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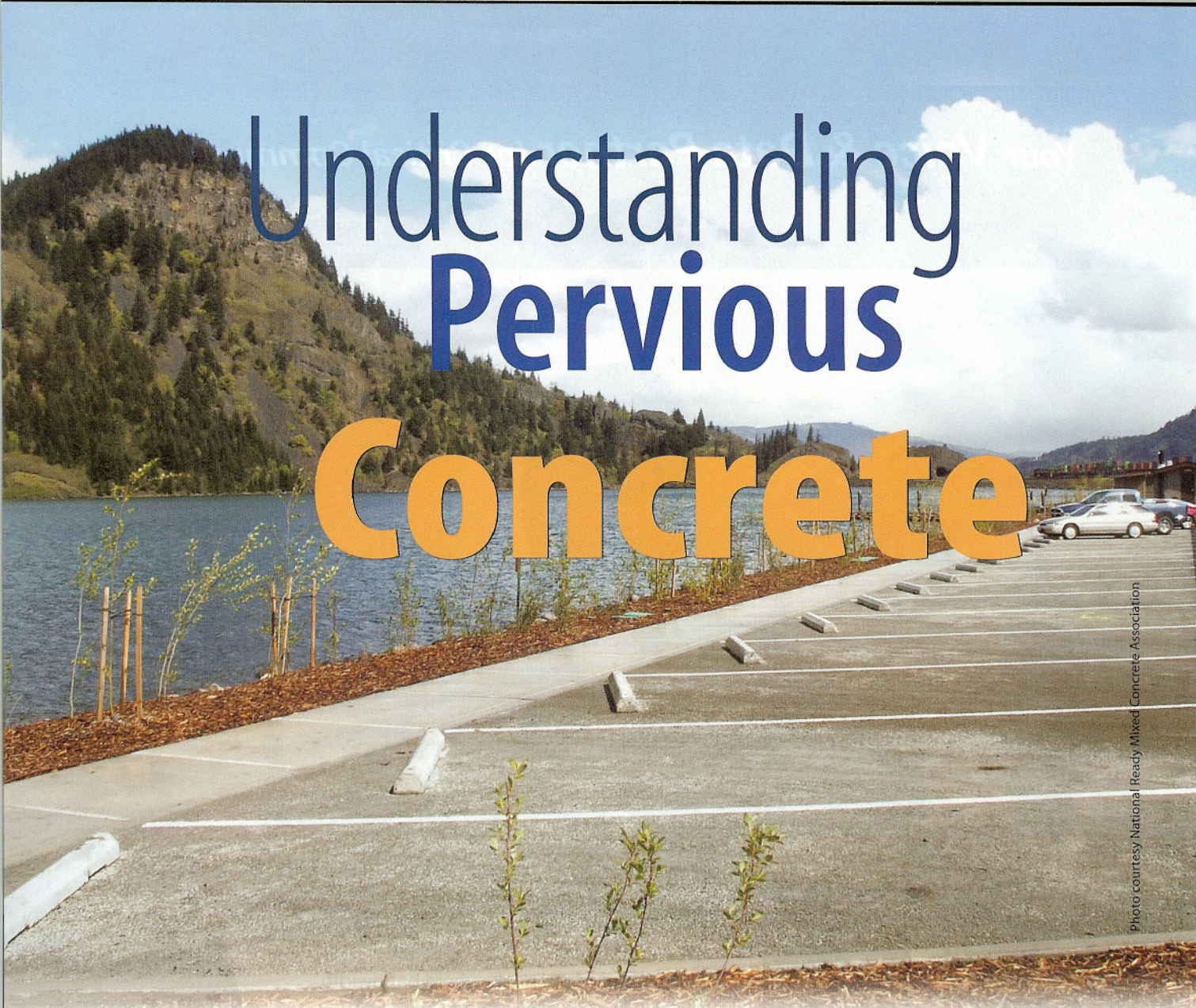
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Understanding Pervious Concrete

Photo courtesy National Ready Mixed Concrete Association

by Dan Huffman

While pervious concrete pavement has been around for more than 20 years, it has only recently garnered much attention, due to increasingly stringent stormwater management guidelines that now position the product as a sustainable building material. Pervious concrete provides the potential for environmentally responsible site use and lowered construction costs in projects ranging from simple sidewalks, driveways, and patios, to major pedestrian plazas and full-blown multi-acre parking lots for national commercial big box builders.

