RESERVOIR PAVEMENTS FOR DRAINAGE ATTENUATION

SUMMARY

This document provides requirements and guidance for reservoir pavements that may be used on trunk roads.

INSTRUCTIONS FOR USE

This is a new document to be incorporated into the Manual.


3. Insert HD 221/18 into Volume 4, Section 2, Part 4.

4. Please archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.
Reservoir Pavements
For Drainage Attenuation

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VOLUME 4  GEOTECHNICS AND DRAINAGE
SECTION 2  DRAINAGE

PART 4

HD 221/18

RESERVOIR PAVEMENTS FOR DRAINAGE ATTENUATION

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1. INTRODUCTION

Background

1.1 Government strategy, planning policy and legislation introduced through the Water Framework Directive (ref. 30) reflect the implications of climate change, the associated changes to flood risk and the need to address both flood risk and pollution risk to controlled waters (surface water and groundwater). Current global climate models are predicting warmer and generally drier summers and wetter winters. This suggests that flows in watercourses are likely to become lower in the summer, which will lead to a reduced dilution capacity with consequent effects on water quality. In the winter, the risk of high rainfall intensity, and hence also flooding risk will increase. It is recognised that appropriately designed road drainage can reduce both flood risk and pollution risk. Impermeable surfaces such as paved roads and parking areas are often cited as one of the major causes of storm water runoff. Water from rainstorms quickly runs off these surfaces and it can then overload the storm drain systems and waterways. Balancing ponds are often used to collect and attenuate the rate of run-off from these surfaces, but while effective, they tie up expensive land. Overseeing Organisations also have a duty under pollution protection legislation to ensure road runoff does not pollute receiving waters. Prior to undertaking drainage design, an assessment of the flood and pollution risk from highway runoff should be undertaken in accordance with HD45 (DMRB11.3.10).

1.2 The standard for the design of surface and subsurface drainage HD33 (DMRB 4.2.3) and the current suite of design Advice Notes (ref.2) provide guidance on alternative approaches to drainage design and means to address the impact of road drainage on the water environment with respect to water quality, impact on groundwater and flood risk.

1.3 Along with a number of approaches described in HA103 (DMRB 4.2.1), HA118 (DMRB 4.2.8), HA119 (DMRB 4.2.9), reservoir pavements adopt SuDS concepts which deal with runoff at source by mimicking the natural processes of redistributing rain water to surface water, to the ground and (by evaporation) to the air.

1.4 This document was produced in collaboration with the Environment Agency. Reservoir pavements are outside the remit of the Reservoirs Act.

1.5 Reservoir pavements can offer alternative drainage systems with many advantages. The risk of run-off contributing to flooding can be considerably reduced by developing systems that attenuate the water flow by first storing it in a reservoir layer beneath the pavement surface before allowing it to dissipate gradually at controlled, reduced rates into the subsoil or via discharge pipes to an outfall (which may be to surface water or via a soakaway to ground).

1.6 A number of different types of reservoir pavement structure may be constructed, depending upon a range of site specific conditions including the topography of the ground, the nature, condition and permeability of the subgrade and the sensitivity of receiving waters (both surface and groundwater).

1.7 In certain applications they may eliminate the need for kerbing, gullies, pipework and balancing ponds and require lesser land-take than many other drainage systems as significant parts of the system lie beneath the road surface. As with other buried drainage structures, designers must consider the need to accommodate other buried services when considering these systems.

1.8 Reservoir pavements are also known to attenuate pollutants associated with road runoff or can be designed to trap these pollutants. This benefit therefore supports the aims of HD 45 (DMRB 11.3.10), which provides guidance on methods to assess pollutant risks and mitigate their impacts, together with a description of the legislative setting, and roles and responsibilities of both Overseeing Organisations and...
the Environmental Protection Agencies. Where pervious\textsuperscript{1} surfaces are used, reservoir pavements may also reduce noise, glare and spray.

1.9 Special care should be taken when a reservoir pavement is constructed alongside, or in the vicinity of, a conventional pavement. Measures will be required to prevent water from the reservoir pavement entering the conventional pavement, where it will damage its structure and weaken the subgrade.

1.10 In the current situation of incomplete knowledge on design, materials, construction and performance of reservoir pavements, it is recommended that these pavements should initially be constructed in situations of low risk outside the main trafficked lanes of trunk roads. These pavements will be used to acquire information and thereby build up confidence in their performance prior to use in other situations. Although reservoir pavements may be constructed on all soil types, risk is reduced by construction on non-moisture susceptible subgrades or, possibly, on subgrades that have been rendered non-moisture susceptible by treatment such as soil stabilisation. To control risk, construction of these pavements will only be permitted following an approval of a Departure from Standards and until further experience is gained of these types of drainage system, they are not to be installed over moisture susceptible subgrades unless the approach and design is first agreed with the Overseeing Organisation.

1.11 This Document should be read in conjunction with the DMRB documents (ref. 2) listed in the Reference section.

Scope and Purpose

1.12 This document provides guidance on reservoir pavements used for drainage attenuation. Reservoir pavements may be described as a Sustainable Drainage System (SuDS) and may be considered to be one of a number of possible drainage solutions available to highway designers. Consequently, for hydraulic design, this Document should be read in conjunction with descriptions of these other solutions given in DMRB 4.2. For structural design, construction and maintenance of the road pavement, this document should be read in conjunction with the guidance given in DMRB 7.2, 7.3, 7.4 and 7.5. The design of reservoir pavements cannot be prescribed. Each situation shall be considered individually as there are many factors that should be taken into consideration. Guidance on the application, hydraulic design, structural design, construction and maintenance of these reservoir pavements is provided. Additional benefits for pollution control are outlined.

Design Policy

1.13 HD 49 Highway Drainage Design Principal Requirements (DMRB 4.2) (Ref 2) describes the policy for the selection and design of road drainage systems for sustainability and the relevant legislation. The design of drainage systems for all trunk roads and motorways in England and Wales is subject to certification and specific guidance on the certification process is given HD 50: The Certification of Drainage Design (DMRB 4.2).

Definitions, Acronyms and Abbreviations

1.14 The definitions of the various drainage asset types are contained in HD43: Drainage Data Management Systems for Highways England, (DMRB 4.2) whereas environmental definitions are contained in HD 45 Road Drainage and the Water Environment (DMRB 11.3.10).

\textsuperscript{1}In this document the term pervious pavement is used to denote any type of pavement surface that allows direct downward water infiltration – the terms porous and permeable pavement (see glossary), where used, comply to the definitions in the CIRIA SUDs Manual (ref.12).
Mutual Recognition

1.15 Where there is a requirement in this document for compliance with any part of a “British Standard” or other technical specification, that requirement may be met by compliance with the Mutual Recognition clause in G.GP 01 General information: Introduction to the FDN.

Equality Impact Assessment

1.16 An Equality Impact Assessment is not considered necessary for this document.

Application in Devolved Administration

1.17 In Northern Ireland, this Document will be applicable to those roads designated by the Department for Regional Development Northern Ireland (DRDNI).

Implementation

1.18 This Document shall be used forthwith for all schemes currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay progress. Design Organisations shall confirm its application to particular schemes with the Overseeing Organisation (see HD 33 – DMRB 4.2).

1.19 Notwithstanding the above, designers are encouraged to identify all opportunities to incorporate reservoir pavements that may be adopted as full scale trial sites and used to provide feedback to the Overseeing Organisation, increase the level of experience of the use of these types of drainage systems and lead to improvements in design advice.

1.20 The design process shall ensure that water infiltrating soil beneath a reservoir pavement, either by design or due to leaks from a tanked reservoir, does not weaken the soil beneath an adjacent conventional pavement or its overlying pavement structure.

Recording of asset inventory and condition data

1.21 Data regarding the inventory and condition of the drainage assets described in this document, and their connectivity with the rest of the drainage system, is to be uploaded and maintained in the drainage data management system described in HD 33 Chapter 10 (DMRB 4.2). This is applicable to England and Wales only; for Northern Ireland and Scotland consult the relevant Overseeing Organisation. All continuous assets must be connected to a point asset at each end, with one point defined as upstream and the other as downstream.

1.22 Reservoir pavements are recorded as point assets.

Assumptions made in the Preparation of the Document

1.23 Not applicable.

Feedback and Enquiries

1.24 Users of this document are encouraged to raise any enquiries and/or provide feedback on its contents and usage to the dedicated Highways England team. The email address for all enquiries and feedback is: standards_enquiries@highwaysengland.co.uk
2. APPLICATION AND PAVEMENT TYPES

General

2.1 In reservoir pavements, the rain percolates through pervious surface layers of the pavement, or (depending upon the design) is diverted via gullies, edge drains and pipes into a porous subbase material (reservoir). Here, water from sudden downpours accumulates before it slowly percolates into the soil subgrade or through drains into the main surface water drainage system. This process attenuates the run-off, reduces the outflow rate and thereby relieves storm water surges and reduces the risk of flooding as the result of drainage systems (both natural and man-made) becoming overloaded. Traditionally these pavements have been used for lightly trafficked areas, but, for wider application on the road network, designs of reservoir pavements are given in Chapter 6 that may be applied to more heavily trafficked roads. These pavements with only a thin bound surfacing or block paving etc., or unpaved with an unbound granular surface, can also be used in the verge and other areas that are only occasionally trafficked for temporary storage of water before its dissipation at much attenuated flow rates.

2.2 Reservoir pavement systems can also be used to filter out pollutants, and with these systems, it is also possible to incorporate interceptors, or other containment facilities, to trap accidental hazardous spillages.

2.3 To encourage the wider adoption of reservoir pavements on UK roads, Highways England has sponsored a research programme to assist the development of guidance on the use of reservoir pavements within the Highways England’s primary road network (ref. 10) with specific attention to designs for heavy traffic. This involved reviewing existing practices and the construction of short trial sections of reservoir pavement using different design configurations including sealed drainage systems and those draining into the underlying ground. The hydraulic and structural performances of these test pavements under traffic were studied to assess their potential to attenuate run-off and their suitability for inclusion in the UK primary road network. The outcomes of these studies have been used to inform this guidance note.

2.4 Unless agreed otherwise by the Overseeing Organisation, these reservoir systems are to be utilised only in the following locations:

Trafficked

- In hard shoulders of motorways (unless subject to hard shoulder running including the hard shoulder of sections of road that are in the SMART motorway programme) and central reservations, including those with concrete barriers, where moisture susceptible subgrades beneath adjacent conventional pavements constructed with dense materials are isolated from wetted subgrades of reservoir pavements.
- Parking areas including motorway service areas.
- Isolated emergency refuge areas as well as emergency access and egress areas of motorways.

Occasionally trafficked or untrafficked

- Lay-bys.
- Approaches to toll booths in occasionally or lightly trafficked areas.
- As a replacement of granular drains to avoid stone scatter.
- All occasional trafficked areas in the confines of junctions, including those areas with hatched road markings.
- Within the confines of roundabouts.
- Within verges, footways and cycleways and other non-trafficked areas.
Design configurations

2.5 There are several configurations of reservoir pavements that are available to designers. The CIRIA SUDS manual, Report C753 (ref. 13) identifies three basic configurations, each with pervious surfaces. These basic configurations may also be reproduced using conventional surfacing (asphalt or concrete) with edge drains collecting runoff for injection into the underlying reservoir layers. With suitable design, there are no constraints to the size of reservoir pavements that can range from that used in roads to extensive parking areas.

2.6 Design configurations featuring pervious surfaces are shown schematically in Annex A Figures A1 to A3 and are as follows:

(i) Reservoir Pavement Type I (equivalent to CIRIA Type A) – wherein rainfall passes through a permeable or porous surface (see Glossary), into a porous subbase (which provides the reservoir layer) and then is “discharged” by infiltration into the ground beneath (subgrade).

(ii) Reservoir Pavement Type II (equivalent to CIRIA Type B) – wherein the flow path is as above, but where the ground (subgrade) is insufficiently permeable to allow dissipation of all design storm events (i.e. there is insufficient infiltration capacity) and requires a network of perforated pipes at the base of the reservoir layer to convey discharge to a receiving drainage system. In lower permeability soils this type prevents water levels in the reservoir layer rising and causing potential stability problems in the overlying structure.

