Porous Concrete Test Pour for Market Implementation
Testing for the Viability of a Consumer Product

Dr. Annie Pearce and Marc Marinchak

Introduction

Porous concrete, also called pervious or permeable concrete, is a concrete mix designed to maintain void space within the concrete slab once it has been placed (GCPA, 2006). Porous concrete is used for slab applications, usually as walkways or in parking lots. Because of the void space maintained from pervious concrete, fluids, specifically stormwater, are allowed to percolate through the concrete surface and subsequently infiltrate into the groundwater (GCPA, 2006). By allowing stormwater to infiltrate groundwater, retention basins and other stormwater management techniques intended to reduce peak flows to nearby waterways. By allowing this infiltration, not only are natural groundwater recharge processes kept in place, but also valuable land that might otherwise be required for stormwater retention structures can now be used for other purposes.

While porous concrete allows for stormwater retention, certain factors play into the effectiveness of the material, namely the slab base or subsurface, and the design of the mix of the concrete. According to Stoney Creek Materials, for a 4" porous concrete slab, an underlayment of 8" of compacted aggregate is required to provide a proper base where stormewater can remain, where it will then percolate into the subgrade (SC, 2006). This 8-inches of underlayment is necessary to allow the stormwater to move unimpeded through the concrete, and be held underneath to prevent the possibility of freezing in winter months (SC, 2006). As for the concrete mix itself, there are many specific characteristics designed into the batch recipe to ensure void spaces are maintained. According to Graniterock, a California-based concrete contractor, an ideal mix design for porous concrete is rather labor intensive. The basic materials for a batch include 3/8 inch to No. 8 aggregate, Portland cement, and water (GR, 2006). While the specific batch is somewhat simple, the preparation for these materials at the batch plant, as well as transportation and placement, are somewhat extensive. Starting at the batch plant, the aggregate for the porous concrete must be washed to remove fines/dirt, and then dried. The fines and dirt are recommended to be washed away to decrease the likelihood of those particles decreasing the void space. Because pervious concrete is a difficult product to work with, it is recommended that water is not added to the batch until it reaches the site. Therefore, the aggregate must be dried to prevent the cement from hydrating prior transportation/placement. Also, the concrete truck must also be dried, as well, to prevent hydration. Once the aggregate has been properly prepared, and the cement has been added to the batch, the mix can be transported to site. Once on site, the required amount of water is added to the truck, and mixed. Because of a relatively low water/cement ratio in the mix design for porous concrete, only approximately .40, the concrete must be placed quickly to facilitate placement and finishing. It is recommended that the placement of concrete take, at maximum, one hour of time. In this time, the concrete must be placed, worked, and finished. Because of the low slump nature of the concrete, and because the goal is to achieve void space in the slab, it is critical to move the concrete as little as possible. The concrete must be placed directly, and will not flow to fill the formwork. Within the formwork, the concrete must be placed ¼ to 5/8 of an inch above the formwork, once it has been screeded. The concrete is then compacted to the height of the formwork, and covered with plastic. Studies recommend that the concrete remain covered for seven days to allow proper curing. (SC, 2006; GR, 2006; Villanova, 2006)

Because of the aforementioned specifications with batch design and handling requirements, the School of Construction at Virginia Tech sought to study the properties associated with porous concrete. Through analysis of past studies, the department wished to test the viability of bringing porous concrete to market. Issues concerning time, placement, and finishing were discovered specifically in the Villanova Urban Stormwater Partnership report on porous concrete. Within this case study, local vendors and state concrete association representatives, along with students and faculty from Virginia Tech School of Construction, design a porous concrete batch viable for the consumer market, and test the workability of the mix. The participants in this test pour want to determine first-hand the difficulties involved with porous concrete. Considering the specialized handling requirements for the batch ingredients, and that many batch plants do not have the capability of washing and drying aggregate, achieving the previously mentioned batching requirements would prove very difficult for the average concrete batch plant. Therefore, this test pour utilizes readily available materials and handling methods common and most batch plants, such as unwashed aggregate and automated batching technology. Not only does this test pour utilize common batching materials and methods, but typical concrete placing and finishing tools as well, with the only exception being a lawn roller used for the rolling compactor to finish the concrete. By using these methods, this test pour determines the viability of porous concrete being adopted by batch plants as an available mix.

To overview the following report, a brief background is given to highlight issues involved with placing porous concrete. This case study then highlights how the involved participants prepare the site and place the concrete. Detail is also given to the batch design used for this report, as well as the materials handling methods for this test pour. Any issues that were faced during this pour, as well as recommendations for future pours, are discussed. Finally, the test pour is summarized, and conclusions are made in regards to the commercial viability of porous concrete using current concrete industry standards.

