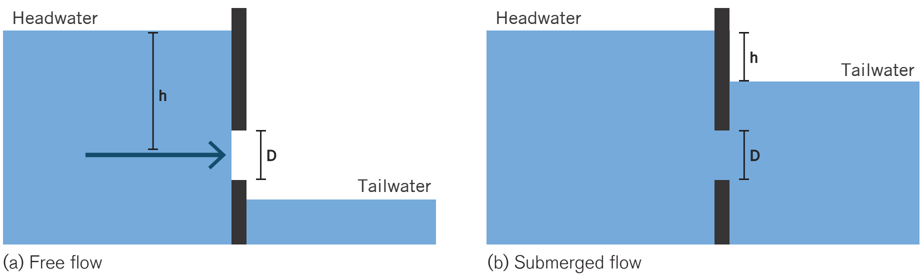


Figure 24: Effective head for orifice discharge calculations.

A number of flow control devices may be required to manage the flow of water from different parts of a CBPP system.

In drainage systems that use gullies, channels and pipes it is possible for quite large obstructions to enter the drainage system. For this reason water companies would limit the orifice size in a normal drainage system to a minimum between 75mm and 150mm diameter. Water entering a CBPP is filtered and therefore the risk of blocking the flow control device is much less than for piped drainage. Thus it is possible to use flow control devices as small as 15mm diameter in these systems, provided that they are protected from blockage and maintained as described in the SuDS Manual (CIRIA, 2015). An example is shown in Figure 25 of a perforated guard with holes of a smaller diameter (generally 10mm) than the internal orifice.

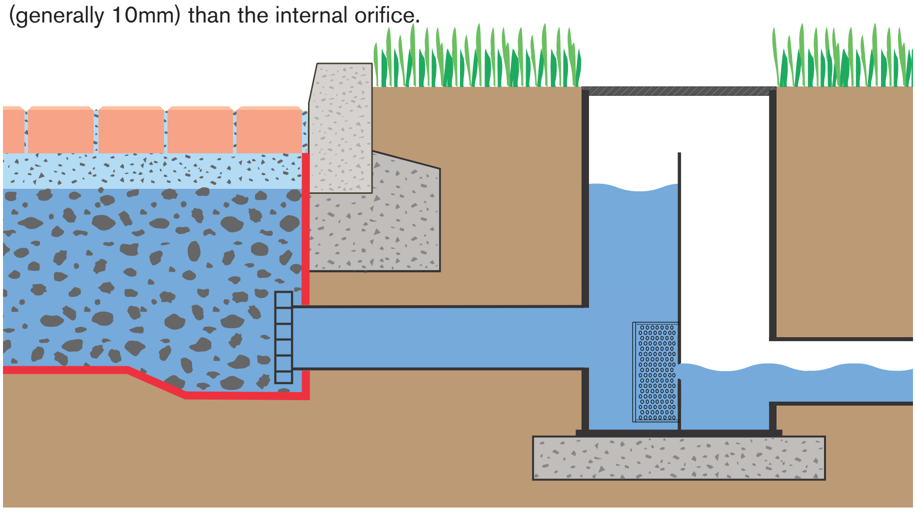


Figure 25: Protected orifice flow control device from CBPP

A 75mm diameter orifice with 450mm driving head will limit flows to 7.8 l/s. If the greenfield runoff rate is 7l/s/ha then the minimum catchment area this can effectively control is 1.1ha or 11,000m^2.

A 15mm orifice with 450mm driving head of water will limit flows to 0.3l/s. If the greenfield runoff rate is 7l/s/ha then the minimum catchment area this can effectively control is 0.043ha or 428m^2.

Thus the use of small diameter orifices allows the effective management of runoff from much smaller areas of permeable paving, such as modest parking areas. For small areas of shallow CBPP, simple unguarded orifice flow control devices may be used, such as the example shown in Figure 26.

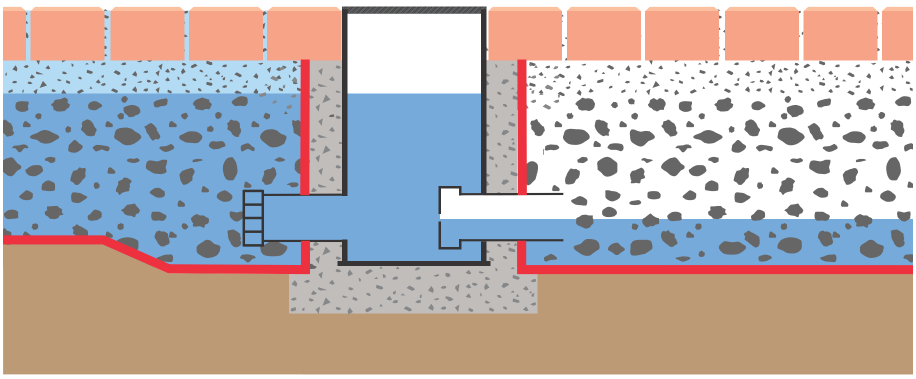


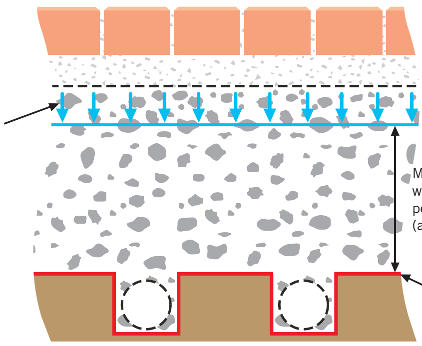
Figure 26: Simple shallow flow control device for small areas of CBPP

9.13 CONVEYANCE OF WATER TO OUTFALL

In System C pavements the water will need to flow horizontally through the underlying permeable construction towards an outfall. In many designs the permeable construction will be present as discrete areas below the CBPP, separated by impermeable construction. Careful consideration is required of water flows between different areas of permeable construction to ensure that it is held in storage in the correct area and can flow to the outfall where necessary. Flow control devices on outfalls can assist with achieving and demonstrating this within a design.

Other options to collect and discharge water include outfall pipes within or below the permeable construction. Water can be moved between areas using pipes, geocellular boxes or a layer of coarse graded aggregate. Water can also flow along areas of permeable construction. There should be sufficient capacity in pipes, boxes or permeable construction to convey the water to the outlet(s). On sites that are level it is usually possible to use flow control devices to ensure that the use of storage in each area of permeable construction is optimised. In this case the main consideration is ensuring that all conduits for water flow (pipes, permeable construction, etc.) have sufficient flow capacity to drain the area without causing a restriction that would increase the volume of water being stored. On sloping sites a greater number of flow control devices are usually required to hold water in the appropriate storage area, as discussed in section 4.2.

The spacing of the outlet pipes or collector pipes for System C pavements can be determined in an approximate manner using guidance provided by Cedergren (1974). The maximum surface runoff rate that can be removed by a flat permeable sub-base can be estimated using the equation given in Figure 27.



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

q = maximum intensity of rainfall entering into the pavement sub-base that can be drained by pipes at spacing of 2b and sub-base thickness of h (m/s)

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

h = maximum depth of water stored in sub-base (and base if appropriate) above impermeable formation or membrane (m)

2b = distance between pipes (m)

Figure 27: Estimating outfall pipe spacing

Water must flow horizontally through the sub-base to reach the outlet collection systems and there must be sufficient capacity in any aggregate to convey the rates of flow required. Horizontal water flows can very crudely be estimated using Darcy's law (Interlocking Concrete Pavement Institute, 2017) as follows.

$Q = A.k.i$

Where:

Q = flow capacity of sub-base (m^3/s)

A = cross-sectional flow area, ie height x width of sub-base through which water is flowing (m^2)

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

i = hydraulic gradient (assumed to be the slope of the subgrade towards the outlet – generally a conservative assumption) (m/m)

Darcy's Law to calculate sub-base flow (opposite)
Outflow from the permeable construction should be via a system of perforated pipes, fin drains or a proprietory CBPP drainage system that provide a large surface area for water to flow into. Outlets that comprise simply the open end of a pipe (wrapped in geotextile) are prone to clogging and are not suitable. Perforated pipes should extend at least 1m into the sub-base and the pipes should be slotted or have circular holes formed as part of the manufacturing process. Perforations should not be made in pipes by site operatives. The perforated section of pipe should have sufficient flow capacity through the walls to manage the anticipated flows and the perforations should be compatible with the aggregate size such that migration of aggregate particles into the pipe is prevented. The capacity of the pipe to convey water along it should also be sufficient to manage anticipated flows. The open ends of any pipes that end in contact with gravel should be capped.

The choice of outlet pipe spacing is normally influenced by the physical layout of the CBPP (e.g. in roads and car parks where the areas of discrete CBPP are relatively narrow and constrained by kerbs, etc.). The pipe diameter should be chosen so that it can manage the rate of water that will discharge from the pavement. For small areas such as a row of parking bays (24 bays at 2.5m x 5m) or a small road (6m wide by 50m long) with a design rainfall intensity of 75mm/h a 100mm diameter pipe at a gradient of at least 1 in 100 should be sufficient according to BS EN 752-4 (BSI, 1998).

For larger areas the pipe spacing should be calculated using the Figure 27 equation. For example, a pavement with the following parameters would require 100mm diameter pipes spaced at 13m centres:

Rainfall intensity, $q = 75$mm/h

Sub-base permeability, $k = 1 \times 10^{-2}$m/s (conservative assessment without any permeability test results on the sub-base)

Maximum depth of stored water, $h = 0.3$m

Results in $b = 6.5$m and pipe spacing of $2b = 13$m.

9.14 HALF EMPTY TIME

The permeable construction should empty from full to half-full within a reasonable time so that the risk of it not being able to manage a subsequent rainfall event is minimised. Where pavement systems are designed to manage the 1 in 10 year or 1 in 30 year event it is usual to specify that half emptying occurs within 24 hours so that sufficient empty volume is available to store runoff in subsequent events. This is a fairly conservative assumption when pavements are designed to manage events of 1 in 100 year plus an allowance for climate change. When a long return period is combined with infiltration rates at the low end of the acceptable range of permeability or where very low discharge rates are allowed the requirement to half empty in 24 hours may prove difficult to achieve in a cost effective manner.

In such instances the requirement to half empty in 24 hours may be relaxed and a longer emptying time allowed such that storage is provided after 24 hours for a subsequent 1 in 10 year or 1 in 30 year event. The decision to allow longer emptying times for systems designed to manage longer return period events should be based on an assessment of the performance of the CBPP and the risk and consequences of consecutive rainfall events occurring.