(iii) Reservoir Pavement Type III (equivalent to CIRIA Type C) – wherein there is an impermeable flexible membrane placed below and around the sides of the reservoir layer, and water that has percolated into and through this layer is discharged to a receiving drainage system by perforated pipes (or similar) at the base providing attenuation for both flow and pollution.

2.7 With both the infiltrating and under-drained options it is also possible to use conventional impermeable surfacing materials, with runoff “injected” into the reservoir layer from side drains. Design configurations are shown schematically in Annex A Figures A4 to A6 and are as follows:

(i) Reservoir Pavement Type IV – wherein road runoff enters the edge drain and is injected into the underlying reservoir layer (usually via pipes set at appropriate intervals) and then, as in Type I above, is “discharged” by infiltration into the ground beneath.

(ii) Reservoir Pavement Type V – wherein road runoff enters the edge drain, is injected into the underlying reservoir layer and as a result of low subgrade permeability, as in Type II above, requires a network of perforated pipes at its base to convey discharge to a receiving drainage system.

(iii) Reservoir Pavement Type VI – equivalent to Type III above but with injection via edge drains as with Types IV and V.

Advantages and disadvantages and typical applications (with reference to specific site conditions) are given on Table 2.
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<thead>
<tr>
<th>Reservoir Pavement Type</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Typical Applications</th>
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<tbody>
<tr>
<td>Reservoir pavements with pervious surfaces</td>
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| Type I | • Simplest, cheapest design  
• Self contained (no outlet drainage other than emergency overflows for design exceedance)  
• No land requirement adjacent carriageway  
• Only emergency outfall (for design exceedance) required | • Surfaces susceptible to blockage from silt and other road borne materials  
• Require regular inspection, intervention and maintenance to maintain pervious surfaces  
• Less durable pavement surface than Types IV to VI  
• De-icing using rock salt must be avoided due to potential blocking of pervious surface  
• Potential susceptibility to spillage which may enter directly into the reservoir  
• Increased maintenance over conventional pavement and drainage systems | • Over permeable subgrade with non sensitive groundwater  
• In trafficked areas (see Section 2.4) with low accretion of silt  
• Non trafficked areas such as laybys, footpaths and cycleways |
| Type II | • Surplus storage may be used as an in-line balancing facility  
• Minimal additional landtake (for buried pipeworks and discharge) | • As Type I above  
• Additional costs/complexity from pipeworks and outlets  
• Potential difficulties in maintenance of buried pipe systems  
• Requires downstream drainage system | • Over poorly permeable subgrade  
• In trafficked areas (see Section 2.4) with low accretion of silt  
• Non trafficked areas such as laybys, footpaths and cycleways |
| Type III | • As Type II above  
• May be used over moisture susceptible or contaminated soils, and sensitive and shallow groundwater | • As above  
• Additional costs of membranes (if installed)  
• Effective sealing of membranes | • Over barely permeable subgrade  
• Over sensitive groundwater areas  
• In areas of potential contaminant migration  
• Over moisture susceptible soils/subgrade (e.g. low strength, dissolution) |
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<tr>
<td></td>
<td>• Shallow water tables (within 1m of subbase/reservoir layer) • In trafficked areas (see Section 2.4) with low accretion of silt • Non trafficked areas such as laybys, footpaths and cycleways</td>
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<tr>
<td>Reservoir pavements with impervious surfaces</td>
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<tr>
<td>Type IV</td>
<td>• More durable, lower maintenance surfaces (than Types I-III) • Allow capture of accidental spillage (e.g. using decantation chamber in edge drains) • Self contained</td>
<td>• Increased complexity (design, construction) and costs over Type I due to additional edge drainage/ pipework • Increased maintenance over conventional pavement and drainage systems</td>
<td>• As Type I above</td>
</tr>
<tr>
<td>Type V</td>
<td>• More durable, lower maintenance surfaces (than Types I-III) • Allow capture of accidental spillage (e.g. using decantation chamber in edge drains) • May be used as an in-line balancing facility</td>
<td>• As Type II with increased complexity and cost due to additional pipework</td>
<td>• As Type II above</td>
</tr>
<tr>
<td>Type VI</td>
<td>• As Type V above • May be used over moisture susceptible or contaminated soils, and sensitive and shallow groundwater</td>
<td>• As Type III with increased complexity and cost including additional costs of membranes (if installed) • Effective sealing of membranes</td>
<td>• As Type III above</td>
</tr>
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Table 2.1: Advantages/Disadvantages and Typical Applications of Different Design Configurations

Reservoir pavement components

2.8 A reservoir pavement with a pervious surface (Reservoir Pavement Types I – III described above) typically consists, from the bottom up, of the following components:

- A trimmed subgrade that is lightly rolled to maximise infiltration.
- A porous geotextile to prevent contamination of the subbase (reservoir layer) by the subgrade. When required, an impermeable membrane can be used on the subgrade and up the sides of the subbase to form a tank.
• A subbase (reservoir layer) consisting of essentially single size coarse granular aggregate (CGA) with 30 to 40% air voids. This reservoir temporarily stores storm water while it infiltrates into the subgrade. Perforated drainage pipes may be needed in conjunction with overflow pipes.

• A blinding layer consisting of a single size aggregate about one fifth of the aggregate size of the reservoir layer. A geotextile may also be used. This stabilises the surface for the paving equipment.

• Open graded asphalt and/or cement bound layers with interconnecting voids of base, binder course and surfacing that allow water to flow through the pavement into the reservoir layer.

2.9 Where edge drains are used with impermeable surfacings (Reservoir Pavement Types IV-VI), sediments which could otherwise be introduced directly into the reservoir layer and could compromise its efficiency, shall be controlled and contained.

2.10 For pervious pavements that are designed to pass rainfall straight through their complete depth, there is no requirement for a cross-fall. It is then often practicable to design a large area of paving with a perfectly flat surface. Although a cross-fall is not required at the surface, however, experience has shown that pavements drain more efficiently and water does not stagnate when there is a slight gradient of the order of 1 percent in the subgrade (ref. 8). Therefore, on flat ground it is best to shape the subgrade; otherwise best use of natural undulations in the ground topology is advised.

2.11 Steeper slopes do not lend themselves naturally to drainage pavements of the type described above. A gradient of less than 5% is recommended (refs. 8, 20). With a higher gradient and an excessively permeable subbase, water may well up through the surface of the pavement towards the bottom of the slope. One technique for overcoming this flooding is to introduce impermeable barriers (or buffers) within the subbase layer, effectively parceling the pavement area up into smaller sections, each with its own drainage outlet. However, this approach adds considerably to design complexity and cost. Where gradients are greater than 5%, these types of drainage systems would not generally be recommended and further advice should be sought from the Overseeing Organisation at an early stage if these systems are being considered.

Use of geocellular units

2.12 In all the design configurations described above, the subbase (reservoir layer) of CGA may be replaced by proprietary geocellular units. In SuDS applications these usually comprise built up modular systems, including the cell unit(s), inspection access points, inflow/outflow pipework, interception chambers (for sediment and other pollutants) and flow controls. Manufacturers of these units provide full design guidance including information on hydraulic design and capacity (including storage capacity, flow/discharge control), layout and installation, use of geotextiles and impermeable membranes, integration with granular materials, strength and bearing capacity constraints etc. A comprehensive CIRIA guide (ref 30) has been produced for the structural design of these geocellular tank systems, and this should be referred to, however, their use on Highways England roads requires specific approval, depending on the intended use, location and design. Those systems that have attained accreditation or certification by one of the accepted United Kingdom Accreditation Service (UKAS) accredited certification bodies, as listed in Appendix B of Volume 1 of the MCHW, or alternative product conformity certification schemes subsequently accepted by the Overseeing Organisation, are more likely to be approved. One such scheme currently in use by Highways England is BBA HAPAS (Highways Authority Product Approval Scheme) or BBA R&B certification schemes. It is accepted that many such products/systems have yet to attain approval or have approval pending and these will need to be considered on their individual merits and specifications.
3. **CONTROL OF FLOODING AND POLLUTION**

**General**

3.1 Reservoir pavements capture and attenuate road runoff allowing slow release into the environment and thereby reduce flood risk. In addition they retain pollutants washed from the road surface. Unlike other systems that provide similar benefits (such as ponds or vegetated treatment systems), they require little landtake and may be fully integrated into the curtilage of the road.

**Flow attenuation**

3.2 As reservoir pavements provide storage capacity within the drainage system they may be used to attenuate the outward discharge to the receiving waters. Where this discharge is into a conventional conveyance system for discharge to a surface water outfall, the outlet from the subsurface reservoir may be throttled (through the use of small diameter pipes, orifice plates or other flow control systems) to reduce the rate of discharge. The combination of throttled discharge and subsurface storage serve to control the rapid storm discharge and high peak hydrographs typical of run-off from paved surfaces during high intensity storms.

3.3 Through designing the appropriate storage, it is possible to balance input from the design storm such that the outflow may be reduced (for a newly developed site) to a discharge rate equivalent to that of a greenfield runoff rate (typically 2-5 l/sec/Ha). This significantly reduces flood risk from road drainage outfalls. The actual rate must be agreed with the appropriate Environment Protection Agency (EPA).

**Pollution containment and control**

3.4 Collaborative research carried out for Highways England and the Environment Agency has identified the key pollutants from road runoff as:

- Sediments (and associated bound pollutants);
- Metals (zinc, copper, cadmium);
- Hydrocarbons (oil and fuel) including polycyclic aromatic hydrocarbons (PAH);

Pollutants may also be associated with maintenance activities, such as pesticides and herbicides from landscape or verge maintenance. Guidance on the assessment and mitigation of these pollutant risks is given in HD 45 (DMRB 11.3.10).

3.5 The interception of runoff by reservoir pavements may be expected to limit the direct discharge of pollutants into surface waters.

3.6 There are no documented cases of the use of pervious surfaces (and associated reservoir pavements) causing deterioration in the quality of receiving waters (ref. 11). All the evidence to date has demonstrated an improvement in water quality. Pollutants may be filtered from the percolating water. This may occur through entrapment (filtration), adsorption or biodegradation. Filtration can occur within the soil, the aggregate matrix or on geotextile layers within the construction. Adsorption occurs when the pollutant attaches or binds to the surface of soil or aggregate particles. Microbial communities can become established that biodegrade organic pollutants such as oil or grease (refs. 24, 26). A number of research studies (refs. 5, 16, 18, 21, 25 and 27) have identified the benefits of pervious and reservoir pavements in attenuating pollutants in drained water. Reductions are recorded in, for example, suspended solids, oil, copper, lead, zinc and cadmium. Chemical oxygen demand (COD) was also reduced. If pollution performance is a design criterion, then pollution performance efficiency needs to be agreed with the Overseeing Organisation and the relevant EPA.
3.7 There is less direct evidence for the pollutant attenuation effects of edge drained, injected type reservoir pavement systems (i.e. Types IV-VI). Many of the attenuation processes described above, however, will still be active when water is injected into the subbase reservoir as opposed to percolating down from the surface. In addition, edge drained, injected systems provide the opportunity to fit pollution containment within the edge drain system itself. This design might include, for example, sediment or hydrocarbon traps. With an appropriate maintenance regime, these traps will both address pollution issues and mitigate one of the more significant disadvantages of reservoir systems; their potential susceptibility to clogging by washed off sediments. Disposal of residues is discussed under section 8.14.

