



# WATER-ABSORBING ROADS AS SUSTAINABLE URBAN DRAINAGE INFRASTRUCTURE

Submitted by

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## ABSTRACT

Permeable pavement systems are designed to admit rainfall through a porous surface or permeable joints and manage it within an underlying pavement structure. This paper reviews the engineering principles and practical considerations of porous asphalt, pervious concrete and permeable interlocking concrete pavement (PICP), with particular attention to urban stormwater management in India. The study is a literature-supported review and conceptual engineering assessment; it does not report original laboratory or field experiments. The discussion synthesises the system-level roles of surface infiltration, aggregate-reservoir storage, subgrade hydraulic conductivity, underdrainage, overflow and maintenance. It also considers structural loading, groundwater conditions, clogging, construction quality and potential water-quality impacts. The reviewed literature indicates that permeable pavements can reduce or delay runoff under suitable conditions, but the magnitude and durability of performance depend on rainfall, design, site conditions and maintenance. They should therefore be treated as site-specific stormwater infrastructure that complements rather than universally replaces conventional drainage. A conceptual design framework is presented to guide future site investigation, hydraulic sizing, structural design and performance testing. Since no site-specific calculations or experiments are reported here, the paper does not claim a quantified reduction in flooding or universal structural or economic superiority. Future work should validate the framework through locally calibrated design calculations and monitored pilot installations.

Keywords: permeable pavement; porous asphalt; pervious concrete; stormwater management; infiltration; India



Pervious concrete surface (illustrative photograph).



Porous asphalt surface (illustrative photograph).

## 1. INTRODUCTION

### Background and engineering context

Road pavements are traditionally designed primarily as structural transportation systems, while drainage is commonly treated as a complementary component that removes water from the pavement and road environment. This separation is increasingly difficult to sustain in densely developed areas. Urbanisation replaces permeable ground with roofs, pavements and other impervious surfaces, altering the timing and pathways of rainfall runoff. A road therefore becomes both a load-bearing transportation asset and an important element of the urban water cycle. Sustainable pavement practice increasingly considers these functions together rather than treating stormwater as an entirely external problem.

Permeable pavement systems respond to this challenge by allowing rainfall to enter the pavement structure rather than forcing all water to remain at the surface. Depending on the design, water may infiltrate through porous asphalt, pervious concrete or permeable joints in concrete blocks, pass through bedding and aggregate layers, be temporarily stored within an open-graded reservoir, and then infiltrate into the subgrade. Where infiltration is unsuitable or insufficient, an underdrain and controlled outlet can be incorporated. The system is therefore better understood as a distributed stormwater-management structure than as a pavement that simply “absorbs” water.



Added illustrative photograph: permeable pavement after rainfall.

The terminology matters because “absorption” can imply permanent uptake or storage within the pavement material. In reality, the dominant mechanisms are hydraulic transmission through connected voids, temporary detention within the aggregate structure, infiltration into soil and controlled drainage. Scholz and Grabowiecki (2007) describe permeable pavement as a family of systems intended to manage water through infiltration and storage, while Ferguson (2005) presents porous pavement as a structural and hydraulic system requiring deliberate design of surface, reservoir and soil conditions. These concepts are consistent with current technical practice for pervious concrete and permeable pavement systems (ACI

522R; ASTM test methods).

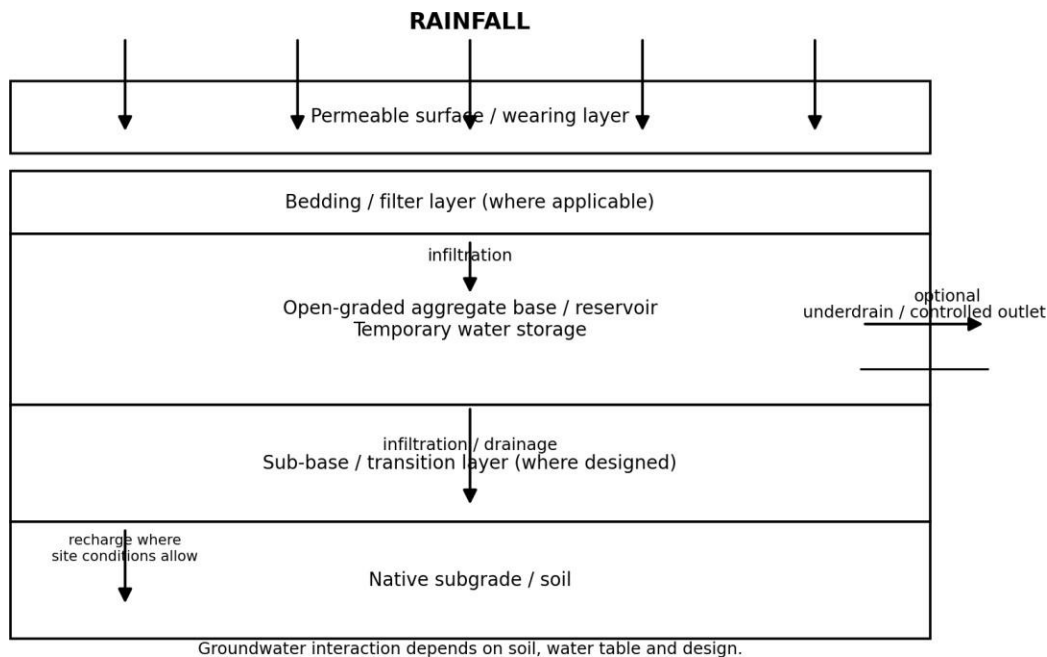


Figure 1. Complete water-absorbing/permeable road cross-section showing rainfall, permeable surface, bedding, reservoir, subgrade, optional underdrain and groundwater interaction.

### Conventional pavement and stormwater runoff

A conventional flexible or rigid pavement normally presents a relatively impermeable riding surface. Rainfall that cannot infiltrate through the surface becomes runoff and is directed by crossfall, kerbs, channels, gullies, drains and pipes. This approach remains essential for many roads and is not inherently unsustainable. Its limitation arises when the receiving drainage network is undersized, obstructed, overloaded by intense rainfall, or disconnected from available opportunities for infiltration and storage. Surface ponding and local waterlogging can then occur even when the pavement itself is structurally adequate.

Permeable pavement changes the first part of this sequence. Instead of directing all rainfall laterally from the road surface, a portion of the rainfall can enter the pavement. The resulting reduction in immediate surface runoff depends on rainfall characteristics, the condition and permeability of the pavement, available storage, subgrade infiltration capacity and the operation of any underdrain. Consequently, “permeable” should not be interpreted as “zero runoff under every storm.” Extreme rainfall can exceed infiltration and storage capacity, and a properly designed system must have a safe overflow or bypass pathway.

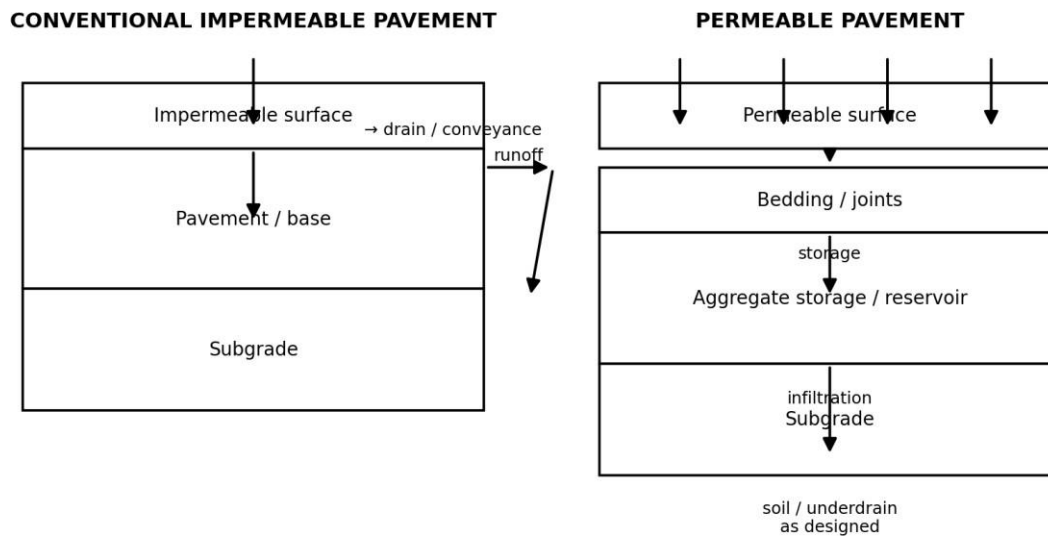


Figure 2. Conceptual comparison of conventional impermeable pavement and permeable pavement.