Pervious concrete has been specified as pavement in Florida for more than 20 years, earning a fine record of durability and high performance. Still, the history of the material also known as 'no fines concrete' stretches even

further back abroad—substantial amounts were produced in Europe immediately following the Second World War, some still in service today.

Pervious concrete is a performance-engineered structural material using the usual constituents of conventional portland cement concrete, only with little or no sand in the mixture, allowing for a 15- to 30-percent air void factor. Taking advantage of the corresponding decreased density, the concrete is incredibly permeable while still able to provide a quality structural pavement. Instead of moisture (e.g. rain/snow melt) running off the surface horizontally, virtually all stormwater falling onto pervious concrete immediately drains directly down through the pavement to the subgrade, eliminating runoff while providing filtration and ground water recharge. A pervious concrete system can



At the University of California, Berkeley's botanical gardens entryway, pervious concrete (the darker material) provides functional drainage and highly complementary architectural design with conventional concrete.

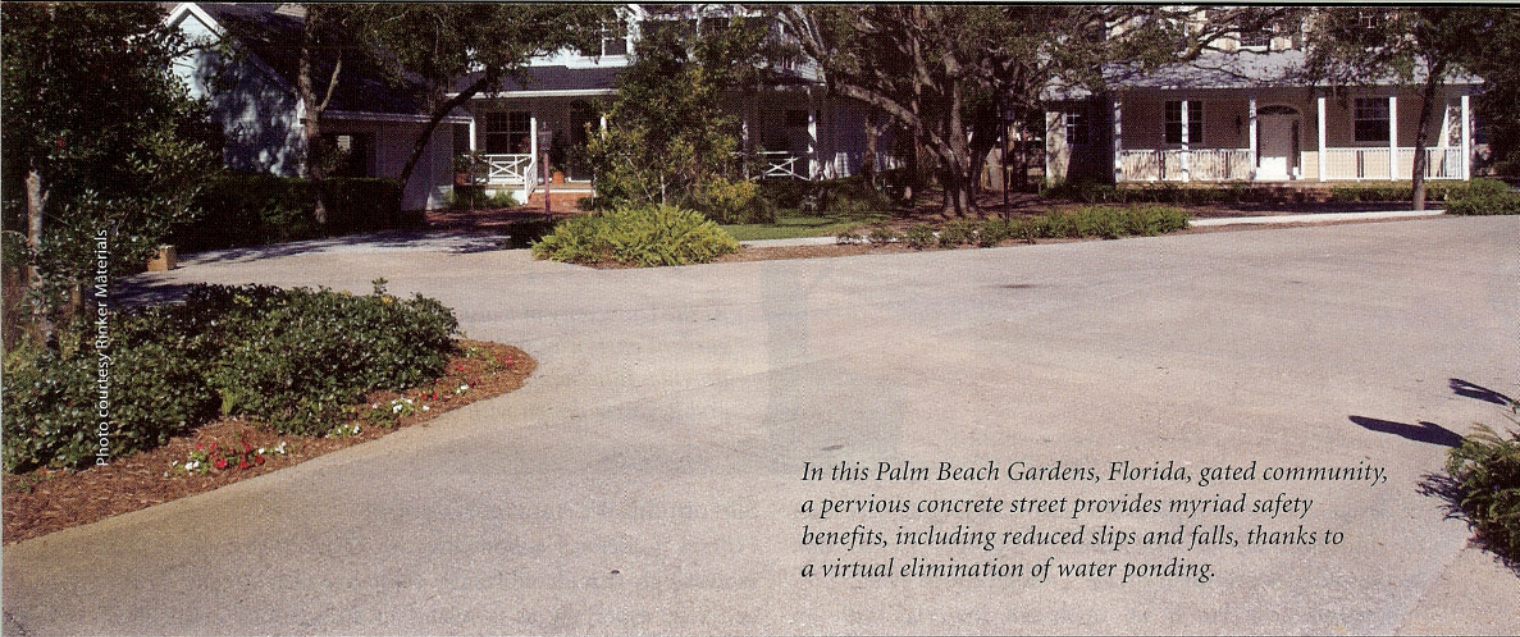
Photo courtesy Concrete Promotion Council of Northern California.
Photo © Rob Wallace.