Background

As previously mentioned, there are numerous steps in the batching and placing process that are unique to porous concrete, including a somewhat temperamental mix, along with a rapid placement and finishing speed. Through studying the Villanova case study of a test pour on their campus, issues related to porous concrete were clearly addressed. These issues primarily involved the speed of placement, finishing, and curing, which are

Figure 1: Villanova Porous Concrete Application

http://egrfaculty.villanova.edu/public/Civil_Environmental/WREE/VUSP_Web_Folder/PC_web_folder/PC_main.html addressed below in a brief summary of the case study. (Villanova, 2006)

The Villanova porous concrete pour initially took place in August of 2002, and was for a pedestrian walkway on the campus of Villanova University, out side of Philadelphia, PA. The site consisted of 50,000 square feet of impervious surfaces, including rooftops, existing walkways, and compacted soil. As for the specific area of porous concrete, an estimated 17,000-20,000 square feet of concrete were poured, based on a visual estimated of available pictures. Figure 1 provides a depiction of the Villanova site. During the construction process for the porous concrete walkway, the existing site was removed of the current walkway, and excavated accordingly. Once the site was graded and formed, placement of the concrete could occur. For the material placement, the original plan "was for the material to be batched off-site, poured and spread, leveled using a traveling vibratory screed, hand compacted, and finally covered. An admixture to improve bonding and thus strength of the concrete would be added to the drum at the site prior to pouring." However, issues with the material were apparent from the beginning of placement. According to the study, the first delivery of concrete lacked a desired consistency for placement, which "resembled wet, loose gravel." This material was discarded, and was hypothesized that too much water was added at the batch plant. The second batch that arrived on-site appeared to have a better consistency, and was placed. However, after placement, and an attempt to level the material with a vibratory screed, which proved ineffective at leveling the concrete, a modified vibratory tamper was utilized. Despite the relative success of the second delivered batch in regards to consistency and workability, the third batch proved to be unworkable shortly into the pour. After the difficulty associated with the initial pours, the decision to add water to the batch on-site was made. This was done in order to "better control and predict the workability of the concrete." (Villanova, 2006)

While adding water on-site was performed to control concrete consistency and workability, and discontinuing the use of a vibratory screed and replacing it with a modified vibratory tamper was implemented to control finishing, other issues arose with curing. Once the porous concrete at the Villanova site was placed and finished, plastic was placed over the slab to promote curing. Despite covering with plastic, the porous concrete cured unevenly, which is attributed to various factors, with one of these factors being the placement of the plastic over the concrete. Due to the relatively large size of the pours, securing the plastic properly proved to be a challenge, often times having wind move the plastic off of the concrete. This promoted uneven curing and evaporation of water from the concrete mix. Another factor that influenced curing was the theorized lack of hydration within certain areas of the cement, which leads to dips/ruts, along with loose sections of gravel. These sections were patched with additional porous concrete; however, the color and consistency of the patch varied, and proved to be an unacceptable alternative for finishing. (Villanova, 2006)

Because of the difficulties associated with the Villanova pour, the August 2002 pervious concrete pour had to be demolished and replaced in May 2003 with new pervious concrete. During this pour, temperatures were in the 70's, whereas temperatures during the initial August 2002 pour where in the mid-90's, and the spring temperatures proved ideal for hydrating concrete. While temperatures were somewhat more favorable in the spring, different control methods for placing the concrete were the determining factors in providing an effective second pour. For the May 2003 pour, more control was exhorted over the mix. A dry mix was transported to the site, which was ensured to be free of fines, as well as dry. Once on-site, the project foreman was the sole individual in charge of adding the appropriate amount of water, along with the required amount of hydration-retarding admixture. Also, only a portion of the 9-cy capacity concrete truck was used to ensure that only the appropriate amount of porous concrete was used, to promote workability of the product, and prevent hydration before the concrete could be placed. On average, 10 gallons of water were used per cubic yard of concrete, 3.3 gallons of admixture, and only 6-7 yards of material in each truck. For placement, minimal movement of the concrete from the truck to the site was performed. This improved the final finish and prevented any surface consolidation of the aggregate. The concrete was allowed to be moved by rake, however, only minimally, and when necessary, and no more than two-feed distance. Once placed, the concrete was compacted using a 50-gallon roller compacter. This allowed for better control and finished surface over the previously used vibratory tamper. These finish methods were facilitated by pouring smaller, more easily worked sections. Once placed and finished, the porous concrete was covered with plastic, properly secured, and allowed to cure for 48-hours. These alterations in controlling the pour proved to create an acceptable finished product (Villanova, 2006). Table 1 provides a summary of the issues and solutions related to porous concrete.

Table 1: Villanova Porous Concrete Issues

Placement Process	Standard Practice	Villanova 1st pour practices	Villanova 2nd pour Modification	Effectiveness of Modification
Batching	Mix all batch materials at batch plant	Standard Practice	Transport batch dry, add water on-site	Prevented premature hydration
Placement	Pour concrete and let distribute throughout forms	Place by hand throughout forms	Placed by hand in smaller sections	Improved workability and finished surface
Finishing	Screed and float	Vibratory screed and modified vibratory tamper	Rolling compactor	Improved uniformity of finished surface
Curing	Cover with plastic of dampened fabric	Covered entire day's work with plastic	Covered smaller sections with plastic	Facilitated secure anchoring and curing

The information previously provided is only a summary of some of the key issues related to porous concrete. For the original case study on the Villanova project, please refer to the references provided at the bottom of the page.

