Porous Pavements: The Overview

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Abstract

Eight years of research have recently concluded with the first comprehensive review of porous pavement technology and applications. It defines nine families of porous paving material, each of which has distinctive costs, maintenance requirements, advantages and disadvantages for different applications, installation methods, sources of standard specifications, and performance levels. The research is supported by 800 literature citations, 170 interviews with experts in the field, and the author's firsthand survey of 280 installations of all types of porous pavements in all parts of North America (about 30 of which were porous concrete). The resulting 577-page book (Ferguson, 2005) defines and organizes the field for the first time.

Where porous pavements are properly selected, designed, and installed, they can naturally biodegrade the oils from cars and trucks, give long-lived urban trees viable rooting space, make streets quiet, make driving safer, preserve native ecosystems, and reduce development costs. Where proper design and installation are neglected, failures — clogging and structural degradation — result.

The purposes of this paper are:

1) to describe the research process behind the document;

2) to review the range of competing porous paving materials, and the range of overlapping purposes for which they are being installed nationwide today;

3) to outline the advantages and disadvantages of porous concrete for specific applications, in comparison with those of other materials;

4) to review the history and current status of porous concrete paving applications in North America; and

5) to document selected case studies of porous pavement installations in North America, to explain their successful and unsuccessful aspects, and to point out their lessons for future porous pavement selection, design, and construction.

Introduction

Porous pavements are those made with built-in void spaces that let water and air pass through. They are the most radical, most rapidly developing, and most controversial way of restoring large parts of the urban environment. They have been called "the holy grail of environmental site design" and "potentially the most important development in urban watersheds since the invention of the automobile".

Recently, an eight-year-long research project concluded with the publication of this technology's first comprehensive overview (Ferguson, 2005). This paper describes the making of the book *Porous Pavements*, and the current types and extent of applications of porous concrete and other porous paving materials in North America.

Project background

What brought the subject to the author was previous work in stormwater management, which had included a particular critique of downstream detention basins and a particular contribution to stormwater infiltration (Ferguson,1998). Porous pavements seemed to be the next step: research had found validity in them (Day, 1978; Thelen et al., 1972); some practitioners were using them repeatedly (www.thcahill.com; www.andropogon.com); they could solve the stormwater problem at the source; and they had vast potential for doing good, because pavements are two-thirds of the potentially impervious surfaces in typical urban watersheds.

However the technical questions about porous pavements were numerous and detailed. They took the form of, "But how about freeze-thaw? But how about clay soil? But how about compaction? …Clogging? …Durability? …Maintenance? But how about root heaving? But how about where to get specifications?" It is valid that these questions be asked, and vital that they all be answered.

Therefore the purpose of the book project was to give practitioners what they need to use this technology. This included answering the challenging questions up to the limit of scientific knowledge, demonstrating use in case studies (both successes and failures), and making specifications accessible. In other words, the purpose was to define, organize, make accessible, and substantively evidence this potentially powerful new technology.

The project ended up taking eight years of research. It included 170 interviews with experts in the field, reading 800 technical articles and reports, and a firsthand survey of 280 installations in the field, of all kind of porous pavements, in all parts of North America. Most of the surveyed installations were in the eastern United States, largely because several kinds of porous pavements, including porous concrete, originated in the East, so the East has the longest history and largest accumulation of installations.

Porous paving materials

Porous pavements are made of the same generic components as dense pavements: surface course, base course, and subgrade. Each layer is multi-functional, and each can be given alternative materials and configurations by applying the same physical principles that apply in all pavement design.

There are nine families of porous paving materials, each of which presents distinctive costs, installation methods, performance levels, maintenance requirements, and advantages and disadvantages for any specific application. For example:

- Porous aggregate is very inexpensive, and very permeable;
- Porous turf is living and dynamic;
- Open-jointed block is sturdy, attractive and reliable;
- Porous concrete depends for its quality on a qualified installer;
- Porous asphalt's technology is advancing, allowing it to avoid clogging problems which haunted it in the past.

It is vital to put the right material in the right place. No single material, porous or dense, should be smeared thoughtlessly everywhere. A development site should be analyzed in detail to distinguish pavement settings where different, optimally suited materials could be placed. One can distinguish accessible routes from "general" routes; different amounts of vehicular braking and turning (parking stalls from driving lanes, parking near commercial buildings from overflow parking); “calmed” traffic from swiftly, smoothly moving traffic; different slopes (which have different erosion concerns); different maintenance regimes (which might or might not invite turf); and different needs for tree rooting, appearance, and hydrology.

