Virginia Tech College of Architecture and Urban Studies
Myers-Lawson School of Construction
Department of Building Construction

Master's Exit Option: Project and Report
Contractor Recommendations for Implementing Pervious Concrete

Marc Marinchak
May 3, 2007

Project Committee:
Dr. Georg Reichard
Dr. Annie Pearce
Dr. Michael O'Brien

Abstract

This report, Contractor Recommendations for Implementing Pervious Concrete, provides contractor recommendations for handling and placing pervious concrete. While there is an abundance of quality literature on such a topic from both product associations and academic sources alike, this report focuses on experienced contractors to provide beneficial information for handling and placing pervious concrete. Within this report, background information is given on pervious concrete, including current handling and placing procedures, as well as case studies highlighting the difficulties of placing this material. A methodology is then described to interview a certain population of pervious concrete contractors and address questions related to batching, mixing, transportation, placing, finishing, curing, and maintenance. This report has found specific recommendations for dealing with fines, admixtures, mixing process, placement procedures, and experience issues related to pervious concrete. Specifically, no fines should be used in the pervious concrete mix, acid-based hydration retarders and stabilizers are preferred.

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1 An Introduction to Pervious Concrete

The introduction for this study provides a general overview of what pervious concrete is, its characteristics, how it's used, benefits, pros, cons, why its used over traditional concrete, structural considerations, rainwater percolation, and mix considerations. Information contained in this introduction is gathered from various literatures concerning pervious concrete. These resources include, but are not limited to, the National Ready Mixed Concrete Association, Portland Cement Association, and other various state concrete, cement, or aggregate associations. While there exists a plethora of resources concerning general overviews, they are similar to the aforementioned association articles. The information in the following section, if not specified, is generated from Pervious Concrete Pavements, authored by Paul D. Tennis et al. Since this article nicely overviews pervious concrete, this section summarizes and reorganizes the information from this article.

1.1 General characteristics

Pervious concrete, also called pervious or permeable concrete, and according to the Georgia Concrete and Products Association, is a concrete mix designed to maintain void space within the concrete slab once it has been placed (GCPA, 2006). While pervious concrete is experiencing popularity as a new technology (Tennis, 2004), it has actually been around for well over 150 years (Ghafoori and Dutta, 1995). Despite the long existence of this product, and its revitalized popularity in recent years, various concrete contractor websites characterize the steady use of this material for the past 20-25 years in certain geographical locations of the United States (Charger, 2005). But what makes pervious concrete unique—what are its properties? Pervious concrete is unique in that void space is maintained throughout the structure, allowing fluids to pass through the material. On the surface, this material resembles a rise cake, and depending on the concrete mix design, maintains void space between 15-25% of the total volume of concrete (Tennis, 2004). Pervious concrete can be used for a number of different applications, and possesses different characteristics and abilities when compared to traditional concretes, and these characteristics and applications have the ability to change depending on the mix design. In order to visually represent pervious concrete, Figure 1 provides a photograph of this unique material.

Figure 1: Example of Pervious Concrete Patio

According to different sources, pervious concrete has different applications, like traditional concrete, in which it can be used, including pavements and walls (Tennis, 2004; CS, 2005). For pavements, pervious concrete can be utilized for pedestrian walkways, parking lots, roads, and other applications, and in walls, this material is useful for providing a semi-lightweight concrete load bearing walls, and is desirable for its

good acoustical properties. This material has also been used as well linings and swimming pool decks—essentially in any application that traditional concrete has been used (Tennis, 2004). Regardless of the numerous uses in which this material can be used, this report focuses on pervious concrete as a pavement, and does not look into how it functions in other vertical-type applications.

Most likely the biggest difference of pervious concrete over traditional concrete is its ability to allow fluids to pass through a slab application. 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. Because of these unique properties, pervious concrete is recognized by the U.S. Environmental Protection Agency as a Best Management Practice for controlling stormwater runoff (Tennis, 2004). Not only can this material be utilized to maximize development of a given lot, there has also been studies suggesting that the overall costs of pervious pavement systems, when compared with the total costs of traditional paving systems, such as asphalt, is less expensive (UCF, 200X).

Although pervious concrete posses unique benefits over impermeable pavements, this material also exhibits certain characteristics that make it less advantageous than traditional concrete, namely in the workability of the product. While some articles state, "pervious concrete is not difficult to place, but is different from conventional concrete," (Tennis, 2004) first-hand experience, as well as various case studies, describe the difficulties associated with placing this material. There is also contradictory evidence of the ease associated with placing pervious concrete, as "an experienced installer is vital to the success of pervious concrete pavements" (CIP-38), which could lead one to conclude that pervious concrete is difficult to place, and requires specialized skills to properly implement. These difficulties and information concerning placement are discussed more in- in the background section of this report..