## Relevance to India

Indian cities experience highly variable rainfall regimes, with many regions receiving intense seasonal rainfall during the monsoon. The engineering response to urban stormwater must therefore account for short-duration high-intensity events as well as cumulative seasonal rainfall. Indian roads also operate under diverse traffic conditions, from pedestrian and parking areas to heavily trafficked urban and highway facilities. Soil type, groundwater level, dust and sediment loading, construction quality and maintenance capability can vary substantially between sites. These conditions make permeable pavement a site-specific engineering option rather than a universal road standard.

The Manual on Storm Water Drainage Systems published by the Ministry of Housing and Urban Affairs provides an Indian institutional context for integrated urban drainage planning. Permeable pavement can complement, but does not replace, conventional drainage infrastructure. Its suitability depends on the relationship between rainfall, runoff generation, pavement storage, soil infiltration, groundwater protection and the required level of flood protection. The need for systematic design is especially important where rainfall intensity can exceed the infiltration capacity of the complete pavement–soil system.

## Aim and research positioning

The aim of this report is to examine permeable pavement as a technically defensible form of “water-absorbing road” for sustainable stormwater management. In the absence of original laboratory or field data, the report is deliberately positioned as a literature-supported conceptual study. It does not claim that a proposed pavement has been experimentally validated, that flooding will always be eliminated, or that permeable pavement is structurally or economically superior for every road. Instead, it identifies the conditions under which permeable pavement can be considered and the investigations required before implementation.

## Scope of the study

- Terminology and engineering principles of permeable, pervious and porous pavement.
- Hydraulic behaviour, infiltration, temporary storage, underdrainage and overflow.
- Porous asphalt, pervious concrete and permeable interlocking concrete pavement.
- Pavement structural, materials, geotechnical and drainage considerations.

## 2. LITERATURE REVIEW

### Evolution of Permeable Pavement Technology

Permeable pavement has developed as an alternative approach to conventional stormwater management, particularly in urban areas where roofs, roads, footpaths and parking surfaces reduce the amount of exposed soil available for natural infiltration. Unlike conventional impermeable pavement, permeable pavement is designed to allow rainfall to pass through a porous surface or permeable joints into underlying aggregate layers. These layers temporarily store water before it infiltrates into the subgrade or is discharged through an underdrain.

Scholz and Grabowiecki (2007) reviewed permeable pavement systems and discussed their potential role in stormwater management. Their work highlights the importance of considering the pavement as an integrated system rather than evaluating only the surface material. Ferguson (2005) also presents porous pavement as an engineering approach that combines surface permeability, subsurface storage, drainage and structural requirements. These contributions establish that successful implementation depends on coordinated hydraulic, geotechnical and pavement design.

The development of permeable pavement technology has expanded beyond runoff reduction to include water-quality management, groundwater interaction, material durability and long-term maintenance. However, the effectiveness of a system varies according to rainfall characteristics, pavement condition, soil permeability, groundwater level, aggregate storage capacity and the presence of drainage outlets.

### Permeable Pavement and Stormwater Management

One of the principal objectives of permeable pavement is to reduce and delay surface runoff. Conventional roads generally direct rainfall towards kerbs, gutters, roadside drains and stormwater networks. During intense rainfall, these systems may become overloaded, potentially contributing to local waterlogging and flooding. Permeable pavement provides an additional pathway for managing rainfall by allowing a portion of the water to enter the pavement structure.

Brattebo and Booth (2003) investigated the long-term hydrological and water-quality performance of permeable pavement systems. Their study provides evidence that permeable pavement should be assessed over its service life rather than only under initial operating conditions. This is important because surface clogging, changes in drainage conditions and maintenance practices can influence performance over time.

The literature indicates that runoff reduction is not determined by surface permeability alone. Rainwater must pass through the surface, enter the bedding or filter layer, occupy the aggregate reservoir and then infiltrate into the soil or leave through an outlet. If the underlying soil has low permeability or the reservoir becomes full, additional rainfall may produce surface runoff. Therefore, permeable pavement should be designed to manage a specified range of rainfall conditions and should include a safe overflow or bypass arrangement where required.

### Types of Permeable Pavement

#### 2 Porous Asphalt

Porous asphalt is produced using an asphalt mixture with interconnected voids that permit water to pass through the wearing course. It can be considered for suitable parking areas, access roads and other applications where its hydraulic and structural properties meet project requirements. Its performance depends on aggregate characteristics, mixture design, layer thickness, construction quality and maintenance.

A major concern with porous asphalt is the accumulation of dust, fine particles and other sediments within surface voids. This can reduce infiltration capacity and increase the possibility of ponding. Appropriate site selection,

sediment control and periodic maintenance are therefore essential.

### **Pervious Concrete**

Pervious concrete is manufactured with a connected pore structure that allows water to pass through the concrete layer. It is commonly considered for applications such as footpaths, pedestrian areas, parking spaces and selected low-volume traffic facilities, subject to structural design.

Its performance is influenced by aggregate grading, cement paste characteristics, compaction during placement, curing and construction quality. The interconnected voids provide pathways for water movement, but excessive compaction or unsuitable mixture proportions may reduce permeability.

Conversely, inadequate construction control may affect strength and durability. A suitable balance between hydraulic capacity and structural performance is necessary.

### **Permeable Interlocking Concrete Pavement**

Permeable interlocking concrete pavement consists of concrete blocks separated by permeable joints filled with appropriate aggregate. Rainwater passes through these joints into a bedding layer and a granular base that may provide temporary storage. The system can be useful for pedestrian areas, parking spaces and selected road applications.

Its performance depends on joint aggregate, bedding material, reservoir design, subgrade conditions and the stability of the pavement structure. Joint clogging is a significant maintenance concern, particularly where sediment-laden runoff enters the pavement. The surface and underlying layers must therefore be designed as a complete system.

### **Hydraulic and Geotechnical Performance**

Hydraulic performance refers to the ability of the pavement to admit, temporarily store and release rainfall. Important parameters include surface infiltration rate, subgrade infiltration capacity, available storage volume, groundwater depth and underdrain discharge capacity. These parameters should be considered together because the overall performance of the pavement may be controlled by its most restrictive layer or drainage condition.

The aggregate reservoir provides temporary storage beneath the wearing surface. Where the native soil has adequate infiltration capacity and groundwater protection requirements are satisfied, some stored water may infiltrate into the ground. Where infiltration is unsuitable or insufficient, an underdrain may be required to convey water to an approved drainage system. In either arrangement, the design must consider the possibility of saturated conditions and rainfall exceeding the available storage capacity.

Geotechnical investigation is therefore essential before construction. Soil classification, permeability, bearing capacity, groundwater level and settlement potential can influence both drainage and structural performance. Fine-grained soils may drain slowly, while unsuitable groundwater conditions may restrict infiltration. The pavement design must also account for traffic loading, aggregate stability and the risk of weakening the subgrade when it becomes wet.

### **Water Quality and Groundwater Considerations**

Permeable pavement can provide opportunities for stormwater treatment as water moves through aggregate and soil layers. Some suspended particles may be retained, and certain pollutants may be reduced through filtration and other processes. However, treatment performance depends on the pollutant type, pavement materials, site conditions and maintenance.

Infiltration is not automatically beneficial in every location. Runoff from industrial areas, vehicle-maintenance facilities or other potentially contaminated sites may contain substances that could affect groundwater quality. High groundwater levels, contaminated soils and sensitive aquifers may also limit the suitability of infiltration-based designs. Site assessment and appropriate environmental safeguards are necessary before selecting a system that allows water to infiltrate into the ground.

Consequently, groundwater recharge should be treated as a potential benefit rather than a guaranteed outcome. It depends on the local hydrogeology, the amount of water infiltrated and the quality of that water.

### **Clogging, Maintenance and Durability**

Clogging is one of the major challenges identified in permeable pavement research. Fine sediments, dust, organic matter and debris can accumulate within surface pores or permeable joints. As these openings become obstructed, infiltration capacity may decrease, increasing the likelihood of ponding and runoff.

