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## **Porous Pavements in North America: Experience and Importance**

### **Revêtements poreux en Amérique du Nord : expérience et importance**

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#### **RÉSUMÉ**

En Amérique du Nord, l'expérience de l'utilisation des revêtements poreux a bénéficié des développements à l'étranger, et a apporté des contributions originales dans ce domaine. Le béton perméable a maintenant été installé dans pratiquement toutes les conditions climatiques et pédologiques du continent ; des normes ont été adoptées et sont continuellement améliorées grâce à la recherche et à l'expérience. Initialement, la technologie de revêtement perméable est venue d'Europe ; un vaste champ de recherche et de mise à profit de l'expérience a permis d'élaborer des normes Nord Américaines conduisant à des revêtements résistants et hautement perméables. Le suivi scientifique a été vital pour le rôle des revêtements poreux comme surface véritablement perméable. Le rôle d'absorption et de restauration des revêtements poreux représente un nouveau modèle unifié et optimiste dans la relation entre les villes et les processus environnementaux. Contrairement aux technologies du passé, les revêtements poreux représentent une construction urbaine avec intégration des processus environnementaux. Ils s'intègrent dans les communautés humaines par le biais d'effets économiques et d'utilisation des sols perçus. Les revêtements poreux soutiennent une forme de conception urbaine dans laquelle l'économie, la communauté humaine, et l'environnement fonctionnent ensemble, sur un même site urbain dense.

#### **MOTS CLÉS**

Revêtement, urbanisme

#### **ABSTRACT**

North America's porous pavement experience has both benefited from developments overseas, and made some original contributions to the field. Pervious concrete has now been installed in almost all the continent's climatic and soil conditions; industry standard have been adopted and are continuing to be upgraded with ongoing experience and research. Permeable paver technology was originally brought from Europe; wide experience and research have shaped North American industry standards that assure strong and highly permeable pavements. Scientific monitoring has been vital in supporting porous pavements' role as a truly pervious surface. Porous pavements' absorptive, restorative role presents a new, unified, optimistic model for the relationship between cities and life-supporting environmental processes. Unlike the technologies of the past, porous pavements represent urban construction with environmental process included. They integrate themselves into human communities through perceptual, economic, and land use effects. Porous pavements support a kind of urban design in which economy, human community, and environment thrive together, in the same dense urban place.

#### **KEYWORDS**

Pavement, Urban design

## 1 INTRODUCTION

This paper reviews the development and applications of porous (permeable) pavements in North America, and their implications for a type of urban design that integrates environmental processes. The author has surveyed approximately 500 installations of all types of porous pavements in the United States and Canada, both as research for the book *Porous Pavements* (Ferguson, 2005) and following the book's publication. The total number of installations in existence is presumably several times that number, and is growing rapidly. This paper emphasizes pervious concrete and permeable pavers, which have been the most prevalent porous materials for bearing substantial moving traffic.

## 2 PERVIOUS CONCRETE

Pervious concrete pavement for stormwater management originated in the state of Florida in the 1970s. Its development was motivated by the state's requirement of stormwater retention to protect water quality, long before the US Federal Environmental Protection Agency brought concern about nonpoint-source pollution to the rest of the country. With pervious concrete, a developer could meet Florida's volume requirement for stormwater retention within the pavement's void space, without the expense of buying additional land on which to place a retention basin. Florida's frost-free climate and permeable sandy soils invited rapid adoption of the material. Its application remained confined to the state for many years because other states had neither Florida's jurisdictional requirement for stormwater retention nor its benign environmental conditions.