10. PAVEMENT DESIGN

10.1 DESIGN THICKNESS

To determine the design thickness, the total thickness of the permeable layers derived from the structural design process, which could include capping, CGA or Type 3 sub-base and HBCGA base, is compared with the permeable thickness from the hydraulic design process. Note that the paving layer and CAC base have no hydraulic storage capacity. Therefore the thicknesses of these layers are not used in this comparison.

Software is available to design the complete pavement or just the hydraulic thickness required. If drainage software is used to design the hydraulic thickness only, then the determination of the structural thickness must be undertaken separately and the thicknesses from both designs compared to determine the design thickness.

If the hydraulic thickness is greater than the structural thickness, then the design thickness will be the thickness determined by the hydraulic design process. So, effectively the permeable structural thickness is increased, as shown in the following example.

If the structural design thickness was determined to be:

Paving layer - 120mm
Base - HBCGA 100mm
Sub base – CGA 150mm

and the hydraulic design thickness required a permeable thickness of 300mm, then the design thickness would be:

Hydraulic thickness > structural thickness
300mm >100mm + 150 mm
300mm >250mm

Therefore, the design thickness is defined as 300mm.

10.2 SPARE HYDRAULIC CAPACITY

If the structural thickness is greater than the hydraulic thickness, then the design thickness will be the thickness determined by the structural design. This will result in spare hydraulic capacity, as shown in the following example.

If the structural thickness was determined to be:

Paving layer 120mm
Base - HBCGA 125mm
Sub base – CGA 150mm

and the hydraulic design thickness required a permeable thickness of 210mm, then the design thickness would be:-

Hydraulic thickness < structural thickness
210mm < 125mm + 150 mm
210mm < 275mm

Therefore, the design thickness is defined as 275mm.

With a design thickness of 275mm, but only 210mm required for the temporary storage of water, there would be 65mm of spare hydraulic storage capacity. It may be possible to utilise this spare hydraulic capacity by draining adjacent impermeable areas, such as roofs or parking bays into the permeable pavement. Often this is achieved at no or nominal additional cost.

If adjacent areas are drained into the permeable pavement to use up the spare hydraulic capacity, the hydraulic design process and the determination of the design thickness must be repeated to ensure that the hydraulic thickness does not come to exceed the structural thickness.

10.3 DEFINING THE FINAL DESIGN

In addition to recording all the design parameters, it is recommended that outcomes from the design process are recorded and should include the system type, paving unit thickness and laying course thickness, pavement layer types and thicknesses and any other relevant information.

11. SPECIFICATION AND MATERIALS

11.1 PAVING BLOCKS

Interpave members manufacture concrete paving blocks specifically for use in permeable pavements. Paving blocks should be manufactured and tested in accordance with BS EN 1338:2003 - *'Concrete paving blocks - Requirements and test methods'* (BSI, 2003a).

The strongest laying pattern is herringbone and it is recommended that for Traffic Category 5 or greater the paving units should be laid in herringbone pattern. Some types of paving unit can be machine laid. It is recommended for Traffic Category 4 or greater that the paving unit thickness is 80mm. For all other traffic categories the paving unit thickness can be 60mm. Advice should be sought from the manufacturer on colours, paving types, paving thickness and suitable laying patterns for particular applications.

11.2 LAYING COURSE AND JOINTING AGGREGATE

The laying course aggregate must be sufficiently coarse to allow the free vertical flow of water and to prevent its intrusion into the underlying CGA, Type 3 or HBCGA, and yet be sufficiently fine to permit the accurate installation of the paving units. It should also have sufficient durability to resist traffic loads and comply with the physical properties stated in Table 13 except for the grading requirements.

Typically, the laying course and jointing aggregate should fall within the Particle Size Distribution envelope of Table 11, but advice should be sought from the manufacturer on specific gradings suitable for their products/systems. The aggregate should comply with the requirements of an aggregate of type 2/6.3 Gc 80/20 according to BS EN 13242:2007 *'Aggregates for unbound and hydraulically bound materials for use in civil engineering works and road construction'* (BSI, 2007) as shown in Table 11. Note that the term 2/6.3 means that the aggregate has particle sizes that are predominantly within the range of 2mm to 6.3mm. This is the way in which aggregates, including fine aggregates, are designated in BS EN 13242:2007 which states: "This designation accepts the presence of some particles which are retained on the upper sieve (oversize) and some which pass the lower sieve (undersize)", i.e. there is a small proportion of aggregate that is greater than 6.3mm and less than 2mm.

Paving block manufacturers produce permeable paving units that have specific joint sizes or voids. Therefore it is important to ensure the aggregate used for jointing will be able to flow freely into the full depth of the joint during the joint filling and compaction operation to ensure good structural integrity of the paving surface. Advice can be sought from the manufacturer on their recommendations.

Table 11: Typical Particle Size Distribution limits for laying course aggregate.

BS Sieve size (mm)	Percentage Passing (%)
14	100
10	98-100
6.3	80-99
2.0	0-20
1.0	0-5

11.3 HYDRAULICALLY BOUND COARSE GRADED AGGREGATE (HBCGA)

In the case of more heavily trafficked CBPPs (Traffic Categories 5 – 8), a layer of HBCGA is included to strengthen and stiffen the pavement.

The HBCGA should be manufactured using aggregate that meets the requirements of Section 11.5. Usually compliant CGA is cement modified to produce HBCGA and should comply with the following:

CEMENT BOUND MIXTURES

- BS EN 14227-1:2013. *'Hydraulically bound mixtures – Specifications – Part 1: Cement bound granular mixtures'* (BSI, 2013b).
- Minimum cement content by mass = 3%. Strength Class = C5/6 (As defined in Table 2 of BS EN 14227-1:2013.)
- Minimum permeability 20,000mm/hour.
- The 28 days Elastic Modulus would be expected to be approximately 10,000MPa but this is not a specification requirement.

11.4 ASPHALT CONCRETE (AC)

The AC should be an AC32 dense base 40/60 as defined in BS EN 13108-1:2016, '*Bituminous mixtures. Material specifications. Asphalt Concrete'* (BSI, 2016). The material should be specified and constructed in accordance with clause 929 of the *'Specification for Highway Works'* (Highways Agency, 2018). Prior to the installation of the paving units the AC is cleaned, if required, to remove mud and detritus and then cored or perforated with 75mm diameter holes on a 750mm orthogonal grid to form CAC. The holes are filled with CGA, Type 3 or laying course aggregate.

11.5 SUB-BASE – COARSE GRADED AGGREGATE (CGA)

The sub-base should have a minimum porosity that is consistent with the design calculations (normally at least 30%). The sub-base should also have a minimum permeability that is consistent with the design calculations. Typically the open graded sub-base aggregates in Table 12 will have a permeability greater than 1 x 10^{-2}m/s.

The requirement for low fines content means that the surface loading will essentially be carried by point-to-point contact between aggregate particles in the sub-base. In order to maximise the friction between particles and thus increase strength, the particles should be rough and angular to give good interlock. Crushed rock (granite, basalt, gabbro) or concrete with > 90 % fracture faces or blastfurnace slag is required to achieve this. Sand and gravel with rounded particles should not be used in CBPP sub-base construction. Aggregates should comply with BS EN 13242 (BSI, 2007) or BS 12620 (BSI, 2008). The choice is a compromise between stiffness, permeability and storage capacity. Typical gradings for sub-base aggregates are provided in Table 12. Other gradings, such as 4/40 and 10/63, may be used if they are more readily available and meet all the necessary requirements, and provided the quarried aggregate is sufficiently durable.

Table 12: Typical grading requirements for sub-base aggregates (BS7533-13)

Sieve size (mm)	Percent passing	
	Coarse graded aggregate 4 mm to 20 mm (4/20) BS7533-13	Type 3 sub-base 0 mm to 40 mm (0/40) SHW Series 800
80	--	100
63	--	
40	100	80 – 99
31.5	98 – 100	
20	90 – 99	50 – 78
10	25 – 70	31 – 60
4	0 – 15	18 – 46
2	0 – 5	10 – 35
1	--	6 – 26

As the sub-base will be in contact with water for a large part of the time, the strength and durability of aggregate particles when saturated and subject to wetting and drying should be assessed. The aggregates should also not crush or degrade either during construction or in service. The specification of 'Los Angeles' test values, micro deval tests and flakiness tests will address these issues. Sub-base aggregate physical property requirements are summarised in Table 13. The properties in this table should be applied to all the different types of sub-base aggregate (including recycled aggregates). **Note that these durability requirements are as, if not more, important than the grading and should not be ignored.**

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	FI_{20}
Resistance to fragmentation	LA_{30}*
Durability: Water absorption to BS EN 1097-6:2000, Clause 7 – for WA > 2%, magnesium sulphate soundness	$WA_{24}2$ MS_{18}
Resistance to wear	$M_{DE}20$
Acid-soluble sulphate content: – aggregates other than air-cooled blastfurnace slag air-cooled blastfurnace slag	$AS_{0.2}$ $AS_{1.0}$
Total sulphur: – aggregates other than air-cooled blast-furnace slag air-cooled blast-furnace slag	≤ 1% by mass ≤ 2% by mass
Volume stability of blast furnace and steel slags: air-cooled blastfurnace slag – steel slag	Free from dicalcium silicate and iron disintegration in accordance with BS EN 13242:2002, 6.4.2.2 V_5
Leaching of contaminants	Blastfurnace slag and other recycled aggregates should meet the requirements of the Environment Agency 'Waste Acceptance Criteria' for inert waste when tested in accordance with BS EN 12457-3

Note: * The durability of aggregates will depend on the nature of the source. In some instances a lower value of LA may need to be specified based on local experience.

Table 13: Physical property requirements for sub-base.

Recycled aggregate can be used where a source is conveniently available but care should be taken that this is of consistent quality, has an appropriate grading and is free of unacceptable materials such as organic matter or steel scrap. Leachate from crushed concrete is likely to have a high pH value, which could impede vegetation growth and thus lead to soil erosion at the drain outlet and/or cause the growth of precipitates at the drain outlet. Therefore, outlets from recycled concrete sub-bases below pervious surfaces should be designed to minimise blockage by having a large surface area through which water is collected and the outlets must be accessible to remove build up of precipitates.