Brattebo and Booth (2003) demonstrate the value of evaluating permeable pavement over an extended period, while the broader engineering literature emphasises the importance of maintenance in preserving hydraulic performance. Maintenance may include removing surface debris, vacuum cleaning where suitable, inspecting drainage outlets and assessing infiltration performance at regular intervals. The appropriate method depends on the pavement type and the nature of the clogging material.

Durability must also be evaluated in relation to traffic loading, construction quality, aggregate properties, moisture conditions and local climate. A pavement that performs well hydraulically may still be unsuitable if it cannot safely support the expected traffic. Conversely, a structurally adequate pavement may fail to provide the intended stormwater benefits if its surface becomes clogged.

Hydraulic and structural performance should therefore be monitored together.

### **Relevance to India**

The application of permeable pavement in India requires consideration of regional rainfall patterns, monsoon intensity, soil conditions, groundwater levels, traffic demand and local maintenance capacity. In areas experiencing intense seasonal rainfall, the pavement must be designed for the expected rainfall conditions and should not rely solely on infiltration for flood protection.

The Manual on Storm Water Drainage Systems published by the Ministry of Housing and Urban Affairs provides a relevant Indian planning context for urban drainage management. Permeable pavement may complement conventional drainage networks by creating additional opportunities for infiltration and temporary storage. However, it cannot replace the need for adequate drainage, safe overflow routes and appropriate flood-management planning.

Potential applications include footpaths, parking areas, residential streets, pedestrian zones and selected low-volume roads. Suitability for heavily trafficked roads must be established through detailed structural design, material testing and site-specific hydraulic assessment. Local trials and long-term monitoring would help establish performance under Indian environmental and operational conditions.

### **Critical Synthesis of Previous Research**

The reviewed literature indicates broad agreement that permeable pavement can contribute to stormwater management by admitting rainfall, providing temporary subsurface storage and reducing or delaying runoff under suitable conditions. Research by Scholz and Grabowiecki (2007), Ferguson (2005), and Brattebo and Booth (2003) supports the need to consider the pavement as an integrated system and to evaluate performance over time.

However, the literature also shows that the benefits are conditional. High surface permeability does not guarantee rapid drainage through the entire pavement structure. Low-permeability subgrade soils, insufficient reservoir capacity, high groundwater levels, clogging and inadequate maintenance can limit performance. Environmental benefits also depend on the quality of infiltrating water and the characteristics of the receiving soil and groundwater system.

A further consideration is that the most suitable pavement technology depends on the intended use. Porous asphalt, pervious concrete and permeable interlocking concrete pavement differ in construction, structural behaviour, joint or pore characteristics and maintenance requirements. They should not be treated as interchangeable solutions. Selection must be based on site investigation, traffic requirements, hydraulic calculations, environmental assessment and life-cycle considerations.

## Research Gap and Need for the Present Study

Although previous studies have established the potential of permeable pavement for stormwater management, its performance cannot be generalised across all locations and road categories.

Differences in rainfall, subgrade permeability, groundwater conditions, sediment loading, traffic and maintenance practices can produce different outcomes. In particular, the suitability of different permeable pavement systems under local Indian conditions requires careful site-specific evaluation.

The present study addresses this need through a conceptual engineering review of water-absorbing roads, using the technically appropriate term *permeable pavement systems*. It brings together the principles of surface infiltration, aggregate storage, subgrade drainage, optional underdrainage, structural requirements, maintenance and environmental protection within a single design framework.

The study does not claim original field measurements, laboratory experiments or validated site-specific design results. Instead, it identifies the principal factors that should be investigated before implementation and provides a foundation for future work involving local soil testing, rainfall analysis, infiltration measurements, structural evaluation, cost comparison and long-term field monitoring. Such studies would help determine where permeable pavement can provide reliable and sustainable benefits in Indian road infrastructure.

## Comparative synthesis of the literature

| Theme         | Broad finding from literature                                                                      | Engineering implication                                     |
|---------------|----------------------------------------------------------------------------------------------------|-------------------------------------------------------------|
| Hydrology     | Permeable surfaces can reduce and delay direct runoff when storage and infiltration are available. | Size surface, reservoir and drainage as one system.         |
| Permeability  | Initial infiltration can be high but may decline with sediment accumulation.                       | Treat permeability as a monitored and maintained attribute. |
| Subgrade      | Native soil can control overall drainage where its infiltration capacity is low.                   | Investigate soil and consider underdrainage.                |
| Structure     | Open voids support hydraulic function but can reduce solid load-bearing area.                      | Balance hydraulic and structural requirements.              |
| Water quality | Filtration and attenuation are possible but pollutant removal is site dependent.                   | Avoid universal removal claims; assess source water.        |

|             |                                                            |                                                               |
|-------------|------------------------------------------------------------|---------------------------------------------------------------|
| Maintenance | Sediment and fines can reduce hydraulic performance.       | Provide inspection and maintainability from the design stage. |
| Climate     | Performance is climate and site dependent.                 | Use local rainfall, soil and groundwater information.         |
| Economics   | Costs depend on site, materials, drainage and maintenance. | Use project-specific life-cycle assessment.                   |

### Research gap / need for the present study

The literature establishes the potential of permeable pavement but also shows that performance is strongly site and system dependent. A defensible research need for a civil-engineering seminar therefore lies not in claiming that permeable pavement is a universally new technology, but in integrating hydraulic, structural, geotechnical, environmental and maintenance requirements

## 3. CONVENTIONAL ROAD PAVEMENT AND STORMWATER

### Conventional pavement structure

A conventional road pavement transfers traffic loads through a layered structure to the subgrade. Flexible pavements generally use bituminous surfacing over granular and/or bound layers, while rigid pavements use a concrete slab supported by base and subgrade layers. Drainage design protects the riding surface and pavement structure by removing water that would otherwise affect skid resistance, durability, material behaviour and subgrade performance. The surface is normally graded so that water flows laterally toward shoulders, kerbs or drainage inlets.

### Runoff generation and collection

When rainfall reaches an impervious pavement, the proportion that becomes direct runoff can be substantial, depending on rainfall intensity, surface storage and surrounding conditions. The runoff must be collected and conveyed without creating unsafe ponding. Conventional drainage can include longitudinal drains, kerb-and-gutter arrangements, side drains, catchpits, gullies, culverts and pipe networks. These systems remain indispensable even where permeable pavement is used because extreme events and non-permeable areas still generate runoff.

### Limitations of conventional drainage

Conventional drainage concentrates water and transfers it rapidly downstream. In a highly urbanised catchment, many impervious surfaces can contribute simultaneously, creating peak flows that challenge downstream capacity. Drainage systems can also be affected by blockage, sediment deposition and inadequate maintenance. Permeable pavement offers an opportunity to decentralise part of the stormwater response by storing and infiltrating water closer to where rainfall occurs.

This does not mean that conventional drainage should be eliminated. A resilient road system often combines distributed infiltration and storage with conventional conveyance and emergency overflow. The appropriate balance depends on flood-risk requirements, land use, soil conditions and the consequences of drainage failure.

## 4. CONCEPT OF WATER-ABSORBING ROAD

### Terminology

The phrase “water absorbing road” is retained in this report because it is the seminar topic supplied for the project. Technically, the report uses “permeable pavement”, “pervious pavement” or “porous pavement” when referring to engineered systems. Porous asphalt, pervious concrete and PICP are specific pavement technologies. The word “absorbing” is therefore interpreted as a simplified description of rainfall infiltration and temporary storage, not as a claim that the pavement permanently takes up water.

## Working principle

The basic hydraulic sequence is rainfall → permeable surface → connected pores or joints → bedding/filter layer where applicable → aggregate reservoir → infiltration into soil and/or underdrain → controlled discharge. The reservoir serves both hydraulic and structural functions. It can temporarily hold water and also provide a load-distributing base. Its effectiveness depends on void space, thickness, aggregate characteristics, drainage outlets and the capacity of the layers below.