During those early years in Florida, industrial standards and installer certifications had not yet been established, so some of the installations were failures. Some extant examples from the early 1980s show clogging by cement paste, and raveling (separation of particles from the surface, leaving pits of loose gravel). In retrospect, those conditions are attributable to improper control of water content during placement and curing. It is now known that pervious concrete's quality control requirements are exacting. It is a low-water-content mixture, and sensitive to small variations in water content (ACI, 2006). In a mixture that is too wet, the paste drains through the voids, producing a clogging layer at depth and leaving surface particles raveling without binding. In a mixture that is too dry, water is insufficient for complete curing; aggregate particles are again left to ravel. Only a scrupulously correct mixture has moist paste uniformly clinging around all the particles, giving complete curing and a stable, porous, permeable structure.

Industry experience and research have now established, and are continuing to upgrade, desirable and achievable standards such as those listed in Table 1. Under them, a mixture containing strictly single-sized aggregate can produce compressive strength of 2,500 psi (17 Mpa) or more, with minimum permeability of 140 in/hr (3600 mm/h). At these performance levels, pervious concrete is structurally adequate for many applications with low and medium traffic levels, while absorbing any possible rate of natural rainfall. Custom mixes can produce higher strength, with correspondingly lower permeability.

<u>Item</u>	<u>Reference or agency</u>
<u>Concrete design and installation</u>	
Concrete production	ACI 522.1
Installer certification	National Ready Mixed Concrete Association
Example of recent specification	Mackenzie (2009)
<u>Testing</u>	
Freshly mixed density & porosity	ASTM C 1688
Hardened density & porosity	ASTM Subcommittee C09.49
Infiltration rate	ASTM Subcommittee C09.49
Compressive & flexural strength	ASTM Subcommittee C09.49

Table 1. Pervious concrete industry standards

Today, pervious concrete has gained experience in almost all climatic and soil conditions in North America. On slowly permeable clay soil, it has been installed with thick base reservoirs to satisfy stormwater requirements without the need for additional retention ponds: in Atlanta, Georgia, this effect has allowed the construction of a library on a small in-town lot which otherwise would have had to remain vacant. It has been installed even on swelling soils such as Texas' notoriously swelling Houston Black Clay, where the soil has been compacted and stabilized as it is for any construction; then the perforated pipes that drain the base reservoir have been placed a couple of inches above the subgrade surface, permanently saturating the soil and perhaps producing some infiltration through the

compacted clay. Pervious concrete has been installed in the cold climates of northern and high-elevation areas, where it has proven free from freeze-thaw damage as long as the concrete surface course is installed according to contemporary standards and is installed to drain downward freely into the base reservoir, thence into permeable soil or a perforated pipe. Winter meltwater drains downward rather than ponding at the surface, producing safer walking and driving conditions and reducing the need for deicing salt. Pervious concrete has been installed under industrial truck traffic, using custom mixes that were selected after testing for strength and permeability. Its firm, regular surface and fine pores have been used to satisfy all criteria for universal accessibility.

Nevertheless installation errors continue to be made, showing up as severe raveling. After a notable failure in Denver, Colorado, the regional drainage agency investigated the installation in a scientific, evidence-based manner, released their reports to the public, and used the results to upgrade regional standards for pervious concrete production and placement (MacKenzie, 2009). Wherever failures are used in such responsible ways, pervious concrete continues to be brought into a better known and more trustworthy status than before the failures happened. Everywhere local designers, suppliers, installers, and regulators must continue to be made aware of the availability and importance of evolving industry standards.

### 3 PERMEABLE PAVERS

Permeable pavers, also called open-jointed blocks or PICP (permeable interlocking concrete pavement) have been installed in North America since the 1980s. This technology uses manufactured paving units shaped such that when they are placed side-by-side in a pavement they leave permeable openings in the joints. The first installations were in Ontario, where German companies, after originating the technology in Europe, chose to place their North American offices. Most of the available models are of concrete and were developed by the Europe-headquartered companies, which license them to North American manufacturers. Indigenous North American companies have recently developed several additional models, some of which are shaped for improved accessibility, and some which are of clay brick; the entry of the brick industry to the market brings a new alternative in porous pavement material selection.

