Lessons Cast in Pervious Concrete

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For many years on the campus of an ACCE accredited construction management program architecture and construction students have collaborated on the design and construction of concrete service projects. As part of the requirements of a Junior level course in concrete design and construction, these students have planned and executed all phases of small construction projects for a variety of non profit organizations on their college campus and in the larger community. The benefits gained by students have added immeasurable value to their technical education. Simultaneously, positive relationships have been cultivated among academicians, material and equipment suppliers, and clients as they combined their collective abilities to support learning experiences for students. The most recent development in this collaborative venture is a four year series of projects with a challenging new material, pervious concrete. This paper will define pervious concrete, review a brief history of the material, and review lessons learned by students, faculty and the larger support group of collaborators as they cast pervious concrete slabs-on-grade in and around their college campus. In addition to the technical lessons; service-oriented collaborative projects bring valuable intangible benefits to the collaborators, which will be reviewed in the paper.

Key Words
Pervious Concrete, Sustainable Construction, Collaborative Learning, Service Learning

Introduction

Each semester over the past 18 years construction students in an ACCE accredited program have been working in integrated teams with architecture students to gain practical knowledge and skill with concrete. This service learning requirement is woven into a semester course in reinforced concrete and represents 15% of the student's course grade. The major objectives of the project are for students 1) to learn in the most practical way about concrete materials and methods, 2) to work across disciplinary lines designing and building as a team, and 3) to serve the university or its larger community by creating useful products. Since the project's inception, students have cast thousands of yards of concrete for schools, churches, clubs, retirement communities, health care facilities, and other non-profit organizations. The projects range in size and scope, depending on the needs of the client. A few examples are walkways, staircases, basketball courts, handicap access ramps, and baseball field bleachers. These encounters with real world problems require students to execute all phases of designing and building a small community service project while learning about concrete. Students in very different disciplines are given the opportunity to discover and learn from each other's talents. Collaboration, communication, and teamwork are intangible benefits they encounter along the way.

A number of projects have been done on the university campus, where students are fortunate to work alongside members of the campus facilities division. These experienced workers construct numerous concrete projects on campus year round, which include sidewalks, wheelchair ramps, retaining walls, stairways, etc. The experience of these seasoned workers, combined with the enthusiasm of motivated college students has made for many successful projects and learning experiences for all of the collaborators.

The latest trend in the course has been pervious concrete, as a new generation of architecture and construction students has arrived on campus with a keen interest in green building and sustainable materials. The first pervious concrete project was initiated by the interest and enthusiasm of a single student. This initial spark has spread to other students, faculty and campus workers over a period of four years in the form of eight unique pervious concrete projects on campus. This paper will review some of the lessons learned by the collaborators as they cast the first pervious concrete in and around their university campus.

Pervious Concrete

Pervious concrete would qualify as a green construction material according to the USGBC LEED Green building Rating System, since it can be the essential component of a sustainable development plan designed to control both quantity and quality of stormwater runoff. (USGBC, 2005) There are many other potential positive environmental impacts, which will be discussed later.

Pervious concrete is a highly porous concrete mixture that readily passes water. It consists of little to no fine aggregate, a narrow range of small coarse aggregate particle sizes, bound together by a stiff mixture of Portland cement paste. Table 1 is a comparison of the components of pervious and conventional concrete.

***Table 1*: Typical concrete mix designs**

Ingredient	Pervious Concrete	Conventional Concrete
Cement	300-600 lb/yd^3	400-500 lb/yd^3
Coarse Aggregate	2400-2700 lb/yd^3	1800-2100 lb/yd^3
Fine Aggregate	0	1200-1400 lb/yd^3
Water/Cement	0.27-0.34	0.4-0.6
Admixtures	Yes	Yes

Hardened pervious concrete contains random connected air passages making up about (15%-25%) of the concrete volume. When mixed and placed properly, pervious concrete hardens into a solid mass easily achieving compressive strengths of 2,500 psi and capable of draining from 100 to 700 in/hr of water. (Tennis, Leming, Akers, 2004) Finished pervious concrete has a unit weight of 100-125 pcf compared with 145 pcf for conventional concrete. See Figures 1 and 2.