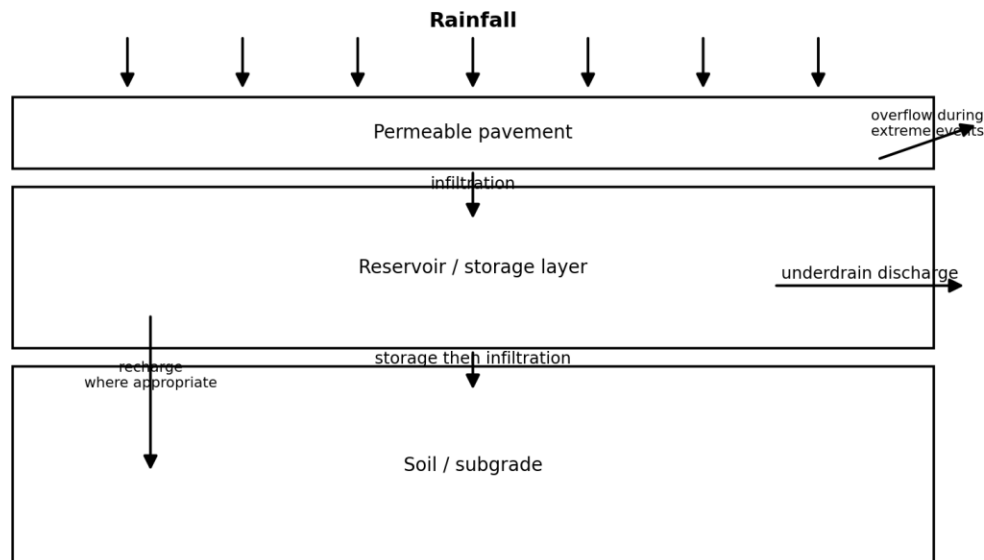


Figure 4. Water flow and infiltration pathways through a conceptual permeable pavement system.

## Infiltration versus absorption

Infiltration is the movement of water from the pavement system into the surrounding or underlying soil. Absorption, by contrast, usually describes uptake into a material. Permeable pavement is not designed primarily as an absorbent material. Its key characteristic is connected hydraulic void space. This distinction prevents a common conceptual error in which a pavement is assumed to hold an unlimited volume of water. The actual water balance must consider rainfall input, initial storage, infiltration, underdrain discharge, evaporation and overflow.

## Partial, full and no-infiltration configurations

Three broad configurations can be considered. In a full-infiltration system, the reservoir is intended to drain primarily into the native soil. In a partial-infiltration system, some water infiltrates while an underdrain controls excess water. In a no-infiltration or lined system, the reservoir is hydraulically isolated from the native soil.

## 5. TYPES OF PERMEABLE PAVEMENT

### Porous asphalt

Porous asphalt is an asphalt mixture intentionally designed with interconnected voids. Unlike dense-graded asphalt, the aggregate structure provides continuous pathways through which rainfall can move. The surface may be placed over an open-graded base/reservoir that provides both storage and structural support. The system is attractive where an asphaltic pavement appearance and construction process are desirable.

Important engineering considerations include aggregate gradation, binder selection, mixture stability, surface durability, support conditions, construction temperature and compaction. Excessive densification during construction can reduce the intended void structure. Conversely, inadequate structural control may reduce durability. The reservoir and subgrade remain critical because surface permeability alone does not determine total drainage performance.

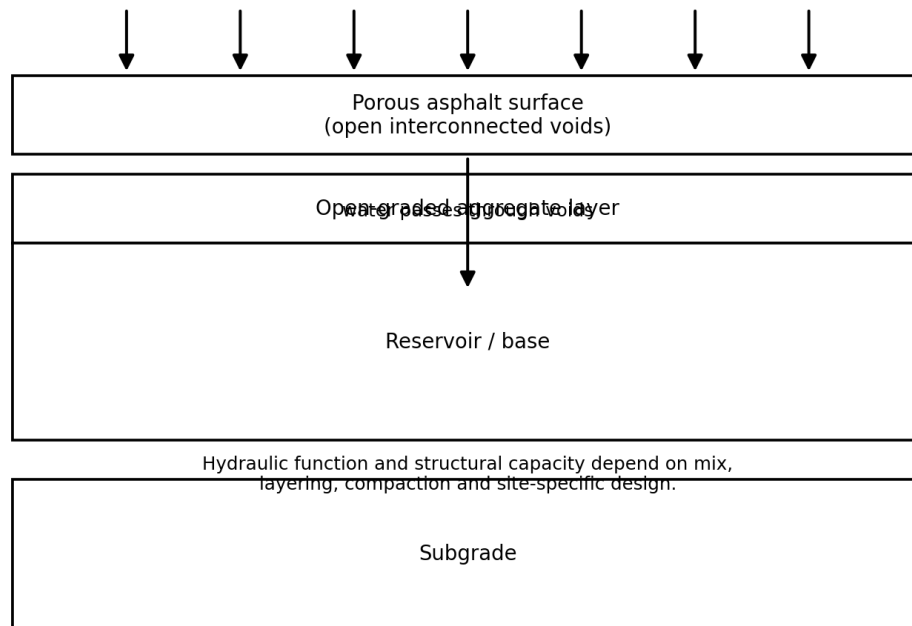


Figure 5. Conceptual porous asphalt cross-section showing the permeable wearing layer and aggregate reservoir.

### Pervious concrete

Pervious concrete contains a network of interconnected voids formed by the aggregate structure and relatively limited paste content. It can be used for pavements where concrete is suitable and stormwater infiltration is desired. ACI 522R provides guidance on materials, mixture proportioning, placement, curing and quality considerations. The technology requires careful construction because excessive paste, poor aggregate grading or inappropriate compaction can close pores, while inadequate bonding or curing can compromise mechanical performance.

The key design trade-off is hydraulic openness versus mechanical capacity. Pervious concrete must retain enough solid skeleton and paste bonding to carry the intended loading while preserving interconnected pathways. This is why strength and infiltration should be evaluated together rather than optimising only one parameter.

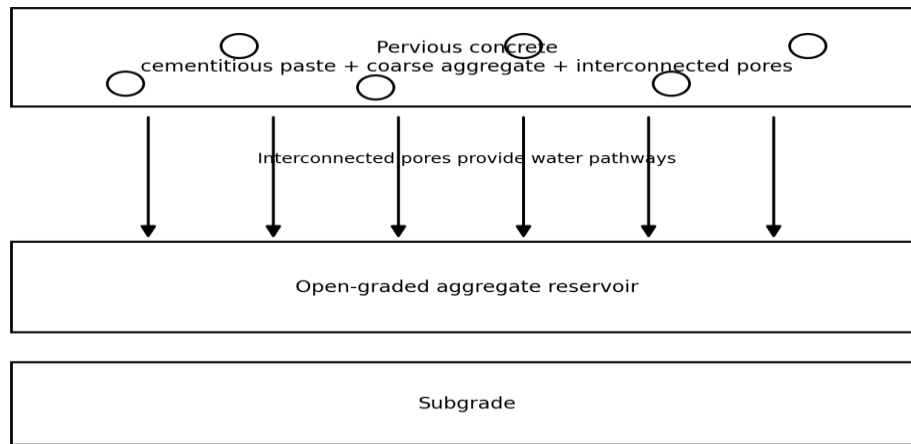
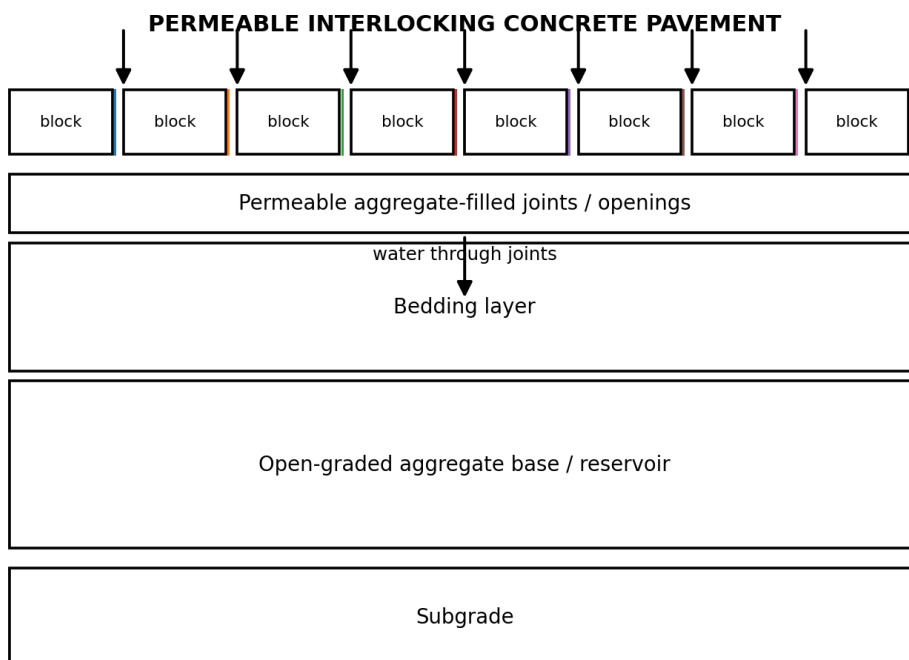


Figure 6. Conceptual pervious concrete cross-section showing interconnected pore pathways.