Early installations were slowly permeable by today's standards, because they used relatively dense-graded aggregate in the joints. The manufacturers' written guidelines of the day specified such aggregate, for the purpose of maximizing interlock and stability. The results of subsequent research and experience have allowed the use of strictly single-size aggregate, producing high permeability without loss of pavement stability. Today's industry standards are listed in Table 2. Under such standards, the pavement's minimum infiltration rate is at least as high as that of pervious concrete; the value of 140 in/hr is cited for convenience to match that of pervious concrete. Structurally, the block layer forms a "flexible" pavement, with structural "layer coefficient" equal to that of an equal thickness of conventional impervious asphalt. Installation is relatively problem-free, because there is no on-site chemical curing to be overseen: after selecting block and aggregate that have been produced to industry standards, the project designer and installer need only assemble them correctly.

<u>Item</u>	<u>Reference or agency</u>
<u>Paving unit manufacture</u>	
Concrete units	ASTM C 936
Clay units	ASTM C 902 & C 1272
<u>Aggregate</u>	
Joint fill	Per Smith (2002): ASTM No. 8 or No. 10
Setting bed	Per Smith (2002): ASTM No. 8
<u>Installation</u>	
Overall guidelines	Smith (2002)
Installer certification	Interlocking Concrete Pavement Institute

Table 2. Permeable paver industry standards

Under today's standards, successful paver installations have been numerous and widespread. In Ontario, where North America's paver industry started, installations from the last 10 years infiltrate rain water rapidly through their single-sized aggregate, while durably withstanding vigorous winter snow-plowing as the concrete units have always been capable. On slowly permeable clay they have been installed with highly permeable aggregate in every layer of the constructed cross-section: rain water that enters the pavement is treated and detained within the structure; excess water discharges out a

perforated pipe. They have been installed in cold climates and under traffic of heavy vehicles such as fire trucks.

#### **4 MONITORED PERFORMANCE**

The performance of porous pavements in meeting environmental protection goals has now been monitored by numerous organizations, in numerous North American locations. Two research programs that are currently notably broad and productive are at the University of New Hampshire and North Carolina State University. North American data combines with that from Europe and other areas to make a considerable global body of scientific knowledge. This is very important, because in North America the field of porous pavements has in the past been plagued by rumor and supposition. Research results are not the imaginings of committees; they are what actually happened when someone built an installation, and watched and measured. Today's scientific monitoring overcomes the uncertainty of the past with observed, quantitative, documented fact, to which professional and legal decisions can hold firmly.

An example of a useful discovery came from the monitoring of the water stored in a pavement's base reservoir installed on clay soil (Estes, 2009). The water level's decline after each rain storm indicated that water infiltrated gradually even into this clay soil, there to recharge aquifers, maintain stream base flow, and further treat water quality. These and other findings have resolved a question that has pestered jurisdictions that regulate impervious surface coverage: should porous pavements be given full credit as "pervious" surfaces? Science has shown that correctly installed porous pavements have infiltration rates higher than any natural soil and any natural rainfall rate, and generate no more runoff than any predevelopment condition — so they are more pervious than anything that is already called "pervious", and must be given "100 percent credit".

#### **5 THE CONCEPTUAL PROBLEM OF URBAN ENVIRONMENTAL PROCESS**

The underlying problem that porous pavements address is the alteration of environmental processes by construction. Modern cities are constructed in the midst of natural hydrologic flows which originate in rainfall and connect to regional systems of ground water, streams, and evapotranspiration. Cities have spawned impervious surfaces from their transportation modes, types and intensities of land use, and types of construction. Impervious surfaces seal a landscape, annihilating absorption and creating the problems which are now so familiar in urban watersheds: during a storm come flooding and erosion, with oil and bacteria flushed into surface streams; after the storm, there is no ground water, because water was flushed out of the watershed when it was available; base flow and the aquatic habitat it supports are lost; some communities are left with local water shortages.