Groundwater recharge

3.8 Where discharge to the ground is proposed, it is important to first undertake a risk assessment to evaluate both potential risks to groundwater (for example shallow water tables, Source Protection Zones, sensitive groundwater dependant ecosystems). Groundwater risk assessment advice is provided in HD 45 (DMRB 11.3.10). The hydraulic properties of the subgrade also need to be considered with respect to potential damage to road substrates. However, where infiltration to the ground is possible, there may be considerable environmental benefits through increased recharge to local aquifers. For roads over permeable soils, this effectively mimics the natural situation maintaining the groundwater balance.
4. SELECTION OF PAVEMENT TYPE FOR A SPECIFIC SITE

General

4.1 The following aspects need to be considered for the design of a reservoir pavement drainage scheme:

- Topography of the ground.
- Limitations of the existing drainage system.
- The nature of the local rainfall and the rainfall intensity acceptable to the scheme.
- Proximity of open water.
- Characteristics of the soils – mechanical and hydraulic properties.
- Traffic to be carried.
- Consideration of porous materials available.
- Depth of layers.

4.2 In response to these various considerations, there are a number of design configurations, which can be applied to the various situations that will be encountered. The flow diagram shown in Figure 4.1 gives a sequence of decisions that may be used to establish the most appropriate design of a reservoir pavement for the circumstances being considered.
Establish construction traffic loading and select foundation class

Establish design storm, run-off rate/volume and outfall constraints

Establish topographic/environmental constraints (slope, groundwater depth and sensitivity, ground permeability, sediment sources)

Establish whether subgrade infiltration/non-infiltration types appropriate

Select direct or extended reservoir pavement

Select layer materials:
- Porous/non-porous surfacing, base materials of pavement (asphalt/concrete), reservoir materials (CGA or geocellular)
- Characterise soil and determine CBR

Select thickest requirement for reservoir from hydraulic/structural design and optimise foundation design

Determine factors of safety and needs for extreme event management (e.g. overflow/outfalls)

Select thicknesses of overlying pavement component materials for in-service traffic. Provide storage for excess water

Consider reservoir/drainage components (geotextiles/impermeable membranes, under-drainage/edge drainage methods, pollution control measures) and assess outfall rates

Check time to empty reservoir and design outfall control, when required

Establish inspection/maintenance regime

Figure 4.1 Design process flow chart
5. HYDRAULIC DESIGN PRINCIPLES

General

5.1 The design of pervious pavements is more advanced in France and a comprehensive design manual was produced in 1999 by CERTU – Centre d’Etudes sur les Reseaux les Transport, l’Urbanisme et les Constructions Publiques – (ref. 8). That design guide deals with the use of asphalt, concrete and concrete paving blocks and covers most aspects relating to pervious pavements. In the USA pervious pavements have been in use since the late 1960s and there are a few state highways that have pervious construction. NAPA – National Asphalt Pavement Association – (ref. 20) produced a design guide in 2008, but this only deals with lightly trafficked areas. However, in the USA it is recognised that there are considerable environmental benefits in extending the technology to carry heavy traffic and Delatte (ref. 15) has proposed a design methodology for heavy trafficked porous concrete pavements. In the UK, CIRIA Report C582 (ref. 11) provides guidance on the use of pervious surfaces for SuDS and the CIRIA SUDS manual, Report C753 (ref. 13) also provides design guidance for pervious pavements, although this is largely focussed on lightly trafficked areas, car parks etc. A number of design manuals are also available. The majority of these are manufacturer’s instructions and recommendations for their proprietary systems and the Trade Association Guide. They mostly deal with permeable pavements comprised of concrete block paving and porous pavements for lightly trafficked applications.

5.2 Although these guides are mostly focussed on lightly trafficked roads, the hydraulic design principles remain the same. The hydraulic design of porous asphalt, concrete or concrete block pavements is essentially identical and therefore the following applies to any type of pervious pavement. The design of a pervious pavement should consider many factors. The three primary considerations are the amount of rainfall expected, pavement characteristics, and underlying soil properties.

5.3 Where surface water channels, pipework and other more conventional components are incorporated into these drainage systems (for example where using reservoir pavements for flow attenuation in an otherwise conventional system), then advice provided in HD33 (DMRB 4.2.3) and associated documents must be followed in addition to other HA standards for structural design that may include HD26 (DMRB 7.2.3), HD27 (DMRB 7.2.4) and IAN 73 (ref. 2). Proprietary edge channel systems design for use with geocellular systems should be designed in accordance with the manufacturer’s guidance, as these may not follow design procedures according to conventional edge drainage. Any such approach must first be discussed with the Overseeing Organisation.

5.4 Design storms for drainage systems are identified in HD33 (DMRB 4.2.3).

5.5 The return periods of the storms identified in HD33 (DMRB 4.2.3) are intended for positive drainage systems and may not be wholly appropriate for the design of reservoir pavements. Guidance by CIRIA in Reports C582 and C753 (refs. 11 and 13) suggests at minimum a 1:10 year design storm. For the purposes of this advice note, a design storm of 1:10 years is adopted, which is also in line with the 1 in 10 year design storm used in soakaway design of HA118 (DMRB 4.2.8).

5.6 The key hydraulic design processes for reservoir pavements are:

- Confirmation of adequate rate of infiltration through the pervious surface (Types I-III only).
- Determination of the storage capacity required to manage the design storm.
- Determination of the outlet capacity and approach (either by infiltration into the soil or by provision of subsurface drainage pipes or a combination of these methods)
- Management of extreme events (in excess of the design storm).

A worked example of the design process is provided in Section 9.
Infiltration through the Surface

5.7 For pervious pavements, the rate of infiltration through both the surface layer, which may be porous asphalt, porous concrete or permeable concrete blocks (the latter in lightly trafficked areas), and the underlying foundation must be checked to ensure that they can accommodate the design storm rainfall. Values of infiltration rates of pervious surfaces comprised of porous asphalt and block paving given in the literature are recorded in Table 5.1. The infiltration rates are significantly in excess of a high 1 in 10 year storm intensity (of the order 100’s mm/h). For design, it is normal practice to allow for a 90% loss in surface permeability due to clogging of the pervious surface (CIRIA C582, ref. 11). Designers must demonstrate that the pervious surface used exceeds these requirements.

<table>
<thead>
<tr>
<th>Surfacing</th>
<th>Infiltration rate (mm/h)</th>
<th>Typical 1 in 10 year storm (mm/h)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Typical</td>
<td>Design(^3)</td>
<td></td>
</tr>
<tr>
<td>Porous asphalt</td>
<td>&gt; 10,000(^1)</td>
<td>&gt; 1,000</td>
<td>Aggregate Industries</td>
</tr>
<tr>
<td></td>
<td>10,000(^1) to 39,000(^2)</td>
<td>1,000 to 3,900</td>
<td>CIRIA C582 (2002) (ref. 11)</td>
</tr>
<tr>
<td>Concrete block paving</td>
<td>4,000(^1)</td>
<td>400</td>
<td>CIRIA C753 (2015) (ref. 13)</td>
</tr>
<tr>
<td></td>
<td>1,000 to 5,000(^1)</td>
<td>100 to 500</td>
<td>CIRIA C582 (2002) (ref. 11)</td>
</tr>
</tbody>
</table>

\(^1\) New.
\(^2\) This exceptionally high rate is quoted in C582 for measurements taken in Nottingham for a porous asphalt comprising 10 mm gap graded aggregate and is a mean value after 4.5 years with no maintenance.
\(^3\) Design values of infiltration rate are 10% of typical infiltration rates.

Table 5.1: Rates of water infiltration through various surfacings

Surface runoff from “impermeable” surfaces to edge collector drains.

5.8 Where test data suggest that spare drainage capacity is available, reservoir pavements may be used to drain a larger area than that of the immediately overlying roadway; that is, taking drainage from adjacent pavement with an impermeable surfacing. These pavements are referred to as “extended” reservoir pavements (as opposed to “direct” systems, which drain only the overlying pavement). Extended systems may utilise the pervious surface of the reservoir pavement, although the additional sediment generated by this extended surface should be taken into account. Interpave (ref. 17) suggests that the ratio of impermeable to permeable surface should be no greater than 2:1. Such extended systems may be more suitable for “injected” reservoir pavement types (Types IV-VI), where separate silt/sediment control is available. It is important that this additional drainage does not include areas that could generate large amounts of sediment, for example runoff from embankments or verges.

Use as attenuation storage

5.9 Spare storage capacity within the reservoir pavement, may also be used as an attenuating facility within a larger main surface water drainage system, by diverting runoff from elsewhere into the reservoir layer (either acting as an in line balancing facility or as a “supplementary” soakaway). This configuration can work well with very porous, non-moisture susceptible subgrades.

5.10 A subsurface reservoir may also be used in verges or in other off line locations to provide flow and pollutant attenuation in an otherwise conventional drainage system. Strictly speaking these are not reservoir pavements as verge locations would not be subject to the same structural loadings as trafficked pavements, and structural design requirements would be site specific. Hydraulic design would in this case
be determined by the inflow from piped systems and outflow either by infiltration or by discharge from pipework. The discharge may be throttled by flow controls to meet specific discharge rate requirements. Geocellular systems are particularly suited to these types of applications, and examples have already been approved for use on the M25. A conceptual design showing a typical arrangement of such a buried attenuation structure is provided on Figure 5.1. In either approach to attenuation storage, appropriate measures to control and contain the movement of sediment to the reservoir will be required.

Subsurface storage capacity

5.11 To balance inflow into the subsurface reservoir and the rate of discharge out of the system, it is necessary to store the water temporarily. This requirement may either be because of constraints from the natural infiltration rate into the subgrade (as identified by site specific infiltration tests) or due to requirements to limit the discharge rate into a receiving system, whether this flow is to an existing drainage system or a natural water course.

The first part of this process is to determine the storage volume required for the retention of water generated by the design storm. The internal storage volume, and thus thickness of the storage layer (which depends on the void ratio), is calculated from the steady state mass balance of inflow and outflow from the pavement, i.e.

\[
\text{Storage volume} = \text{Volume of rainfall during storm} - \text{Volume of outflow during storm}
\]

For a reservoir pavement system that allows infiltration out of the bottom of the reservoir, the method of determining the required storage volume for plane infiltration systems given in CIRIA Report 156 (ref. 12) may be used. For systems with a piped discharge, the guidance in CIRIA Report C582 (ref. 11) notes that there is insufficient information available to model accurately the internal flow and storage properties within the subbase and therefore no allowance need be made for any outflow during the storm, when calculating the storage volumes with piped outflows. Making no allowance for this outflow will lead to an overestimate of the required storage capacity. However, practical experience suggests that discharge pipe systems can easily accommodate the required flow rate and that they need to be throttled to meet outflow discharge restrictions. Designers may therefore allow for outfall discharges in the calculation of required storage capacity at up to the agreed greenfield runoff rate if it can be demonstrated that the piped discharge systems are able to fully drain the reservoir storage volume (i.e. the location of the outlet will allow complete drainage to the base of the reservoir layer).

5.12 The method of calculating volume given in CIRIA Report 582 (ref. 11) is given below:

The required input parameters for infiltration systems are:

\[
\begin{align*}
q &= \text{Infiltration coefficient of the subgrade from percolation tests (m/h) – determined by following procedure in CIRIA report 156 (ref. 12).} \\
Ad &= \text{Total pavement area (m}^2\text{) to be drained including any impermeable areas adjacent to the reservoir pavement.} \\
n &= \text{Porosity of subbase material.} \\
i &= \text{Rainfall intensity (m/h)} \\
D &= \text{Rainfall duration (h)} \\
Ab &= \text{Base area of infiltration system beneath reservoir pavement (m}^2\text{).}
\end{align*}
\]

For internal storage, the maximum depth of water (hmax) that will occur in the subbase is based on:

\[
h_{\text{max}} = (R_i - q).D/n
\]
Where, $R = \text{ratio of the drained area to base area of reservoir pavement, } \frac{A_d}{A_b}$.

The calculation is carried out for a range of storm durations (15min, 30min, 60min etc.) for the 1 in 10 year design storm return period, to determine the maximum value of $h_{\text{max}}$. This value is then the required minimum thickness of the subbase for storage. (Note depths for structural requirements and resistance to freezing will also need to be taken into account).

For piped outflows the calculation is simplified to:

$$h_{\text{max}} = (R_i)D/n$$

The calculation is simply carried out for the required design period and range of storm durations.