As described in the aforementioned study, porous concrete evidently posses unique properties that greatly influence its workability and finish. Based on the lessons learned in the Villanova study, the School of Construction at Virginia Tech wanted to implement its own test pour to prove the viability of using this product in the consumer market. Specifically, issues of using commonly available batch ingredients and placement tools are desired to produce a readily available porous concrete product, and, therefore, such materials and methods are used for this test pour. This processes is described in-depth later in this report. In order to do so, multiple parties were involved, including a local homeowner located in Blacksburg, Virginia, Marshall

Concrete, located in Christiansburg, Virginia, and representatives from the Virginia Ready-Mixed Concrete Association. During this test, Marshall Concrete donated the porous concrete batch, while the Virginia Ready-Mixed representative provided oversight. Virginia Tech students provided Labor for preparing the site and placing the concrete, while funding by Virginia Tech provided for excavation, underlayment, and formwork.

Initial Preparation/Stakeholder Communications

Initial preparation for the porous concrete test pour initiated in the Sustainable Building Construction class at Virginia Tech. During this class, porous concrete examples were examined and discussed, and the decision to progress the initial class discussion into a test pour was made. After initial literature reviews and research, the class found that the available tests for porous concrete dealt with larger-scale pours, such as the previously mentioned Villanova case study. Because of this information, the class decided to pursue a smaller-scale application of porous concrete, and felt it would beneficial to test this material on a residential scale, such as a backyard patio or driveway.

After deciding the size of the project, and the necessary resources for the job, which are described in-depth later in this case study, the various players involved in the pour were contacted. The Virginia Ready-Mixed Association (VRMA) representative was first contacted for this case study, during which he provided additional information, courtesy of the Kentucky Ready-Mixed Association, on placing porous concrete, which provided application examples of porous concrete. During this contact, the representative also provided valuable insight for the need of such a study, stating that no such pour of porous concrete had been performed in the southwestern Virginia area, and that a local example of a porous concrete application would be beneficial for promotional purposes. The VRMA representative also provided contact information for a local concrete contractor that would likely be able to provide resources, specifically the materials necessary for the concrete batch for the pour. (Nablo, 2006)

After the VRMA representative was contacted, finding a viable location to perform the test was necessary. Since the scale of the project was intended for a small scale-residential application, primarily because such a pour had not been performed in the area, and discussions between the class and VRMA representative led the parties to believe residential customers would be a viable consumer market, an appropriate location specific to these three factors needed to be found. Through conversation amongst faculty and staff within the Virginia Tech School of Construction, a suitable site was found for the porous concrete test pour. The homeowner had recently purchased the house, situated in downtown Blacksburg, Virginia, and was currently going through home renovations. The only requirements necessary of the homeowner were to provide the site and help in the labor required by the project.

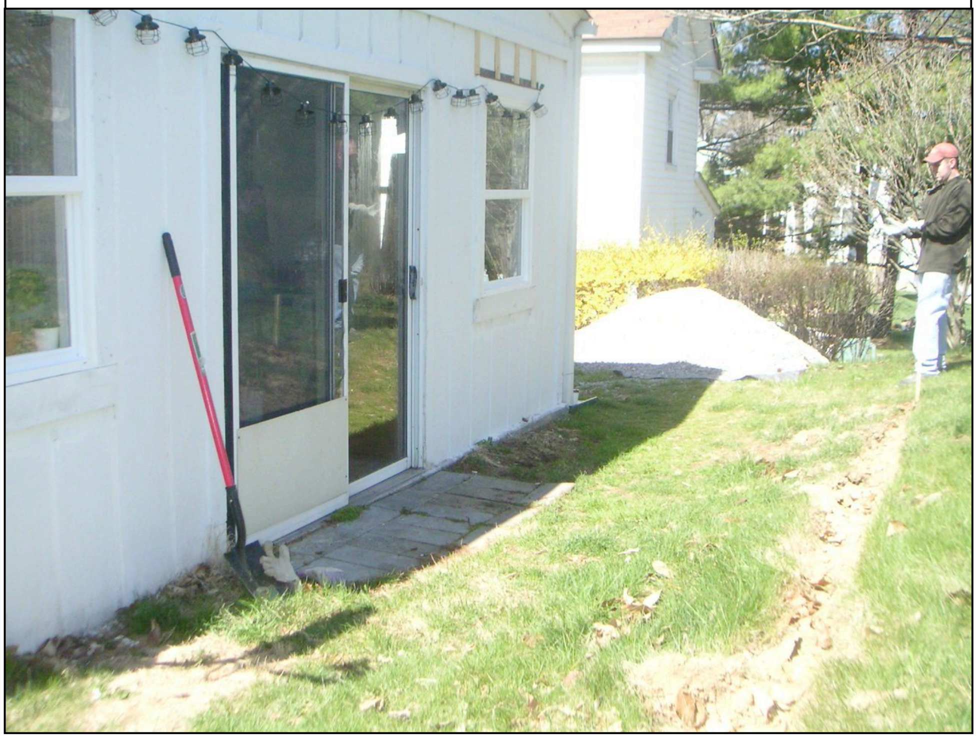
Last to be contacted for the porous concrete pour was Marshall Concrete, the local concrete vendor needed for the test pour. The initial correspondence with Marshall Concrete described the scale of the project, which consisted of an 8’x20’4” slab of porous concrete. The representatives of Marshall Concrete had heard of porous concrete; however, had never placed the material before, and were interested to participate in this study. Upon agreement, design specifications, which were taken from web sources (GR, 2006), were developed and sent to