A bulleted list follows to provide a summary of general characteristics exhibited by pervious concrete:

- Pervious concrete has been steadily utilized for approximately 25 years.
- Maintains void space to allow fluid to pass through the material.
- Can be used in similar applications to traditional concrete.
- Aids in groundwater recharge
- Facilitates on-site environmental compliance
- Increases usable land for development

1.2 Technical Characteristics

Given some of the general characteristics and background information of pervious concrete, this report can now highlight some of the more technical characteristics and properties of pervious concrete, namely specific void space and water flow rates through a typical pervious concrete pour, structural integrity of the material, and mix guidelines of pervious concrete—basically to provide an overview of the properties associated with pervious concrete outlined by "Pervious Concrete Pavements" (Tennis, 2004). Beginning the properties overview are the density, porosity, and permeability characteristics. The density of pervious concrete can range between 100 lb/ft^3 to 125 lb/ft^3, and terms of porosity, a 5-inch thick slab with 20% voids can store 1-inch of stormwater. Porosity calculations can be determined based on percent void space in relation to total slab thickness. For permeability, stormwater flow rates through pervious concrete can range between 3 $gal/ft^2/min$ to 8 $gal/ft^2/min$. Keep in mind that these are just ranges, and can

vary dramatically based on concrete mix design and placement procedures. The technical data for density, porosity, and permeability was taken from "Pervious Concrete Pavements", page 5.

Other properties associated with concrete and pervious concrete include compressive strength and flexural strength, as well as durability of the finished concrete product. In regards to compressive strength, pervious concrete typically ranges between 500psi and 4000psi, while flexural strength is typically between 150psi and 500psi (Tennis, 2004). Much like the aforementioned properties of density, porosity, and permeability, structural and flexural strength varies drastically depending on the composition of the pervious concrete mix, placement techniques, and finishing and curing methods. Regarding the durability of pervious concrete, factors such as freeze-thaw, sulfate, and abrasion resistance all attribute to pervious concrete's lifespan. Freeze-thaw resistance is primarily based on water saturation levels within the void space of pervious concrete during freeze-thaw cycles, where temperatures fluctuate throughout the day and night to cause freezing and thawing. If water exists in void space, such cycles can cause pervious concrete to deteriorate through the expansion of water. The main factor affecting freeze-thaw and saturation levels in pervious concrete is how well the slab percolates stormwater. Given proper design, freeze-thaw should not present an issue, because stormwater migrates through the slab and into the subbase, thus leaving the void space free of water that could crack the concrete (NRMCA2, 2004). As with traditional concrete, chemicals in soils and water that can degrade concrete also affect pervious concrete, however, because of increased surface area present in pervious concrete from void space, these chemicals can have an amplified impact on this material (Tennis, 2004). But, like in freeze-thaw conditions, these impacts can be minimized or prevented given proper design with an appropriate subbase that isolate the pervious concrete slab from such factors. Lastly is the affect of abrasion on pervious concrete. As with freeze-thaw and chemical issues that may arise because of the void space/increased surface area associated with pervious concrete, this void space and increased surface area give pervious concrete a more abrasive surface than traditional concrete. When wear factors are applied to the pervious concrete surface, the rough surface can ravel, and aggregates can be freed from the slab. While raveling may be higher than traditional concrete slabs, raveling is most likely during the initial weeks after pervious concrete has been placed and open for use. Raveling and abrasion factors can be minimized during this time by allowing proper curing times, as well as through suitable compaction and finishing techniques (Tennis, 2004). Table 1 outlines the technical characteristics/properties associated with pervious concrete, as well as the factors that influence these properties.

Table 1: Technical Properties or Pervious Concrete and their Influencing Factors

Property	Characteristic	Influencing Factor
Density	100 lb/ft^3 to 125 lb/ft^3	Mix Design and Placement Technique
Porosity	10% to 20% void space	Mix Design and Placement Technique
Permeability	3 $gal/ft^2/min$ to 8 $gal/ft^2/min$	Mix Design and Placement Technique
Compressive Strength	500psi and 4000psi	Mix Design and Placement Technique
Flexural Strength	150psi and 500psi	Mix Design and Placement Technique
Freeze-Thaw	Void space may trap water.	Placement Technique and Subbase
Chemical	Subsurface chemicals may deteriorate concrete.	Placement Technique and Subbase
Abrasion	Increased surface area may lead to increased raveling and wear.	Mix Design and Placement Technique