Blastfurnace slags have been used successfully as CGA and Type 3. Blastfurnace slag should comply with BS13242 (BSI, 2007). Leaching tests should be carried out in accordance with BS EN12457-3 (BSI, 2002) and the results should meet the requirements of the Environment Agency's 'Waste Acceptance Criteria' for inert waste.

Details on the availability and suitability of sub-base aggregates should be obtained from paving block manufacturers or local aggregate suppliers.

11.6 LAYING COURSE AND PERMEABLE CONSTRUCTION GRADING COMPATIBILITY

If the gradings of the laying course aggregate and the sub-base or base aggregate are compatible to avoid migration of the laying course into the pavement layer below, then a geotextile is not required between these two layers. Therefore, it is necessary to verify that the gradings of these two layers meet the criteria set out below.

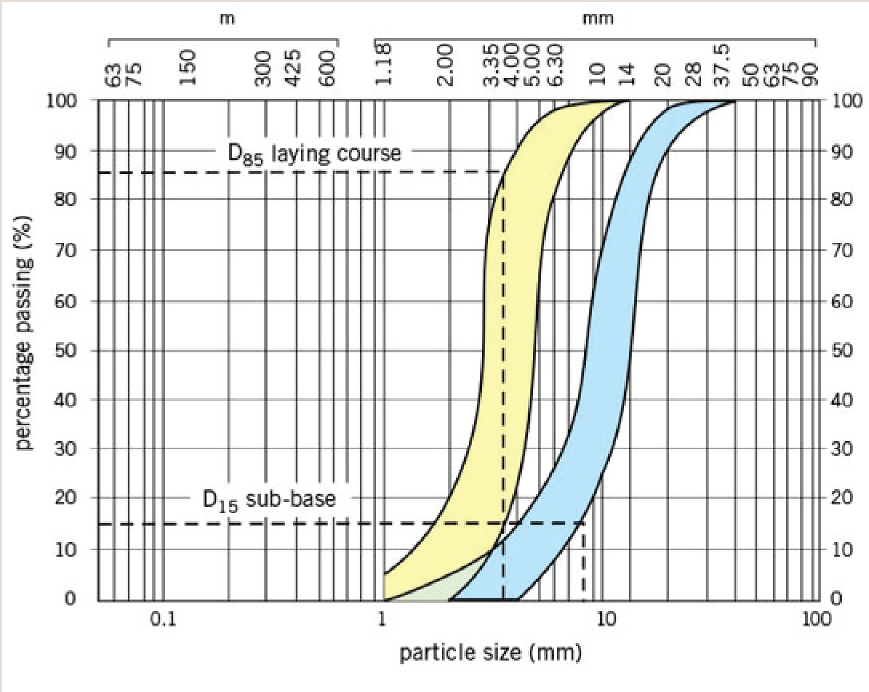


Figure 28: Grading compatibility curve.

The aggregates should meet the following criteria:

$$\frac{D_{15}\text{ permeable construction}}{D_{85}\text{ laying course}} \leq 5$$

and

$$\frac{D_{50}\text{ permeable construction}}{D_{50}\text{ laying course}} < 25$$

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 an aggregate for which 15% of the particles are smaller than D and 85% are coarser.

The example shown in Figure 28 gives

D_{15} permeable construction = 8.0mm and D_{85} laying course = 3.7mm

$$\frac{8.0\text{mm}}{3.7\text{mm}} = 2.16 \leq 5,\ \text{therefore OK}$$

It is advisable to check visually that the laying course particles fit into the voids of the permeable construction material without excessive migration into the permeable construction.

An aggregate meeting the average of the laying course and permeable construction grading limits recommended in this guide should meet these requirements. However, a check should always be made on the actual aggregates proposed for use on a site to make sure they are compatible with each other.

11.7 CAPPING

Capping is required if the subgrade has a design CBR value less than 5%. Fill materials for capping normally comprise low cost locally available aggregates capable of achieving a CBR of 15%.

The two recommended fill materials are either 6F1 (finer aggregate) or 6F2 (coarser aggregate) as defined in Table 6/1 of Highways Agency's *'Specification for Highway Works – Series 600 – Earthworks'*. In the case of 6F2 fill materials, when used in a System C pavement, it may be necessary to blind the surface with fine aggregate to protect the overlying impermeable geomembrane. A capping layer may also be used below System A and B pavements. In this case the capping layer must have a permeability that is at least equal to the design infiltration rate of the soil below including the relevant factor of safety and be unaffected by infiltration of water.

11.8 IMPERMEABLE GEOMEMBRANE

System C pavements include an impermeable geomembrane which holds all of the water entering the pavement and being detained within it. It is important that the impermeable geomembrane is installed above those materials that would deteriorate if they were saturated. The impermeable geomembrane is brought to just below the surface of the pavement at its perimeter to maximise the detention volume of the pavement.

Geomembranes used below CBPP are typically manufactured from high density polyethylene (HDPE), polypropylene or ethylene propylene diene monomer rubber (EPDM). Whatever the base material the geomembranes should be:

- Durable, robust and able to withstand construction and operational forces
- Resistant to puncture, multi-axial stresses and strains associated with movement and environmental stress cracking (or protected by geotextile or sand layers above and below as required; the greatest risk of puncture is often from the sub-base aggregate laid on top of the geomembranes). Consideration can be given to protecting geomembranes with geotextile fleeces where the risks associated with puncture are particularly high
- Unaffected by potential pollutants
- Installed with fully watertight joints and discharge outlets unless the design is based on an assumption of some water leakage from the pavement. The SuDS Manual (CIRIA, 2015) recommends that where joints between geomembrane sheets are required to be watertight then they should be welded. Fully waterproof joints can only be provided by welding and they should be tested to ensure the integrity of the system. Taped joints are not suitable for water retaining applications and it is unlikely that taped joints could be formed effectively with a geomembrane laid below a CBPP. Effective forming of taped seams requires firm even support to allow pressure to be applied with a roller. This would not be provided by most road pavement formations. Joints in geomembranes below pavements are also likely to be subject to tear and shear stresses during trafficking and taped joints will provide less resistance to these stresses.

Advice on specifying appropriate properties for geomembranes is provided in CIRIA Report C748 (CIRIA, 2014a).

Where the consequences of localised failure of the impermeable geomembrane are minor, 2000 gauge polythene can be used with overlapping joints but it must be recognised that this is not completely watertight and water will reach the subgrade and soften it. The 2000 gauge polythene should be protected from puncture using sand blinding or geotextile fleeces.

Where it is important that there is no escape of water (where, for example, contamination would be unacceptable), a more durable material should be specified. In these situations it is important that all joints and seams are visually inspected and, in cases where the geomembrane is critical, possibly tested on site to ensure they meet the required standard. The main places where leaks are likely to occur are around penetrations such as where a pipe passes through the material (e.g. where a pipe passes into a lined geocellular tank). Advice on inspection and testing methods that can be applied to geomembranes below CBPPs is provided in CIRIA Report C735 (CIRIA, 2014b).

Thickness of a geomembrane is very important when considering welding. Geomembranes less than 1mm thick are much more prone to problems when welding, especially burning holes in the material (Schiers, 2009). However, thinner geomembranes of the same material tend to be more flexible and are easier to install especially around corners and other details. Flexible geomembranes can also be prefabricated into panels in the factory. There is therefore a trade-off between robustness and the risk of defects due to difficulty of installation. If a geomembrane is less than 1mm thick it should be shown (by testing a trial joint using a seam test) that it can be welded in a satisfactory manner to give the same joint strength as the strength of the parent material.

In the case of impermeable geomembranes installed over occupied buildings (including car parks), seek specialist advice.

11.9 GEOTEXTILES

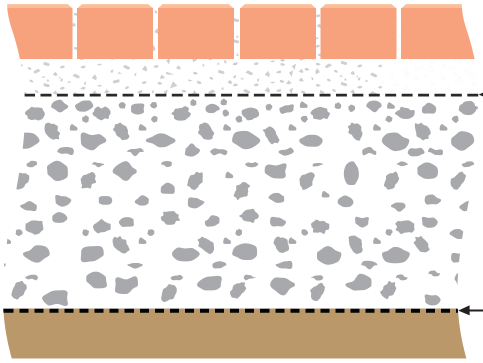


Figure 29: Locations of geotextiles.

Geotextiles may be used in two locations within CBPPs (shown in Figure 29):

- An optional upper geotextile at the laying course/sub-base (or base) interface may be included according to the paving block manufacturer's recommendations or if the grading of the laying course and base or sub-base are not compatible - see Section 11.6.
- Between the subgrade or capping and the sub-base.

A report prepared by The Environmental Protection Group Limited (2007) on the efficacy of geotextiles used in CBPPs is available to download from **www.paving.org.uk**

The geotextile should function as a filter and must be installed according to the manufacturer's requirements, and should be submitted for approval by the engineer. The geotextile can be either a monofilament woven, non-woven firmly bonded or needle punched non-woven fabric. The geotextile should be manufactured from a suitable polyethylene or polypropylene filament able to withstand naturally occurring chemical and microbial effects.

The tensile properties of the material should be verified in accordance with BS EN ISO 10319 (BSI, 2015) by both internal quality assurance and external quality control and assurance by an independent authorised laboratory. The production of the geotextile shall be BS EN ISO 9001 certified. Each roll shall have at least one identification label with roll number and product type in accordance with BS EN ISO 10320 (BSI, 1999) and carry a CE mark.

Adjacent rolls of the geotextile should be overlapped by at least 300mm, without any folds or creases. All vehicles should be prevented from trafficking directly over the material. The material should be protected from ultraviolet light.

Table 14: Filter geotextiles specifcation

Characteristics	Standard	Non-woven geotextile filter
Thickness @ 2kPa	BS EN ISO 9863-1	≥ 1.1 mm
Ultimate tensile strength • Longitudinal • Transverse	BS EN ISO 10319	 ≥ 8.0 kN/m ≥ 8.0 kN/m
Strain at norm tensile strength • Longitudinal • Transverse	BS EN ISO 10319	 ≤ 60% ≤ 60%
CBR puncture resistance	BS EN ISO 12236	≥ 1,500 N
Cone drop	BS EN ISO 13433	≤ 38 mm
Pore size (mean AOS)	BS EN ISO 12956	≤ 0.075 mm
Water permeability (H50)	BS EN ISO 11058	≥ 55 l/m2s
Weathering 50MJ/m2 exposure #	BS EN 1224	>90 %
Microbiological resistance #	BS EN 12225	No loss
Resistance to acids and alkalis #	BS EN 14030	No loss
Oxidation at 85 days #	BS EN 12225	>90 %
Packaging and identification	BS EN ISO 10320	Full compliance
Quality assurance	BS EN ISO 9001	Full compliance
CE marking	CPR 305/2011	Full compliance

Durability - retained strength after test.
Note:
1. Advice should be sought from the paving block manufacturer on recommendation for suitable geotextile requirements.