be designed with an appropriate porous aggregate base layer to function as a stormwater storage basin that accommodates precipitation for a design storm event.

Pervious concrete is an open-cell material with an appearance sometimes described as that of a Rice Krispies® treat. Nevertheless, the product can be integrally colored, painted, or otherwise modified to be aesthetically in tune with the project environment in the same ways as conventional concrete. It can even be made acceptably smooth for good shopping cart mobility by the means of rapidly advancing placing techniques, equipment, and concrete mix design technology while still maintaining a non-slip surface for *Americans with Disabilities Act* (ADA)-compliance.

Site optimization and cost control

Federal guidelines supporting the *Clean Water Act* have increasingly stimulated facility owners to consider pervious concrete, especially as it relates to commercial and light industrial construction. U.S. Environmental Protection Agency (EPA) Phase II regulations require owners of newly developed (or redeveloped) sites of 0.4 ha (1 acre) or more to have an on-site management system for treating all stormwater before it leaves for conveyance by the respective local agency. To do this, owners frequently find themselves dedicating 10 to 20 percent of the overall site to non-revenue-generating detention/retention ponds, swales, or other surface treatment devices. Their other option usually involves specifying potentially expensive underground



In this Palm Beach Gardens, Florida, gated community, a pervious concrete street provides myriad safety benefits, including reduced slips and falls, thanks to a virtual elimination of water ponding.

treatment systems—for big box builders, these can cost in the millions per project.

As opposed to such heavy investment in space and/or stormwater treatment devices, by employing infiltration technology acceptable to EPA, pervious concrete pavement can be used as both a parking facility and the stormwater treatment system itself. Pervious concrete eliminates the runoff on the parking lot surfaces or other paved areas where it might be applied (e.g. sidewalks, plazas) and, via its filtering action, significantly improves the quality of the water passing through. Its use is a recommended Best Management Practice (BMP) of the EPA for first-flush pollution mitigation within the realm of stormwater management.¹

In early 2005, the designers of a light industrial facility project for a wood structural building component manufacturer in Westminster, Maryland, had an approximately 5-ha (12-acre) site, which included a 3.2-ha (8-acre) parking lot. Through the specification of pervious concrete for the entire lot, the 0.6-ha (1.5-acre) retention pond and underground drainage system were eliminated from the original design plans (which called for an asphalt parking lot), allowing the team to recover about 13 percent of the site. This move saved \$400,000 in underground drainage construction costs alone.

In the public sector, agencies devote huge financial resources to stormwater conveyance—where treatment is actually part of an agency's wastewater system, such facilities can be massive and extremely expensive. Additionally, a great deal of public inconvenience and traffic control problems can result from streets and roads torn up as ever-increasing storm sewers and drains (due to the large volume of runoff) are being deployed because of new development (or existing ones are in need of repair or replacement). As such, some government agencies have implemented stormwater impact fees on all impervious

outdoor areas. Limiting the volume of stormwater runoff takes pressure off existing infrastructure, thereby saving taxpayer dollars and improving overall water quality.