Besides the general and technical characteristics that have been highlighted, pervious concrete also differs from traditional concrete in the mix design. As with the aforementioned characteristics, much of the literature associated with pervious concrete outlines basic mix designs, and ample information can be gathered through online sources. The following pervious concrete mix information has been compiled through various resource gathered from the National Ready Mixed Concrete Association (NRMCA) and Portland Cement Association (PCA) (NRMCA1, 2004; PCA, 2004). As with any basic concrete mixture, pervious concrete requires cement, aggregate, and water to form concrete. Usually accompanying the basic concrete constituents are various fines and admixtures that influence different properties in both the plastic and solid states of concrete. While traditional concrete mixtures can be adjusted through various proportions of such ingredients to form a wide array of different mix designs, pervious concrete is somewhat limited in the ranges and proportions of the different components in concrete.

1.3 Mix Design

Figure 2: Pervious Concrete Mix

The basic components necessary for pervious concrete include cement, aggregate, water, and admixtures, all in certain proportions so that void space is created and maintained during placement. The following proportions are in lb/yd^3 of pervious concrete. For cementitious material, 450 to 700 lbs are recommended, with aggregate ranging from 2000 to 2500 lbs. As with traditional concrete, portland cement and blend cements may be used, along with a limited amount of additives like fly ash or blast slag. Typical aggregates include No. 67, 8, 89-stone, with the aforementioned fly ash and slag not exceeding a 1:1 ratio. Fly ash and slag, according to the NRMCA and PCA (NRMCA1, 2004; PCA, 2004), will decrease void space, but increase pervious concrete strength. With regards to water per cubic yard of pervious concrete, the recommended water:cement ratio is between 0.27 and 0.34. This ratio is relatively low when compared to 0.4 to 0.7 ratios used in traditional concrete (E2, 2007), and produces a stiff concrete with virtually no slump. The consistency of the concrete is putty-like, and does not flow. Not only does the low water:cement ratio make a stiff mix, the low water content also accelerates hydration and reduces working times Figure 2 provides a visual of the consistency of pervious concrete. Because of the low/no-slump pervious mix; admixtures must be utilized to improve the workability of this material, with typical pervious admixtures of hydration retarders and stabilizers. These admixtures increase both the working times and concrete workability to create a more forgiving pervious concrete mix. This is just a basic overview of pervious concrete mixes and characteristics. Figure 3 located on the following page provides a summary of pervious concrete mix constituents. This is just a guideline, and any pervious mixes should be trial batched before implementations.

Figure 3: Pervious Concrete Mix Constituents (source?)

Cementitious materials	270 to 415 kg/m^3 (450 to 700 lb/yd^3)
Aggregate	1190 to 1480 kg/m^3 (2000 to 2500 lb/yd^3)
Water-cement ratio (by mass)	0.27 to 0.30***
Aggregate-cement ratio (by mass)	4 to 4.5:1***
Fine-coarse aggregate ratio (by mass)	0 to 1:1****

* These proportions are given for information only.

** Chemical admixtures, particularly retarders and hydration stabilizers, are also commonly used. Use of supplementary cementitious materials, such as fly ash and slag, is common as well.

*** Higher ratios have been used, but reductions in strength and durability may result.

****Addition of fine aggregate will decrease the void content and increase strength.

Along with the basic characteristics, technical properties, and mix design, there are also recommended procedures for preparing the aggregates for the mix, site preparation, and placement methods. According to Stoney Creek Materials, for a 4" pervious concrete slab, an subbase of 8" of compacted aggregate is required to provide a proper base where stormwater can remain, where it will then percolate into the subbase (SC, 2006). This 8-inches of subbase 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 pervious 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 pervious 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 pervious 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)

This introduction, and its aforementioned information, provides a somewhat thorough overview of the different attributes of pervious concrete, and a baseline summary of the more popular information regarding pervious concrete. Given this introduction, this report is able to illustrate that pervious concrete possesses unique characteristics that differentiate it from traditional concrete. Whether in the function of the final product, the batching, or placement procedures, pervious concrete is different from traditional concrete, and must be treated as such. As this report progresses, these unique characteristics are discussed more in depth, and provide the reader with information on just what these differences mean when utilizing pervious concrete.