12. DETAILING

This section considers a selection of details for a range of typical situations to illustrate the basic principles involved. These and other details are available at the www.paving.org.uk information resource.

12.1 EDGE RESTRAINTS

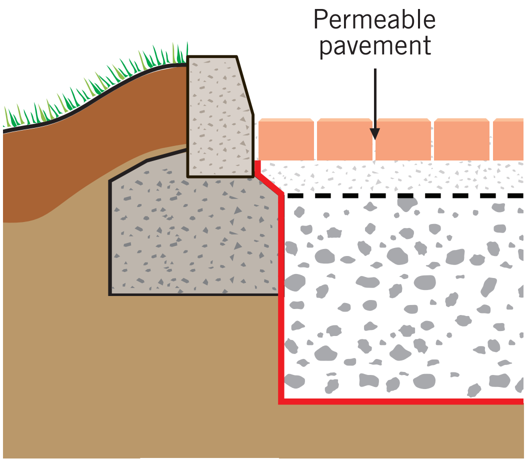


Figure 30: Typical concrete kerb edge restraint (shown with System C) with grass sloping away from the kerb.

As with conventional block paving, the provision of adequate edge restraints is vital to the successful performance of a CBPP.

Research and experience shows that correctly laid concrete block paving develops an inherent interlock, uniting the surface of even the largest areas. There is therefore no need to artificially introduce restraints to contain the paving units. However, restraints at the edges of a pavement or where changes in the paving (such as materials, shapes or laying patterns) interrupt the interlock are essential. If suitable edge restraint is not provided the paving units can rotate, joints can spread and loss of laying course aggregate can cause surface settlement. The form of restraint normally used is a precast concrete kerb or edging placed in a concrete haunch (as shown in Figure 30 and 31). Further advice is available via the Concrete Kerbs guide at **www.paving.org.uk.**

It is recommended that the geomembrane is trimmed after the screeding of the laying course prior to the placement of paving units to ensure that the top of the geomembrane is at the correct level and effective in containing all the surface water.

12.2 EDGES ADJACENT TO SOFT LANDSCAPING

Landscaping should be designed so that it does not cause soil and mulch to be washed onto the CBPP and cause clogging. Detailing of the landscape edge is especially important and, wherever possible, landscape areas adjacent to CBPPs should have a topsoil level that is at least 50 mm below the top of the kerb. Preferably, the areas should slope away from the CBPP (see Figure 30). Where landscaping slopes towards the pavement, an under-drained swale can be used to intercept runoff and silt (see Figure 31).

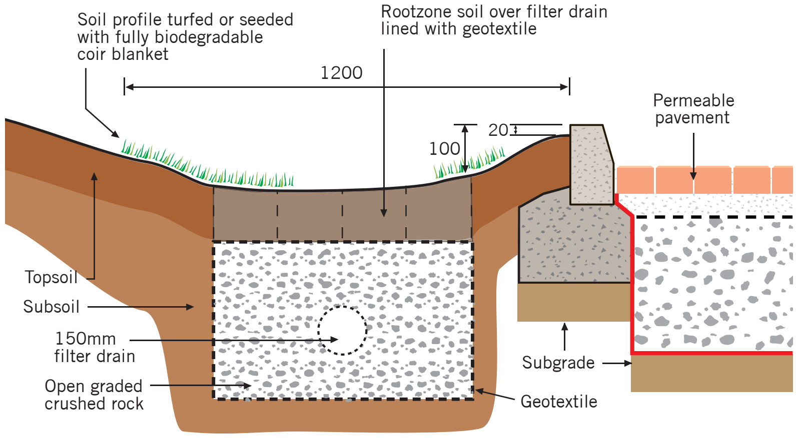


Figure 31: Under-drained swale intercepting runoff and silt close to CBPP

If the possibility of runoff from soft landscaping onto CBPP cannot be eliminated, clogging should be minimised through more frequent sweeping regimes. The required frequency of sweeping should be established through visual monitoring of the surface, particularly following intense rainfall.

Trees or woody shrubs to be planted close to CBPP should be carefully selected. The CBPP below or near trees/shrubs may require more regular sweeping to maintain the surface infiltration rate, although this is not likely to be excessive.

12.3 TRANSITIONS

There may be a need to differentiate areas of CBPP or abut CBPP with conventional block paving (shown in Figure 32) or other surfaces such as asphalt, without a level change, using a flush concrete kerb. This delineation may be needed for visual design considerations or other techniques discussed in Sections 4.3 and 4.4.

Where conventional block paving abuts CBPP, stabilisation of the joints in the former may be considered to avoid migration of jointing sand onto the CBPP.

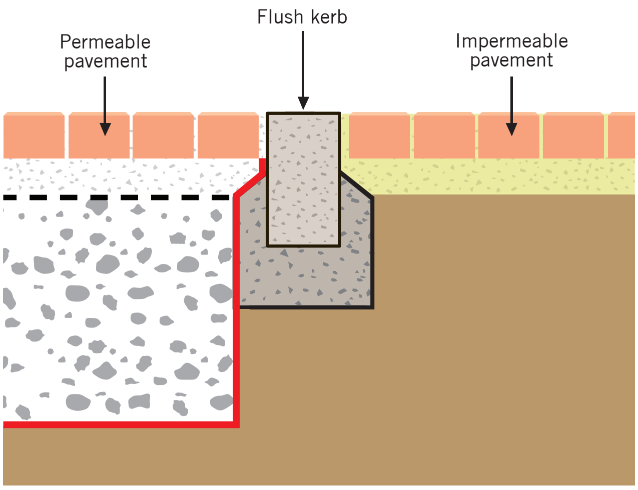


Figure 32: Flush transition of CBPP with conventional block paving,

12.4 INLETS FROM ROOF DRAINAGE

As discussed in section 5.3, CBPP can generally accept runoff from roofs. For smaller areas and capacities, downpipes can discharge directly onto the CBPP surface. The water discharged from the downpipe should be directed away from the building and so as not to scour the jointing aggregate between the paving units. This can be achieved with discharge onto the centre of a larger concrete block or concrete paving flag introduced in the location of the roof water discharge. This method may be preferable to systems that connect directly into the sub-base because no maintenance of filters is necessary.

For larger outlets and roofs, rainwater can be discharged into the CBPP via accessible filter chambers leading to diffusers within the sub-base (see Figure 33).

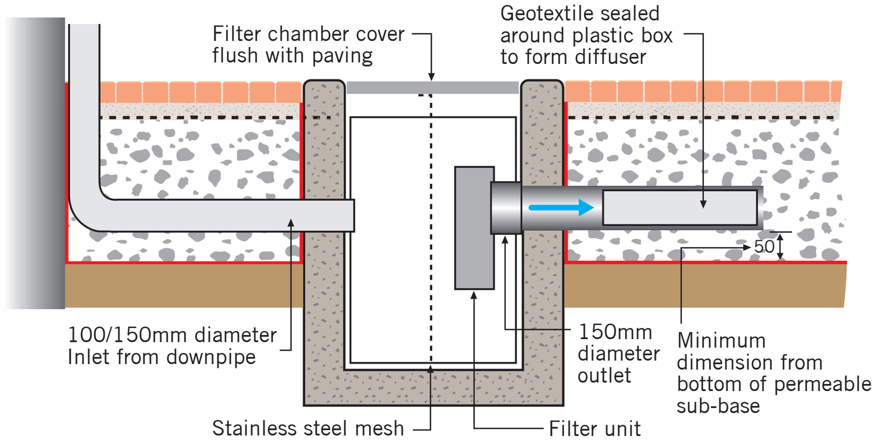


Figure 33: Typical roof drainage outlet within CBPP construction.

Syphonic roof drainage can also be connected to CBPPs. However, this type of roof drainage directs large volumes of water into the pavement very quickly which results in very high flow velocities. Therefore inlet diffusers that connect the syphonic drainage into the permeable sub-base should be designed to allow the water into the pavement without affecting the flow rate. It is best to recommend that the manifold is designed by the syphonic drainage design consultant.

An impermeable geomembrane below the permeable sub-base can be used to prevent water infiltration from rainwater discharge close to the foundations. This would typically extend for 2m to 5m depending on the ground conditions and the risk of water adversely affecting the foundations. A typical detail is shown in Figure 34.

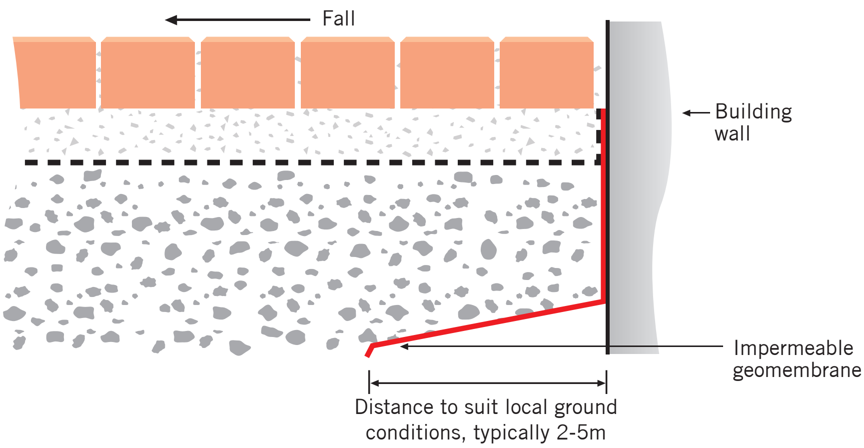


Figure 34: Typical abutment to building where rainwater is discharged.

12.5 OUTLETS AND CONVEYANCE

System B and C pavements require an outfall from the permeable sub-base to allow the water to drain. There are various ways of collecting the water from the permeable sub-base. The main concern is to ensure that a large surface area is provided to allow water to flow through and that watertight joints are achieved.