Pervious concrete is not a new material; it was first used in pavements following WWII primarily for improving drainage and traction on roads. As an environmental product it was first used in Florida in the 1970's where the combination of drainable soils and strict stormwater laws led to its rapid development. Florida's success with pervious concrete, especially in commercial parking lots and driveways continued through the 1980's and influenced the spread of the material into other southern states. By 1990 more than 20 acres of pervious pavement had been placed in Florida and installations of the product had been made in Tennessee, Kentucky, Georgia, and the Carolinas. By the mid 1990's installations were being made on the West Coast. In the early 2000's the first pervious concrete pavements were tried on clays in central Alabama and by 2005 applications and testing of the material had spread into the cold climates of Colorado, the Northwest and Midwest US. (Ferguson, 2005)

Figure 1: Pervious Concrete (100-125 pcf)

Figure 2: Conventional Concrete (145 pcf)

Pervious concrete is part of a paving system consisting in cross section of typically a minimum of 6" thick pervious concrete, supported by a porous gravel subbase (e.g. #57 stone) that can vary in depth from 4" to much greater depths, depending on water storage needs. In fine soils such as clays, silts and highly organic soils, the system is bounded by a geotextile fabric to help prevent infiltration of fines and clogging. A cross section profile through a pervious concrete system is shown in Figure 3.

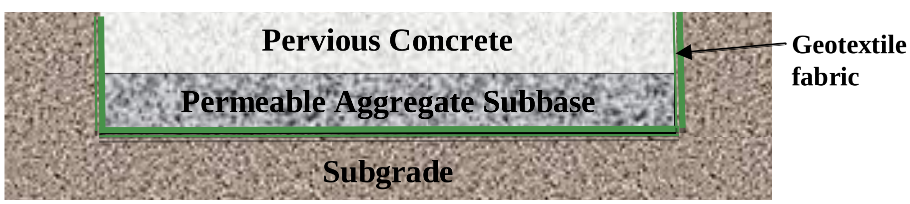

Figure 3: Pervious concrete system cross section

There are many benefits in using pervious concrete paving systems as an alternative to traditional concrete or asphalt. These advantages have been proven in numerous research studies conducted across the US. Pervious concrete reduces stormwater runoff that contributes to erosion and stream turbidity. Its ability to store water allows it to recharge groundwater, even in clay soils. Its filtration improves the quality of runoff water. It promotes more efficient land use, eliminating the need for retention ponds, swales, culverts, and other stormwater management devices. Its sound absorption characteristic helps reduce road noise. It has been used to create safer pavements by reducing noise, water spray, hydroplaning and skids. Finally, as a cooler pavement it can contribute to the reduction of the heat island effect. (Schaeffer, 2006)

Pervious Concrete on Campus

Over a four year period, students in the course have cast nearly 1000 linear ft. of pervious concrete walkways and approximately 2500 additional sq ft of pervious concrete slabs on grade on or near campus. Figure 4 shows a casting of colored pervious concrete walking trail in the university arboretum. Figure 5 shows a close-up of the 6” thick walkway section and gravel subbase indicating porous nature of the finished pervious system.

Figure 4. Arboretum pervious trail

Figure 5. Pervious close-up

This effort represents the first pervious concrete installations in the university vicinity and some of the first installations in the state. Each placement was conducted by teams of students working side-by-side with facilities workers, and under the watchful eyes of the faculty, suppliers and consultant collaborators. (PCIC, 2005)

Table 2 summarizes the eight major pervious concrete projects to date:

***Table 2*: Pervious Concrete Student Projects**

Date	**Project**	**Location**
11/01/2003	pervious **sidewalk** - 5 ft. x 100 ft. x 6 in. thick, conventional concrete curb banding	main campus
4/26/2004 4/28/2004	pervious **parking lot** - 35 ft. x 35 ft. x 8 in. thick repair patch, 5 ft. wide alt. strips	main campus
11/29/2004	colored pervious **walking trail** - 5 ft. x 160 ft. x 6in. thick	University Arboretum
5/2005	pervious **slab** - 25ft. x 35ft. x 6 in. foundation for picnic tables, 5 ft. wide alternate strips	Asphalt Technology Track
11/30/2005	colored pervious **walking trail** - 5 ft. width x 100 ft. x 6in. thick	University Arboretum
4/13/2006 4/20/2006	pervious **sidewalk and patio** - 5 ft. width x 60 ft. length, conventional concrete patio band	Aids Outreach House
6/21/2007	colored pervious **walking trail** - 5 ft. width x 100 ft. x 6in. thick	University Arboretum
11/2007	colored pervious **walking trail** - 5.5 ft. width x 300 ft. x 6in. thick w/ control joints	University Arboretum

Placing Pervious

Table 3 shows the typical steps in casting pervious concrete sidewalks in the university arboretum.