### Permeable interlocking concrete pavement (PICP)

PICP uses manufactured concrete units separated by aggregate-filled openings. The blocks provide the wearing surface and distribute traffic loads, while the joints admit rainfall. A bedding layer supports the units, and an open-graded aggregate reservoir provides storage and structural support. The modular nature of PICP can simplify local repair because individual units can be lifted and reinstated, although the hydraulic performance of the joint system still requires maintenance.



## Comparative evaluation

| Characteristic    | Porous asphalt                                      | Pervious concrete                            | PICP                                                 |
|-------------------|-----------------------------------------------------|----------------------------------------------|------------------------------------------------------|
| Hydraulic entry   | Through interconnected mixture voids                | Through interconnected pores                 | Primarily through permeable joints/openings          |
| Riding surface    | Continuous asphaltic surface                        | Continuous concrete surface                  | Modular concrete units                               |
| Reservoir         | Commonly integrated below surface                   | Commonly integrated below surface            | Commonly integrated below surface                    |
| Key risk          | Loss of permeability, mixture/structural durability | Pore closure, curing and strength control    | Joint clogging and joint aggregate condition         |
| Maintenance focus | Surface sediment management                         | Surface cleaning and infiltration monitoring | Joint cleaning/replenishment and surface maintenance |
| Design priority   | Mix, voids, support and drainage                    | Void structure, strength, curing             | Unit/joint behavior, bedding and reservoir           |

## 6. PAVEMENT STRUCTURE AND LAYER FUNCTIONS

### Typical layer arrangement

A permeable pavement is best treated as a layered system. The exact arrangement differs by technology and infiltration strategy, but a representative conceptual structure includes a permeable wearing layer, bedding or filter layer where applicable, an open-graded base/reservoir, a sub-base or transition layer, a geotextile/filter where appropriate, the native subgrade and an underdrain where required.

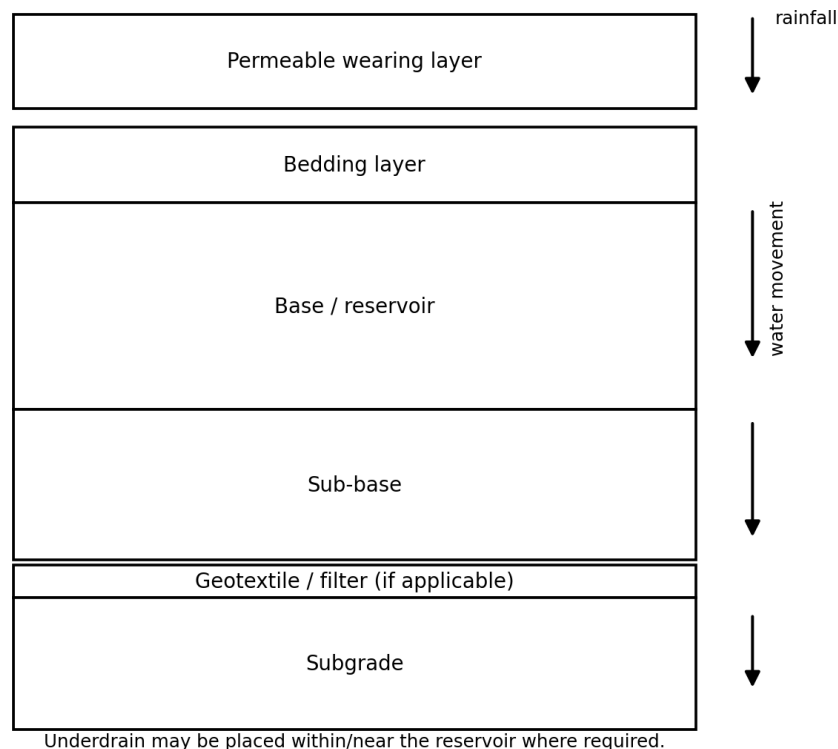


Figure 3. Detailed permeable pavement layer arrangement with hydraulic and structural roles.

## Surface / permeable wearing layer

The surface provides the traffic interface and the primary rainfall entry zone. Its material must provide the required skid resistance, durability and structural performance while maintaining hydraulic openings. Surface condition is also the first line of defence against clogging. Sediment entering the system can reduce permeability, so surrounding landscaping and construction activities should be managed to prevent uncontrolled fines from reaching the pavement.

## Bedding and filter layers

Bedding material is particularly important for modular systems such as PICP because it supports and levels the units. Its grading must be compatible with hydraulic flow and particle stability. Filter or separation layers may be used where needed to prevent migration of fine particles between layers. A geotextile is not automatically required in every permeable pavement; its use should be based on the grading relationship, filtration requirements and design guidance because an inappropriate fabric can itself become a hydraulic restriction.

## Base / reservoir

The open-graded aggregate reservoir is a central component of many permeable pavement systems. It provides temporary water storage through interconnected voids while also contributing to structural load distribution. The required reservoir depth is a design output rather than a universal value. It depends on rainfall, contributing area, allowable drawdown time, subgrade infiltration, underdrain configuration, traffic loading and structural requirements.

## Subgrade

The native subgrade provides structural support and, in infiltration-based systems, is a major hydraulic boundary. Its soil texture, density, moisture condition and hydraulic conductivity influence drainage. Highly impermeable soils can restrict infiltration and create prolonged saturation unless an underdrain is provided. Very permeable soils may permit rapid infiltration but can require careful groundwater and water-quality assessment.

## Underdrain and overflow

An underdrain provides controlled removal of water from the reservoir when infiltration alone is insufficient or undesirable. It can be placed within or near the reservoir depending on the design. Inspection and clean-out access should be considered. An overflow pathway is also important because no permeable pavement should be assumed to pass an extreme storm without a bypass. Safe exceedance routing protects both the pavement and adjacent property.

# 7. HYDROLOGICAL AND HYDRAULIC CONSIDERATIONS

## Rainfall and runoff

Hydraulic design begins with the rainfall regime and contributing catchment. Rainfall intensity, duration and temporal pattern affect the rate at which water reaches the pavement. The contributing area should be defined because permeable pavement may receive runoff from adjacent impervious surfaces in addition to direct rainfall. Such off-surface inflow can substantially change the required storage and drainage capacity.

## Water balance

A simplified conceptual water balance for a permeable pavement reservoir can be written as:

**Change in stored water = rainfall/runoff inflow – infiltration – underdrain discharge – other losses ± overflow**

This is a conceptual relationship rather than a complete design equation. A detailed design should account for rainfall time series, initial moisture condition, surface entry, reservoir void volume, subgrade infiltration, underdrain controls and overflow. The key point is that storage is finite.

## Hydraulic conductivity and infiltration

Hydraulic conductivity describes the ease with which water moves through a porous medium under a hydraulic gradient. Pavement-layer conductivity and native-soil conductivity are not interchangeable. The pavement may be highly conductive while the subgrade is relatively restrictive. Conversely, a permeable subgrade can drain a reservoir rapidly. Site testing should therefore identify the hydraulic behaviour of both the constructed pavement and the underlying soil where infiltration is part of the design.

## Storage capacity

The usable storage of an aggregate reservoir is related to its void volume rather than its gross geometric volume. In conceptual terms, storage increases with reservoir plan area, thickness and effective void ratio. However, not all theoretical void space is necessarily available for the design storm because some water may remain after the previous event or be unavailable due to geometry and drainage constraints. Drawdown time is consequently as important as maximum storage.

## Overflow and extreme rainfall

A permeable system should be designed for exceedance. During a storm larger than the design event, rainfall can exceed the combined infiltration and storage capacity. The resulting water should have a defined safe route to an underdrain, overflow structure or conventional drainage network. Designing only for the nominal permeable condition without considering exceedance can create unacceptable flood pathways.