5.13 In order to accept subsequent storms, the design must ensure water held in storage under the design storm should empty from full capacity to 50% or less within 24 hours, but without exceeding the discharge limits.

5.14 Notwithstanding the need for overflow facilities where the design storm is exceeded (see Section 5.20), where infiltration forms the sole discharge (i.e. there is no supplementary drainage), a factor of safety should be introduced – i.e. assuming a reduced infiltration rate. For the purposes of this document a factor of safety of 10 is to be used, (i.e. the measured subgrade infiltration rate used in the above calculations should be divided by 10). This is in line with CIRIA 156 (ref.12), which allocates factors of safety based on the level of confidence in the adopted design parameters. These include uncertainties in the field testing for determining infiltration rate as measured using methods described in CIRIA 156 (ref.12) and the potential for infiltration rate to decline with time. The factor of safety also allows for the consequences of failure, which is deemed to be significant in the case of road drainage. The suggested factor of safety is not based on specific studies or historic data and relies on engineering judgement, but should be adopted until greater experience and feedback is gained with the design of these systems.

5.15 Single sized unbound aggregates (larger than 2.5 mm) with high voids content will hold water internally. The storage volume should be increased by 30% to allow for any ice formed in cold conditions to expand into the free space without disturbing the structure. The CERTU (ref. 8) design guide recommends that a minimum thickness of 350 mm be used to ensure that there is sufficient reserve capacity, even for more arid areas. Should the thickness resulting from the structural design exceed the storage requirement, then the structural design thickness should be used in preference.

Outflow from subsurface structure

5.16 Infiltration of water into the subgrade depends on the properties of the soil. Permeability of the order of $5 \times 10^{-6}$ m/s will allow water to seep into the soil. For any permeability lower than this value and the discharge component from infiltration is likely to be insufficient and underdrained and piped systems will be required.

Infiltration into the subgrade is important for both direct and extended systems. Estimating the infiltration rate for design purposes is imprecise, and the actual process of soil infiltration is complex. A simple model is generally acceptable for these applications, and initial estimates for preliminary designs can be made with satisfactory accuracy using conservative estimates for infiltration rates. Where ground/subgrade conditions are particularly variable, there may be no option other than to undertake in situ infiltration tests using CIRIA 156 (ref. 12) as described above. Once the final design process is underway in situ measurements of infiltration rate must be undertaken at the proposed location.

Guidance on the selection of an appropriate infiltration rate to use in design can be found in the literature. For example, Table 5.2 gives ranges of hydraulic conductivity of soils reproduced from Interpave 2010 (ref. 17).
### Soil Classification

<table>
<thead>
<tr>
<th>Soil Classification</th>
<th>Typical range of hydraulic conductivity $k$, (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy clay</td>
<td>$10^{-10}$ to $10^{-8}$</td>
</tr>
<tr>
<td>Silty clay</td>
<td>$10^{-9}$ to $10^{-8}$</td>
</tr>
<tr>
<td>Sandy clay</td>
<td>$10^{-9}$ to $10^{-6}$</td>
</tr>
<tr>
<td>Poorly sorted$^1$ sand</td>
<td>$5 \times 10^{-7}$ to $5 \times 10^{-6}$</td>
</tr>
<tr>
<td>Well sorted$^1$ sand</td>
<td>$5 \times 10^{-6}$ to $5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Well sorted$^1$ sandy gravel</td>
<td>$10^{-5}$ to $10^{-3}$</td>
</tr>
</tbody>
</table>

$^1$ A poorly sorted soil contains an assortment of particles covering a wide range of grain sizes which reduce permeability through restriction of pore spaces and interconnectivity, whereas a well sorted soil has particles that are more uniform in size.

### Table 5.2: Soil Classification (adapted from Interpave, 2010)

5.17 Whereas the conventional approach to pavement design is to protect the subgrade from ingress of water to the maximum extent possible, a drainage pavement deliberately permits water to come directly into contact with the subgrade. The only exception is for those situations when the subgrade is to be protected by an impermeable membrane. The mechanical properties of the subgrade required for pavement design are therefore those relating to a wetted condition. In the case of very lightly loaded pavements (pedestrian areas, car parks), this will generally not be a significant factor, but in more heavily loaded cases it is clearly a key design issue (See Chapter 6).

### Outlets to piped drainage or to natural water courses

5.18 Where the reservoir is discharged via pipes to an existing piped drainage system or piped to a natural water course, there may be constraints on the rate of discharge. The actual outflow rate should be controlled as follows:

- To less than, or equal to, the original runoff rate for newly developed areas.
- To less than the capacity of the downstream network.

5.19 If the maximum discharge rate from the reservoir is higher than that required to protect the downstream network, then a suitable throttle, with associated bypass or overflow, must be provided. The use of robust and simple control devices is preferred; for example, throttle pipes. Where the discharge is to a natural watercourse the outflow should be limited to greenfield runoff rates (see Section 3.3).

### Design exceedance events

5.20 Additional overflows and outlets will be required for extreme events, which are in excess of the design storm and may cause backing up of water within the reservoir pavement. Without these emergency outlets, this excess water may possibly compromise the integrity of the surface of the pavement or, at worse, its entire structure. Any water from emergency overflows and outlets must be routed safely to avoid flooding the road and also must not impact upon the land of third parties adjacent to the Highway.

### Sediment deposition

5.21 Although reservoir pavements entrap sediments and the contained pollutants, silt and particulates also cause the most significant drawback with these systems in that they are susceptible to clogging. The pores in a pervious surface can be clogged and / or sediment can be deposited within edge drains and channels. Site selection should therefore take this problem into account. HA 219 (DMRB 4.2.4), in giving guidance on the assessment of sediment deposition to aid pipeline design, predicts sediment load for a section of road that takes account of adjacent land use, geographical location, road size by number of lanes and
profile or whether the road is level, in cutting or on embankment. Such a prediction could be used with local factors to guide the likely severity of sediment deposition for a particular location. A site will be unsuitable for a pervious pavement where a significant sediment load is likely to be washed onto its surface.

5.22 With appropriate sediment control, edge drained injected systems may be able to handle more significant sediment loads, but only if sediment may be trapped (and as importantly, removed) prior to injection of water into the subsurface reservoir. Any such systems would require the development of a site specific and well managed maintenance regime. Where possible, grassed verges, landscaped ground etc. should slope away from the reservoir pavement and soils should be at least 50mm below kerbs at the edge of the reservoir pavement as advised in CIRIA C753 (ref.13). Where verges drain toward the reservoir pavement, these areas should be well vegetated or stabilised so that silt and sediment mobilisation is minimised. During construction, additional measures to trap sediment may be required before the vegetation is fully established.
Typical Arrangement of On-line Buried Attenuation Storage Structure using Geocellular Storage

NOTES:
1. The cell storage modules to be suitable for installation in trafficked locations and subject to approval by the overarching organisation.
2. The jointing and arrangement of the cell storage modules shall be in accordance with the recommendations of the manufacturer.

Flow control device (not shown) within outlet chamber
Sub-surface storage in geocellular units

Figure 5.1
6. STRUCTURAL DESIGN PRINCIPLES

General

6.1 Reservoir pavements in the UK have been used for lightly trafficked areas such as parking areas or small estate roads. However, internationally, their use is being more widely adopted. In France, asphalt, reservoir pavements are used on moderately trafficked roads that are designed to carry cumulative traffic of just over 2 msa\textsubscript{150} and porous concrete, reservoir pavements for cumulative traffic loads of up to 6 msa\textsubscript{130}. France uses a 130 kN axle load as the reference for pavement design purposes, whereas in the UK an 80 kN axle load is used. In UK terms, using the fourth power loading equivalency factor, the French designs can be estimated to cover the traffic range of about 15 to 40 msa\textsubscript{80}.

6.2 The various designs of reservoir pavements are schematically illustrated in Appendix A. The standard structural design examples given in this section are for a flexible pavement that incorporates porous concrete as a lower base of the pavement as this structure is considered more likely to provide roads for moderately heavy traffic. Guidance for pavement designs for other hydraulically bound lower base materials and for flexible pavements with porous asphalt lower base are given under Alternative designs (See 6.23 to 6.46).

6.3 The standard structural designs for a flexible pavement with a porous concrete base on an unbound granular subbase are derived from HD26 (DMRB 7.2.3). Initially the foundation is designed for the envisaged CBR (California Bearing Ratio) strength of the subgrade. For a given design traffic, the thickness of the concrete base is dictated by the quality of the foundation and the design traffic. The thickness of the asphalt surfacing is solely dependent on the design traffic.

Standard designs

Subgrade

6.4 Current design practice uses the CBR of the underlying subgrade. The conventional approach to pavement design is to protect the subgrade from ingress of water. A reservoir pavement, however, can deliberately permit water to come into contact with the subgrade. In this case, the CBR of the subgrade required for pavement design is therefore the value that relates to this wetted condition. Soaked CBR tests should be carried out on soil representative of the \textit{in situ} compacted condition of the subgrade to provide guidance.

6.5 The other property of the subgrade, which is of key importance, is its permeability. The permeability of the subgrade will affect the decision as to whether positive drainage is required at some level in the pavement because a highly impermeable soil will never be able to absorb a significant percentage of the incident rainfall. A minimum subgrade permeability of 5x10^{-6} m/s is currently recommended.

6.6 Where natural vertical drainage into the subgrade is unlikely or undesirable, it is possible to place an impermeable membrane on the surface of the subgrade. The pavement will then require a positive drainage system to take water out of the reservoir layer. The CBR of the subgrade for pavement design can therefore be higher than the value that is applicable to the subgrade when used to drain infiltrated water.

6.7 The long-term CBR value of a particular soil subgrade during the reservoir pavement’s service life is dependent on whether, or not, the soil is regularly wetted by the infiltration of water from the subbase reservoir. The value used in design is the lower of the construction CBR and this long-term CBR of the soil subgrade. Guidance on its determination is given in IAN 73 (ref. 2) and HA44 (DMRB 4.1.1) with modifications, when necessary, as a result of the wetting of the subgrade by infiltrated water.
Membranes

6.8 In many cases water can be allowed to percolate into the subgrade. But, where the subgrade has a high silt and/or clay content and where traffic levels are significant, there is the danger that the porous subbase can be contaminated by subgrade material rising up through the subbase. This problem can be avoided by placing a permeable membrane on the subgrade. The membrane should have an adequate permeability that is greater than that of the underlying soil to allow for the effect of fine material washed down through the pavement.

6.9 When infiltration of water into the subgrade is not permissible, the membrane should be impermeable and all joints suitably overlapped and welded.

6.10 If a membrane is used, it should be tough enough to avoid ripping under the impact of sharp stones within the subbase, principally during compaction of the subbase layer.

Subbase reservoir and foundation design

6.11 The subbase is normally a structurally significant layer that provides a working platform on which materials can be transported, laid and compacted. In a conventional pavement, unbound granular Type 1 subbase is often used. This is a continuously graded, dense material that has a low permeability when well compacted. In a reservoir pavement, however, the subbase is used to temporarily store heavy rainfall. This function requires the granular subbase to be designed with a high air voids content so that the quantity of water anticipated from a heavy storm can travel freely through this layer and also be stored without saturating the subbase. This behaviour can be achieved by removing the fine fraction from granular subbase to produce a material with air voids content in the 30 to 40% range and by building the subbase sufficiently thick. The subbase should be well compacted so that the high voids content is a result of the design grading and not under-compaction.

6.12 To ensure the stability of a reservoir layer of an open graded, unbound granular subbase, the French guide by CERTU (ref. 7) specifies that the ratio of the maximum to minimum stone size should be greater than 3. Cedergren (ref. 6) also proposes that the 85 percentile, aggregate size shall be at least 4 times the 15 percentile size and that no more than 2% of the aggregate should pass a 2.54 mm sieve.

6.13 When large sized granular materials are used in the granular subbase, the surface may not be stable or smooth enough to permit trouble-free construction of the bound base layer. In these instances, a blinding layer of smaller sized aggregates can be racked-in and compacted. The thickness of the main reservoir layer can be adjusted to accommodate this blinding layer.