Table 3: **Steps in casting pervious Concrete**
1. Excavate
2. Set forms and place riser strips
3. Place geotextile filter fabric
4. Place subbase and compact
5. Fill forms with pervious concrete
6. Strike off surface to top of riser
7. Remove riser strips
8. Compress lift with weighted roller (see Figure 6.)
9. Cross roll and form control joints
10. Cover with curing plastic

Images from recent university arboretum placement: Figure 6 shows depositing and striking off a level surface; Figure 7 shows compressing pervious concrete.

Figure 6. Deposit and strike-off

Figure 7. Compressing with roller

When the mixture is right pervious concrete goes into place fairly easily. The mixture is so dry (low w/cm), there is little to no bleeding and no troweling or brooming is done. If the mixture is wrong (i.e. too wet or dry, incorrect ingredient proportions or improper blending), little can be done in the placing process to create quality pervious concrete that is both strong and porous.

Lessons Learned

To advance the state of knowledge of this new material in the region, a process of observation, recording, reflection and discussion among collaborators has been established. The design, composition, and changing condition of supplied concrete have been recorded for each placement. Also placement techniques, climate conditions, and curing methods have been recorded. All products and processes have been well documented by students using still images and video. All projects have been summarized in final reports presented by student groups to their larger class and to attending collaborators. The finished slabs have been visited and reviewed by professors, suppliers and clients, who have proposed changes for better results. This process has resulted in a recommended best practices guide for casting pervious concrete in the area. The professor has presented these best practices at state concrete industries association sponsored seminars. Each semester, both best and worst practices are presented to incoming students to prepare them for the next projects. The following is a summary of lessons learned.

Moisture Content

Most problems with pervious concrete at the university involved incorrect moisture content. Typically the water/cementitious materials (w/cm) ratio must be low to maximize strength and to prevent clogging of pores. However a low w/cm usually means a very stiff mixture; slumps on university projects typically measured 0” - 1”. This translates into tremendous effort getting concrete out of the truck and into place on the ground. Adding water doesn’t help since if the mixture is too wet, excess free paste clogs the pores and inhibits porosity. When the mixture is too dry the finished concrete surface can ravel, leaving an unsightly and unsafe surface. A compromise was found using a blend of plasticizers and viscosity modifying agents to create a more workable mixture; however too much of the chemicals imitated a wet condition and sealed pores. Figure 7 shows a simple hand test recommended by PCA to determine proper consistency for pervious concrete. (Tennis, 2004) University placements confirmed the accuracy of this test in predicting proper consistency for high quality finished pervious concrete.

a. too dry
results in surface raveling

b. correct moisture
good pervious concrete

c. too wet
results in low porosity

Figure 8. Moisture Content in Pervious Concrete Mixtures (Tennis, 2004)

Timing

The lower w/cm ratio and the two-step screeding and rolling process usually mean placement of pervious is much slower than traditional concrete. The longer wait time contributes to further drying of the mixture in the truck and loss of effectiveness of workability agents. If the concrete must be delivered a long distance, it may be better to introduce workability admixtures at the site. To prevent concrete that arrives with correct w/cm from drying by the end of the load, smaller batches are recommended (3-5 cu.yds.) A small amount of water may be added near the end of the load to prevent raveling; however this does weaken the concrete.

Blending

Concrete delivered in the university projects sometimes arrived in an uneven state of consistency, with a wet sheen on segregated aggregates, and with tennis ball sized clumps of cement paste dispersed through the batch. This created raveled regions where aggregate paste was weak and smeared and sealed regions where too much cement was present. This problem was solved by observing the concrete closely and doing the hand test of Figure 7 whenever consistency was in question. Additional revolutions of the mixer helped proper distribution of all ingredients before placing. A consultant has recommended lower cement content.

Placing

When striking off the surface of pervious concrete students found that a forward pull and scoop motion of the screed created less surface smearing than a sideways sawing technique. As in conventional concrete, keeping a small excess of concrete above the bottom of the advancing screed saved time and effort creating a flat surface. If the riser strip is too high or the roller too light the roller will not be able to compress the lift to the top of the side forms, resulting in an insufficiently flat finished surface. On the university projects a ½" compression of the 6" concrete lift was easily achieved with an 8" diameter water filled pipe roller. Loose aggregate from the screeded surface that rolls onto the top of the sideform compromises the rolling operation, either skidding the roller and smearing the surface or creating unevenness where the roller rides over the rocks. Students discovered this can be prevented by sweeping rocks off the form ahead of the roller. A hand tamper can be effective in compressing areas where the roller can't reach. Light cross rolling perpendicular to the heavy roller pass increased surface flatness.