In the twentieth century, impervious surfaces' effects contributed to the belief that cities and the environment are dichotomous and antagonistic. This was a pessimistic view: mankind was seen as a predator upon nature; urban construction was sacrificial of natural processes. It was portrayed vividly in a cartoon by architect Malcolm Wells which portrayed 'The Architect', t-square and blueprints in hand, as a monstrous, grimacing, slug-like creature, devouring beautiful farms and forests in front, and excreting crowded, polluting subdivisions and industries out the back. This dichotomous view was taken to its ultimate practical conclusion by an organization called Earth Liberation Front (ELF), which, choosing the side of nature in its confrontation with urban construction, set fire to homes being built near natural areas, bringing the confrontation into an outright battle.

Although the field of stormwater management has attempted more conciliatory solutions than ELF, it has for a long time worked within the same dichotomous view. Basins and swales are added into urban development projects, to treat and detain impervious surfaces' polluted runoff before it continues downstream. Some of the basins are utilitarian devices, fenced off from surrounding lands: they are voids in a city's activity and economy; from an urban viewpoint, they are wastes. Others are integrated into their urban surroundings with water bodies, greenway trails, plantings, and artistic structures. All of them treat impervious surfaces' downstream symptoms on designated land. All are created for that purpose, no matter how many additional functions are assigned to them once it is decided that they shall exist. The problem still exists in the unchanged urban construction; the basins are added to counteract its still-existing effects. The edge of the basins is a line, on one side of which are the impervious surfaces, generating their runoff and pollutants as cities have done for generations; on the other side are natural vegetation and soil, counteracting the problems generated by the urban construction.

This dichotomous, pessimistic view, and all its outcomes, were possibly justified in the past. The technologies of the time gave us no choice. Mankind did not know how to do otherwise.

## 6 POROUS PAVEMENTS' UNIFYING ROLE

Built structures that have acted as impervious surfaces are opportunities for transformation. In North American cities, roofs typically occupy one third of the built-surface area. The rain water that occurs on roofs is of relatively high quality; it is at high elevation relative to the rest of the urban landscape, which is convenient for water harvesting; the water is of relatively limited amount, because of roofs' small catchment area. In contrast pavements occupy two thirds of the built area. The rain water on pavements is of relatively poor quality, because pavements are where the dumpsters, animals, and vehicles are; it is at low elevation, in contact with soil; and it represents a large water amount because pavements occupy twice the area of roofs.

In this way, porous paving materials address most of a city's rain water and pollution. In contrast with downstream basins, porous pavements are not distinct facilities added to an otherwise unchanged development. They are a new way of building urban structures, restoring environmental processes in-place; water disappears into the materials used to build the urban development program. By bringing natural life-support functions into the hard surfaces constructed for direct human use, they abolish the impervious-surface problem at the source. They represent a more unified and optimistic relationship between cities and environmental processes.

Because porous pavements are absorptive, they also allow trees to grow to the full size for which they are planted by supplying air and water to the rooting soil. North American and European research and experience have combined to produce several means of providing viable rooting space below pavement surfaces, using either aggregate-soil mixtures or bridging of pavement over uncompacted soil. In such installations, the trees supply all the values for which the "urban forest" is advocated: shade, cooling, air quality, removal of carbon dioxide, and the outdoor architecture of canopy, branches, and trunks. The trees' shade counteracts the urban 'heat island', by preventing pavements from absorbing solar heat, while the permeable surface makes the rooting soil viable.

Thus porous pavements, when used to the fullest, bring both the physical process of hydrology and the biological process of living things into urban construction materials. Successful installations like that at Pier A Park in Hoboken, New Jersey have confirmed that today, in a single urban space, there can be a living tree canopy above, a living rooting zone below, absorption and treatment of stormwater, and all the economy, traffic, and activity of a busy city.