## Groundwater interaction

The presence of a shallow groundwater table can limit available storage and reduce the hydraulic gradient driving infiltration. Seasonal groundwater variation should therefore be considered where infiltration is proposed. In addition, water-quality risks must be assessed before deliberately directing contaminated runoff into the subsurface. The design objective is not simply to maximise infiltration; it is to achieve acceptable hydraulic performance without creating unacceptable environmental risk.

## 8. DESIGN CONSIDERATIONS

### Hydraulic and structural design must be simultaneous

Traditional pavement design often begins with traffic loading and material strength, while stormwater design begins with rainfall and drainage. Permeable pavement requires these processes to interact. A reservoir that is hydraulically excellent but structurally inadequate is not a successful road, while a strong surface that clogs and cannot drain is also unsuccessful. The design objective is therefore multi-functional performance.

| Design variable       | Hydraulic relevance                                 | Structural / durability relevance        | Site information needed                   |
|-----------------------|-----------------------------------------------------|------------------------------------------|-------------------------------------------|
| Surface permeability  | Controls entry of rainfall                          | Affects surface structure and durability | Material tests, installed-surface testing |
| Void ratio / porosity | Determines storage and pathways                     | Can influence mechanical capacity        | Material specification and testing        |
| Reservoir thickness   | Controls available storage                          | Supports load distribution               | Rainfall, traffic, subgrade               |
| Aggregate gradation   | Controls connected voids and filtration             | Controls stability/interlock             | Material source and grading               |
| Subgrade conductivity | Controls infiltration below reservoir               | Influences saturation and support        | Geotechnical investigation                |
| Traffic loading       | Indirectly affects design through structural demand | Primary structural input                 | Traffic spectrum / axle loading           |

|                    |                                    |                                        |                                 |
|--------------------|------------------------------------|----------------------------------------|---------------------------------|
| Groundwater        | Can limit infiltration and storage | Can influence saturation and stability | Seasonal groundwater assessment |
| Maintenance access | Preserves hydraulic performance    | Supports serviceability                | Site layout and operations      |

### **Crossfall, edges and shoulders**

Permeable pavement does not eliminate the need for geometric drainage. Crossfall and edge conditions influence surface safety and overflow. Where the pavement interfaces with conventional shoulders or kerbs, differential hydraulic behaviour can occur. Edge details should prevent uncontrolled migration of fine material into the reservoir while allowing safe exceedance drainage.

## **9. STRUCTURAL / PAVEMENT ENGINEERING CONSIDERATIONS**

### **Traffic and load transfer**

The pavement must transfer wheel loads through the surface and reservoir layers to the subgrade without excessive rutting, cracking, settlement or loss of serviceability. Open-graded aggregate provides interparticle contact and load distribution, but its behaviour differs from a dense granular base. The structural design must therefore use material properties appropriate to the selected permeable system rather than assuming conventional dense-graded pavement properties.

### **Strength–permeability trade-off**

A central concept is the trade-off between hydraulic openness and solid load-bearing material. In pervious concrete, increasing connected voids can reduce the amount of cementitious matrix supporting loads. In porous asphalt, the aggregate skeleton must remain stable while preserving connected voids. In PICP, joint openness must be maintained while the blocks and bedding provide adequate support. The optimum condition is not the maximum possible permeability but sufficient permeability combined with required structural performance and durability.

### **Rutting, fatigue and settlement**

Rutting can result from inadequate structural support, unstable aggregate or repeated traffic. Fatigue mechanisms depend on the pavement type and material behaviour. Settlement can occur if the subgrade is weak, compressible or inadequately prepared. Water can worsen some structural problems by reducing effective support in susceptible soils. Consequently, drainage design and structural design cannot be separated.

### **No universal pavement thickness**

A final thickness design requires site-specific traffic, climate, subgrade and material information. A conceptual layer diagram is therefore presented in this report without dimensions. Any dimensions developed later for a physical prototype or site should be explicitly labelled as “Conceptual / Proposed for Academic Study” unless supported by project investigation and applicable standards.

## **10. GEOTECHNICAL CONSIDERATIONS**

### **Soil classification and infiltration**

The subgrade should be characterised using appropriate geotechnical investigation. Soil classification, density, moisture condition, bearing support and hydraulic conductivity are relevant. CBR may be used within pavement design where applicable, but CBR is not a substitute for infiltration testing. A soil can provide adequate structural support while having low hydraulic conductivity, or it can infiltrate rapidly while providing relatively weak structural support.

## Groundwater table

The vertical distance between the reservoir and the seasonal groundwater table affects available storage and infiltration. A high water table can reduce the hydraulic gradient and create prolonged saturation. The appropriate criterion is site-specific and should be established using groundwater information and applicable design guidance rather than a universal clearance value.

## Expansive and problematic soils

Expansive soils can undergo volume changes with moisture variation. Infiltrating additional water into a moisture-sensitive subgrade may therefore have structural implications. Similarly, highly compressible soils, uncontrolled fill or contaminated ground may require alternative drainage arrangements. A permeable pavement should not be selected solely because surface runoff is a problem; the ground beneath the pavement must also be capable of supporting the intended hydraulic regime.

## Geotextiles and filters

Geotextiles may provide separation and filtration between layers where the particle-size relationship makes migration a concern. However, their selection should consider hydraulic transmissivity, clogging resistance, puncture resistance and compatibility with adjacent aggregate. The report therefore treats geotextile use as “where appropriate” rather than as a mandatory component of every permeable pavement.

## 11. DRAINAGE AND UNDERDRAIN SYSTEM

### Full infiltration

In a full-infiltration configuration, water entering the reservoir is intended to infiltrate into the native soil. This arrangement can reduce discharge to conventional drainage networks but requires confidence in soil infiltration, groundwater conditions and environmental suitability. It also requires sufficient reservoir capacity to accommodate the design rainfall while infiltration proceeds.

### Partial infiltration

A partial-infiltration configuration combines infiltration with controlled drainage. An underdrain provides an outlet when the reservoir approaches a predetermined hydraulic condition or when the native soil cannot safely accept all inflow. This configuration can provide greater control and can be useful where infiltration is desirable but uncertain.

### No infiltration / underdrained systems

Where infiltration is unsuitable—for example because of contaminated soil, groundwater constraints, structural concerns or insufficient soil conductivity—the reservoir can be hydraulically isolated and drained through an underdrain. The pavement remains permeable at the surface but acts primarily as a temporary storage and controlled-discharge system rather than a groundwater-recharge system.

### Inspection and emergency drainage

Inspection points, accessible outlets and overflow routes should be incorporated where appropriate. Drainage components that cannot be inspected can become hidden failure points. Emergency drainage should direct exceedance flows toward safe receiving systems without undermining pavement edges or adjacent property.

## 12. CLOGGING AND MAINTENANCE

### Clogging mechanism

Clogging occurs when fine sediment, dust, organic matter and other particles occupy the voids through which water normally enters and moves. The process can begin at the surface and progress downward. The result is an increase in hydraulic resistance and a reduction in infiltration performance. The severity depends on sediment source, particle size, traffic, surrounding land use, surface texture and maintenance.

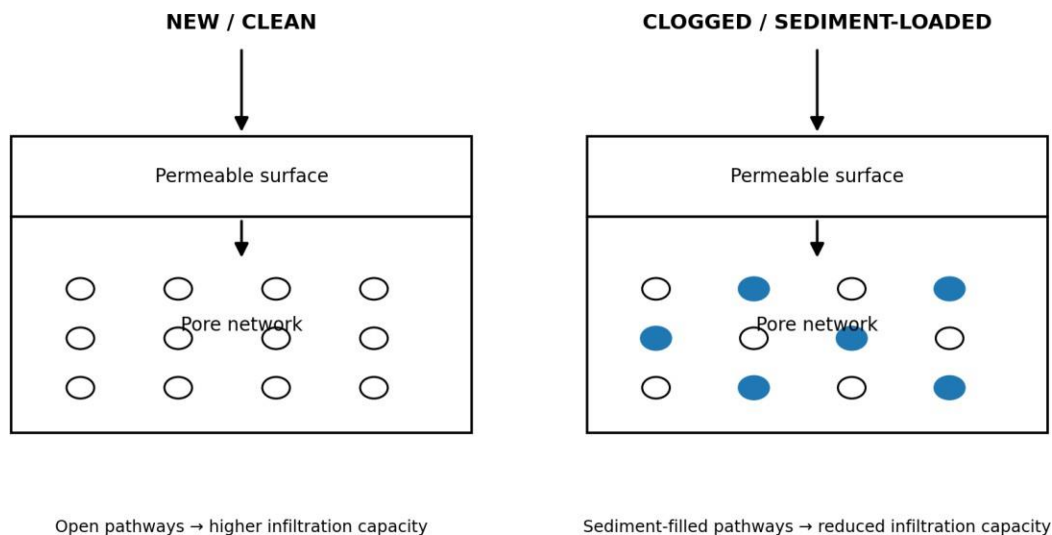


Figure 8. Conceptual clogging mechanism comparing clean pore pathways with sediment-filled pathways.