6.14 It is recommended that a minimum thickness of 350 mm be used to ensure that there is sufficient reserve water storage capacity. Should the thickness resulting from the structural design exceed the storage requirement, then the structural design thickness shall be used in preference.

6.15 The foundation is designed to a chosen foundation class, following the selection of the type of reservoir pavement and whether the subgrade CBR strength is to be based on a wetted state or one protected from infiltrated water. Guidance is given in IAN 73 (ref. 2) with further explanation in Chaddock and Roberts (ref. 9). A foundation that is no better than Class 2 is provided by an unbound granular material.

Porous asphalt and concrete layers

6.16 The bound upper layers of a reservoir pavement comprise a surfacing on an optional binder course over a structural base. The surfacing of reservoir pavements can comprise either porous asphalt for Reservoir Pavement Types I to III or conventional impermeable asphalt for Types IV to VI. For the standard designs,
the lower bound layer is specified as porous concrete. This requirement is maintained for pavements with conventional impermeable surfacings to permit reserve water storage for extreme rainfall events. Guidance on the use of these materials can be found in the relevant HA design advice or, for unspecified specialist porous materials, from manufacturers. The air voids content of the porous asphalt and porous concrete base layer shall be at least 15% to ensure adequate permeability of these materials. Any materials that are not specified in the standards of the Overseeing Organisation will require specific approval for use.

6.17 It is recognised that porous pavement materials have inferior structural properties compared with conventional dense asphalt and concrete.

6.18 Although porous concrete is weaker than traditional pavement quality concrete, its strength is comparable to the cement bound granular material (CBGM) grades used in UK flexible pavements with CBGM bases. The combination of the good load spreading ability of porous concrete and the smooth running surface of asphalt is considered to offer the best potential for reservoir pavement construction for the heavier traffic applications.

6.19 Cracks in CBGMs occur soon after laying as a result of its shrinkage during curing and thermal contraction at night as road temperatures fall. Cracks can appear at the surface of the asphalt a number of years later as reflection cracks. CBGMs are often pre-cracked to inhibit the development of these reflection cracks. A porous concrete base layer is assumed to develop a regular pattern of transverse cracks in a similar way to CBGMs. Therefore, for porous concrete of compressive strength at 7 days of 10 MPa or greater, the Specification 800 Series (MCHW 1) requires the porous concrete to be similarly pre-cracked.

**Layer thickness design of the Standard flexible pavement with porous concrete base**

6.20 The design thicknesses of the porous concrete base and overlying asphalt are based on HD26 (DMRB 7.2.3). Designs for pavements to carry between 10 and 80 msa80 are given in Table 6.1. Designs for other levels of traffic can be similarly derived using HD26 (DMRB 7.2.3). Designs for higher levels of traffic are not currently permitted. When porous asphalt replaces dense asphalt, the thicknesses of porous concrete base, given in Table 6.1, are to be increased by between 5 mm for pavements of design traffic 10 msa and 10 mm for pavements of design traffic 80 msa.

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Coefficient of thermal expansion (1/°C)</th>
<th>Design traffic</th>
<th>Porous concrete of strength class:</th>
<th>Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>80 msa80</td>
<td>C8/10</td>
<td>C12/15</td>
</tr>
<tr>
<td>Crushed rock</td>
<td>&lt; 10x10^-6</td>
<td>210</td>
<td>180</td>
<td>150</td>
</tr>
<tr>
<td>Gravel</td>
<td>≥ 10x10^-6</td>
<td>250</td>
<td>210</td>
<td>180</td>
</tr>
<tr>
<td>Crushed rock</td>
<td>&lt; 10x10^-6</td>
<td>200</td>
<td>170</td>
<td>150</td>
</tr>
<tr>
<td>Gravel</td>
<td>≥ 10x10^-6</td>
<td>240</td>
<td>200</td>
<td>170</td>
</tr>
<tr>
<td>Crushed rock</td>
<td>&lt; 10x10^-6</td>
<td>180</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Gravel</td>
<td>≥ 10x10^-6</td>
<td>215</td>
<td>180</td>
<td>150</td>
</tr>
<tr>
<td>Crushed rock</td>
<td>&lt; 10x10^-6</td>
<td>165</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Gravel</td>
<td>≥ 10x10^-6</td>
<td>200</td>
<td>165</td>
<td>150</td>
</tr>
</tbody>
</table>

Table 6.1: Selected designs for a flexible pavement with porous concrete base under dense asphalt
Maintenance

6.21 Porous asphalt surfacing is permissible only by a specific Departure from Standards. The benefits of its porosity are short lived, unless it is maintained regularly to remove detritus clogging the pores in the surfacing. Traditional “impermeable” asphalt surfaces are also more durable than porous asphalt surfacings. Maintenance operations will require careful attention from Network Managers to ensure porous asphalt surfacing is regularly cleaned. Porous asphalt will also need replacing more frequently and may be more expensive than conventional thin surfacing.

6.22 Adequate overflow drainage for the reservoir is required to prevent damage by loading a pavement whose reservoir is full.

Alternative designs

6.23 The Standard structural pavement designs in Paragraph 6.20 for flexible pavements with porous concrete as base that were derived from HD26 (DMRB 7.2.3) are based on the analytical design method of Nunn (ref. 22). Designs for pavements with other hydraulically bound materials as base can also be derived by this analytical method. The designs, however, should be justified by laboratory testing and in situ trials. The analytical method of Nunn (ref. 22) can also be used to design flexible pavements with asphalt bases. These pavements can either just incorporate porous asphalt in the base for water storage with an impermeable asphalt surfacing or comprise porous asphalt in both the base and, despite the maintenance liability, the surfacing.

6.24 Since the methodology described in Nunn (ref. 22) was developed, the following changes have taken place:

- Harmonisation of European Standards in 2006 that required changes in material composition and designation.
- Revision in 2006 of HD 26 (DMRB 7.2.3) that redefined the standard UK pavement materials.

As a result of these changes, it is best to use the methodology in Nunn (ref. 22) to formulate future design proposals with the following sections as a guide.

Subgrade

6.25 Experience from evaluation of conventional pavements shows that if water is allowed to gain access to the subgrade, for example where serious cracking of the surfacing has occurred, then subgrade CBRs can typically be much lower than where water did not penetrate. Reservoir pavements therefore have to be designed with a lower than usual CBR value in all cases other than for highly permeable, non-moisture susceptible subgrades or where an impermeable membrane is used. Because no absolute rule exists as to the degree of reduction in CBR by infiltrated water, soaked CBR tests should be carried out on soil representative of the in situ compacted condition of the subgrade to provide guidance. In the case of very lightly loaded pavements, this potential weakening of the subgrade will generally not be a significant factor, but, in more heavily loaded cases, it is clearly a key design issue.

6.26 Guidance on the typical ranges of hydraulic conductivity expected for different types of soil can be found in Section 5. Natural soils in the UK can vary in hydraulic conductivity over a very wide range, from about $10^{-3}$ m/sec ($10^{-1}$ cm/sec) for some gravels to as little as $10^{-10}$ m/sec ($10^{-8}$ cm/sec) for high plasticity clays. A minimum value of $5\times10^{-6}$ m/s is currently recommended, which by reference to Table 5.2, implies subgrades that are primarily comprised of sands or gravels. Other subgrades comprised of a mixture of soil types may be suitable to drain water if they contain interconnected drainage paths and can be identified by in situ permeability tests. The hydraulic conductivity of the soil will therefore dictate the degree to which the soil subgrade will be wetted when exposed to infiltrated water, that will, in turn, effect the design CBR of moisture susceptible soils.
Subbase reservoir and foundation design

6.27 The subbase reservoir can comprise open graded, and therefore porous, unbound granular materials or hydraulic bound materials.

6.28 The design methodology for reservoir pavements is identical to that described in TRL Report 615 by Nunn (ref. 22) for the design of flexible pavements with asphalt or hydraulically bound mixture (HBM) bases, which were previously called flexible and flexible composite pavements respectively. In that approach, the road foundation is categorised in terms of foundation stiffness classes. These classes are defined in terms of the long-term, equivalent half-space stiffness of the composite foundation as follows:

- Class 1 ≥ 50 MPa
- Class 2 ≥ 100 MPa
- Class 3 ≥ 200 MPa
- Class 4 ≥ 400 MPa

6.29 A class 2 foundation was designed to be equivalent to the previous standard foundation of 225 mm of Type 1 subbase on a subgrade with a CBR of 5%. The Class 1 construction platform is applicable to construction on a capping layer and Class 3 and 4 foundations will involve bound subbases. Design guidance for road pavement foundations is contained in Interim Advice Note IAN 73 (ref. 2) and in TRL Published Report PPR 127 by Chaddock and Roberts (ref. 9).

6.30 The foundation classes for reservoir pavements that involve subgrade infiltration and unbound granular subbases will generally be Classes 1 or 2. For example, a foundation that consists of about 400 mm of unbound granular material on a subgrade with a CBR of 2.5% could produce a Class 1 or Class 2 foundation dependent on the quality of the unbound granular material. Foundation Classes 3 or 4 could be attained by constructing the subbase reservoir layer with a lower grade, porous concrete and/or by stabilising the subgrade. Although soil stabilisation would make the subgrade less moisture susceptible, it may also make it less permeable. The balance between adequate soil strength for structural performance and sufficient infiltration of water into the soil for attenuation of storm water would then need to be considered.

6.31 Plastic geocellular units can be used for the reservoir layer as an alternative to granular material. These structures are proprietary systems in which the units can be keyed together laterally and vertically, if required, to form a thicker layer. The advice of the manufacturers should be sought for the design and construction of reservoir pavements incorporating these systems. Their use on Highways England roads requires specific approval that depends on their intended use, location and design and whether there is evidence of satisfactory performance for similar conditions and levels of traffic.
Porous asphalt and concrete layers

6.32 As shown in Table 6.2, porous asphalt has about a half to a third of the stiffness of heavy duty macadam (HDM).

<table>
<thead>
<tr>
<th>Material</th>
<th>Dynamic Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard values used in UK pavement design prior to the 2006 edition of HD 26 (DMRB 7.2.3)</td>
<td></td>
</tr>
<tr>
<td>Dense bitumen macadam (DBM100)</td>
<td>3.1</td>
</tr>
<tr>
<td>Hot rolled asphalt (HRA50)</td>
<td>3.5</td>
</tr>
<tr>
<td>Dense bitumen macadam (DBM50)</td>
<td>4.7</td>
</tr>
<tr>
<td>Heavy duty macadam (HDM50)</td>
<td>6.2</td>
</tr>
<tr>
<td>Thin surface course system (TSCS)</td>
<td>2.0</td>
</tr>
<tr>
<td>Porous asphalt (PA)</td>
<td>2.0*</td>
</tr>
</tbody>
</table>

* Value in common use

<table>
<thead>
<tr>
<th>Standard values currently used in UK pavement design following the 2006 edition of HD 26 (DMRB 7.2.3)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DBM125</td>
<td>2.5</td>
</tr>
<tr>
<td>HRA50</td>
<td>3.1</td>
</tr>
<tr>
<td>DBM50/HDM50</td>
<td>4.7</td>
</tr>
<tr>
<td>EME2</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Table 6.2: Comparison of the dynamic modulus of porous and dense graded asphalt

6.33 The advice that is applicable to alternative and standard designs is based on Nunn (ref. 22). In that report, the material designations refer to the traditional UK national specifications used prior to 2004. The approach described by Nunn (ref 22) has been adopted in the following sections using design stiffness values and terminology that was applicable at the time that report was published.