Environmental considerations

The greatest concern about stormwater runoff from existing hardscape and continuing development relates to the amount of inadequately treated pollutants (mostly hydrocarbons) runoff carries with it into waterways, lakes, and oceans. Impervious parking lots, roadways, and rooftops cause more stormwater runoff and pollutant loads than any other type of land use.²

Not only are there concerns about the obvious chemical pollutants (often including the carcinogen, polycyclic aromatic hydrocarbon [PAH]) reaching the human food chain, but runoff has also been deemed a major contributor to thermal pollution caused by the effects of dark, impervious surfaces such as streets and roofs. According to EPA, runoff increases the ambient temperature of the stormwater such that it negatively affects the existence of vegetation, fish, and other aquatic life.³

The U.S. Green Building Council's Leadership in Energy and Environmental Design® (LEED®) rating system gives credit to the effective use of pervious concrete in Sustainable Sites (SS) Credit 6, *Stormwater Management*. Due to its potential to be used for slope protection, pervious concrete pavement could also have positive implications for SS Prerequisite 1, *Erosion and Sedimentation Control*. Other environmentally responsible implications associated with the use of pervious concrete pavement are explored below.

Water filtration

As previously stated, a major positive attribute of pervious concrete paving is its exceptionally high porosity. When the material is designed with typical thicknesses and mix design constituents (as explored later in this article), and supported

with an appropriate base design such that nothing beneath impedes the moisture's passage, its permeability rate exceeds the needs of almost all natural events. With its void factor, pervious concrete handles moisture in excess of 5080 mm (200 in.) of water hourly per 0.09 m² (1 sf)—this translates to 11.4 to 19 L (3 to 5 gal) a minute.

When rain or snow lands on pervious concrete, the moisture goes directly through the pavement and into the ground in much the same way it would if there was no hardscape in the first place.

In addition to improving the overall water quality by reducing the amount of the pollutant-carrying runoff, pervious concrete significantly improves the quality of the water that passes through it via the reduction of the negative effects of hydrocarbon-based materials (e.g. grease, oil) the first flush of stormwater would otherwise carry away. On a parking lot, there is a large surface area that comprises a matrix of small coarse aggregate by which the pervious concrete captures and aerobically degrades the hydrocarbon residue passing through while the pollutants are further converted by the attached microbial growth. The sun also boils off volatile components within the matrix of the open-celled concrete, and the remaining carbon is then absorbed by the native soil where it is digested by plants, fungi, or microbes.

Trees almost always flourish in the presence of pervious concrete. The natural infiltration process allows both moisture and oxygen to reach the roots of trees in a way usually limited by conventional

pavements. (This kind of infiltration can be particularly useful in the dry Western United States, where there is a strong desire to better use what little moisture falls to the earth.) After water passes through this pavement, it can even be harvested for various uses including agriculture.

Heat reflectivity and cold-weather advantages

Other benefits of using pervious concrete are similar to the general environmental benefits of its conventional



Photo courtesy Quality Concrete. Photo © Scott Erickson



Photo courtesy National Ready Mixed Concrete Association

Pedestrian safety at Portland's Oregon Zoo is increased with pervious concrete walkways providing a non-slip surface in all weather conditions without supplemental drainage.

counterpart. With plain gray portland cement as its aggregate binder, concrete has a significant reflectivity advantage over asphaltic products, which are usually very dark in color. Concrete has much higher albedo, which contributes to its ability to earn points within LEED relative to heat island mitigation (SS Credit 7, *Heat Island Effect*). It also offers the potential for lowering the number of light poles in various night illumination environments, saving both money and energy. In addition to its reflectance benefits, pervious concrete's high void factor and lower density means it absorbs less solar heat and cools more rapidly in hot environments.

In cold weather, anecdotal evidence suggests both snow and ice more rapidly leave the surface of pervious concrete than traditional pavements because the moisture has pathways to drain down immediately upon melting. Additionally, since there is no ponding of moisture, there is not the same propensity for re-freezing as with conventional pavements.

In some parts of the country, the dynamics of dealing with traditional non-porous pavement are increasingly costly for owners as taxes and levies are applied in an attempt to limit impervious surfaces. As communities seek the means of compliance with the EPA Phase II stormwater regulations, mandatory applications of pervious surface solutions should be expected to increase.

Location concerns

Design considerations for pervious concrete immediately focus on the qualities of the native soil over which it is to be placed. For every sizable or otherwise important project, a

Vibratory screeds are frequently used in the placement of pervious concrete, such as in this Denver, Colorado, Safeway supermarket project.

geotechnical evaluation is highly recommended. Where expansive soils are known to exist, strategies should be approached with extreme caution. Nevertheless, the vast majority of potential sites in the United States and Canada should be good environments for the effective use of pervious concrete. In areas of high clay content, should the percolation rate be suitable for septic tank systems, it also should be acceptable for pervious concrete.