The most effective ways of connecting the permeable sub-base to the drainage system in Systems B and C is to use fin drains (see Figure 35), proprietary CBPP drainage systems (see Figure 36) or perforated pipes. However, perforated pipes need sufficient cover to carry vehicle loads and may need to be installed in a trench below the permeable sub-base to achieve this (see Figure 37).

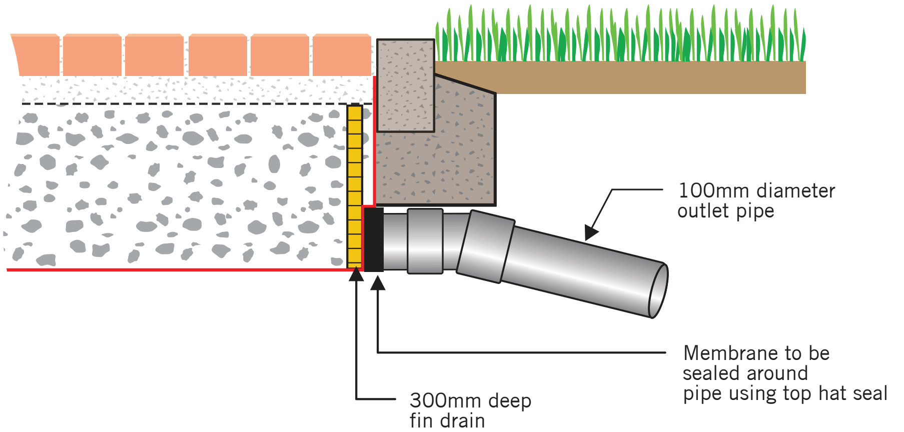


Figure 35: Collection of water by perimeter fin drains.

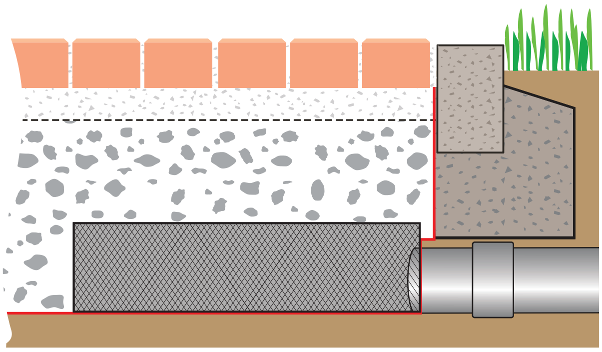


Figure 36: Proprietary CBPP drainage systems e.g. outlet collector box units factory-wrapped in 2mm mesh

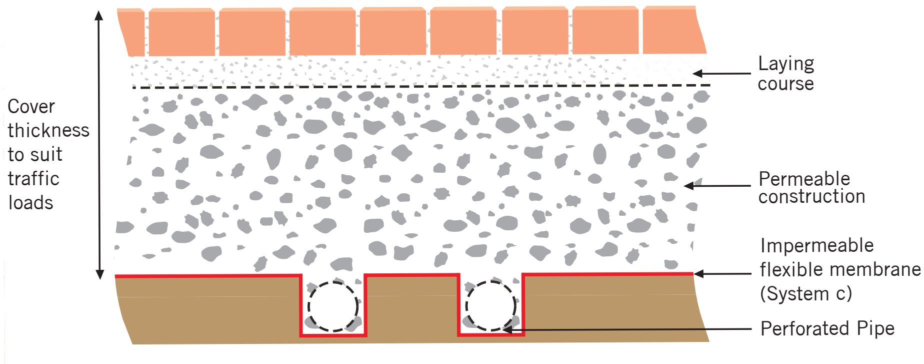


Figure 37: For large areas of CBPP perforated collector pipes in trenches can be used to collect the water.

12.6 CHAMBERS

Chambers related to CBPP are required when collecting and discharging runoff from roofs (see Figure 33). Depending on the volume and velocity of the discharge, more than one chamber may be required. Where there is a requirement to restrict discharge flow so that collected runoff is temporarily stored within the pavement, a chamber containing a flow control device will be required (see Section 9.12). Depending on the size of the pavement and volumes of runoff to be temporarily stored, more than one outflow and flow control chamber may be required. Other chambers unrelated to CBPP, for example foul water sewers, may also be needed.

Wherever possible, all chambers should be located outside areas of CBPP, as recommended for services (see Section 4.4). If this is not possible, chambers can be constructed within CBPP as for other pavements.

Other considerations when designing chambers are:

- simplicity of construction;
- resistance to clogging, blocking or mechanical failure;
- invert level in relation to the CBPP to avoid discharging out of the top of the chamber during an extreme event; and
- accessibility, visibility and ease of maintenance.

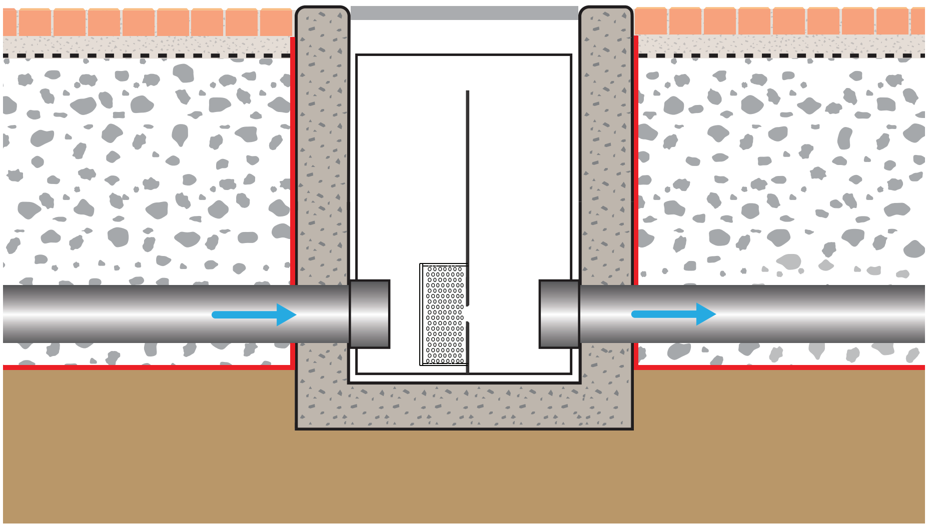


Figure 38: A typical flow control chamber, located within CBPP.

13. CONSTRUCTION

The following guidance is specific to CBPP and additional to general best-practice and other Interpave guidance, notably the Concrete Block Paving guide.

13.1 SITE PRECAUTIONS

Preventing and diverting impermeable contaminants such as soil and mud from entering the base and pavement surface during construction is essential. Simple practices such as keeping muddy construction equipment well away from the area, installing silt fences, staged excavation and temporary drainage swales which divert runoff away from the area should be considered.

13.2 SUBGRADE

Proof rolling of the formation below System A and B CBPP is not recommended as it can reduce the infiltration rate of the subgrade. Subgrade soft spots can be identified using a handheld MEXEcone or similar (i.e. an instrument to measure in situ CBR values). If soft spots are identified, they should be excavated and backfilled with suitable well-compacted aggregate and, for System A and B pavements, the aggregates should be of similar permeability to the surrounding subgrade.

However, if proof rolling is required then the infiltration of the subgrade should be determined after this operation.

The formation should be prepared by trimming to level in accordance with '*Specification for Highways Works'* (Highways Agency et al, 2016b), to a tolerance of +20mm to -30mm. If subgrade improvement is employed, testing will be needed to demonstrate that the design CBR values have been consistently achieved and, for System A and B pavements, that the infiltration rate of the subgrade is equal to or greater than the rate used for the hydraulic design.

The formation below System A and B pavements should be protected from any operations that could reduce the infiltration rate of the soil (e.g. heavy construction traffic, stockpiling fine materials or mixing concrete on it).

13.3 GEOTEXTILE

Any geotextile required between layers should be installed in accordance with the manufacturer's instructions and with overlaps between adjacent strips a minimum of 300mm wide, without any folds or creases. It is recommended that specialist advice be sought from the manufacturer or supplier of the geotextile. On slopes, the upper geotextile strip should overlap above the lower strip.

13.4 IMPERMEABLE GEOMEMBRANE

Impermeable geomembranes are used with System C (no infiltration) and must be correctly specified, installed and treated with care to ensure that they are not damaged during construction.

13.5 PERMEABLE SUB-BASE

As permeable sub-base aggregates (CGA or Type 3) lack fines, there is potential for segregation during the transportation and construction process. Care should be taken to avoid segregation but, if this occurs, remedial, corrective action must be taken. Segregation can be minimised by using an angular, crushed aggregate with high surface friction.

The nature and grading of the permeable sub-base will vary between different sources. Typical sub-base aggregate (CGA) is shown in Figure 39.

Figure 39: Typical 4/20 coarse graded aggregate sub-base.

CGA and Type 3 sub-base should be moistened, laid in 100 - 150mm layers and compacted to ensure that the maximum density is achieved without crushing the individual aggregate particles. This is usually achieved by rolling with little or no compaction. The surface levels should be in the range +20mm to -15mm. An earthworks trial may be required to determine the appropriate methodology to moisten, lay and compact this layer.

With the exception of plant and equipment needed for the installation of the paving units, or if overlaid with HBCGA or AC, no other traffic or equipment should be allowed onto the completed layer as the surface is easily damaged and rutted. Care and precautions are also needed to ensure that the surface is not damaged, rutted or clogged with mud and detritus from the plant and equipment whilst installing the next pavement layer. Precautions should be undertaken to avoid runoff from adjacent areas.

13.6 BASE

13.6.1 PRODUCTION

HBCGA contains only a nominal quantity of binder (cement) and this binder must be evenly distributed throughout the mix to ensure that all the aggregate particles are coated in cement paste. To achieve this it is recommended that HBCGA is produced in a mixing plant as opposed to site mixing in a concrete truck mixer.

13.6.2 CONSTRUCTION

HBCGA shall be constructed in accordance with Volume 1 *'Specification for Highway Works'* – Series 800 (Highways Agency, 2016a).

Site trials may be necessary to determine an appropriate construction methodology and, where necessary, advice should be sought from the HBCGA supplier.

Care must be taken to avoid segregation of the aggregate during transportation and construction. If this occurs, then remedial corrective action must be taken to ensure that the completed base has evenly distributed aggregate particle sizes.