Jointing

Very little shrinkage cracking was observed in the pervious concrete slabs, probably due to the low moisture content. In one location in the arboretum a 160 ft length of pervious walkway was cast without control joints. Three years later there is still no visible sign of cracking. In another area transverse shrinkage cracks have formed at about 30 ft. intervals in a 6" thick by 5 ft wide walkway. These cracks appeared following a drought period over a year after the slab was cast. In subsequent castings, control joints have been placed at approximately 15' intervals with a rolling groover, similar to a giant pizza cutter. It was found that sawing control joints led to raveling of aggregate at the joints; therefore sawing is not a recommended jointing technique.

Curing

It has been shown that conventional concrete properly cured for seven days can achieve a compressive strength nearly twice that of concrete left to dry in air. (Kosmatka 2002) The dry mixture and interconnected pores in pervious concrete creates a more critical condition for loss of moisture necessary for hydration and strength gain. Curing should be done immediately following rolling and jointing and ideally for a minimum of seven days. One of the down sides of curing encountered in the arboretum walkways is that the rich brown coloring admixture was stained with a thin white film of efflorescence left by condensation trapped beneath the curing plastic and settling on the surface. Both clear and black curing plastics were tried without remedy. In the last review students proposed trying a tent configuration of the curing plastic over the slab, which should drain the condensation to the sides of the form.

Collaboration

Collaboration is an important ingredient to the success of any constructed work. Students in the class are assigned to teams of four or five people, mixed to achieve a balance of experience, gender and discipline (architecture and construction). Team members come to know one another well by working closely on three projects, which increase in scope and complexity over the semester, and culminate in the service learning project. In addition to the technical skills they acquire from practice, study and shared experiences, they learn the importance of collaboration and the vital part that communication plays among collaborators in construction.

The pervious concrete initiative on campus began with a student of Architecture, who asked if his project group could experiment with sustainable concrete. Since pervious concrete had never been cast in the region, the course professor sought out personnel in the heavy construction group of campus facilities for a project site and some assistance. With little convincing a 100 ft. length of worn sidewalk was approved for replacement with pervious concrete. Working from specifications obtained by the lead student, the facilities group outsourced the building of a compression roller to a local metal shop. The roller has since been used on every pervious concrete project. Facilities personnel have become vital to the success of the projects, supplying tools, equipment, expertise and patience as they worked closely with students and faculty, developing and refining techniques for casting pervious concrete paving.

During research for the first project, the lead student introduced his construction professor to a civil engineering professor on campus who had extensive research experience with concrete paving materials. The CE professor quickly joined the team as a collaborator and friend, making his knowledge, lab and graduate research assistant available for experimenting and testing mix proportions for the sidewalk project. This professor has become one of the primary collaborators, having consulted on all subsequent pervious concrete projects. He also has served on capstone committees of two construction masters students pursuing topics on pervious concrete.

The next collaborator to join the team was a local concrete supplier. The supplier was eager to experiment with the new material and took an active role in mix design, test batches and placements. He has attended each of the eight placements to closely monitor the mixtures and finished products. As the projects grew in size and difficulty, the supplier enlisted the services of a concrete admixture specialist from a chemical company to provide workability admixtures. The specialist developed a blend of three admixtures that made the stiff pervious mixture much more workable. He was present at two of the early placements, refining the admixture blend.

The course professor found another helpful collaborator in the state concrete industries association. The association's staff engineer supplied reference material, mix design specifications, case studies and contacts, and attended the first four pervious placements. An experienced pervious concrete applicator from a large city nearby attended one of the concrete placements and trained student workers, faculty and facilities workers in his techniques. He loaned the group specialized equipment, shared his considerable knowledge, and was a valuable resource for a graduate student capstone project.

As the fourth year of pervious concrete projects comes to a close and we prepare for future projects, two new collaborators have joined the “pervious concrete” team. A university landscape architect and a bioengineer are contributing their expertise on the potential positive environmental impacts of pervious concrete. With their assistance the lead professor has applied for a major research grant that will support a research study of quantity and quality of stormwater runoff from pervious concrete pavement.

The major client has been the university, primarily the arboretum where over 600 linear feet of colored pervious concrete trails have been cast. The arboretum curator has played an active role in evaluating the quality of the work and in directing teams of students. She is a vital part of the feedback that guides the teams toward better quality pervious concrete.