The design of the aggregate base, an area sometimes also referred to as the 'recharge bed,' is very critical to pervious concrete performance and durability. Directly beneath the slab, this section ensures moisture flows unimpeded through the pavement. It stores the water and allows it to percolate over time into the subgrade. (When necessity dictates, it could also be engineered to move water laterally and dispensed otherwise.) However, in Florida, where the percolation rate of the sandy native soil is quite high, pervious concrete placement directly atop the soil is very common—and supported by more than 20 years of performance. In all cases, the percolation of the soils combined with infiltration rate dynamics is critical, especially in areas where freeze-thaw durability is a concern.

The factors determining the design thickness of pervious concrete include its desired hydraulic (e.g. permeability and voids content) and mechanical properties (e.g. strength and stiffness). The material needs to complement the site-specific stormwater management strategy, the intended traffic loads, and other considerations, such as the amount of rainfall, pavement characteristics, underlying soil properties, tolerable intensity of surface runoff, and rate of infiltration.

Typically, retail-focused parking lots are designed with 152-mm (6-in.) sections of pervious concrete, as opposed to the 102 mm (4 in.) thicknesses most commonly used for conventional concrete lots. Due to pervious concrete's decreased density (resulting from its high air void factor), the simple design mechanism of increasing the slab thickness by 50 percent (conventional to pervious) has proven highly successful in practice. On a national basis, 152 mm of pervious concrete on 152- to 203-mm (6- to 8-in.) aggregate base is the most commonly used equation for parking lots.

With pervious concrete, the use of a flat-grade design otherwise following the contour of the land is all that is necessary—since there is no runoff, there is no reason to grade it.⁴ Successful placements have taken place in California on as much as a 16-percent grade, but in such cases, concerns about the performance of the recharge bed have to be taken into consideration. One of the characteristics of most high-quality pervious concrete is that the material is made with extremely low water-to-cement (W/C) ratios (typically 0.25 to 0.35). Due to the very low W/C ratio and the way the aggregate interlock takes place, the shrinkage of pervious concrete is so greatly reduced that jointing intervals of every 6 m (20 ft) are common in many parts of the country. (In California, a substantial amount has even been placed with joint spacing greatly exceeding 6 m.)

Material considerations

In cold-weather climates subject to freeze-thaw cycling, cement paste in pervious concrete should be treated with air-entraining admixtures as is the case for the material's

conventional counterpart. While its 15- to 30-percent air void factor also allows for expansion of frozen moisture, it is still critical to the integrity of the slab that it should not be totally saturated under freeze-thaw conditions. Whether durability issues come into play, typical thicknesses for the granular base are 150 to 300 mm (6 to 12 in.) with a material such as #57 stone (with a 40-percent void factor). A complementary and adequate aggregate base design is perhaps the most critical element in pervious concrete's freeze-thaw durability after its ability to transfer moisture through the concrete's own expected porosity.

Pervious concrete mix designs vary broadly around the country. In most regions, rich cementitious mixes using 272 kg (600 lb) of cement and more per cubic yard are frequent. Smaller coarse aggregate sizes such as 9.5-mm (0.4-in.) rounded pea gravel are most common, but crushed materials and larger dimensions are sometimes also used.⁵ Contrary to traditional concrete (where larger sizes and angular-shaped aggregate materials frequently provide the best performance) smaller aggregate and rounded shapes appear to not only provide the best porosity for pervious concrete, but also better strength, smoothness, and appearance characteristics.

In addition to conventional concrete admixtures, some of the hydration-stabilizing and viscosity-modifying admixtures increasingly used in conventional concreting can be selectively employed in pervious concrete, along with the same integral coloring, various fibers, and supplementary cementitious materials (SCMs), such as fly ash and slag.

As of this writing, most of the quality pervious concrete in the country is being placed at, or less than, a 13-mm (0.5-in.)