Porous concrete

Porous concrete is mixed at the same concrete plants, and made of the same constituents, as conventional dense concrete: Portland cement, water, and aggregate. But the aggregate is single-sized; there is no sand or fines filling the voids between large particles. The remaining single-sized aggregate particles leave open voids that give the material its porosity and permeability. Under the porous concrete surface there may be a base course or “base reservoir” of further single-sized aggregate.

Properly installed porous concrete can bear frequent traffic, and is universally accessible by most measures. It can be stained to match the color of local natural or architectural features. Its application is supported by general technical information such as Ferguson’s (2005) *Porous Pavements* and ACI Committee 522’s planned technical report (www.aci-int.org). It is capable of infiltrating water at 50 inches per hour and more. Its stormwater-management performance has been monitored at the Florida Aquarium in Tampa (Rushton and Hastings, 2001; further and broader monitoring would be beneficial). At least theoretically, its light color and porosity may combat the urban “heat island”, but this has yet to be scientifically observed; research directly and conclusively comparing the thermal behavior of porous concrete and dense concrete is needed.

Porous concrete pavements started in Florida in the 1970s, using the material’s pores and the state’s typically sandy soils to meet the state’s stormwater retention requirements without the expense of off-pavement stormwater control facilities; more or less successful installations from the 1980s are still extant there.

It has been used in other southeastern states since the 1990s, first in southern Georgia for native ecosystem preservation at an ecological research center on sandy Coastal Plain soils like those in Florida; getting over the political boundary into another state was an important psychological step. In 1996 it was used for the first time on compacted clay subgrade, at a research institute in Atlanta; this was an important physical step in expanding porous concrete’s application onto inland clay soil.

The geographic range of the material’s use is expanding rapidly. It has been in Tennessee since 1997, where in Chattanooga a plastic sheet at the base of the pavement collects rainwater and directs it to a central reservoir, from which it is pumped to irrigate the trees and plantings elsewhere on the site. It has been used on the West Coast since 2001; the first installation there was to counteract the urban “heat island” by aerating the roots of shade trees, and hopefully benefiting from concrete’s light color. Brand-name varieties such as Ecocreto are now being applied in Texas and elsewhere, with credible results.

To date, the applications in the coldest settings are in Asheville, North Carolina (at elevation 2,500 feet), central Maryland, and Washington State. In cold locations air entrainment and polymer-fiber reinforcing may help prevent freeze-thaw damage, if proper mixing can be furnished. In still colder locations, further installations should be attempted carefully, and monitored.

Correct layout, installation, and maintenance

Installation of porous concrete is not more difficult than that of dense concrete, but it is different, and its different specifications and procedures must be followed.

Correctly installed porous concrete is vividly recognizable: it has uniformly open surface pores, no loose particles at the surface, no cracks, and no pits; its surface infiltration rate is high. In contrast, poorly installed porous concrete has a closed, smeared-over surface and low infiltration rate; within a year after installation it has loose particles rolling around on the surface, and surface pits from which the particles are raveling.

Publications of the Florida Concrete and Products Association (www.fcpa.org) are helpful guides to the technicalities of installation. Further guidance will come from forthcoming technical reports of the American Concrete Institute's Committee 522, Pervious Concrete (www.aci-int.org).

At the current state of technology, porous concrete's installed quality depends vitally on a qualified installer. A qualified installer can be identified on the basis of documented experience, installation of a test panel before proceeding with the rest of the project, or special certification by the Portland Cement Pervious Association (contactable through www.petrusutr.com) or NRMCA (www.nrmca.org).

During installation, porous concrete is a "zero-slump" mixture: it contains only enough water to make the paste stick to the aggregate particles. At this water content, the mixture is so "stiff" that it must be pulled with rakes and shovels down a delivery chute and into place. The exact water content is critical: too much would make the paste drain to the bottom of the slab; too little would prevent the paste from curing completely. At the current state of technology, evaluating the exact water content depends on the judgment of the installer at the time of placement. Research to develop objective, impersonal methods of measuring and controlling exact water content would be justified.

The in-place mixture should be leveled and compacted by rolling, not screeding, in order to avoid smearing the paste across the surface pores. It must then immediately be securely covered with plastic sheets for a number of days. Because the mixture has low water content and its pores invite evaporation, the mixture's available water must be scrupulously preserved for complete curing.

An open-graded aggregate base makes a reservoir for storing and treating stormwater before it is discharged. On soft clay soil, a base makes a stable platform for placing the concrete. A nonwoven geotextile under the base prevents plastic soil from flowing into the aggregate's void spaces.