Marshall Concrete. Marshall Concrete representatives then adjusted the batch design to incorporate materials that are readily available at batch plants. (Kuhn, 2006)

Site Preparation

After all of the test participants had been brought on-board, the initial requirements to carry out the test pour could be performed. Before concrete work could begin, extensive grading was necessary. The existing site where the concrete was to be poured consisted of an area level with the back door, extending 4 feet from the back of the house. At the four feet point, the ground sloped severely, and rose nearly 3 feet, and then leveled off. Figure 2 provides a photograph of the existing site conditions. In order to efficiently grade the site, excavation equipment was required. There was an initial attempt to excavate the site by hand, but this approach quickly proved to be ineffective. After the manual excavation attempt, a skidsteer was rented from a local hardware store. Grade stakes were placed to mark the dimensions of the patio, and excavation began. Excavation took place in mid-April, with the weather in the mid-60's and dry. Site excavation/grading required approximately 5 hours. Once the site was sufficiently graded, gravel was spread over the substrate to form the patio underlayment. The gravel was delivered to the site prior in the week. The underlayment consisted of #57 stone gravel, and was placed to a depth of 6". While 8" inches were earlier recommended, participants felt a 6" base was adequate for this small application. After underlayment placement, the skidsteer was driven over it, and the skidsteer bucket was used to compact the gravel, which was improvised due to the absence of a vibratory compactor. Once the underlayment was placed, the formwork for the patio was installed. The formwork consisted of untreated 2x4's, the exterior/existing slab from the back of the house, and an architectural block retaining wall. The 2x4's were appropriately staked off to support the lateral load of the concrete, while the retaining wall was stacked 3 blocks high to provide sufficient weight to resist the loads, as well. Figure 3 shows the finished grading and installed formwork. The underlayment and formwork was completed 2 days prior to the expected pour date. While the patio size was intended to be

Figure 2: Pre-existing Site conditions



8'x20', the formed size of the area ended up being 7'x20', and was done so to reduce the workload by the laborers. Two students and the homeowner provided the labor required for excavation and grading.

Figure 3: Grading and Formwork

Concrete Placement

With the initial grading and formwork in place, the site was ready for the pour. The pour occurred on Friday, March 31, and began at 11:00 AM. There were unique circumstances associated with the final batch design and placement techniques, which are discussed below.

Prior to concrete placement, correspondence with Marshall Concrete generated a porous concrete batch design slightly different than the one recommended in the initial literature review. The original batch design, which was used from the Stoney Creek web site, consisted of using #8 stone gravel, which was to be washed and dried. The cement amount was estimated to be between 400 and 600 pounds per cubic yard of gravel, with 24 gallons of water per cubic yard of concrete. This would ensure a water/cement ratio between 0.35 and 0.45. The initial batch design also requested that the truck be dry, and water to be added on-site. Table 2 provides the initial batch design.

Table 2: Initial Porous Concrete Batch Design (per CY0			
Material	#8 Stone	Cement	Water
Amount	2500 lbs.	400-600 lbs.	~ 24 gal.

After the initial batch design, mentioned above, was sent to and reviewed by the Marshall Concrete representative, various changes were made to the design, including batch ingredients as well as aggregate preparation and handling. The batch recipe generated by Marshall Concrete consisted of #8 stone, sand, cement, fly ash, and water. Table 3 provides the specific batch design recommended by Marshall Concrete.

Table 3: Marshall Concrete Porous Concrete Batch Design (per CY)					
Material	#8 Stone	Sand	Cement	Fly Ash	Water
Amount	2228 lbs.	222 lbs.	486 lbs.	114 lbs.	22 gal.

