Pervious in Practice

Methods, materials, mixtures

PIP 4 – Guide to Pervious Concrete Mix Design

Because proportioning pervious concrete mixtures is different from conventional concrete, this guide is designed to assist producers in developing a workable, durable pervious concrete mix. When developing a pervious mixture, the goal is to match the cement paste with aggregate voids to maintain enough interconnected voids to allow the rapid infiltration of water through the concrete into the sub-base. It is critical to understand that any pervious concrete mix design must not only be durable but also workable so that the contractor may quickly place, compact and cure the concrete.

Importance of Aggregate on Mix Design

The void content of a pervious concrete mixture is determined by the characteristics of the ingredients and how they are proportioned. More so than in any other concrete mix design, coarse aggregate properties affect the proportions of all other materials within a pervious concrete mix. While the suggested void range of a pervious concrete mixture is 15 to 25 percent voids, most professional pervious mixes target 18-22% interconnected void content.

All coarse aggregates are not created equal. Characteristics such as size, shape and absorption must be taken into consideration in the mix design process. Therefore, the first step in proportioning the mix is determining the void content of the aggregate. This is accomplished by obtaining both the SSD unit weight via ASTM C29 and the aggregate specific gravity and entering them into a pervious concrete mix proportioning spreadsheet. The density of the aggregate, combined with the unit weight, is used to determine the volume of solids and voids in the aggregate.

A properly proportioned pervious concrete mix contains enough cement and water to coat and bond the aggregate without filling all the voids. If the coarse aggregate is reasonably uniform in size (gap graded), the voids will be large enough to accommodate an adequate quantity of paste while leaving enough interconnected voids for good permeability. As the gradation of the aggregate becomes more varied the size and quantity of voids will change, and such aggregates may not be suitable for quality pervious concrete.

The ideal aggregate voids range is the high 30's to low 40's percent. However, voids outside this range can still be used. In some regions, the available coarse aggregate has voids ranging from mid to upper 40's percentage. If the aggregate voids exceed 43%, concrete sand can be added to the mix as needed to adjust the finished voids to meet the specification.

Similarly, if the aggregate voids are low (mid 30's or lower), the quantity of cement paste is lowered considerably and consequently may not provide sufficient strength to adequately bond the aggregates.

Research indicates that pervious concrete made with limestone aggregate may be more susceptible to degradation from deicing chemicals than other aggregates. Therefore, it may be advantageous for ready mix producers in severe freeze-thaw regions to consider alternate aggregates and/or other means to protect from such degradation. Both lab and field studies have demonstrated that the use of vinyl acetate-ethylene (VAE) polymers can minimize chemical deterioration from deicing salts and significantly prolong the life and durability of the pervious pavement. Furthermore, the VAE polymer improves the abrasion and impact resistance of pervious concrete, which results in lower surface raveling and ultimately improves the life cycle of the pervious pavement.

Fig 1. Aggregate that is uniform in size (gap-graded) is preferred for a pervious concrete mixture.

Cementitious Content and Water-to-Cement (W/C) Ratio
With traditional, conventional concrete, more cement equates to stronger concrete. While it seems logical to apply this thinking to pervious concrete, it may not be the case. In the past, it was not unusual to see pervious concrete mix designs calling for 600 to 700 pounds of cement per cubic yard with water-to-cement (w/c) ratios in the 0.25 to 0.28 range, resulting in a dry, heavy mix. Not only is such a mix very difficult to discharge from the truck, but it is equally difficult to place and compact. Adding more water would improve workability, but more importantly it would increase paste volume and therefore reduce permeability, so much so that often the pavement would become impervious.

Many of these early mixes also experienced significant raveling due to poor aggregate bonding as well as having other issues regarding durability. Utilizing petrography to analyze some of these compromised pavements, researchers discovered large amounts of un-hydrated cement, causing a weakness within the paste. From a microscopic viewpoint, the early zero slump/high cement factor pervious concretes were littered with dead cement. This was especially problematic in hot dry conditions where moisture loss and the lack of humidity contributed to low cement hydration.

Because pervious concrete is limited to a particular maximum quantity of cement paste based on the aggregate voids, high cementitious contents require restricting the amount of water. Besides the previously mentioned impact on aggregate bonding, too much cement paste can also lead to sealing of the slab, while too little water severely limits the ability of cement to hydrate.

Fig 2. A properly proportioned pervious concrete mix will display a wet, metallic sheen..

Quite surprisingly, dropping the cement content and increasing the water volume, while maintaining the same paste volume, resulted in significant improvements in both the installation process and quality of the finished product. Field experience shows that a target cementitious content generally in the range of 450 to 550 pounds per cubic yard, and water-to-cement ratios in the 0.34-0.41 range are most desirable and will produce a manageable and durable pervious concrete mixture. A properly proportioned pervious concrete mix will display a wet, metallic sheen as discharged from the truck.

With regard to mix water, it is important to introduce the right amount of water at the appropriate time during the batching process. If too little water is used or too much water is batched before the aggregates and cement, "cement balling" may occur. Unlike conventional concrete, a pervious concrete mix may experience balling if more than 70% of the water is added before the aggregate and cement. Some producers have found that adding 50% of the water at the beginning of the batching sequence, and the balance at the end, has minimized the occurrence of balling.