By allowing moisture to filter through into groundwater, the Rice Krispie-like structure of pervious concrete helps reduce the environmental problems of stormwater runoff.

slump due to the extremely low W/C ratios required for acceptable strength, porosity, and durability. With the progress in admixture technology increasingly focused on pervious concrete, the ability to increase the slump (a measure of the concrete consistency, which affects placeability) is likely in the near future.

Practical use

Parking lot construction is usually accomplished with 'strip placements.' After proper compaction of the native soil, a geotextile fabric is usually placed to protect against fines migrating up into the aggregate base. The aggregate base (recharge bed) is placed and compacted and then the ready-

mixed concrete is placed, spread and leveled with various types of vibratory screeds or friction tubes. This is followed by some form of surface rolling process designed to compact approximately the top 13 mm (0.5 in.) of the surface, adding increased consolidation and satisfactory smoothness.⁶

Very soon after pervious concrete is placed, the joints should be cut—most often, these are tooled joints cut with a modified rolling device within minutes behind the final rolling process. The method of curing pervious concrete is a seven-day wet cure, and attention to this process cannot be over-emphasized. When this type of porous, extremely low-W/C-ratio concrete does not get proper curing, its performance rapidly deteriorates under normal use.

As a generalization, the amount of labor devoted to properly placing pervious concrete can actually be less than that of its conventional counterpart. However, the contractor's judgment and adherence to the basics of good concreting (along with an awareness of the particular mixture's appropriate water content as placed that comes only with experience) is more critical to the success of pervious concrete placement and in-service performance than is the case of more conventional products.

In response to the need for a larger group of quality contractors to meet the rapidly expanding demand, the National Ready Mixed Concrete Association (NRMCA) has begun rolling out a national pervious concrete contractor certification program. The initiative aims to train, test, and certify qualified installers and other individuals wanting to better understand the technology.

Additional Information

Author

Dan Huffman is the Portland, Oregon-based national resource director for the National Ready Mixed Concrete Association (NRMCA). He has almost 30 years of concrete materials experience and is a voting member of

the American Concrete Institute's (ACI's) Board Advisory Committee on Sustainable Development (AC-SD) and the ACI 522 technical committee on pervious concrete. Huffman can be contacted via e-mail at dhuffman@nrmca.org.

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G2010—Roadways
G2020—Parking Lots
G2030—Pedestrian Paving

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Abstract

Increasingly stringent stormwater management guidelines are increasing applications for pervious concrete, which provides the potential for environmentally responsible site use and lowered construction costs in projects ranging

from sidewalks to multi-acre parking lots. A performance-engineered structural material, it allows virtually all stormwater to immediately drain down through the pavement to the subgrade, eliminating runoff while providing filtration and ground water recharge.

The program is being sponsored on both the state and local levels by the respective state ready-mixed concrete associations, American Concrete Institute (ACI) chapters, and some contractor organizations.

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Notes

¹ About 90 percent of pollutants—mostly hydrocarbons contributed by grease and oil by motor vehicles—on parking areas get carried away by runoff during the first 38 mm (1.5 in.) of any rain event, described by stormwater experts as the ‘first flush.’ First-flush pollution mitigation is one of pervious concrete’s most pronounced benefits. For more information, visit

www.stormwatercenter.net.

² Visit www.nrcd.org/water/pollution/storm/execsum.asp.

³ See EPA 841-F-03-003, *Protecting Water Quality from Urban Runoff*.

⁴ When pervious concrete is properly designed and placed, its performance capability far exceeds normal maximums—it handles in excess of 5080 mm (200 in.) of hourly rain per 0.09 m² (1 sf). In many cases, runoff from roofs and other hardscapes can be designed to flow onto pervious concrete sections. However, adjacent vegetative/soil areas can be problematic as they could release organics and other particulate matter contributing to clogging.

⁵ “3/8” is exact U.S. designation per sieves.

⁶ Ride-on slip-form pavers are beginning to appear as projects are increasing in size, but the vast majority of work is still done with the screeds and rollers described.



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