6.34 It should be noted that European terminology is now applicable and BS EN 13108-1 (ref 3) requires that asphalt mix designation consist of four sections: i) mixture type – ii) upper aggregate sieve size in mm – iii) layer type – iv) binder grade. For example, dense asphalt concrete with maximum aggregate size 20 mm for binder course with paving grade bitumen, grade 100/150 is designated as “AC 20 dense bin 100/150”. This description would have been previously designated as “0/20 mm DBM 125 binder course” or “0/20 DBM 125”, or similar.
6.35 European specifications for hydraulically bound materials are now also applicable and therefore the use of the traditional materials should be related to material covered with the European specification. Nunn (ref. 22) give designs for cement bound material bases (CBM grades: CBM3, CBM4 and CBM5). The use of these types of material are now covered by EN 14227 Part 1 (ref. 3) and are referred to as Cement Bound Granular Material (CBGM). Equivalence between these two systems of characterisation, shown in Table 6.3, is described in Appendix E of the report by Nunn (ref. 22). The European specifications make no distinction between the thermal properties of the aggregates used in CBGM. These properties, however, remain an important part of the design process. Therefore, for a given strength class, the type of aggregate used (gravel – G and crushed rock – R) should still be declared for design as shown in Table 6.3.

<table>
<thead>
<tr>
<th>Traditional Material Class</th>
<th>CBGM Strength Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMB3(G)</td>
<td>C8/10(G)</td>
</tr>
<tr>
<td>CMB3(R)</td>
<td>C8/10 (R)</td>
</tr>
<tr>
<td>CBM4(G)</td>
<td>C12/15(G)</td>
</tr>
<tr>
<td>CBM4(R)</td>
<td>C12/15(R)</td>
</tr>
<tr>
<td>CBM5(G)</td>
<td>C16/20(G)</td>
</tr>
<tr>
<td>CBM5(R)</td>
<td>C16/20(R)</td>
</tr>
</tbody>
</table>

Table 6.3: Design classifications

6.36 The UK analytical design method of Nunn (ref. 22) uses the structural properties of hydraulically bound material at 360 days rather than 28 days that were used previously. For conventional CBMs the 360 day compressive strength of CBM is about 25% higher than the 28 day strength. For faster curing porous concrete this relationship may not apply and it should be assumed that no further strength gain occurs after 28 days.

6.37 Guidance on the properties of grades of cement bound materials (CBMs) with gravel aggregate (G) and porous concrete is given in Table 6.4 for an age of 28 days.

<table>
<thead>
<tr>
<th>Material</th>
<th>Compressive Strength (MPa)</th>
<th>Flexural Strength (MPa)</th>
<th>Dynamic Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBM3G</td>
<td>12.5</td>
<td>1.38</td>
<td>30.3</td>
</tr>
<tr>
<td>CBM4G</td>
<td>18.75</td>
<td>2.06</td>
<td>36.1</td>
</tr>
<tr>
<td>CBM5G</td>
<td>25</td>
<td>2.75</td>
<td>40.3</td>
</tr>
<tr>
<td>Porous concrete (range)</td>
<td>3.5 to 28*</td>
<td>1.0 – 3.8*</td>
<td>25 to 45**</td>
</tr>
<tr>
<td>Porous concrete (typical)</td>
<td>17.0*</td>
<td>2.5*</td>
<td>38**</td>
</tr>
</tbody>
</table>

* Values given by the American National Ready Mix Concrete Association
** Determined using equation 6.1
All other values are standard values used in UK pavement design

Table 6.4: Mechanical properties of porous concrete and dense graded CBMs at 28 days

6.38 Porous concrete can be seen to have a 28 day flexural strength between 1.0 to 3.8 MPa. These values are less than the range of 5 to 7 MPa for pavement quality concrete but encompass the flexural strengths of CBM3G, 4G and 5G.

6.39 As references for typical values of dynamic modulus of porous concrete could not be found in the literature, it was assumed that the dynamic modulus of this material could be calculated from its flexural strength. The relationship between elastic stiffness and flexural strength for concretes containing various
aggregates are shown graphically by Croney (ref 14). Nunn (ref 22) represented these relationships for traditional CBMs with gravel aggregate in the UK pavement design method of Powell \textit{et al} (ref. 23) by the following equation:

\[ E = \frac{\log (f_f)}{0.0301} + 0.77 \quad \text{... [6.1]} \]

Where, \( f_f \) (MPa) is the flexural strength and \( E \) (GPa) the dynamic modulus. For porous concrete, the relationship between flexural strength and dynamic modulus may differ from that of traditional CBM materials and should be derived for more precise designs.

6.40 Table 6.4 suggests that the Contractor can design a porous concrete to at least achieve the properties of CBM3G and that it may be possible to achieve comparability with the higher strength grades. With hydraulically bound road base, it is desirable to have a high flexural strength and a relatively low modulus, as a material with a high modulus attracts stress.

6.41 The function of the depth of asphalt surfacing in a flexible pavement with CBGM base is primarily to delay the onset of reflection cracking. Delatte (ref. 15) points out that, as there is less shrinkage with porous concrete, it is not necessary to construct porous concrete pavements with construction joints. Consequently transverse cracks may not develop so readily in these pavements. For conservatism, however, porous concrete and all other HBM layers, which are expected to reach a compressive strength of 10MPa at 7 days, must have cracks induced in accordance with Clause 818 of the Specification (MCHW 1, ref. 1) until sufficient performance data is attained for a review of this requirement. Where induced cracks are required in an HBM, these should be aligned (maximum 100mm tolerance) with any induced cracks in the underlying construction.

\textit{Layer thickness design of flexible pavements with HBM or asphalt bases}

6.42 The stiffness modulus of porous asphalt given in Table 6.2 is about one third of that used for heavy duty macadam before HD 26 (DMRB 7.2.3) was issued in 2006. For a flexible pavement with a porous asphalt base, structural design theory indicates that the thickness of the asphalt layer would need to be about 40% thicker to accommodate this stiffness reduction. This calculation suggests that such a flexible reservoir pavement would be much more expensive than conventional construction. There are, however, other advantages of reservoir pavements that include savings on drainage costs, which should be taken into account to justify the adoption of this pavement type. The thickness of the asphalt is designed according to the method described in Chapter 4 of Nunn (ref. 22).

6.43 For flexible reservoir pavements with porous concrete bases, there are a number of factors for moderately heavily trafficked pavements in their favour:

- The current designs require little modification to accommodate porous concrete.
- Porous concrete can be designed with a stiffness modulus and strength comparable to those of CBGM used in the design of flexible pavements with an HBM base of HD26 (DMRB 7.2.3).
- Compared with conventional CBGM, porous concrete cures more quickly and does not require 360 days to achieve its long term stiffness and strength.
- Porous concrete shrinks less than CBGMs.

6.44 Optimisation of designs for flexible reservoir pavements with CBGM bases as well as designs for these pavements with other HBMs as base materials require laboratory determinations of the compressive and flexural strengths of the HBM base materials and the estimation of their dynamic modulus using equation 6.1.
6.45 The combination of stiffness and strength is crucial for design of a hydraulically bound base. Two different hydraulically bound materials can have the same base thicknesses for a given level of traffic, provided their flexural strengths compensate for any differences in their levels of stiffness. If stiffness is increased, the traffic induced tensile stress in the base of the pavement, which influences performance, will also increase; therefore the strength of the base would need to be higher to achieve the same performance. Relationships between dynamic elastic modulus and flexural strength have been developed by Nunn (ref. 22) for equivalent performance and grouped into nine zones of hydraulically bound base (H1 to H9). These zones are shown in Figure 6.1.

![Figure 6.1 Classes of hydraulically bound materials](image)

6.46 The range of values for the flexural strength and estimated dynamic stiffness of porous concrete given in Table 6.4, suggest that it could be characterised as a Zone H4 material for the weakest material up to Zone H8 material for the stronger end of the range. The mean values for porous concrete used in the USA suggest that it is possibly a Zone H7 material. However with no measurements available for the dynamic modulus of porous concrete, it is suggested that porous concrete should be limited to a Zone H5 material for design purposes until further experience is gained. In a similar way, other HBMs can be conservatively assigned a strength/stiffness zone. The thicknesses of the HBM bases are then derived using the process described in Appendix C of Nunn (ref. 22). Using the process, which is given in Figure C1 of that report, automatically accounts for the use of porous instead of dense asphalt. The thickness of the asphalt surface is primarily to delay the onset of reflection cracking and is dependent on the design traffic. The assigned values are given in Chapter 3 of Nunn (ref. 22).
7. **DESIGN AND CONSTRUCTION**

**Site specific design**

7.1 Reservoir pavements can be built as new pavements or as part of road improvement schemes where they are required to interface with existing conventional pavements. Scheme specific designs can be more complicated in the latter case.

7.2 When a reservoir pavement abuts a pavement of traditional construction comprised of dense materials, the wetted subgrade of the reservoir pavement must be isolated from the subgrade of the conventional pavement, unless the subgrade is highly permeable with a deep watertable and whose strength is not moisture susceptible such as one comprised of certain gravels, rock and chalk materials. The wetted subgrade could be isolated by a cut-off drain of depth appropriate to the expected extent of infiltration and/or by enclosing the reservoir by an impermeable membrane. As the cut-off drain needs to have access points to inspect and clean pipework, this type of construction is expected to be for short lengths of reservoir pavement as occurs with lay-bys and safe havens.

7.3 The pavement and drainage designs must also ensure that water cannot be trapped within pavements of traditional construction. Water infiltrating through conventional pavements should be drained at their low side by a pavement drain to current procedures or allowed to discharge in an alternative manner such as into the reservoir pavement. Typical obstructions within the pavements downstream could be thicker, relatively impermeable pavement layers or impermeable membranes encasing reservoirs. Possible solutions include cut-off drains, reverse interlayer gradients compared to the pavement crossfall, substitution of dense by permeable materials and changes in layer thicknesses.

7.4 An alternative to abutting reservoir and conventional pavements, but at the cost of increased landtake, is to separate these pavements types by a reserve whose width depends on whether, or not, a cut off drain is used to reduce the extent of the wetted subgrade. Guidance on the potential extent of the wetted subgrade is given by Nakashima (ref. 19).

**Construction**

7.5 During the construction phase, reservoir pavements need to be protected from construction debris and soil contaminated storm water runoff from other parts of the site as this occurrence will cause clogging of the pavement. For this reason, reservoir pavements should be built, with special care, late in the construction schedule when most of the dirty work, including grading and landscaping are complete. If this is not possible, specific measures may be required to isolate and protect the reservoir pavement.

**Asset management**

7.6 For all Highways England schemes, the details of any reservoir pavements installed on the network must be reported in Highways England Drainage Data Management System (HADDMS) and on Highways England Pavement Management System (HAPMS). Further information about HADDMS is given in HD 43 ‘Drainage Data Management System for Highways’ (DMRB 4.2).
8. **MAINTENANCE**

**General**

8.1 Highway run-off contains a significant amount of particulate material, in the form of road stone and tyre fragments, mud and dust. Without periodic removal these materials may lead to the decline in performance and eventual failure of any design of drainage system.

8.2 For reservoir pavements the maintenance approach to be adopted will be dependent upon the nature of the surface – whether impermeable or pervious. When the surface is impermeable, standard methods of maintaining conventional pavements can be applied. In the case where the reservoir structure is covered by a pervious surface, the maintenance will generally follow those for conventional pavements with a porous asphalt surface course. Frequent cleaning of the surface will be required to reduce the risk of clogging of the reservoir layer. A porous asphalt surface will also be less durable than a conventional thin surfacing.

8.3 The principal maintenance problem is that of sediment causing superficial blocking of the pervious surface course. A programme of regular preventive maintenance is required to extend the functional drainage life of a pervious system.

8.4 Maintenance requires an understanding of the nature of porous materials and aspects such as smoothness, texture and aesthetics need to be considered. The permeability of drainage pavements changes over time reflecting changes in the nature of the air voids content whose volume, form and interconnections alter by compaction of materials under traffic and as they gradually clog up with fines carried by air (dust) and water. The sensitivity to silting up depends on the distribution, dimension and percentage of voids. The factors that most influence clogging are:

- The immediate environment: e.g., falling leaves from trees.
- The environment as a whole: industrial pollution, runoff from road works, building sites, etc.
- The flushing of surface detritus into the structure by the flow and speed of traffic are important.

If the permeability falls below a certain level, blockage is very rapid. For this reason, the layers should be designed to have their air voids content as high as possible, compatible with structural and durability requirements, to delay the onset of blockage.

