

ITE District 6 Annual Meeting

Porous Concrete Sidewalks

- How to Build Sidewalks and Not Stormwater Ponds

Abstract

Building sidewalks typically triggers stormwater mitigations requirements. Sometimes the cost of the creating the stormwater mitigation for a new sidewalk can exceed the cost of constructing the sidewalk. Using permeable pavements is one way to create sidewalks without triggering stormwater mitigation requirements.

The City of Olympia, Washington has installed over 7,500 square yards or about two miles of pervious concrete sidewalk to date, with more projects coming each year. Three different types of pervious concrete materials have been used over an eight-year period. Materials range from the regular “no fines” pervious concrete to a new form of 100 percent sand “all fines” concrete.

This paper presents the lessons learned and current state of pervious sidewalk technology in Olympia. Our experience with different materials, design, construction, and maintenance is provided along with construction and operating costs.

Sidewalks in Olympia

A 2000 survey in Olympia found that sidewalks and walking facilities are the top choice for neighborhood public improvements. In 2003, citizen volunteers completed an inventory of arterials, major collectors, and neighborhood collectors that did not have sidewalks. These streets compose 42 percent of the City’s street system. The inventory found 84 miles of missing sidewalks on these high-volume streets. At previous funding levels, it would take the City 180 years to construct the needed sidewalks.

In 2004, a funding measure was placed on the ballot for parks and sidewalks facilities. Voters approved an increase of the private utility tax resulting in approximately \$1 million dollars annually for sidewalk construction.

In addition, a survey of residents using that sidewalk in 2000 found that 52 percent of sidewalk users liked the appearance of the regular porous concrete surface; 25 percent did not. When asked about the walking surface, 49 percent said it was less slippery, while 9 percent said it was more slippery than a regular sidewalk. If the price was comparable to traditional concrete, 52 percent said they would consider using it at their homes; 15 percent said they would not try it at their homes. When asked if the City of Olympia should encourage developers and builders to use porous pavements 72 percent said yes, while 11 percent said no.

Sidewalk construction typically triggers the installation of stormwater controls.

These stormwater controls often require the acquisition of additional land or right-of-way. The total cost for the stormwater mitigation can exceed the cost of the sidewalk construction. The land required for stormwater controls can be expansive; on retrofit projects, it is sometimes simply not available. Pervious concrete does not generate increased stormwater runoff and therefore does not trigger the need for stormwater controls. Pervious concrete allows Olympia to build sidewalks without building costly stormwater ponds.

Since 2000, there have been advances in the use of finer aggregates in pervious concrete. These finer aggregates result in smoother surfaces with more and smaller surface voids than compared to regular pervious concrete. This finer aggregate pervious concrete may be less prone to clogging.

Olympia also installed a section of Stoney Creek pervious concrete sidewalk in 2004. Stoney Creek uses ¼-inch sized aggregate. The concrete is also self-consolidating, meaning that after screeding no additional surface rolling or compressing is needed. The surface texture of Stoney Creek is much smoother than regular pervious concrete. Cleaning of Stoney Creek pervious concrete should be easier and more effective than regular pervious concrete.

Percocrete pervious concrete uses sand aggregate and is similar to regular concrete in texture. The surface voids of Percocrete pervious concrete are smaller than most of the leaf litter material that falls on a sidewalk. For this reason, Percocrete pervious concrete may be the less susceptible to surface clogging. Olympia has been using Percocrete pervious concrete in sidewalks since 2004 and plans to continue to use it in the future.

Current State of Technology

Pervious concrete is a type of concrete having sufficient interconnected voids to allow water to pass through the material. Pervious concrete starts as “no-fines” concrete, a regular concrete material without fine aggregates. This lack of fines results in an increase in the amount of voids.

The defining feature of all pervious concrete is the low water-to-cement ratio used during mixing. Traditional concrete has a water-to-cement ratio that allows the cement to form a slurry and bond the aggregate together. The slurry fills all of the voids between the aggregate. Pervious concrete reduces the water-to-cement ratio such that the cement forms a paste. The goal of the mixing process is to coat the aggregate with the cement paste and then compress or consolidate the material to increase bonding strength. Given that the original aggregate has large amounts of voids between them, the addition of the paste does not completely fill the voids. This results in the presence of voids connected completely through the pervious concrete.