The HBCGA should be laid in 100 – 150 mm layers, levelled by hand or machine and compacted to ensure that the maximum density is achieved for the particular aggregate type and grading, without crushing the individual particles, which could reduce the voids and permeability below the design value. The aggregates are relatively self-compacting and heavy vibrating compaction is not usually required. Satisfactory results may be achieved by rolling without vibration, with four to five passes of the roller often proving to be adequate. The surface level tolerance shall be within +20 mm to –15 mm of the design levels.

Setting times for HBCGA vary dependent upon many factors including the ambient temperature and wind speed. Compaction of the HBCGA must be completed before the onset of setting.

The HBCGA should not be laid during heavy or persistent rain as there is a danger that the cement paste will be washed off the surface of the aggregate and be flushed into the lower layers of the pavement.

Being open textured, fresh HBCGA loses water rapidly to the atmosphere. As a consequence it needs to be placed and compacted as soon as possible after mixing. During hot weather, there is a danger that the HBCGA will dry out rapidly during transport, laying and compaction and so care must be taken to ensure that the HBCGA does not dehydrate. On warm or dry days it may be necessary to dampen down the sub-base on which the HBCGA is to be placed in order to prevent the sub-base excessively drying out the HBCGA.

Care must be taken for 24 hours to 48 hours after placing the HBCGA to prevent it drying out too quickly and not curing adequately. On warm or dry days it may be necessary to cover the surface of the HBCGA to maintain moisture. The HBCGA surface must also be protected from rain and surface water runoff during the first 48 hours after placing. No construction traffic should be allowed upon the HBCGA surface and care must be taken to ensure that it is kept clean and free of any detritus and contaminants.

13.7 PROTECTION FROM CONSTRUCTION TRAFFIC

As discussed in Section 5.7 (Construction Traffic) there is often a need to use the partially or completed CBPP as access roads or storage areas during the construction of the project. If the CGA or Type 3 sub-base is trafficked, the unbound surface will rut and the surface will become clogged. If the HBCGA base or paver surface is trafficked, it will become clogged.

There are various options to overcome these issues that should be considered at the concept and design stage and construction programming, such as:

- For System C, construct a normal capping layer and use this as the temporary road surface. Construct the CBPP over it towards the end of construction.
- Construct the permeable sub-base and then cover it with a sacrificial layer of geotextile and hardcore (100mm thick). Use this as the temporary road surface. Towards the end of construction remove the sacrificial layer and construct the laying course and paver surface. The removed geotextile should not be re-used as an upper geotextile layer.
- Consider the construction process during design and identify areas and routes for construction traffic and others that are prohibited. Use conventional construction in the former and CBPP in the latter.
- Construct the permeable sub-base and then cover it with an impermeable layer of AC. Use this as the temporary road surface. The AC forms part of the structural design of the pavement (see Section 8.9) and should be constructed as described in 13.8.

13.8 ASPHALT CONCRETE (AC) LAYER

Construct the permeable sub-base and then cover it with an impermeable layer of AC (see Table 8 for AC layer thicknesses). Use this as the temporary road surface. The AC material should be installed in accordance with BS 594987:2015 + A1:2017 - Asphalt for roads and other paved areas. Specification for transport, laying, compaction and product type testing protocols (BSI, 2017).

Experience has demonstrated that a tracked asphalt-paving machine (see Figure 40) is easier to manoeuvre over 'unbound' CGA or Type 3 sub-base than a wheeled paving machine. Towards the end of construction, core or punch holes in the AC to form CAC and fill the holes with the CGA, Type 3 or laying course aggregate. Construct the laying course and paver surface over the CAC. Typically, holes should be 75mm diameter on an orthogonal grid of 750mm. The CAC layer remains in situ throughout the service life of the pavement.

Figure 40: Tracked asphalt paving machine installing AC over a permeable sub-base.

13.9 PAVER SURFACE CONSTRUCTION PROCEDURES

The following flowchart illustrates the step-by- step procedures for the construction of the paver surface for a CBPP. It follows the basic recommendations in BS 7533-3:2005 + A1:2009 (BSI, 2009b), but, where appropriate, changes and modifications have been incorporated based upon best practice.

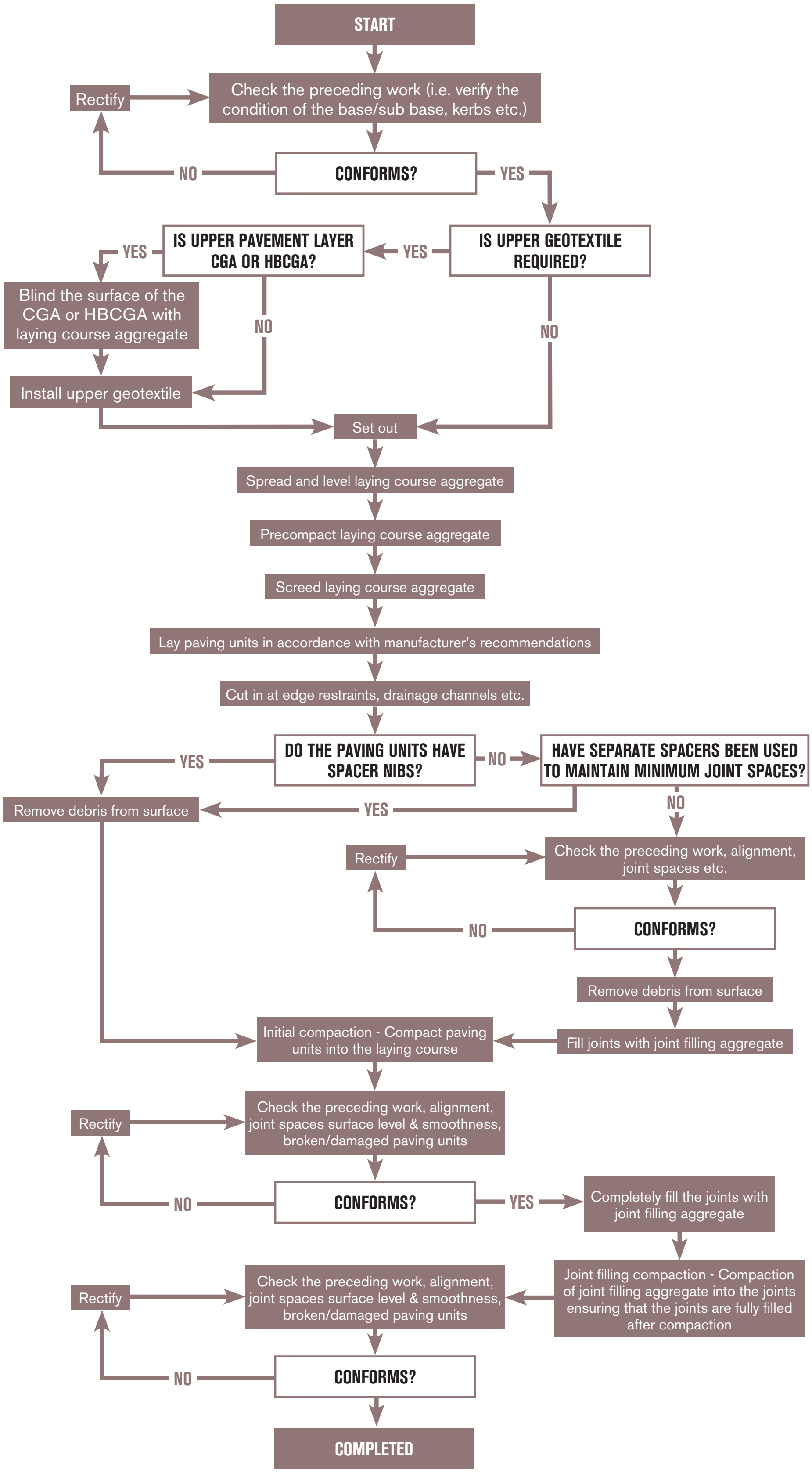


Figure 41: Flowchart of paver surface construction sequence.

13.9.1 LAYING COURSE AND JOINT FILLING

If upper geotextile is to be installed between the CGA, Type 3 or HBCGA and the laying course, it is recommended to blind the surface of these layers with a small amount of laying course aggregate prior to installing the geotextile. This process will fill voids in the surface and avoid the geotextile "spanning voids" and potential settlement.

The laying course thickness should be 50mm ± 20mm.

When either machine laying (see Figure 42) or hand laying paving units on a CGA or Type 3 sub-base or HBCGA base, with no upper geotextile, the laying course aggregate is compacted to ensure that the surface of the underlying layer is fully blinded by the laying course aggregate.

For the recommended grading requirements and physical properties of the laying course aggregate see Section 11.2.

Figure 42: Machine laying of concrete paving units offers a particularly efficient solution for permeable as well as conventional block paving.

13.9.2 JOINT SPACES

Unlike conventional block paving that requires joint spacing between 2 and 5mm, the requirements for joint spacing for permeable paving varies depending on the paving unit type. Therefore information needs to be sought from the manufacturer on the recommended joint spacing.

13.9.3 JOINT FILLING

For concrete paving units specifically manufactured for CBPPs, or other types of paving unit laid with separate spacers, the filling and compaction of the joint filling aggregate into the joints should proceed after the compaction of the paving into the laying course, and after compliance checks and corrections have been undertaken. Joint filling must not be undertaken prior to compaction of the paving units into the laying course.

For concrete paving units with no spacers, compliance checks and corrections are undertaken prior to the filling and compaction of the joint filling aggregate into the joints.

In all cases, the laying course aggregate can be used for joint filling, but care needs to be exercised to ensure that the maximum aggregate size particles can infiltrate into the joints.

Completely full joints are necessary to ensure structural integrity of the paving surface layer. It is recommended that in the early life of the pavement, inspections are undertaken and if necessary the joints topped up with jointing aggregate.

To minimise the risk of damage and contamination of the surface it is recommended that at the cessation of each workday, the paver surface layer is fully compacted and jointed to within 1m of the laying face.

13.9.4 JOINT SEALING

If required, joint sealants specifically designed to bond the jointing aggregate but also to allow infiltration of all the surface water are available: only these types of sealants should be used on CBPPs. Advice should always be sought from the sealant manufacturer on the appropriate type and method used. Never use conventional block pavement sealants.

13.9.5 MANUFACTURER SPECIFIC REQUIREMENTS

Information should also be sought from the manufacturer on laying patterns for particular paving unit types and any special design or construction requirements.