8.5 To ensure good durability, the maintenance agent needs to be aware of their principle of operation and the precautions required. These include:

- Avoiding the deliberate disposal of used water in a drainage pavement.
- Prevention of the pollution of run-off water with oil or hydrocarbons.
- Avoiding storage or stockpiling of materials on the pavement surface.
- Keeping verges vegetated to prevent erosion run-off silting up porous material.

**Maintenance plan and schedule**

8.6 During design, a Management Plan should be developed for the entire drainage system for each road (refer also to similar approaches in HA118 (DMRB 4.2.8) and HA103 (DMRB 4.2.1)). This Management Plan should:

- Set out the objectives of the drainage systems (which might include, for example, flow and pollutant attenuation).
• Formulate an adaptable programme of maintenance to include cleaning or replacement of clogged materials.

• Establish procedures for observing and monitoring the behaviour of the drainage system (for example through permeability testing).

• Plan for regular reviews of the maintenance scheduling, which could lead to increased or decreased frequency of inspections, cleaning etc.

8.7 The Management Plan should prescribe the various maintenance operations that may be required. Specific maintenance requirements suggested below should be adapted as necessary to site and system specific requirements. The proposed field trials of section 1.15 and feedback on their performance will inform the development of maintenance requirements and procedures.

Inspection

8.8 Inspection should be carried out regularly to ensure the system is working according to design. Inspection schedules should be drawn up as part of the Maintenance Plan. For Highways England schemes, records of these plans should be retained in HADDMS. When possible, inspections should be carried out during, or immediately after, heavy rainfall to check effective operation and identify any areas of water ponding.

8.9 The inspection should also examine the surroundings, for example to evaluate if runoff from adjacent areas is allowing silt to run onto pervious areas. Inspection chambers built into the reservoir, including those in geocellular units, and/or discharge pipework from, or to the reservoir, if used as an in-line attenuation facility, should be inspected for build-up of sediment. Inspection periods may be set at a frequency according to estimated silt build up rates, but should be carried out at least annually.

8.10 Maintenance activities and their timing for the reservoir pavements should be established on a site by site basis soon after completion of the inspection. The required maintenance should then be performed before pervious surfaces and internal porous materials are clogged to such an extent that adequate permeability cannot be recovered by cleaning.

Cleaning

8.11 Pervious structures are maintained using the traditional techniques for maintenance of drainage networks: hydro pressure cleaning and purging with compressed air. The recommended preventative maintenance is cleaning the surfacing by simple suction over the whole width of the pervious surface. Sweeping is not advised as it forces the fine particles into the holes and blocks the voids rapidly.

8.12 Pre-emptive treatment should be applied when blockage reduces the permeability of the pervious surface to between $3 \times 10^{-3}$ m/s and $2 \times 10^{-3}$ m/s. For drainage pavements with between 5 and 10 years of service, cleaning always produces a gain in hydraulic efficiency (Riambault, ref. 28). If the pavement is allowed to clog excessively, then it is difficult, or almost impossible, to recover satisfactory hydraulic properties.

8.13 Purpose built pressure cleaning machines for hydro-mechanically cleaning the surface may be used. These machines are also used for the regeneration of surface course characteristics. The most effective cleaning principle involves two simultaneous actions:

• Spraying with high pressure water jets, usually rotating. These jets unseat the silt (coating on the aggregates) and flushes it to the surface, without disrupting the granular particles. It is necessary to have the machine continually advancing an even pace.

• Powerful suction to recover the silt over the full width of the area being treated.
The machine settings should be set compatible with the strength of the surfacing material. If possible cleaning is recommended after a period of wet weather. Experience in France using these machines has shown that permeability after treatment is always superior to that measured just before treatment (Richard and Rouaud, ref. 28). Values of between $5 \times 10^{-3}$ and $8 \times 10^{-3}$ m/s are generally attained compared with values of $2 \times 10^{-3}$ to $3 \times 10^{-3}$ m/s before treatment. It is not possible to regain the original value because of post compaction of material by traffic and the complete blockage of some of the pores, which translates into a reduced efficiency of the hydraulic structure.

8.14 Measures to recover the ejected material should be put in place. These sediments may have significant metals content and appropriate means to dispose of the material waste must be agreed with the Overseeing Organisation.

8.15 It is difficult to predict the period between treatments for maintenance. Silting up is very variable and it will depend on the characteristics of each site. Cleaning should be carried out in accordance with the Management Plan. This is likely to require cleaning at regular intervals, preferably every 1 or 2 years, but any such frequencies should be based on observation and permeability measurements.

**Repair and replacement**

8.16 The repair technique to be adopted depends on the degree and extent of the degradation. The first consideration should be to replace material on a like for like basis.

8.17 When damage is localised and limited to loss of material by fretting under traffic, or gouging as a result of an accident, it is not necessary to intervene. In general this situation is stable.

8.18 For surface damage limited to a few square metres, for example, in the event of incidents of pollution or fire, repair of pervious surfaces can be carried out using conventional materials. In these cases, the discontinuity in the surface does not represent a difficulty for the flow and circulation of water at the location of the repair. Only the aesthetic aspect of the pavement is altered.

8.19 If it is important to maintain the existing pervious nature of the pavement, then the damaged material will have to be removed by, for example, planning and vertical joints will need to be prepared by application of a suitable bonding agent before repairing with material that has characteristics similar to those of the original material.

**Winter maintenance**

8.20 The absence of standing water will reduce the risk of ice formation. Grit should not be used in de-icing operations because it can accelerate blockage of pervious surfaces. Also, grit should not be applied to adjacent conventional surfaces if it is likely to be transported on to the pervious surfaces. A saline solution sprayed over the surface is one possible solution. Areas of pervious pavement need to be clearly marked on site and notified to winter maintenance teams so that grit is not used in their vicinity.

8.21 The insulating effect of the porous layers should both reduce frost penetration (and the need for salting in mild winters) and reduce the risk of frost damage to the underlying pavement. Claims in the USA suggest that, even in very cold climates, freezing is less of an issue with drainage pavements (Adams, ref. 4). The underlying stone beds are believed to retain heat and allow slightly warmer air to flow to the surface so that freezing rain and snow melts faster on the pervious pavement. The water then drains through the pavement and into the reservoir below with sufficient void space to prevent any heaving or damage on freezing. The formation of black ice is rarely observed. These claims have yet to be substantiated by UK experience.
9. REFERENCES

Informative

   Specification for Highways Works (MCHW1)
   Notes for Guidance on the Specification for Highways Works (MCHW2)

2. Design Manual for Roads and Bridges (DMRB).
   HD 26 Pavement Design (DMRB 7.2.3)
   HD 27 Pavement Construction Methods (DMRB 7.2.4)
   HD 28 Skidding Resistance (DMRB 7.3.1)
   HD 29 Data for Pavement Assessment (DMRB 7.3.2)
   HD 30 Maintenance Assessment Procedures (DMRB 7.3.3)
   HD 31 Maintenance of Bituminous Roads (DMRB 7.4.1)
   HD 33 Surface and Subsurface Drainage Systems for Highways (DMRB 4.2.3)
   HD 36 Surfacing Materials for New and maintenance Construction (DMRB 7.5.1)
   HD 37 Bituminous Surfacing Materials and Techniques (DMRB 7.5.2)
   HD 43 Drainage Data Management System for Highways Agency (DMRB 4.2.4)
   HD 45 Road Drainage and the Water Environment (DMRB 11.3.10)
   HA 37 Hydraulic Design of Road Edge Surface Water Channels (DMRB 4.2.4)
   HA 39 Edge of Pavement Details (DMRB 4.2.1)
   HA 40 Determination of Pipe and Bedding Combinations for Drainage Works (DMRB 4.2.5)
   HA 44 Design and Preparation of Contract Documents (DMRB 4.1.1)
   HA 78 Design of Outfalls for Surface Water Channels (DMRB 4.2.1)
   HA 103 Vegetated Drainage Systems for Highway Runoff (DMRB 4.2.1)
   HA 107 Design of Outfall and Culvert Details (DMRB 4.2.7)
   HA 118 Design of Soakaways (DMRB 4.2.8)
   HA 119 Grassed Surface Water Channels for Highway Runoff (DMRB 4.2.9)
   HA 219 Determination of pipe roughness and assessment of sediment deposition to aid pipeline design. (DMRB 4.2.4)

Normative

3. British Standards Institution


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   Moutier F and Y Chauvin. The construction of the project.
   Raimbault G, Marcos L and J M Rouaud. The hydrological behaviour of the structure.
   Metois C. Perception of the users and local authority.


Glossary

CBR value  California Bearing Ratio; an empirical measure of the stiffness and strength of soils, used in road pavement design.

Controlled Waters  In England, Scotland and Wales, a term used to describe groundwater and surface waters.

Continuously graded  A soil or aggregate with a balanced range of particle sizes with significant proportions of all fractions from the maximum nominal size down.

Elastic modulus  Also known as Youngs Modulus or stiffness modulus; the ratio of stress divided by strain for a particular material.

Geomembrane (membrane)  An impermeable plastic sheet, typically manufactured from polypropylene, high-density polyethylene or other geosynthetic material.

Geotextile  A plastic fabric which is permeable.

Groundwater  All water which is below the surface of the ground in the saturation zone (below the water table) and in direct contact with the ground or subsoil.

Infiltration  The passage of water through a surface, either the pervious surface or into the underlying ground.

Open graded  A description of the particle size distribution of a particulate material that is designed so that the compacted material contains interconnected void spaces to increase its permeability to water.

Permeability  A measure of the ease with which a fluid can flow through a porous medium. It depends on the physical properties of the medium, for example grain size, porosity and pore shape.

Porosity  The percentage of the bulk volume of a rock or soil that is occupied by voids, whether isolated or connected.

Porous Pavement  A porous pavement allows water to infiltrate across its entire surface, or example porous concrete or porous asphalt.

Permeable Pavement  A permeable pavement is formed of a material that is itself impermeable but that is laid to provide a void space through the surface to the subbase (e.g. concrete block paving designed to allow water at the surface to penetrate through joints or voids between the blocks into the underlying structure).

Pervious Pavement  A pervious pavement is any type of pavement surface that allows direct downward water infiltration; the terms porous and permeable pavement (see above) are specific types of pervious pavement.

Subbase  An unbound or bound layer laid on the soil (or a capping layer) in traditional construction to provide a stable foundation for construction of the road pavement.

Subgrade  The soils onto which the road pavement is constructed.

SuDS  Sustainable Drainage Systems: a sequence of management practices and control structures designed to drain surface water in a more sustainable fashion than some conventional techniques.
10. APPROVAL

Approval of this document for publication is given by:

Highways England
Temple Quay House
The Square
Temple Quay
Bristol
BS1 6HA

Transport Scotland
8th Floor, Buchanan House
58 Port Dundas Road
Glasgow
G4 0HF

Welsh Government
Transport
Cardiff
CF10 3NQ

Department for Infrastructure
Clarence Court
10-18 Adelaide Street
Belfast
BT2 8GB

Department for Infrastructure
Clarence Court
10-18 Adelaide Street
Belfast
BT2 8GB

All technical enquiries or comments on this Document should be sent to
DMRB_Enquiries@highwaysengland.co.uk
ANNEX A: WORKED EXAMPLE

Background

9.1 A dual carriageway road is to be upgraded to include the provision of a hard shoulder. This means that the existing drainage (primarily in filter drains) will need to be replaced. For a 1km section of the road widening, space constraints are such that there is insufficient space to provide a conventional drainage system.

9.2 An assessment carried out using HD45 has demonstrated that there are not expected to be significant risks of spillage along this stretch of the road.

9.3 As the site does not overly a sensitive groundwater body, it is intended that this 1km stretch will be drained using a reservoir pavement with edge drainage “injected” (Reservoir Pavement Type IV) into the reservoir layer beneath the hard shoulder and subsequently by infiltration into the underlying permeable subgrade.