What started as an idea in a single student has grown into a collaborative process that has included many students, faculty, researchers, industry personnel and campus facilities workers. The collaboration among these people has accelerated the learning process of all participants while magnifying the lessons learned. As each new student, faculty member, and industry collaborator becomes engaged in the discovery of pervious concrete they become another advocate for the advancement of this remarkable material, and they carry practical knowledge of a sustainable paving alternative far beyond the classroom.

Future Projects

The author plans to continue to introduce students to the state of the art of pervious concrete through hands-on projects at the university and in the community. He has accompanied university facilities personnel at training workshops on pervious concrete, an indication of their commitment to continue to assist in the collaborative effort on campus. The author and two new collaborators have applied for a grant from the state’s Water Resources Research Institute and have received a commitment of matching funds from a variety of donors on and off campus. The group has proposed to replace half of a deteriorated parking area in the university arboretum with a pervious concrete paving system and test the quality of storm water runoff in a side by side comparison with the undisturbed asphalt half. The study will be an attempt to add to the body of knowledge on the effectiveness of pervious concrete systems to improve quality of stormwater runoff. Beyond this, one commercial project has been conducted in the community and two others are planned. In addition the university has specified pervious concrete paving in a new large dormitory project on campus. These commercial projects are indication that pervious concrete is becoming an accepted material in the local community. These commercial projects will provide faculty and students opportunity to observe the rapidly evolving practices with materials, equipment and methods used for pervious concrete.

Conclusions

Over a four year period more than 100 students, four faculty members, eight university facilities workers and supervisors, and several material suppliers and concrete industry representatives have become engaged in use and development of pervious concrete in a region where the material had not been previously used. These collaborators have worked side by side researching, experimenting, designing and building a series of small pervious concrete slabs on a university campus. While the surfaces created from their efforts meet the utilitarian needs of local clients, they have also provided pathways to learning about pervious concrete, which is rapidly gaining popularity as an important sustainable material. New alliances have been formed among collaborators as they have explored working with the new material. Two Masters capstone projects have been completed by graduate students studying the undergraduate projects. One of the most important technical lessons learned is that creating pervious pavements is not as simple as it looks. Concrete, which for centuries has been prized for its impervious qualities, needs understanding and assistance to reverse its natural tendency. Creating a concrete surface with uniformly distributed connected voids that can pass and store water requires more than just omitting fine aggregates. A small change in free water content of a pervious concrete mixture has a large impact on the behavior of the mixture. Too dry a mixture creates raveling of the finished surface, while too wet a mixture can render the surface impervious. Other variables affecting the results are aggregate type, compaction effort, deformation from compaction, thickness of slab, type and thickness of subbase material, and use of chemical admixtures.

Although pervious concrete costs more today to produce and deliver, the total cost of a pervious concrete system is probably still less when all ancillary stomwater management systems required for impervious paving are considered in a cost analysis. All indications show a growing interest in the material due to its positive environmental impacts.

The collaborators look forward to building on these important lessons. Future projects will include more careful observation, testing, and measurements. While students and facilities workers continue to learn by building, the author plans to experiment with measuring the relationship between strength and porosity of past and future works. The anticipated WRRI grant will allow the author to work with two new collaborators investigating the effectiveness of pervious paving systems to reduce harmful chemicals from stormwater runoff.

References

Ferguson, Bruce K. (2005). Porous Concrete. In Taylor and Francis Group, *Porous Pavements (pp. 417-455)*. Boca Raton, FL: CRC Press.

Kosmatka, B. Kerkhoff, W. Panarese (2002) Design and Control of Concrete Mixtures, 14th Edition, Portland Cement Association

PCIC, Pervious Concrete Information Center, (2005). Case studies retrieved December 21, 2007 from https://fp.auburn.edu/heinmic/PerviousConcrete/case_studies.html

Schaefer, V.R., Suleiman, M.T., Wang, K., Kevern, J.T., & Wiegand, P. (2006, April). An overview of Pervious concrete applications in stormwater management and pavement systems.

Tennis, Paul D., Leming, Michael L., Akers, David J. (2004). *Pervious Concrete Pavements*. Skokie, IL: Portland Cement Association.

USGBC, Green Building Rating System for New Construction & Major Renovations Version 2.2 (2005). U.S. Green Building Council. Retrieved December 21, 2007. from http://www.usgbc.org/ShowFile.aspx?DocumentID=1095