In general, there are three major groups of pervious concrete. They are

categorized by the name of the admixture used in the material: regular (no admixtures, Stoney Creek, and Percocrete. The major difference between the groups is the size of the aggregate that can be used in the material. The more expensive the admixture, the smaller the aggregate that can be used. The smaller the aggregate used, the smoother the surface texture of the pervious concrete. Table 1 below provides a summary of the general properties of the three pervious concrete groups:

Table 1: Pervious Concrete Properties

Pervious Concrete Group	Typical Smallest Aggregate Size	Surface Texture	Material Cost	Finish Technique
Regular	3/8-inch	Coarse	Lowest cost	Roller or self-consolidating
Stoney Creek	1/4-inch	Medium	Medium cost	Self-consolidating or slip form
Percocrete	Sand + 1/2-inch	Smooth	Most expensive	Plate compactor

Typical strength of most pervious concrete is 2,000 to 3,000 pounds per square inch (psi) compressive strength and 200 to 300 lbs tensile strength. Some mixtures can have significantly more or less strength depending on the materials used in the design. Generally, fractured aggregate has a higher strength than naturally round aggregate. Aggregates that are a blend of different aggregate sizes generally result in stronger pervious concrete, but typically have less voids content. Pervious concrete that has a higher water-to-cement ratio is generally stronger than materials with a lower water-to-cement ratio. Materials with a higher water-to-cement ratio generally have more cement slurry and generally have lower voids and lower infiltration rates.

Typical voids contents of pervious concrete range between 10 percent and 20 percent. Generally, at least 15 percent voids are needed in the final material to create a product that is highly pervious. Aggregate used in the material need to start out with at least 30 percent voids. The more uniform the aggregate size, the more voids there are in the material. This relationship holds true for sand and rock aggregate. Thus, sand materials can have similar voids contents to large aggregate.

Benefits of Pervious Concrete

The major benefit of pervious concrete is the ability of water to completely pass through the material. Rainfall can be infiltrated into the soils underlying the pavement. Infiltration not only reduces or eliminates the need for stormwater mitigation, it also recharges groundwater. Typical initial infiltration rates of pervious concrete are 100's of inches per hour to 10's of inches an hour. While some clogging of the surface pores is inevitable, pervious pavement only fails when it does not pass typical rainfall intensities of the region. In Olympia, typical rainfall intensities are less than one inch per hour. Given this precipitation intensity, infiltration of the pervious pavement is not a limiting factor.

The large voids content of pervious concrete makes the material able to withstand freezing and thawing. Even when samples are completely soaked in water and rapidly frozen, voids left within the material are sufficient for ice crystal expansion.

The voids content of pervious concrete allows water and air to flow through the material. The flow of air and water is a two-way process. During rainstorm events, water is able to flow into the underlying soils. Between rainstorm events, water is able to leave the underlying soils and evaporates back into the air. At all times, air is able to exchange between the underlying soil and the atmosphere. These characteristics of pervious concrete result in the soils underlying pervious pavement being a suitable growing medium for tree roots. Pervious pavement also stays cooler than traditional concrete materials.

A significant benefit of pervious concrete is the reduction of the heat island effect associated with traditional concrete materials. Pervious concrete materials are slower to heat up and faster to cool down than traditional concrete. A disadvantage of this property is that pervious concrete sidewalks can freeze sooner than traditional pavements. When air temperatures are just below freezing, pervious concrete sidewalks can freeze and allow ice to accumulate on the surface while traditional concrete may remain unfrozen. This effect is reversed when air and soil temperatures result in thawing of pavements.

Maintaining Pervious Concrete Sidewalks

The City of Olympia installed its first 1,500 feet of pervious concrete sidewalk in 1999 along North Street in East Olympia. The sidewalk was adjacent to an existing roadway. Due to the stormwater regulations and price of land in Olympia at the time, the sidewalk saved an estimated \$140,000 in initial construction cost. Maintenance costs were unknown.

The City started to explore ways to clean the North Street sidewalk five years after the sidewalk was built. Without any maintenance, some sections of the regular pervious were clean and free of debris; other sections were almost completely clogged and had moss growing on the surface. Clogging of the pavement was dependant on the amount of leaf litter it received. Where there were trees adjacent to the pavement, it contained moss. Where there were no trees, the pavement was clean. Adjacent homeowners mowed the grass adjacent to the sidewalk. Some homeowners discharged the lawn clippings onto the sidewalk, others did not. After five years of doing nothing, it was evident that pervious pavements need some form of regular maintenance if the infiltration capacity was to be maintained.

The City has tried many different types of cleaning machines on the North Street sidewalk. The initial cleaning was performed by pressure washing. Pressure washing is an expensive maintenance technique and should only be used as a last resort to revitalize clogged pavements. A cleaning machine that combines pressure washing and vacuum extraction of the wash water was also tried on the North Street sidewalk. This cleaner was more effective than pressure washing alone, but was also more expensive than

pressure washing. Several other sweeping and sweeping-scrubbing machines were tried for cleaning the North Street pavement. The sweeping machines typically have a horizontally mounted broom and a vacuum system for dust control. The vacuum is applied at the back of the broom and not at the pavement surface. These machines could loosen and pick up some of the leaf litter from the pavement surface. Pine needles and material lodged deeper in the surface voids remained after cleaning. If these machines applied vacuum to the pavement surface they would be very effective at pervious pavement cleaning.