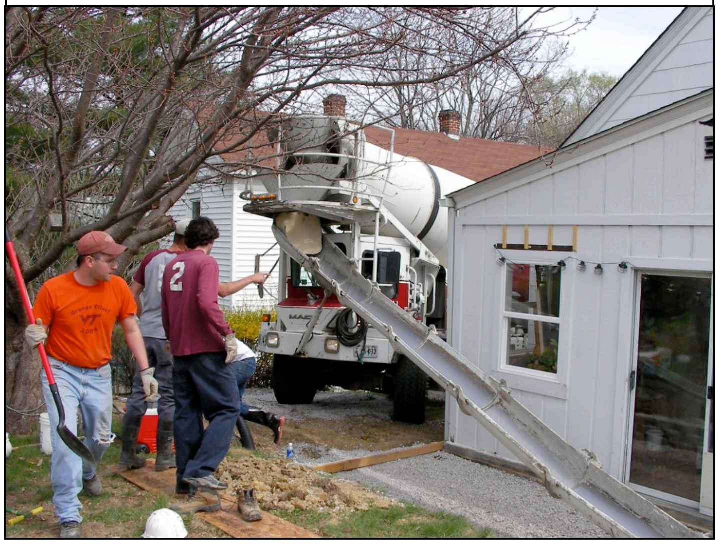
This design varies rather drastically from the recommended batch design, especially considering the addition of sand and fly ash. Not only was the design different, but the batch handling procedures as well. According to the Marshall Concrete representative, the #8 stone would not be washed prior to mixing, and water would be added at the plant. While these batch additions and handling procedures seemed counterintuitive to previous studies, there were appropriate justifications for these differences provided by Marshall Concrete. For justification for the additions, sand and fly ash were added to provide additional strength in the mix. While concern was taken that these materials would reduce the void space in the final product, Marshall Concrete was confident that this design would yield a cement/water ratio of .31 percent, and maintain a void space of 25%. As for handling, the explanation provide by Marshall Concrete concerned commercial viability of this product. While nearly all concrete batch plants have access to #8 stone gravel, very few facilities have the ability to wash the aggregate, while even fewer plants have the ability to dry the washed aggregate. In order for porous concrete to be a commercially viable product, the batch design would have to account for the abilities of the concrete vendors. Therefore, leaving the aggregate unwashed accounted for the abilities of this particular concrete vendor. Marshall Concrete also called for water addition at the batch plant, which was not recommended by both Stoney Creek and the Villanova project. Marshall Concrete stated that premature hydration would be controlled by the addition of a hydration-retarding admixture. . Since the aim of this project was to determine the viability of porous concrete given the constraints of concrete industry standard practices, these recommendations and batch design characteristics were acceptable for this test pour. (Kuhn, 2006)

Once the batch design was specified and accepted, the process of placing the pad could begin. On the day of the pour, a student representative visited the Marshall Concrete facility in Christiansburg, Virginia, in order to ensure all the needed resources were available for the pour. Planning for the pour also occurred at this time, with a general overview of how the laborers planned to place, finish, and cure the concrete. After the meeting at Marshall Concrete, the student representative left to await the porous concrete, while Marshall Concrete began to prepare the batch. For this patio, which turned out to be 7'x20'x4", 2.5 cubic yards of concrete were used. This amount was the original quantity of porous concrete for the 8'x20' pad, however, extra was ordered to ensure there would be ample concrete to finish the pour. Once the concrete was batched, it was transported to the site via an over-the-cab concrete truck. Because of the constraints of the site, and the tight parameters within which to work, this truck set-up was ideal to direct the concrete to the desired location with minimal handling.

The student laborers arrived on-site approximately 45 minutes prior to the concrete delivery. At this time, all of the necessary equipment was staged, and the strategy for placing and finishing the concrete was discussed. The equipment used for this pour were simple hand tools, including shovels and rakes, while a 2x4 was used to level and screed the material. A lawn roller was used as the compacting roller, which was filled with approximately 10 gallons of water to provide sufficient weight to compact the placed porous concrete. Rolls of plastic sheeting were available to cover the concrete after finishing to facilitate hydration, and scrap formwork was available to secure the plastic on the concrete. After the equipment was staged, the formwork and slab underlayment were watered down and dampened to prevent the material from absorbing moisture in the concrete necessary for hydration.

The next step in this test pour was the actual porous concrete placement. Once the laborers and equipment were ready, and the concrete arrived on site, placement began. The concrete truck moved into position, and maneuvered as close as possible to the patio location. After final maneuvering, the chute was extended, and came within 8 feet from the far end of the formwork. Figure 4 depicts the equipment location during the first stages of the pour. When the concrete truck was in place, a representative from Marshall Concrete checked the consistency of the batch, and gave the "OK" to begin placing. The drum was put into gear, and the porous concrete began to flow.

Figure 4: Equipment Location



From the start of the pour, the parties involved realized the difficulty with placing porous concrete. The batch design used for this test pour had virtually no slump, and resembled the consistency of wet, muddy gravel. Figure 5 is a close up of the porous concrete in the chute. Because of the mix consistency, the concrete did not flow down the chute. In order to move the concrete from the truck, along the chute, and to final placement, 4-5 laborers were required just for this small patio. 2-3 laborers, equipped with shovels, moved the concrete from the end of the chute to the placement location, while 2 additional laborers, also equipped with shovels, were located at the top of the chute, where the concrete is expelled from the truck, and midway down the chute, to move the concrete to the placement laborers.