14. POST CONSTRUCTION

CBPP technology has proven itself over decades of successful use in the UK and around the world - notably Germany since the mid-1980s. Experience of CBPP in use in the UK over more than 20 years has demonstrated its long-term performance with minimal, if any, maintenance. Routine maintenance should be no more onerous than for impervious paving and the maintenance required for conventional below-ground gulley and pipe drainage is eliminated.

14.1 INFILTRATION PERFORMANCE

The infiltration rate into CBPP will decrease but stabilise with age, due to the build-up of detritus in the jointing aggregate. This effect is discussed in Section 9.4 and summarised in Figure 20, where it can be seen that long service lives can be expected from permeable pavements, which is borne out by experience of older pavements. To ensure a long service life, it is essential that care be taken to protect the pavement during construction and from landscape runoff.

14.2 COLD WEATHER PERFORMANCE

'Frost heave' is not a problem for CBPP as water drains through the pavement before there is time for it to freeze. CBPPs have been used successfully in particularly cold climates. In the unlikely event that freezing does occur, it generally does not develop in a uniform manner and this allows the water displaced by the expanding ice to move within the open graded permeable construction, thus limiting the heave effects on the pavement.

Frost heave does not occur if the pavement is designed correctly. If the pavement is full and prolonged freezing does occur (a virtually impossible combination as the pavements are designed to drain down quickly after a rainfall event) then ice 'mushrooms' may appear at the surface in the joints between the paving units as the water expands in the pore spaces between the aggregate. The only record of this happening is in the Midwest of the USA where the winter climate is far more severe than the UK.

It is of note that one of the most comprehensive studies into the performance of CBPPs undertaken in the USA by Ferguson (2005) failed to find an example of a CBPP in a cold climate that had failed due to frost damage. This included one example of a 550mm deep pavement in an area with frost penetration up to 1800mm that had not experienced any significant distortion over 10 years. It was also found that frost penetration was shallower below CBPPs than conventional dense construction because of the insulating effect of the pavement.

14.3 HEALTH AND SAFETY

There is sometimes a perception that water within a CBPP might cause a potential health and safety issue, either due to stagnation of the water or freezing. This is not the case, as the systems are designed to drain quickly after a rainfall event and thus there should not be water standing for any significant period of time. In fact, CBPPs provide a firm, level, well-drained surface that meets current accessibility requirements. Recent research in Ireland also shows that CBPPs without slopes improve safety when using shopping trolleys in retail car parks, where discharged trolleys could run away into vehicles or pedestrians.

There is less risk of sheet ice forming on CBPPs compared to normal pavements because puddles do not form on the surface. However hoar frosts may occur more frequently

(CIRIA, 2001). Hoarfrost is a white frosting that appears after a cold night. It comprises a covering of minute ice crystals, formed from the atmosphere at night upon the ground and any exposed objects when they have cooled by radiation below the dew point.

Hoarfrost can be slippery, depending on people's choice of footwear. It is mostly dealt with by gritting or salting surfaces to make them less slippery. Apart from hoarfrost, pavements also become slippery when ice forms in cold weather after a damp spell, or when snow gets compacted or re-freezes after melting. CBPP is no exception and can be salted in the same way as other pavements. If grit is used, then the granules should be sufficiently large not to clog up the joints between paving units.

14.4 ROUTINE MAINTENANCE

Correct design, detailing and construction are essential to the long-term performance of CBPP and minimising maintenance. In particular, the following aspects have been discussed earlier in this Guide:

- design and detail soft landscaping to prevent soil and mulch being washed onto the CBPP.
- prevent impermeable contaminants such as soil and mud from entering the base and paving surface both during and after construction.
- ensure that joints between paving units are filled with the correct, permeable jointing aggregate. Joints filled to within 10mm or so of the top surface do not require action.

Over time, detritus and silt collects in the upper part of the jointing aggregate between paving units where a surface 'crust' is formed, protecting the laying course and permeable construction material while allowing infiltration. As discussed in Section 9.4, reduction in the infiltration rate of CBPP stabilises with age, normally well above UK hydrological requirements. Also, the performance of CBPP is not significantly affected by moss or weeds in the joints, or by leaves collecting on the surface.

Generally, any problems will be revealed on the surface by ponding (permeability issues) or damaged or displaced paving units (structural issues). In the absence of these indications, no remedial action is necessary. Current routine maintenance regimes for other paving can be applied to CBPP as follows:

- **Cosmetic Cleaning** – non-aggressive brushing of the whole surface (avoiding disruption of the jointing aggregate, with suction rates and brush angles/speed adjusted, based on a trial), either manually or mechanically, will help maintain performance and appearance. This can be carried out at the same intervals as for conventional pavements (to suit local rotas), annually or at intervals resulting from local observations of silt and debris build-up. More information on cleaning surfaces generally can be found in Interpave's guide *'Concrete Block Paving'*.
- **Visual inspections** - should be carried out and recorded during maintenance visits. Inspection of piped outfalls (where used) and flow control devices is also advised.
- **Winter maintenance** - controlled use of standard road de-icing techniques including rock salt may be used without detrimentally affecting the CBPP performance. De-icing chlorides should be used in accordance with suppliers' recommendations and are unlikely to result in an increase in ground chloride levels. CBPP generally requires less de-icing than impervious paving, although it can exhibit hoar frost sooner.
- **Weed control** – excessive weed growth, typically where vehicles do not pass over (trafficking prevents weed growth), can be managed by localised spot-treatment with weed killers containing Glyphosate, in accordance with suppliers' recommendations.

14.5 REMEDIAL ACTIONS

Over the longer term allowance should be made to deal with any permeability or structural issues that might arise.

With the former, action will only be necessary with loss of permeability indicated by ponding on the surface of CBPP. In this event and in affected areas only, water-jetting or agitation brushing (either manually or mechanically with a suction brush set at a 30° angle to the pavement, to prevent aggregate migration) can be used to dislodge the affected jointing aggregate. Joints should then be refilled with the correct, clean aggregate and compacted into the joints.

Information on structural repairs and reinstatement for block paving generally can be found in Interpave's guide *'Concrete Block Paving'*.

14.6 REINSTATEMENT

As discussed in Section 4.4, underground services can be located outside CBPP to avoid the need for disturbance to gain access, or located within service corridors. However, there may be situations where this is not possible, such as sewers located below CBPP because they cannot run with other services and, as a result, future excavation may be unavoidable. Localised structural failures of the pavement may also require reinstatement.

Unlike other pavement materials, with CBPP as well as conventional block paving, reinstatement work can be carried out with no visual evidence that a repair has been undertaken. Reinstatement techniques for both types are discussed in detail in Interpave's guide *'Concrete Block Paving'* while the following additional guidance applies specifically to CBPP.

Understanding the CBPP

- Is the pavement System A or B (infiltration), or System C (non-infiltration)? This may influence how you manage the water passing through the pavement and prevent any flooding on the upstream side.
- How deep is the open-graded CGA or Type 3 aggregate? This will influence how to dam the opening so that water passing through does not interfere with the works.
- Consider the area to be excavated. Think about the angle of repose for the open-graded aggregate or use of damming or supporting features for the permeable construction.

Opening-up the Pavement

- Remove the paving units as for conventional block paving and retain.
- Remove laying course aggregate.
- Excavate into pavement taking care to note the presence of any geotextile or geogrid layers. Where present, carefully cut out these layers.
- Consider the angle of repose for the unbound aggregates as this may dictate a larger excavation than with impermeable materials or the unbound sub-base is restrained around the perimeter of the excavated area so that no aggregates enter. Any restraints need to be removed prior to the completion of the works.
- The nature of the excavation will influence how any water in the pavement is to be managed. For example, an excavation within the body of the pavement allowing water to pass either side may be acceptable. However, a trench running across the carriageway may create a dam effect within the base, in which case consideration as to how to manage the water flow (e.g. temporary pipework passing through the excavation) should be given.

Reinstatement

- Any temporary and/or permanent reinstatement must ensure that the hydraulic performance of the pavement is retained.
- Only 'like-for-like' permeable construction, base, sub-base and laying course aggregates should be used.
- Ensure that the excavated base is fully compacted prior to reinstatement.
- Replace geomembranes, geotextiles, geogrids, etc., on a 'like-for-like' basis with original installation. Tie-in these items with the remaining originals (which may involve sealing geomembranes to retain impermeability).
- Compact each layer to the correct thickness.
- Reinstate the paver surface, ideally with paving units previously lifted. Otherwise, compatible replacement paving units should be used.

15. REFERENCES

ASTM International	(2015)	*ASTM C1781-15 Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems*	
Beecham S, Lucke T and Myers B	(2010)	*Designing porous and permeable pavements for stormwater harvesting and re-use*	In: Proceedings of the 1st European Congress of the International Association for Hydro-Environment Engineering and Research
British Standards Institution	(1990a)	*BS 1377-4:1990 - Methods of test for soils for civil engineering purposes. Compaction-related tests*	
British Standards Institution	(1990b)	*BS 1377-9:1990 - Methods for test for soils for civil engineering purposes. In-situ tests*	
British Standards Institution	(1998)	*BS EN 752-4: 1998 - Drain and sewer systems outside buildings – Part 4: Hydraulic design and environmental considerations*	
British Standards Institution	(1999)	*BS EN ISO 10320:1999 - Geotextiles and geotextile-related products. Identification on site*	
British Standards Institution	(2002)	*BS EN 12457-3:2002 - Characterisation of waste. Leaching. Compliance test for leaching of granular waste materials and sludges. 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)*	
British Standards Institution	(2003a)	*BS EN 1338: 2003 - Concrete Paving Blocks – Requirements and test methods.*	
British Standards Institution	(2003b)	*BS EN ISO 14689-1:2003 - Geotechnical investigation and testing. Identification and classification of rock. Identification and description*	
British Standards Institution	(2007)	*BS EN 13242:2002+A1:2007 - Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction*	
British Standards Institution	(2008)	*BS EN 12620:2002+A1:2008 - Aggregates for concrete*	