## Maintenance planning

Maintenance should be considered during design rather than after performance has declined. The maintenance plan should identify inspection locations, responsible agencies, acceptable performance criteria, cleaning methods, access requirements and rehabilitation triggers. Vacuum sweeping is commonly used for permeable surfaces, but the appropriate method depends on pavement type. PICP may require attention to joint aggregate, while pervious concrete may require cleaning methods suited to its surface and pore structure.

## Monitoring

Field infiltration testing can be used to track changes in surface performance. ASTM C1701/C1701M provides a method for in-place pervious concrete, while ASTM C1781/C1781M addresses infiltration associated with PICP and similar permeable surfaces. Monitoring should use a consistent method and comparable test locations. A single test result should not be treated as a complete representation of the whole pavement if spatial variability is significant.

## Maintenance is part of design life

Initial permeability is not equivalent to long-term permeability. A system with excellent commissioning performance may deteriorate if sediment sources are uncontrolled or maintenance is neglected. Conversely, a well-maintained system can preserve its intended hydraulic function more effectively. This makes life-cycle maintenance a core engineering requirement, not an optional operational activity.

## 13. MATERIALS AND CONSTRUCTION

### Materials

- Open-graded aggregate for reservoir and structural support, selected for grading, strength and durability.
- Cementitious materials and coarse aggregate for pervious concrete where that technology is selected.
- Bituminous binder and aggregate for porous asphalt.
- Concrete paving units and permeable joint aggregate for PICP.
- Bedding and filter materials selected for particle stability and hydraulic compatibility.
- Geotextiles or separation layers where required by the design.

- Perforated drainage pipes, clean-outs and outlets where underdrainage is provided.

### Conceptual construction sequence

A generic construction sequence is: site investigation; design and setting-out; subgrade preparation; installation of filter/separation measures where specified; placement and quality control of reservoir aggregate; installation of underdrains and inspection points; construction of the selected permeable surface; edge treatment; protection from sediment; inspection and hydraulic/structural quality testing; commissioning; and implementation of the maintenance plan. The actual sequence must follow the selected pavement system, project drawings and applicable specifications.

### Protection from construction sediment

Construction-phase sediment is a particular risk because a permeable surface can be clogged before it is even opened to traffic. Upstream earthworks should therefore be controlled so that fine soil does not enter completed permeable layers. The permeable surface should be installed after high-sediment construction activities where feasible, or protected by appropriate temporary measures that do not themselves contaminate the system.

## 14. TESTING AND PERFORMANCE EVALUATION

### Laboratory testing

Laboratory testing may include material gradation, density, void ratio or porosity, hydraulic conductivity or permeability, compressive strength for concrete-based materials, flexural properties where relevant, abrasion or durability testing where required, and controlled clogging experiments. The selected tests should correspond to the pavement technology and the governing specification.

### Field testing

Field evaluation can include in-place infiltration testing, surface condition surveys, drainage observations, reservoir inspection where accessible, structural condition surveys and monitoring after rainfall events. Field tests should be repeated sufficiently to account for spatial variability and should be interpreted in the context of recent weather and maintenance history.

| Performance domain | Possible indicator / test                               | Purpose                                  |
|--------------------|---------------------------------------------------------|------------------------------------------|
| Hydraulic          | In-place infiltration rate                              | Evaluate surface hydraulic performance   |
| Material           | Void ratio / porosity                                   | Characterise available void structure    |
| Concrete           | Compressive / flexural strength as applicable           | Evaluate structural capacity             |
| Aggregate          | Gradation and durability tests                          | Verify material suitability              |
| Drainage           | Drawdown / outlet observations                          | Assess storage and controlled discharge  |
| Clogging           | Before/after infiltration testing                       | Quantify maintenance-related change      |
| Structural         | Visual distress and load-response tests where justified | Assess serviceability                    |
| Environmental      | Water-quality sampling where required                   | Evaluate site-specific treatment or risk |

### No experimental results are claimed

No laboratory or field tests were performed as part of the supplied project brief, and no results are invented in this report. The tests listed above constitute a proposed evaluation framework for a future experimental or field phase. If the student later constructs a physical model, all dimensions, material sources, measured infiltration rates and observations should be

recorded separately and labelled as project data.

## 15. ENVIRONMENTAL BENEFITS AND RISKS

### Potential benefits

- Reduction and delay of direct surface runoff where infiltration and storage capacity are available.
- Reduction in surface ponding at suitable locations.
- Temporary stormwater storage within the pavement reservoir.
- Potential contribution to groundwater recharge in appropriate full-infiltration systems.
- Reduced peak discharge to conventional drainage networks in suitable applications.
- Potential physical filtration and attenuation of some pollutants.
- Multifunctional use of road space for transport and stormwater management.

These are potential benefits rather than universal outcomes. Performance depends on rainfall, pavement condition, soil, groundwater, drainage configuration and maintenance. A site should be evaluated against the actual stormwater objective rather than assuming a generic percentage reduction in runoff.

### Environmental risks

Infiltration can be undesirable where runoff contains pollutants that should not enter soil or groundwater. Sediment accumulation can also create a concentrated pollutant reservoir that requires appropriate maintenance and disposal. Poorly managed systems may produce standing water or drainage problems if the reservoir does not draw down as intended. Environmental assessment should therefore consider both the benefits of distributed infiltration and the consequences of moving water into the subsurface.

### Urban heat and co-benefits

Permeable pavements can interact with surface moisture, material thermal properties and urban microclimate, but temperature benefits are not guaranteed and vary with climate, material and moisture condition. Such co-benefits should be treated as secondary to the demonstrated hydraulic and structural objectives unless supported by site-specific evidence.

## 16. LIMITATIONS AND ENVIRONMENTAL RISKS

### Clogging and maintenance

The most direct limitation is loss of hydraulic performance caused by sediment and fines. This is especially relevant in environments with high dust loads, unpaved shoulders or poorly controlled construction sediment. Maintenance capability must therefore be considered during site selection.

### Soil and groundwater limitations

Low-permeability subgrades can limit infiltration, while high groundwater can reduce storage and hydraulic gradient. Contaminated soil or sensitive aquifers may make full infiltration inappropriate. Underdrainage or a lined configuration may then be more suitable.

### Structural limitations

Open structures can have different strength and durability characteristics from conventional dense pavement. Heavy traffic, high-speed operation, aggressive turning and repeated loading can require more rigorous structural design. Permeable pavement should not be specified for a traffic environment without appropriate structural verification.

### Extreme rainfall

A permeable pavement is not a substitute for flood-resilient drainage design. Extreme rainfall can exceed surface infiltration, storage and underdrain capacity. A safe overflow route is therefore a fundamental component of a resilient system.

## Construction and quality limitations

The system can be damaged by poor grading, unsuitable aggregate, over-compaction, poor concrete curing, contamination during construction or inadequate edge restraint. Quality control is therefore as important as the conceptual design.

## 17. INDIAN CONTEXT

### Monsoon rainfall and urban drainage

The Indian context makes stormwater management particularly relevant because many urban areas experience seasonal rainfall concentrated into monsoon periods. The design challenge is not merely annual rainfall volume but the timing and intensity of individual storms. A pavement may have enough average annual infiltration capacity while still generating runoff during an intense short-duration event. This reinforces the need for event-based hydraulic analysis and safe exceedance drainage.



### Sediment and clogging

Dust, road-side soil, construction activity and sediment carried from adjacent areas can be important clogging sources. Permeable pavement should therefore be integrated with source-control measures such as clean construction sequencing, stable shoulders, sediment management and routine surface maintenance. This issue is particularly relevant to Indian urban roads where maintenance resources and road-edge conditions can vary widely.