Figure 5: Porous Concrete

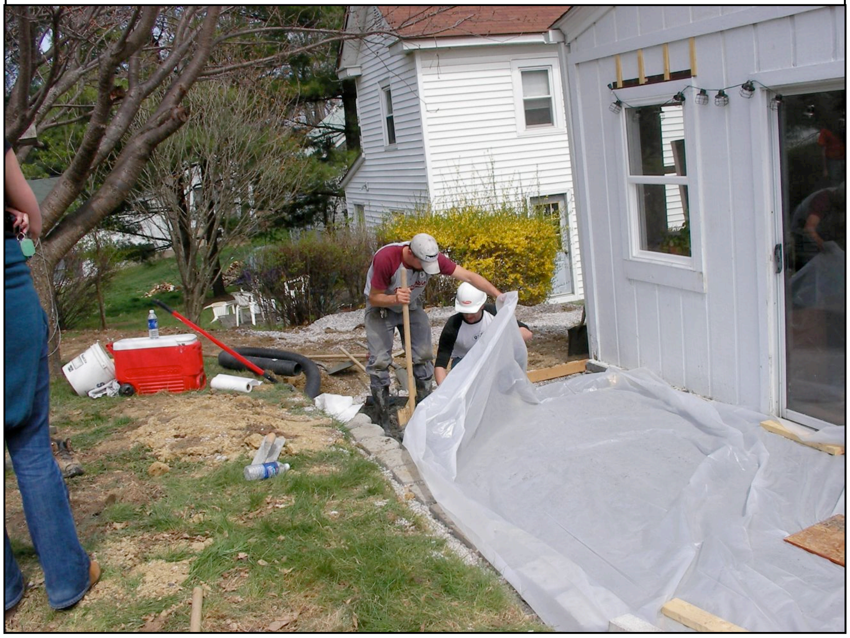
Moving and placing the concrete proved to be somewhat labor intensive, considering the number of individuals required to move the concrete, along with the speed at which the concrete needed to be placed to prevent premature hydration.

While placing the concrete seemed somewhat labor-intensive, at least for out-of-shape college students, the process progressed swimmingly. The laborers fell into swing, and the concrete placement fell into rhythm. The steps for placing the concrete included placing approximately 4'x8', which was then leveled/screeded with the 2x4, using the formwork as a guide. Any low spots in the surface of the concrete were filled in, and then screeded again. The screeding process can be described well as a rocking/tamping technique. The 2x4 was used to level off high spots, while ruts were filled with concrete and then re-leveled. Figure 6 depicts the process of placement and screeding. After the first section of concrete was screeded, the next 4'x8' section was placed and leveled/screeded. This completed approximately 2/5 of the patio, at which point, the placed concrete was compacted with the rolling compactor. While formwork was used as a guide with shims to dictate the amount of compaction in other porous concrete pours, this test pour did not use this method, primarily because the rolling compactor could not span the 8' width of the patio. The rolling compactor was simply moved across the surface of the concrete, and appropriate compaction was determined visually based on the appearance of the slab surface. The VRMA representative, because of experience with past porous concrete tests, aided in the compaction inspection, and determined the appropriate amount of compaction. Once compacted, which also accounted for the slabs finished surface, the first 2/5 of the patio were covered with plastic, and anchored down with the scrap formwork and bricks that were scattered around the site. The two placement laborers were also responsible for compacting and covering the slab. The placement process progressed, and the next 4'x8' section of patio was placed and screeded. However, throughout the placement of this section, the concrete became increasingly difficult to work. Concrete continuously stuck to the chute, as well as to the shovels. Despite the increasing difficulty, the third section was successfully placed, and was then leveled. Once the fourth section of the patio was being placed, difficulty remained with placing the concrete. Also, during placement of the fourth section, the participants in the test pour realized that there would not be enough concrete to finish the pour. In order to improve the workability of the concrete for the fourth section, additional water was added to the mix. While this improved the workability of the concrete, the additional water jeopardized the porosity of the placed material. Visual clues, such as cement paste rising to the surface of the slab, alluded to the lack of porosity in the fourth section. Despite the decreased quality in the concrete mix resulting from the added water, the material was used for the fourth 4'x8' section. Once this section was placed, the little remaining concrete could not be used because of the amount of water added. The formwork was adjusted to compensate for the lack of concrete, and moved in approximately three feet. The remaining concrete within the formwork was then screeded, compacted, covered, anchored, and allowed to cure for the recommend seven days, per request of Marshall Concrete.

Figure 6: Placement and Screeding

After the remaining patio was covered, the pour was essentially complete. The concrete truck was washed out, and the tools were cleaned. Figure 7 shows the completed work, with the concrete slab covered.