British Standards Institution	(2009a)	*BS 7533-13:2009 - Pavements constructed with clay, natural stone or concrete pavers. Guide for the design of permeable pavements constructed with concrete paving blocks and flags, natural stone slabs and setts and clay pavers*	
British Standards Institution	(2009b)	*BS 7533-3:2005+A1:2009 - Pavements constructed with clay, natural stone or concrete pavers. Code of practice for laying precast concrete paving blocks and clay pavers for flexible pavements*	
British Standards Institution	(2012)	*BS EN ISO 22282-2:2012 - Geotechnical investigation and testing. Geohydraulic testing. Water permeability tests in a borehole using open systems*	
British Standards Institution	(2013a)	*BS 8582:2013 - Code of practice for surface water management for development sites*	
British Standards Institution	(2013b)	*BS EN 14227-1:2013 - Hydraulically bound mixtures. Specifications. Cement bound granular mixtures*	
British Standards Institution	(2013c)	*BS EN ISO 14688-1:2002+A1:2013 - Geotechnical investigation and testing. Identification and classification of soil. Identification and description*	
British Standards Institution	(2015)	*BS EN ISO 10319:2015 - Geosynthetics. Wide-width tensile test*	
British Standards Institution	(2016)	*BS EN 13108-1:2016 - Bituminous mixtures. Material specifications. Asphalt Concrete*	
British Standards Institution	(2017a)	*BS 8533:2017 - Assessing and managing flood risk in development. Code of practice*	
British Standards Institution	(2017b)	*BS 594987:2015+A1:2017 - Asphalt for roads and other paved areas. Specification for transport, laying, compaction and product type testing protocols*	
Building Research Establishment	1991	*Soakaway Design*	BRE Digest 365
Cedergren HR	(1974)	*Drainage of highway and airfield pavements*	Wiley
CIRIA	(1996)	*Infiltration drainage - Manual of good practice*	CIRIA Report C156
CIRIA	(2001)	*Source control using constructed pervious surfaces.*	CIRIA Report C582
CIRIA	(2004)	*Sustainable Drainage Systems. Hydraulic, structural and water quality advice*	CIRIA Report C609
CIRIA	(2006)	*Designing for exceedance in urban drainage - good practice*	CIRIA Report C635

CIRIA	(2014a)	*Guidance on the use of plastic membranes as VOC vapour barriers*	CIRIA Report C748
CIRIA	(2014b)	*Good practice on the testing and verification of protection systems for buildings against hazardous ground gases*	CIRIA Report C735
CIRIA	(2015)	*The SuDS Manual*	CIRIA Report C753
Environment Agency	(2017)	*Guidance - Protect groundwater and prevent groundwater pollution*	
Environmental Protection Group	(2007)	*The performance of geotextiles in concrete block permeable pavements - Literature review for Interpave*	(available on www.paving.org.uk)
Evans E, Ashley R, Hall J, Penning-Rowsell E, Sayers P, Thorne C and Watkinson A	(2004)	*Foresight. Future Flooding. Scientific Summary: Volume II Managing future risks.*	Office of Science and Technology, London.
Ferguson, B	(2005)	*Porous pavements. Integrative studies in water management and land development*	CRC Press
Highways Agency	(2009)	*Design guidance for road pavement foundations (Draft HD25)*	Interim Advice Note 73/06 Revision 1
Highways Agency	(2016a)	*Specification for Highway Works - Series 800*	
Highways Agency	(2016b)	*Specification for Highway Works - Series 600*	
Highways Agency	(2018)	*Specification for Highway Works - Series 900*	
Interlocking Concrete Pavement Institute	(2017)	*Permeable Interlocking Concrete Pavements*	
Interpave	(2012)	*Concrete block paving. Guide to the properties, design, construction, reinstatement and maintenance of concrete block pavements*	(available on www.paving.org.uk)
Interpave	(2012)	*Paving for Rain*	(available on www.paving.org.uk)
Interpave	(2012)	*Concrete kerbs. Guide to the properties, design, handling, installation and reinstatement of precast concrete kerbs*	(available on www.paving.org.uk)
Interpave	(2013)	*Understanding Permeable Paving*	(available on www.paving.org.uk)
Kellagher RBB and Laughlan CS	(2003)	*Use of SUDS in high density developments, defining hydraulic performance criteria*	H R Wallingford Report SR 640
Kellagher RB	(2013)	*SuDS study summary - Interception of 5mm of rainfall*	H R Wallingford Report BE-030-R2
Knapton J and Meletiou M	(1996)	*The structural design of heavy duty pavements for ports and other industries - 3rd edition*	British Precast Concrete Federation, Leicester
Knapton J	(2008)	*Heavy duty pavements - The structural design of heavy duty pavements for ports and other industries - 4th edition*	Interpave publication (available on www.paving.org.uk)

Knapton J, Morrell D and Simeunovich M	(2012)	*Structural design solutions for permeable pavements*	In: Proceedings of the 10th International Conference on Concrete Block Paving
Powell WD, Potter JF, Mayhew HC and Nunn ME	(1984)	*The structural design of bituminous roads*	TRL Report LR1132
Schiers J	(2009)	*A guide to polymeric geomembranes: A practical approach*	Wiley
Shackel B	(2000)	*Computer-based mechanistic methods for concrete block pavement design*	In: Proceedings of the 6th International Conference on Concrete Block Paving
Susdrain	(2012)	*Using SuDS close to buildings*	

16. APPENDICES

APPENDIX 1

GROUND INFILTRATION TESTING

The infiltration rate or coefficient is a measure of how quickly water soaks into the ground below the bottom of the CBPP. Infiltration tests should always be undertaken in order to determine infiltration coefficients for design purposes. Any testing should be as extensive as possible and supported by evidence of wider soil characteristics, in order to avoid misrepresentation of relevant soil properties. Testing may be carried out in conjunction with the site investigation report.

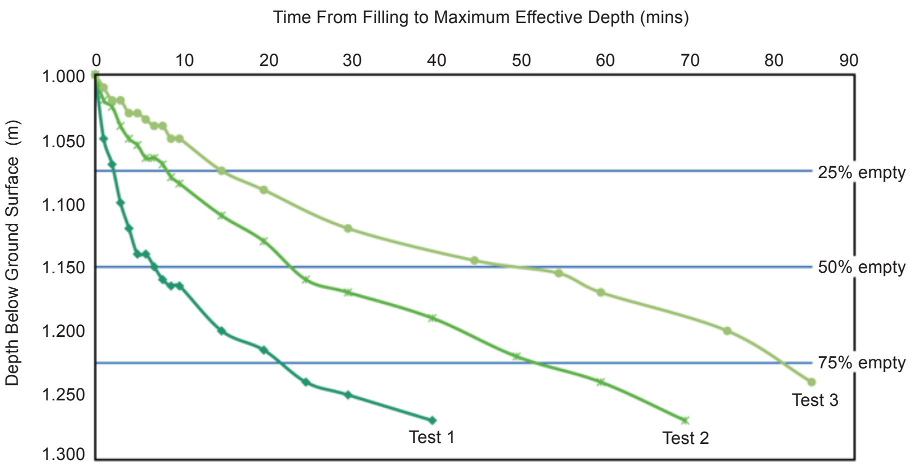


Figure 43: Example of reduction in infiltration rate with successive tests

In some cases it may not be possible to carry out tests in trial pits due to the depth or access constraints. In this instance tests can be carried out in boreholes. The tests should follow the procedure in accordance with BS EN ISO 22282 - 2: 2012 (BSI, 2012). Falling head tests should still be repeated at least three times, as required in BRE Digest 365 (BRE, 1991). Care should also be taken in the interpretation of the results as a smaller volume of water is entering the ground during the test. Ideally, falling head tests should be repeated as many times as possible to increase the volume of water entering the ground.

If the water level in a test does not drop sufficiently quickly to do three tests in a day, it indicates low infiltration capacity and potential risks for long-term performance. The results of incomplete tests should not be extrapolated to obtain design values of infiltration rates. The head of water in the infiltration test should fall to less than 25% of the initial head of water. If this does not occur the results should state that the infiltration rate cannot be determined. If necessary tests can be extended over two days using water level loggers. If pits are left open overnight with water in them, then health and safety issues need to be addressed and as a minimum the areas will need to be securely fenced off.

If other variations to the test method in CIRIA report C156 (CIRIA, 1996) are required, the test results sheet should clearly state what variations have been made to the test and why.

The worse-case infiltration rate value should be used for design (not the mean or any other value) unless a sound justification for doing otherwise is demonstrated.

Infiltration test results should always be provided together with trial pit records that include soil/rock descriptions of the materials in which the test has been completed in accordance with BS EN ISO 14688-1 (BSI, 2013c) or BS EN ISO 14689-1 (BSI, 2003b). The interpretation of the test results should be compared to the soil descriptions; any unusually high or low values assessed against the conceptual site ground model; and confirmation provided that the measured infiltration rates are representative of the wider ground mass (e.g. the test has not been undertaken in a limited extent of sand within a wider mass of clay). The likely impact of water on the soil and long term infiltration rate should also be assessed. This can be done by a geotechnical site investigation company.

The test results sheet should state which stratum the results are appropriate to and any limitations in the test (e.g has the infiltration rate been estimated by assuming water only infiltrates into one particular stratum such as a discrete layer of limestone?)

For preliminary design the typical infiltration coefficients for different soil textures in Table 15 may be used. These values should always be confirmed by site infiltration tests prior to construction.

Table 15: Typical infiltration coefficients for different soil textures

Soil type/texture	ISO 14688-1 description (after Blake, 2010)	Typical Infiltration Coefficients (m/s)
Good infiltration media		
Gravel	Sandy gravel	$3x10^{-4}$ to $3x10^{-2}$
Sand	Slightly silty slightly clayey SAND	$1x10^{-5}$ to $5x10^{-5}$
Loamy sand	Silty slightly clayey SAND	$1x10^{-4}$ to $3x10^{-5}$
Sandy loam	Silty clayey sand	$1x10^{-7}$ to $1x10^{-5}$
Poor infiltration media		
Loam	Very silty clayey SAND	$1x10^{-7}$ to $5x10^{-6}$
Silt loam	Very sandy clayey SILT	$1x10^{-7}$ to $1x10^{-5}$
Chalk (structureless)	n/a	$3x10^{-8}$ to $3x10^{-6}$
Sandy clay loam	Very clayey silty SAND	$3x10^{-10}$ to $3x10^{-7}$
Very poor infiltration media		
Silty clay loam	--	$1x10^{-8}$ to $1x10^{-6}$
Clay	--	$< 3x10^{-8}$
Till	Can be any texture of soil described above	$3x10^{-9}$ to $3x10^{-6}$
Other		
Rock (note: mass infiltration capacity will depend on the type of rock and the extent and nature of discontinuities and any infill)	n/a	$3x10^{-9}$ to $3x10^{-5}$

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