Olympia has decided to clean its pervious pavements with a pure vacuum extraction machine. The City has a walk-behind leaf vacuum and mulcher machine used for leaf collection. This machine does an excellent job of removing the material lodged deeper in the surface pores. The vacuum will pick up large debris and is relatively fast, resulting in an affordable cleaning cost. The estimated cost of the pavement cleaning is \$0.10 per square yard for vacuum cleaning compared to \$1.60 per square yard for pressure washing. Olympia's sidewalk cleaning goal is to clean all pavements at least once a year. High leaf litter sections of pavement require twice-a-year cleaning. Pressure washing will be used when needed as a last resort to revitalize clogged pavement.

Design Experience with Pervious Sidewalks

Pervious pavements must meet two different sets of design requirements: stormwater management and structural strength. The stormwater expectations address infiltration and storage volume of the rainfall; the structural strength expectations address loading and durability.

For the pervious pavement to be successful, the infiltration rate of the pervious pavement at the end of its useful life must be greater than the peak intensity of the design rainstorm event. Most pervious pavement initially infiltrates at rates much higher than needed. Clogging and maintenance determine how effective this pavement remains.

The storage volume under the pavement is a function of the design rainstorm event and the infiltration rate of the underlying soil. The critical design storm event is short-duration, intense rain. Given that the infiltration area is similar to infiltration in the overall catchment area, long-duration events are not critical. With poorly drained soils, the critical storm event is the 2-hour event. A volume of 2 inches of water is required to meet 100 percent of the storage volume of the 100-year hourly storm event. This storage volume applies to very poorly drained soils with an infiltration rate of 0.15 inches per hour. Assuming that the underdrain rock is 30 percent voids, an underdrain rock thickness of 7 inches on flat ground is necessary. The drain rock thickness reduces to 4 inches with an infiltration rate of 0.25 inches per hour.

The depth of the drain rock must be increased in sloped sections of pervious pavement. Water will accumulate horizontally in the drain rock layer. Any slope to the drain rock layer means that there is less storage volume available of water. To prevent lateral movement of water, impermeable barriers or check dams must be placed within

the drain rock. Without a barrier, infiltrated water will flow down slope within the drain rock and exfiltrate out of the pervious pavement at low points. Olympia uses check dams built of compacted native material spaced every 15 feet to prevent lateral movement of water under its pervious sidewalks.

Pervious pavements must be built over uncompacted underlying soils. The structural design of the pavement must consider this need. Sidewalks are an ideal location to trial pervious pavements. Sidewalks are relative lightly loaded with normal pedestrian traffic. It has been Olympia's experience that the typical compressive and tensile strength found in pervious concrete is sufficient to build a strong and durable sidewalk. We have seen sections of broken and damaged sidewalk when vehicles have been allowed to cross or park on the edge of the pervious concrete. We believe the edges of pervious concrete sidewalk are vulnerable to damage due the reduction in support from the movement of the drain rock layer on the edges. On the edges, the drain rock tends to move laterally away from the pavement during sidewalk restoration. We have not seen this edge damage when a curb has been used adjacent to the vehicle travel lane. The practice in Olympia is to place a curb at regular concrete edges that may be subjected to vehicle loading.

The design of the pervious concrete material should consider locally available aggregates. Generic mix designs are available from the admixture and concrete suppliers. These mix designs provide a good starting point. The actual strength and infiltration capabilities of the pervious concrete will depend of the grading and type of local aggregates. It is a good idea to start with trial sections of pervious concrete before committing to large-scale projects. Incorporating the use of test panels in the project requirements is a good way to verify the mix design and application technique.

Construction Experience with Pervious Sidewalks

The two key factors affecting the success of pervious concrete projects are quality control at the supplying batch plant and the experience of the applicators placing the material.

Effective pervious concrete relies on creating a cement paste to coat the aggregate. The success of the material is dependant on the batch plant's ability to control the amount of cement and water in the material. Any factor that changes the water-to-cement ratio is important and needs to be tightly controlled. This includes the correct weight of cement and the correct amount of water in all ingredients. This includes free water, the correct moisture content of the aggregates, and the amount of tail water already in the concrete truck. Generally the more engaged the batch plant is in the pervious concrete project, the more likely the product will be successful. A pre-batch meeting with all parties, as well as feedback about the quality of the material batched, is helpful.