When North America's porous pavements were first developed, they were motivated by immediate practical concerns of satisfying technical jurisdictional requirements at minimal cost. But their absorptive role presents a new model of the relationship of urban construction and environmental processes. We need no longer hold to a dichotomy between cities and the environment. We need no longer say that the building of cities is sacrificial of environmental processes. Cities need no longer treat symptoms of their problems downstream. Porous pavements, unlike the technologies of the past, represent urban construction with environmental processes in it.

## 7 POROUS PAVEMENTS IN HUMAN COMMUNITIES

North American designers, like those in Europe, have learned to integrate today's diverse choices in paving materials with urban spaces. Patterns of permeable pavers reinforce the arrangements of curbs, lights, bollards, and trees, articulating the different spaces and how people are expected to use them. Panels of naturally textured pervious concrete alternate rhythmically with smooth impervious concrete bands. Both materials are used to develop entire parks for full human use, while the park land remains 100 percent pervious. Pervious concrete's pores and permeable pavers' openings make the site's environmental process "readable".

Although porous paving materials and their base reservoirs are more expensive than impervious pavements, they are multi-functional: they are both pavement structures, and at least part of the stormwater management system. It is usual for total site development cost to be lower, using porous pavements, than using impervious pavements with separate stormwater management facilities alongside. Porous pavements' systematic economy is the reason their use has been growing so rapidly.

Porous pavement's investment effect was demonstrated clearly at a small residential development in Sultan, Washington. All pavements in the development — street, sidewalk, residential driveways and

walkways, and guest parking pads – were made of pervious concrete. The runoff from the buildings' roofs drains into the street's base reservoir, terminating the drainage system. The pervious material and its base reservoirs were more expensive than impervious materials. But the developer's net cost was reduced, because there were no curbs, inlets, pipes, or detention vaults, as there would have been with conventional surface drainage. In addition there was value added into the development: because land did not have to be set aside for a stormwater basin, the site was able to be developed at full regulated density; the number of residential lots increased from 18 to 20. When the cost saving and added value are combined, the investment in pervious concrete returned more than \$250,000 to this small development.

In this same small development, from a community viewpoint, the following additional effects happened. The site's population absorption increased by 10 percent. That is consistent with today's urban vision of dense town centers that support public transportation and multiple, mutually supporting land uses, rather than dispersing population growth in sprawling suburbs. At the same time, there was 40 percent more pervious cover within the site, with all the effects that has on the environment.

Porous pavements have now been installed even in retrofits of old impervious city streets, for example in programs to reduce combined-sewer overflow and to protect urban lake water quality. Retrofit application is very important, because most of the world's impervious surfaces have already been built: each year's construction of new pavement is only a small incremental addition. Porous pavements can convert obsolete infrastructure dating from the times of single-function technologies to meet today's multi-functional demands.

In these ways, porous pavements integrate themselves with urban experiential, social, and economic life. They reinforce the organization of urban spaces, make contemporary development more economical, enable developments to be built at full regulated density, support multiple urban uses, reduce the pressure for suburban sprawl, and release formerly passed-over properties for infill development.

## **8 CONCLUSION**

In summary, North America's porous pavement experience has both benefited from developments overseas, and made some original contributions to the field. Some experiences provide models to be emulated; others point out problems to be avoided. Care is required in selection, design, installation, and maintenance. Experience and knowledge are continuing to be built.

There is progress in environmental design. Industry standards have been adopted. Factual performance has been documented. Possible solutions are real. Design advances together with progress in science and technology.

Today's technologies provide a new model for the relationship between cities and the environment. With porous pavements, that relationship is more optimistic. Porous pavements make a city more open, dynamic, complex, and multi-functional. They unify natural and human realms into a single, mutually supportive system. Like ecosystem succession and evolutionary development, they involve development of symbiotic functions (Odum, 1969). Porous pavements allow a landscape's openness, self-regulation, storage and diversity to operate. Urban landscape becomes a unit of biogeochemical cycling. Economy, human community, and environment thrive together, in the same dense urban place.

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