Additionally, it is not a good practice to intentionally hold back significant amounts of water during batching in order to add at the jobsite. Field adjusting a pervious concrete mixture is very time consuming and can dramatically impact its performance and durability. Dispensing the appropriate amount of water in the batching process will play a significant role in both quality control and quality assurance.

Admixtures
As with conventional concrete mixes, pervious concrete utilizes admixtures to enhance performance and assist in placement. In the past it has been a common practice to prepare a "cocktail" of standard high-range water reducers and viscosity-modifying admixtures for use in pervious concrete. Caution should be used when combining these admixtures as they can inadvertently "superplasticize" the mix and cause severe paste drain-down during curing. Most admixture manufacturers now have pervious-specific admixtures that are more suitable for pervious concrete production.

Hydration stabilizing admixtures are extremely helpful in pervious mix designs and should be used. Dosing stabilizers for two or more hours of delayed set is very helpful if there are delays in delivery or placement. Dosage rates for stabilizing pervious mixes is higher than for conventional concrete, due to the rich coating of paste and more exposure to air caused by the 20% voids in the mix. Producers should be aware that conventional retarding admixtures are not the same as hydration stabilizers.

Air entraining admixtures are used in conventional concrete to improve resistance to damage from cycles of freezing and thawing. Entrained air in pervious concrete mixtures will protect the paste from deterioration due to freezing and thawing cycles like it does in conventional concrete. The quantity of entrained air in pervious concrete, however, cannot be directly measured or verified using traditional concrete

test methods. Air entrainment may also improve the flow characteristics of pervious concrete mixtures and facilitate improved discharge.

Color can be added to pervious concrete. Liquid or powdered integral color is often used for uniform distribution when the concrete is mixed. Spray-on colors to create decorative features can also be used if they don't seal the surface. Broadcast dry-shake or acid stains are not recommended on pervious concrete. Matching color in multi-load placements is difficult. Small differences in batch quantities and water between loads and changes in finishing procedures can cause differences in color between sections. The type and color of aggregates also influences the color of the pervious concrete. Additionally, special precautions are necessary when curing colored pervious concrete. A mock up placement may be used to establish a benchmark for subsequent placements to match.
Internal Curing Admixtures (ICA) can enhance both curing and strength for pervious concrete while reducing internal stress and shrinkage (Kevern 2012). When used in a pervious concrete mix, ICA acts as "water entrainment," creating tiny reservoirs that hold an extra supply of water without thinning or lowering the viscosity of the paste. The additional water provides ample moisture for full hydration while also increasing the workability of the mix.

Proper curing is perhaps the most critical component of pervious concrete durability. Even when ICA products are used, surface curing with 6 mil plastic sheeting is required. Producers who use internal curing admixtures must make sure that the installer properly cures the concrete surface.

Silica Fume and Pervious Concrete
The paste which coats the aggregates and forms the aggregate-to-aggregate bridge requires sufficient density for strength and to resist absorption. Research conducted by Dr. John Kevern at the University of Missouri demonstrated that a 5% replacement of portland cement with silica fume can provide increased strength and abrasion resistance. Additionally, at the 5% replacement rate silica fume increases the rheology or "flow rate" of the pervious concrete, making it easier to discharge and place.

Fiber
Fiber reinforcement options are also available in pervious mix designs and can enhance the toughness and durability of the concrete. Research has shown that the introduction of macro-fiber to a pervious concrete mix will not only increase the flexural strength and provide better fatigue resistance but can also reduce the raveling potential. Additionally, fibers keep the cement paste evenly distributed in a fresh concrete mix and can prevent sealing in the tail portion of the load.
The type and volume of fiber varies. It is not uncommon to see fiber dosage rates of 3 to 5 pounds per cubic yard. For extreme applications (heavy traffic areas), macro-fibers with dosage rates up to 7.5 pounds per cubic yard may be used.

Pervious Concrete Mix Design Software
The National Ready Mixed Concrete Association has developed *Mix Proportioning Software for Pervious Concrete Mixtures,* a software program that will help the user establish mixture proportions for pervious concrete for a design void content and optimum consistency. Along with the software, two documents are included. The first document is a guideline that details the pervious concrete mixture proportioning methodology. The second document is a research report that provides experimental validation of the mixture proportioning methodology based on testing conducted at the NRMCA Research Laboratory. The software and reports are available by contacting the NRMCA at info@nrmca.org.

Summary
By following these mix design guidelines, and implementing a good quality control plan, any ready-mix producer can provide a high-quality, durable pervious concrete mix. However, it must be emphasized that the rapidly evolving efforts to improve pervious concrete mixtures necessitates thorough testing and validation with regard to specific materials, means and methods by individual suppliers. Additionally, working closely with an NRMCA certified pervious concrete contractor is key to the success of any pervious concrete project.

Fig 3. Un-hydrated cement causes weakness in the cement paste (left) and will significantly impact the pervious concrete's durability. A target cementitious content of 450 to 550 pounds per cubic yard, and w/c ratio of 0.34-0.41 will produce a manageable and durable pervious concrete mixture (right).