Experienced pervious concrete contractors or applicators may be difficult to find. Olympia does not exclude inexperienced applicators, but rather requires training and test panels from all contractors. Olympia hires experienced contractors from others areas to

train the inexperienced contractors. We provide training videos and other materials to contractors. The more education and experience the contractors have with placing pervious concrete, the more likely it is that the pervious concrete will be successful.

All pervious concrete projects should require a test panel before proceeding with the body of the pervious concrete work. The test panel allows for verification of the mix design and refining of the batching and placing procedure. If, after testing, the pervious concrete does not meet expectations additional test panels should be required before the body of the work starts.

In our experience, the best method for testing and accepting new pervious concrete is by pressure washing with water. Pressure washing allows for immediate verification of the material's porosity and it provides a way to test the strength and durability of the pervious concrete. Pressure washing will immediately identify any portions of weakly cemented concrete. It determines whether the entire concrete is bad, or if there are spots or edge problems. Olympia is currently pressure washing at 3000 psi with a flow rate of 1 gpm. The nozzle is held no more than 3 inches above the surface. Pressure washing is done between 7 and 60 days after placing the material. All previous concrete placed with a project should be pressure washed before accepting the work from the owner.

Even with the best batching quality control and experienced contractors, some failure of some sections of the pervious concrete should be expected. Failure rates of 5 percent are routine. Olympia recently modified its pervious concrete specifications to pay for the removal and replacement of up to 5 percent of the pervious concrete placed in a project. We believe that it is better to address the expected failure up front. It is appropriate for the owner to bear the cost of the risk with this innovative technology.

Pervious Concrete Construction Costs

Olympia typically uses three bid items for its pervious concrete sidewalk projects: Pervious Concrete Sidewalk (SY); Pervious Concrete Underdrain (CY); and, Pervious Concrete Testing (SY).

Pervious Concrete Sidewalk includes the cost to form, supply, and finish the pervious concrete material. The pervious concrete sidewalk is four inches thick. Pervious Concrete Underdrain includes the cost to excavate and place the drain rock. Geotextile is a separate bid item. The Pervious Concrete Testing is payment for the pressure-washing test.

A summary of the bid items for 2005 and 2006 construction are below:

Table 2: Percocrete Pervious Concrete Bid Costs

Bid item	Year	Total Quantity	Range of Bids	Average Bid Price
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Pervious Concrete Sidewalk	2006	4,290 SY	\$88-\$119	\$106
	2005	2,295 SY	\$66-\$102	\$84
Pervious Concrete Underdrain System	2006	1,760 CY	\$43-\$122	\$72
	2005	580 CY	\$44-\$131	\$72
Pervious Concrete Testing	2006	4,290 SY	\$2.25-\$12	\$6.70
	2005	2,295 SY	\$7-\$8.75	\$7.80

These bid costs are high when compared to a traditional concrete sidewalk. For the same time period, the bid prices for traditional concrete sidewalk in Olympia averaged \$40 per square yard. Essentially, pervious concrete sidewalks include a stormwater facility. The cost of building a stormwater facility must be added to the traditional sidewalk bid prices.

Life cycle cost comparison between pervious concrete sidewalks and traditional concrete sidewalks with stormwater facilities result in a variety of conclusions depending on the project assumptions made. The most critical assumptions are land acquisition cost and the life (in years) of the pervious and traditional concrete materials. Generally, as the cost of the traditional stormwater mitigation increases the life cycle, cost comparison favors the pervious concrete. Thus, in retrofit projects where land is not available for stormwater facilities, pervious concrete has an economical advantage.

Future of Pervious Concrete Sidewalks

Pervious sidewalks are an easy first step into permeable pavements. Sidewalks are lightly loaded and generate a significant percentage of the roadway runoff. In Olympia, sidewalks can be up to 50 percent of the impervious surface in a street section. The reduced strength of pervious concrete is less of a concern in sidewalk design.

The use of pervious concrete requires a shift in maintenance responsibilities from traditional stormwater ponds to sidewalk cleaning. This maintenance has to be performed if the concrete voids are to remain open. Funding and equipping the cleaning program may be the most difficult part of working with pervious concrete.

The outlook for pervious concrete sidewalks is good. Pervious concrete sidewalks have a clear environmental benefit over traditional concrete sidewalks. Pervious concrete is accepted by citizens in sidewalk applications. In some cases it can substantially reduce initial construction costs.

More Information Web Sites

City of Olympia www.olympiawa.gov/cityutilities/stormwater/scienceandinnovations

Percocrete www.percocrete.com Stoney Creek www.stoneycreekmaterials.com

WA Concrete and Aggregates Association

www.washingtonconcrete.org/industry/pervious/pervious_pavement.php