Figure 7: Covered Concrete Slab

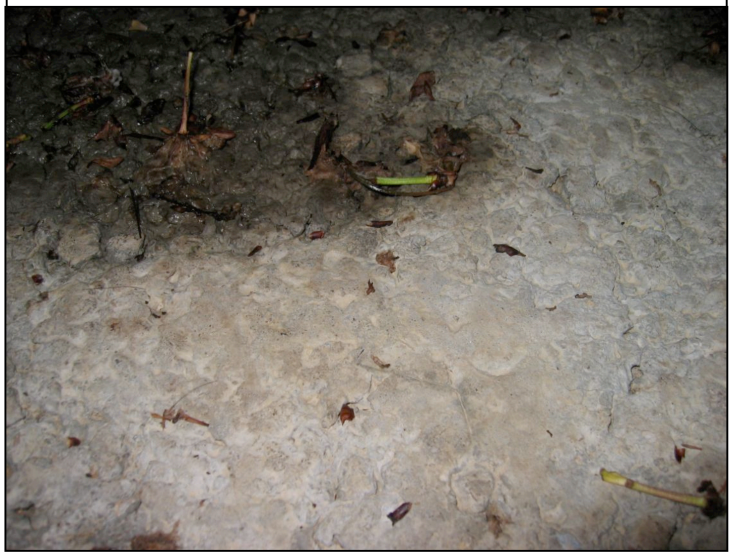


Results/Findings

Through the test pour of porous concrete for a residential patio application, various discoveries were made concerning the workability of porous concrete, and factors that affect the viability to bring this material to the consumer market. The primary findings of this test pour dealt with the workability of the concrete, porosity of the finished slab, finishing, and the amount of concrete needed.

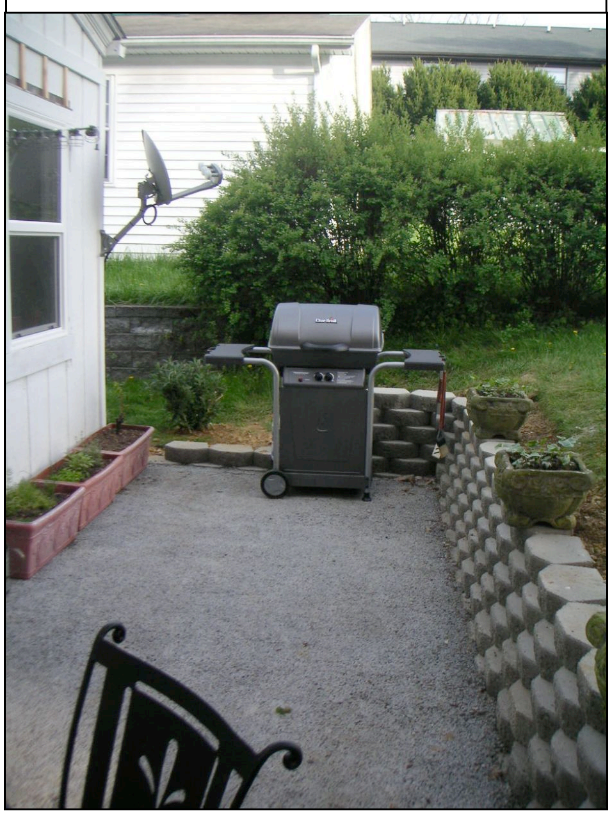
One of the main reasons for this test pour was to determine the workability of porous concrete. After pouring the 7’x20’x4” patio, the laborers determined that porous concrete was more labor intensive to place than traditional concrete. The main reason for this difficulty is attributed to the consistency of the mix. Where traditional concrete flows freely from the truck, down the chute, and to the placement point, porous concrete does not. Porous concrete must be moved from the truck, aided down the chute, and shoveled to the final placement point. If traditional concrete were used in this application, two laborers could have likely placed the concrete in half the time, depending on mix design. Because of the increased time associated with placing porous concrete, premature concrete hydration occurred towards the end of the pour, at which time additional water was added, which can jeopardize the integrity of the mix. While placing the concrete proved difficult, finishing the concrete was rather simple. For this small-scale application of porous concrete, only a 2x4 was needed to level and screed the slab surface, while a rolling compactor was utilized to finish the surface. A slab this size using traditional concrete may require more effort to screed and float to create the desired surface. While placing seemed to be the most difficult variable when compared to traditional concrete, additional tools could be implemented to alleviate these difficulties, especially for moving the concrete from the truck and down the chute. A simple garden hoe would reduce the laborers for this pour from 4 to 3, and the laborer could stand on the ground to reach to the top of the chute and pull the concrete down.