9.4 The hydraulic design for the reservoir pavement will include consideration of the maximum depth of water that will occur in the reservoir layer for a design storm of 1 in 10 years over a range of storm durations (15 mins to 24 hours). The depth of the reservoir shall ensure the water held in storage under the design storm should be able to empty from full capacity to 50% or less within 24 hours.

9.5 Following hydraulic design, the structural design of the subbase will be checked against the bearing capacity of the underlying subgrade (“soil”). The ground is relatively flat with gradients of no more than 1% across the site. The underlying subgrade comprises well sorted sand and in situ infiltration tests have been carried out using the method described in CIRIA 156 to establish the infiltration rate of the subgrade. The worked example is shown for determining subbase design thickness only.

9.6 The principle site features are as follows:-

- **Length of road section** = 1000m
- **Width of drained road section including hard shoulder** = 10.5 m
- **Drained road area (Ad)** = 10500 m²
- **Soil Infiltration rate (to subgrade)** = 4.5 x 10⁻⁵ m/s
- **Factor of safety (x 10)** to be used for the soil infiltration to deal with the design exceedence, to allow for any errors in the field test results and to allow an element for blockage in the reservoir layer – i.e. it is assumed in calculations that the soil infiltration rate is 4.5 x 10⁻⁶ m/s
- **CBR Value (sand; measured as “wetted” value)** = 5%
- **Porosity of the Subbase material (n)** = 30%

9.7 The width of the reservoir is such that the ratio between drained area and the area of the reservoir pavement is greater than 2 (see Section 5.8). This recommendation applies primarily to those reservoir pavements employing a pervious surface (Reservoir Pavement Types I-III) to reduce the potential impact of sediment from the carriageway. With Reservoir Pavement Types IV-VI as applied here, sediment control may be applied by using sumped gullies or other in-line sediment control devices. Suitable maintenance regimes should be put in place to ensure the reservoir itself remains free of sediment.
Hydraulic design

9.8 In line with the guidance, the design follows a number of steps:

(i) Establish the design storm and establish rainfall intensities for the hydraulic region and from the drainage catchment to determine the runoff rate and volume.

(ii) Following the procedure set out in CIRIA Report 582 (refer Section 5.12 of this IAN), determine the maximum depth of water that will occur in the subbase for the design storms and check against the minimum recommended (350mm) depth for the depth of the subbase.

(iii) Check time of emptying to ensure 50% of the available storage is drained within 24 hours (refer Section 5.13 of this IAN).

(iv) Establish structural requirements of the subbase – adopt the greater thickness of hydraulic and structural requirements.

Design Storm

9.9 For the design storm of a 1 in 10 year return period, the rainfall intensity is determined by reference to the hydraulic region. In this example, the hydraulic region is considered with the values of the rainfall ratio (r) as 0.4, by reference to Figure 3.6 in CIRIA Report 582.

9.10 Using the value of r, rainfall intensities for the 10 year storm are determined for the storm durations of 15 to 24 hours, from Table 3.3 of CIRIA Report 582, interpolating as required. The values for the rainfall intensities are presented in Table 9.1 as below:

<table>
<thead>
<tr>
<th>Storm Durations</th>
<th>Rainfall Intensity (mm/hr)</th>
<th>Rainfall Intensity (m/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 mins</td>
<td>62.33</td>
<td>0.0623</td>
</tr>
<tr>
<td>30 mins</td>
<td>39.87</td>
<td>0.0399</td>
</tr>
<tr>
<td>60 mins</td>
<td>24.8</td>
<td>0.0248</td>
</tr>
<tr>
<td>120 mins</td>
<td>14.95</td>
<td>0.0149</td>
</tr>
<tr>
<td>240 mins</td>
<td>8.85</td>
<td>0.0088</td>
</tr>
<tr>
<td>360 mins</td>
<td>6.48</td>
<td>0.0065</td>
</tr>
<tr>
<td>480 mins</td>
<td>5.4</td>
<td>0.0054</td>
</tr>
<tr>
<td>600 mins</td>
<td>4.32</td>
<td>0.0043</td>
</tr>
<tr>
<td>720 mins</td>
<td>4.02</td>
<td>0.0040</td>
</tr>
<tr>
<td>900 mins</td>
<td>3.56</td>
<td>0.0036</td>
</tr>
<tr>
<td>1080 mins</td>
<td>3.11</td>
<td>0.0031</td>
</tr>
<tr>
<td>1440 mins</td>
<td>2.20</td>
<td>0.0022</td>
</tr>
</tbody>
</table>

Table 1: Rainfall Intensity for 10 year storm

[Note that proprietary drainage software may also be used to generate design storm rainfall intensities for given hydraulic regions]

Depth of Subbase (hmax)

9.11 The worked calculations below are shown for the 15 minute duration, 1 in 10 year design storm. A simple spreadsheet calculation was used to determine results for all other storm durations. The results for these calculations are shown on Table 2.
9.12 As discussed within Section 5.12, the maximum depth of water that will occur in the subbase (from CIRIA 582) is based on:

\[ h_{\text{max}} = (R \times i) \times D/n \]

Where,  
- \( R \) = Ratio of the drained area to base area of pervious surface  
  = Total Paved Area (Ad) / Internal Area of Subbase (Ab)  
  = 10500/2500 = 4.2  
- \( i \) = Rainfall Intensity (m/h)  
  = 0.062 m/h for 15 mins 10 year storm  
- \( q \) = Infiltration rate (m/h) into subgrade/subsoil  
  = 4.5 \times 10^{-6} \text{ m/s} \text{ (factor of safety 10 included)} = .00162 \text{ m/h}  
- \( D \) = Rainfall Duration = 15 mins = 0.25 h  
- \( n \) = Porosity of subbase material = 0.3

Therefore, \( h_{\text{max}} = ((4.2 \times 0.062) - 0.0162) \times 0.25/0.3 = .205\text{ m} = 205\text{ mm} \), which is less than the 350mm minimum depth of the subbase currently recommended in the IAN.

[This calculation is that applied to the highlighted row in Table 2, results for other storm durations are shown on Table 2, with the storm giving the highest values of \( h_{\text{max}} \) shown in bold]

(iii) Time of Emptying

9.13 The time taken for the system to half-empty is given by:

\[ T_e = \frac{(h \times h_{\text{max}})}{2q} \]

(Ref CIRIA Report 156 pp60 – Plane Infiltration System)

Where,  
- \( h \) = Porosity of subsurface material  
  = 0.3  
- \( h_{\text{max}} \) = Depth of water within subbase  
  = 0.205m (for 15 mins storm)  
- \( q \) = Infiltration rate  
  = 0.0162 m/h

Therefore, \( T_e = (0.3 \times 0.205)/(2 \times 0.0162) = 1.89 \text{ h} \)

These calculations are shown on Table 3 for the range of storm intensities adopted, with the storm with the longest time to empty shown in bold.

Note that as above, the infiltration rate assumed in calculations is a factor of 10 less than that measured in infiltration testing to accommodate the recommended safety factor.
Summary of hydraulic design considerations

9.14 The summary of the key data (hmax and time to 50% empty) for a range of storms to 24 hours durations are shown in Table 4 below. Note: where figures are negative, the infiltration capacity is in excess of the volume generated by the storm (i.e. there is no accumulated storage within the reservoir layer).

<table>
<thead>
<tr>
<th>Storm Durations</th>
<th>hmax (mm)</th>
<th>Half Drain Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 mins</td>
<td>204.7</td>
<td>1.89</td>
</tr>
<tr>
<td>30 mins</td>
<td>252.1</td>
<td>2.33</td>
</tr>
<tr>
<td>60 mins</td>
<td>293.2</td>
<td>2.71</td>
</tr>
<tr>
<td>120 mins</td>
<td>310.6</td>
<td>2.88</td>
</tr>
<tr>
<td>240 mins</td>
<td>279.6</td>
<td>2.59</td>
</tr>
<tr>
<td>360 mins</td>
<td>220.3</td>
<td>2.04</td>
</tr>
<tr>
<td>480 mins</td>
<td>172.8</td>
<td>1.60</td>
</tr>
<tr>
<td>600 mins</td>
<td>64.8</td>
<td>0.60</td>
</tr>
<tr>
<td>720 mins</td>
<td>26.9</td>
<td>0.25</td>
</tr>
<tr>
<td>900 mins</td>
<td>−61.8</td>
<td>−0.57</td>
</tr>
<tr>
<td>1080 mins</td>
<td>−188.6</td>
<td>−1.75</td>
</tr>
<tr>
<td>1440 mins</td>
<td>−556.8</td>
<td>−5.16</td>
</tr>
</tbody>
</table>

Table 4: Summary of hmax and time to empty by 50%

9.15 For the design storm the maximum depth of reservoir required is circa 311mm (for the 2 hour storm – shown in bold above). The system easily has the capacity to drain by 50% within a 24 hour period. Although the calculated value of hmax is 311mm, the current IAN recommendation of a minimum reservoir thickness of 350mm is adopted.

Structural Design

9.16 As discussed within section 6.15 of the IAN, as the subbase is to be of an unbound granular material, the foundation class is considered to be no better than Foundation Class 2. Referring to IAN 73, Figure 4.3, a CBR value of 5% would result in a layer thickness of circa 220mm for a foundation layer stiffness of 150 MPa.

9.17 This subbase layer thickness is less than the current minimum recommendation for subbase layer thickness.

Comments

9.18 In this case both hydraulic and structural design considerations suggest a reservoir layer thickness less than the currently recommended minimum of 350mm. A case could be made to reduce subbase thickness to the minimum required (310mm) to meet hydraulic requirements, although using the minimum recommended depth provides for a little additional storage capacity. This thickness is still greater than that required by structural considerations.

9.19 Negative values for hmax on the table indicate the infiltration capacity of the subsurface exceeds the rainfall intensity of the design storm.

9.20 For the initial hydraulic design calculations it is assumed that a width of 2.5m beneath the hard shoulder, for the full 1000m road length, will provide the reservoir and that this will infiltrate into the underlying
subgrade. Iterative calculations may be carried out to achieve a compromise between the width and depth of the reservoir layer.

9.21 Figures 1 and 2 provide conceptual sketches of the installation of a reservoir pavement based on this worked example (plan and section respectively). Edge drainage and the means to “inject” water into the reservoir are not presently covered by this IAN. Designers will need to devise methods that are hydraulically proven and that also allow control of sediment to ensure this is not injected into the underlying reservoir layer.

9.22 It is the current recommendation of the IAN not to use reservoir pavements in these applications (i.e. with moisture susceptible subgrades). Where moisture susceptible subgrades are encountered, a cut off drain will be needed to isolate the conventional pavement foundation from the discharge from the reservoir pavement. Where cut off drains are required, designers would need to ensure that these continue to function throughout the life of the pavement.

9.23 Given sufficient hydraulic capacity, the reservoir may be discontinuous beneath the hard shoulder. Thicker reservoirs would be required to provide the necessary storage capacity.

9.24 Consideration should be given for the design to accommodate an overflow to cater for very extreme conditions (i.e. design exceedance). Providing a greater reservoir thickness could give greater storage capacity for more extreme storms, although an overflow is recommended for all installations.

9.25 Pavement layer design will be dictated by traffic requirements, Table 6.1 should be used to select pavement design (e.g. porous concrete and asphalt surface).

Notes:
Various edge drain types might be used, including surface water channels, kerb and gully and linear drainage channels; Combined channel and pipe systems may also be possible. Measures for entrapping sediment before introduction into the reservoir layer must be included.

Figure A1 Worked Example – Conceptual Sketch (plan view)
Notes:
1. Existing foundation and pavement of dense materials.
2. New pavement depth to match existing pavement.
3. Porous concrete provides additional storage; thickness in accordance with Table 6.1.
4. Greater thickness in the reservoir layer may be used to decrease width.
5. Example not applicable in low permeability and/or moisture susceptible sub-grades, or where shallow groundwater is encountered.
6. Permeable geotextile may be required to prevent contamination of reservoir layer by fines in the sub-grade.

Figure A2 Worked Example – Conceptual Sketch (sectional view)
ANNEX B  RESERVOIR PAVEMENTS DESIGN CONFIGURATIONS