### Soil and groundwater diversity

Indian cities and regions contain a wide range of soil conditions, from relatively permeable granular soils to low-permeability fine-grained and expansive soils. Groundwater levels also vary spatially and seasonally. Consequently, there is no single Indian permeable pavement cross-section that can be applied without investigation. Soil infiltration testing, subgrade assessment and groundwater review are essential before selecting an infiltration strategy.

### Suitable application categories

Potential applications include parking areas, pedestrian zones, low-speed streets, selected urban roads and other sites where the traffic and hydraulic objectives are compatible. Heavily trafficked highways may require more rigorous structural and maintenance evaluation. The technology should be selected according to risk and function rather than as a blanket replacement for conventional pavement.

### Indian guidance and standards

Indian road and urban-drainage guidance should be consulted alongside pavement-specific international standards and test methods. The Ministry of Housing and Urban Affairs Manual on Storm Water Drainage Systems provides an important drainage-planning reference. Applicable Indian Roads Congress, Bureau of Indian Standards and local authority specifications should be checked for the actual project. Because standards are periodically revised, the current edition should always be verified before construction or design approval.

## 18. CONCEPTUAL DESIGN FOR THE SEMINAR PROJECT

### Conceptual system description

For academic demonstration, the proposed system consists of a permeable surface over an open-graded aggregate reservoir, with a subgrade capable of receiving some infiltrated water and an optional underdrain/overflow route. The arrangement is intentionally generic so that it can be adapted to porous asphalt, pervious concrete or PICP. No layer thicknesses are specified because such values would require traffic, rainfall, soil and material data.

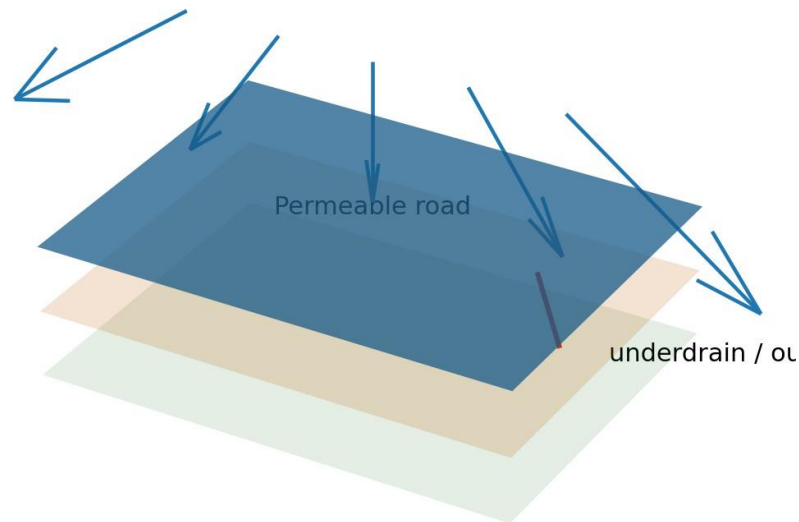


Figure 10. Conceptual three-dimensional road model showing road surface, rainfall, reservoir, soil and controlled drainage.

### Conceptual design criteria

- All dimensions are conceptual / proposed for academic study unless later supported by site investigation.
- Surface permeability must be sufficient for the intended hydraulic objective.
- Reservoir storage must be sized from rainfall, contributing area, drawdown and drainage requirements.
- Subgrade infiltration must be measured or reliably characterised where infiltration is intended.
- Traffic loading must be established before structural thickness is designed.
- Groundwater and environmental conditions must be checked before full infiltration is selected.
- Overflow and emergency drainage must be provided for exceedance conditions.
- Maintenance access and inspection must be incorporated from the beginning.

### 19.3 Conceptual water pathway

During a rainfall event, water reaches the permeable surface directly and may also arrive from adjacent areas if the layout permits. Water enters the surface through pores or joints and moves downward into the bedding and reservoir. The reservoir temporarily stores water while infiltration into the soil occurs. If the soil cannot accept water at the required rate, the water level rises until an underdrain or controlled outlet conveys the excess. If the storm exceeds the design capacity, overflow should bypass the pavement safely.

## Physical model requirements

A physical demonstration model can be constructed using transparent or sectional components so that the pavement layers and water pathway are visible. The model should be labelled as a demonstration rather than a scale engineering prototype unless similarity criteria are deliberately established. Any measured flow or infiltration result should be recorded as experimental project data and should not be presented as a field-performance value.

## 19. ADVANTAGES AND DISADVANTAGES

### Advantages

- Can reduce or delay surface runoff where adequate infiltration and storage exist.
- Can reduce surface ponding at appropriate sites.
- Can provide temporary stormwater storage within road space.
- May contribute to groundwater recharge in suitable full-infiltration configurations.
- Can reduce peak discharge to downstream drainage infrastructure in appropriate applications.
- Can combine transportation and stormwater functions within the same footprint.
- Can support sustainable urban-drainage strategies.

### Disadvantages / limitations

- Susceptible to clogging by sediment and fine particles.
- Requires planned inspection and maintenance.
- May be unsuitable on low-permeability or problematic soils without underdrainage.
- May be inappropriate where groundwater or contamination conditions make infiltration unsafe.
- Structural design can be more demanding because hydraulic voids and load capacity must be balanced.
- Construction quality is critical to preserve the designed void structure.
- Extreme rainfall can exceed storage and infiltration capacity.
- Initial complexity or cost may be higher in some sites, although economic performance is project-specific.
- Long-term hydraulic performance depends on maintenance and surrounding sediment sources.

## 20. CONCLUSION

The study establishes that the term “water absorbing road” is best interpreted technically as a permeable or pervious pavement system designed to manage rainfall through infiltration, temporary storage and controlled drainage. The pavement does not permanently absorb water. Instead, interconnected pores or permeable joints allow water to enter a layered structure in which hydraulic storage, soil infiltration and underdrainage are deliberately managed.

The literature demonstrates potential benefits in reducing and delaying runoff, decreasing surface ponding and integrating stormwater management into transportation infrastructure. However, these benefits are conditional. The overall performance depends on rainfall intensity, surface permeability, reservoir capacity, subgrade infiltration, groundwater conditions, traffic loading, material quality, construction practice and maintenance. The distinction between pavement permeability and native-soil infiltration is especially important because a permeable surface cannot compensate indefinitely for an impermeable subgrade.

Porous asphalt, pervious concrete and PICP provide different combinations of hydraulic and structural characteristics. None should be selected solely because it has a high initial infiltration rate. Structural capacity, durability, traffic conditions and maintainability must be evaluated simultaneously. Clogging is a major long-term issue, making inspection, surface cleaning and performance monitoring integral components of the design rather than optional aftercare.

For India, the technology is potentially relevant to sustainable stormwater management, particularly where monsoon rainfall creates rapid runoff and local waterlogging. Nevertheless, diverse soils, groundwater conditions, sediment loads and traffic environments mean that no universal cross-section or performance value should be assumed. Site-specific

rainfall analysis, geotechnical investigation, groundwater assessment, material testing, structural design, hydraulic sizing and safe overflow planning are required before implementation.

Accordingly, the proposed seminar system should be regarded as a conceptual engineering framework. It provides a technically grounded basis for a future physical model, laboratory investigation or field pilot, but it does not claim experimental validation. The strongest engineering conclusion is therefore balanced: permeable pavement can be a valuable component of sustainable road and stormwater infrastructure, provided that it is designed for the actual site, maintained throughout its service life and integrated with conventional drainage for extreme events.

| Stakeholder                | Relevance                                                            |
|----------------------------|----------------------------------------------------------------------|
| Highway authorities        | Road standards, approvals, asset management and network performance. |
| Municipal authorities      | Urban drainage, flood management and local road maintenance.         |
| Civil / pavement engineers | Hydraulic-structural integration and pavement design.                |
| Environmental engineers    | Water quality, groundwater protection and sustainability.            |
| Urban planners             | Land-use integration and stormwater strategy.                        |
| Contractors                | Construction quality and protection of permeable layers.             |
| Material suppliers         | Consistent aggregate, concrete, asphalt and paving-unit quality.     |
| Researchers / institutions | Testing, monitoring and development of improved designs.             |
| Local communities          | Road usability, drainage benefits and acceptance.                    |
| Maintenance agencies       | Inspection, cleaning, rehabilitation and long-term performance.      |
| Government departments     | Policy, standards, funding and regulatory coordination.              |

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