Figure8: Consolidated Surface



Yet another factor to consider when using pervious concrete is the porosity of the finished slab, along with finishing the slab. While the overall slab maintained porosity, the concrete towards the end of the pour lacked void space that was prevalent during the initial stages of the pour. Figure 8 shows the consolidated surface of the slab towards the end of the pour. This consolidation can be attributed to water added to the mix towards the end of the pour. The additional water created a more fluid cement paste, and once placed, screeding and compacting caused the cement past to rise to the surface. When the cement paste cured, the void spaces were blocked. To prevent loss of void space, additional water should not be added to try and extend the amount of usable concrete contained in a shipment. In addition to surface consolidation apparent on parts of the slab, the finished surface of the patio is somewhat rough. However, this is to be expected—porous concrete, because of the maintained void space, is not like traditional concrete. The slab surface remains rough and resembles an asphalt surface. While this is characteristic of porous concrete, the finished surface for this test pour ended up being somewhat uneven, with various spots having low spots. This characteristic can likely be attributed to the rolling compactor used, being that there was no way to evenly distribute the load of the compactor throughout the entire slab. This could be remedied by using a compactor that could span the width of the slab, which was not available in the area of the test pour. Such a tool is likely to be custom-made for porous concrete applications, and would be a valuable investment for contractors who plan to adopt porous concrete. A modified vibratory tamper could also achieve a desirable finish in the hands of an experienced laborer.

Figure 9: Finished Porous Concrete Patio



The last issue with this test pour is the amount of concrete needed to complete the pour. For this test pour, 2.5 cubic yards of concrete were sent to the site, while approximately 1.7 cubic yards of concrete were needed for this pour. Even with the extra concrete sent, the pour came up short. Though the dimensions were measured properly after the site was graded and formed, there may have been discrepancies in measuring the total volume of the formed area—but discrepancies are unlikely to account for a .8 cubic yard difference. Another factor could be the mix design itself, and somehow the volume created at the batch plant reduces once it is placed and compacted. Additional research is needed to determine this variable.

Despite these few issues related to the test pour, the patio turned out to be a success. Since the past two months the concrete has been in place, it has adequately handled storm events, and has allowed all of the stormwater to pass through the slab and into the subsurface, without backup. Along with the porous concrete performing properly, the finished surface was suitable for the homeowner. Figure 9 shows the finished patio in use by the homeowner. Table 4 also provides a summary of recommendations for working with porous concrete.

Table 4: Recommendations for Working with Porous Concrete

Issue	Recommendation
Workability	Allow for additional laborers. Use additional tools, such as a hoe, to move concrete down chute.
Porosity	Do not add water to mix. If the concrete remaining within the truck is unworkable, leave it. Water helps to decrease the void space
Finishing	Use a rolling compactor that is able to span the formwork, or modified vibratory tamper/screed
Concrete Amount	Allow for additional concrete, mix tends to underyield

Conclusion

Through this porous concrete patio test pour, the participants were able to discover, first-hand, the challenges that porous concrete presents, and the ability of this material to be used for the consumer market. Through research of past porous concrete applications, the participants for this test pour were able to avoid prior mistakes. After thoroughly reviewing the issues with placing, finishing, and curing porous concrete, the participants were able to devise a plan to properly install a porous concrete patio. Once the material handling issues were resolved, a slightly different porous concrete batch design was created that could be easily created at many concrete batch plants, thus making this design commercially viable. Not only were the batch ingredients viable, but the method of handling and batching the materials also proved practicable. After initial research and batch design/handling, the test pour took place. In order to do so, a local Blacksburg, Virginia, homeowner offered a residential site to pour a patio. The site was graded accordingly, and formwork was installed. The pour was then completed, with only minor issues relating to workability of the concrete, porosity of the finished slab, finishing, and the amount of concrete needed. Workability could be improved with the addition of common hand tools, porosity can be maintained within the slab by leaving out additional water, finishing can be simplified by using an adequate compacting roller, and additional concrete can be ordered to account for compaction of the final, placed product.

All in all, this test pour proved to be successful. With the addition of a few tools and modified placement methods, a commercially acceptable product can be achieved. The batch design and preparation methods proved successful. However, future studies are recommended to solve the issues with the apparent reduction in concrete volume between batch and finishing. Also, designing a porous concrete-specific rolling compactor is also recommended to provide a uniform finish. Seasoned concrete laborers may be able to achieve a uniform finish with available tools, and may even be able to adapt vibratory tampers to adequately finish porous concrete. Porous concrete can now be used in the residential arena to facilitate groundwater infiltration of stormwater while providing a durable, finished surface.

References

"Pervious Concrete Pavement." Georgia Concrete and Products Association. 2006. <http://www.gcpa.org/pervious_concrete_pavement.htm>

"Pervious Pavements." Stoney Creek Materials, L.L.C. Accessed 7 May 2006. <http://www.stoneycreekmaterials.com/pervious.html>

"Technical Note—Pervious Concrete Pavement." Graniterock. 2006. <http://www.graniterock.com/tnperviousconcrete.html>

"Villanova Porous Concrete Site." Villanova University. 22 Jan. 2006. <http://egrfaculty.villanova.edu/public/Civil_Environmental/WREE/VUSP_Web_Folder/PC_web_folder/PC_main.html>

Nablo, Robert. Phone Correspondence. April, 2006

Kuhn, George. Email Correspondence. 6 May 2006.