Subgrade compaction during construction greatly reduces soil infiltration rate, but may be necessary for stability where the subgrade is plastic clay or fill, or the pavement will be too thin to compensate structurally for soft wet soil. Compaction might be omitted, and the native infiltration rate preserved, where the subgrade is native cut (and therefore has *in situ* compaction and stability), and adequate pavement thickness will compensate for subgrade uncertainties.

To protect a pavement's surface from sedimentary clogging, it should be laid out to prevent sediment from washing on, and to allow it to wash off. Surface drainage should be away from the pavement edge in every possible direction. On the downhill side, large, numerous curb cuts should be added if necessary. On the uphill side, a swale should be added if necessary to divert potentially sediment-laden runoff. These provisions limit most porous pavements to infiltrating the rain water that falls directly upon the pavement, and not stormwater runoff from surrounding earthen slopes.

In the event sedimentary clogging occurs, the essential step in effective pavement restoration is vacuuming, because vacuuming pulls sedimentary particles back out of the pores. Low-pressure washing may help to mobilize sediment before it is removed by vacuuming. High-pressure washing only drives sediment deeper into the pores. Sweeping is worthwhile only when combined with immediate vacuuming.

Porous concrete’s environmental performance

Properly installed porous concrete has void space of 11 to 22 percent (the amount varies with aggregate type). Its surface infiltration rate is over 55 inches per hour, and can exceed 100 inches per hour.

Like other porous paving materials, porous concrete reduces stormwater rate and volume. Stormwater can be discharged through a perforated pipe at the bottom of the pavement, or at the top of the base reservoir, or water can be allowed to overflow at the pavement surface. Each type of drainage outlet produces different proportions of detention, treatment, infiltration, evaporation, and lateral overflow. Rainwater infiltration through a porous pavement into the underlying soil reduces stormwater volume and restores natural subsurface flow paths. Where slowly permeable soil prohibits significant soil infiltration, and water is discharged through a perforated pipe in the pavement, a porous pavement can perform detention comparable to that in off-pavement reservoirs and ponds: the peak discharge of stormwater from the bottom of a porous pavement is later and lower than that of the rainfall entering it at the top; the total volume of discharge is lower. Reduction of stormwater flow reduces downstream flood frequency, stream channel erosion, sediment loads, and combined-sewer overflows.

It is believed that common urban pollutants are treated in porous concrete, as they are in other types of porous pavement. Metals like cadmium and lead released by automobile corrosion and wear are captured in porous pavements’ voids along with the minute sediment particles to which the ions are characteristically attached. Capturing the metals prevents them from washing downstream and accumulating inadvertently in the environment. In the void spaces, oil leaked from automobiles is digested by naturally occurring microbiota that inhabit the abundant internal surface area. The oil’s constituents go off as carbon dioxide and water, and very little else; the oil ceases to exist as a pollutant.

Porous pavements combine stormwater management with pavement function in a single structure. Developments planned to benefit from this combination tend to cost less than those having impervious pavements with separate stormwater management facilities that incur costs of land acquisition, excavation, piping, and outlet structures.

Porous pavements can give urban trees the rooting space they need to grow to full size, providing the shade, cooling and air quality for which the trees are planted. The rooting zone is an aggregate base, made of large, single-sized aggregate that bears the pavement’s load. Into the aggregate’s void space is mixed 15 to 20 percent by volume of nutrient- and water-holding soil; the remaining unfilled void space maintains aeration and drainage. The base mixture makes the base into a “structural soil”, while the porous surface admits vital air and water to the rooting zone. This is a revolutionary new way to integrate healthy ecology and thriving cities: living tree canopy above, the city’s traffic on the ground, and living tree roots below.

Porous concrete’s potential

Porous pavements are important because they can solve urban environmental problems at the source. In new suburban growth, they protect pristine watersheds. In old town centers, redevelopment and reconstruction are opportunities for environmental rehabilitation simultaneously with urban renewal.

The hydrologic and structural success of porous concrete depends on correct selection, design, installation, and maintenance. Failures — clogging and structural degradation — result from neglecting one or more of these steps.

Porous pavements’ potential application is vast. To date, porous pavements constitute only a minute fraction of the paving done each year in the United States. But their rate of growth, on a percentage basis, is very high, primarily because of public concern about and legal requirements for stormwater management. Properly applied porous pavements can also enlarge urban tree rooting space, reduce the urban heat-island effect, reduce traffic noise, increase driving safety, and improve appearance. Therefore their selection and implementation are integral parts of the multi-faceted concerns of urban design, and all of their effects are considered together in evaluations of potential benefits and costs.

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