2 A Background on Pervious Concrete

Where the introduction of this paper focuses on the general characteristics, technical properties, pervious concrete mix design, and placement processes, the background section expands the general overview and differences from traditional concrete previously mentioned, and fleshes out how these differences have affected handling pervious concrete. Although many avenues that focus on pervious concrete could be followed from the aforementioned section, such as focusing on admixture effects, analyzing the historical context of pervious concrete, or determining compressive strength from various mixes, this report focuses on the process of handling and placing pervious concrete. In this section, this report departs from the general overview of pervious concrete, and presents different case studies and research that has been performed to address the issues inherent in handling and placing this unique, non-traditional material. As mentioned in the introduction of this report, the background section now focuses on aspects that make it less advantageous than traditional concrete.

Given the focus on issues with handling and placing pervious concrete, this report focuses on such studies. This section summarizes various articles that describe some of the issues contractors must be aware of when implementing pervious pavement, as well as a case study of a problematic pervious pour, first-hand testing of placing pervious concrete, and different quality standards/concrete association specifications on pervious concrete, as well as how contractors can be trained to install pervious concrete. As in this report's introduction, the background section's information on handling and placing pervious concrete is derived from various concrete association websites. These websites include different articles from the NRMCA and PCA, and are listed in the bibliography section of this report (Tennis, 2004; CS, 2005; NRMCA1, 2006). The predominate issues and considerations when dealing with pervious concrete include batching, transportation, placement, and finishing. These steps differ when placing pervious concrete as apposed to traditional, and can critically affect the quality of the finished pervious product.

2.1 Pervious Concrete Handling/Placing

According to various sources previously mentioned, batching pervious concrete "require[s] tighter control of mixture proportioning" (Tennis, 2004). With the mix outline described in the introduction, it is apparent, from the need to wash and reduce fines, and even dry the aggregate (for dry transportation) that batching pervious concrete can be rather labor-intensive. One important consideration when batching pervious concrete is the control of water, and the water:cement ratio. From the aforementioned mix designs, pervious concrete has a low water:cement ratio, as well as low cement content. Too much water will lead to a weak mix, and the cement paste will flow too freely and eliminate void space, where too little water will create a dry mix that will not set. And because of the low cement content, added water after batching can impact the quality of the mix. With the use of computerized batching, material proportions can be tightly controlled. With the increased affect water has on pervious concrete, it is also important to consider the moisture level in the concrete aggregates. When shipping concrete ready-mixed/wet, which seems to be the standard found in the literature, it is important to account for the water present in the aggregate, as a dry aggregate may absorb water from the batch. Since concrete components can vary depending on producers and vendors, it is important to consider the affect concrete components can have on a given batch. Lastly, because of the consistency of pervious concrete, being a stiff, "dry" mix that does not flow, equipment, especially trucks, may experience increased wear, specifically on the interior of the drums and fins.

Like tighter controls for batching pervious concrete, transporting the material is also more stringent. Due to the low water content in pervious concrete, concrete hydration takes place sooner, thus decreasing the

time in which contractors can place the material. According to current literature, the time allowed between batching and placing is roughly an hour. Admixtures can increase the working time, but it is recommended that pervious still be placed within the hour window. Given this low working time, it is imperative that traffic considerations and travel times be planned so as to allow maximum time on-site for placement.

As with the previous steps, placing pervious concrete is also different than placing/pouring traditional curing. Starting with on-site preparation, pervious concrete contractors must be prepared for installing every batch/truck from the moment the concrete arrives, due to the low working times. However, before the pervious concrete can be installed, the subbase must be properly conditioned for pervious concrete. Because of the low water content in the pervious mix, the typically stone subbase should be moistened so as to prevent moisture being absorbed from the mix into the subbase (much like the concrete aggregate being moistened). Though the subbase should be moistened, it should be absent any free-stand water, as this may weaken the pervious mix, or lead to consolidation on the slab bottom. As intuition might show, the subbase should be prepared shortly prior to each batch arriving, as weather may evaporate any moistened conditions.

Once the subbase/underlayment has been properly prepared, pervious concrete contractors can then begin to place the mix. Because of the stiff consistency of pervious concrete, it cannot be pumped, and usually requires laborer assistance (NRMCA, 2006). While it cannot be pumped, there have been examples of pervious being placed with a concrete conveyor. Also, minimal handling and movement between the concrete truck and concrete location is ideal to prevent consolidation of the mix, and to maintain void space. Because of the restrictions on placing pervious concrete, site planning, access, and layout are critical to installing pervious in a timely manner. Concrete trucks with wide outlets are recommended, as they allow faster unloading times (Tennis, 2004). Before a load can be placed, pervious concrete, like traditional concrete, must be inspected. While slump and core tests provide accurate information on the strength of pervious concrete, visual inspection is critical to ensure that each load exhibits the required characteristics of pervious concrete, as well as to guarantee that there is consistency between each batch of pervious concrete. Visual inspections determine if the mix is too wet or too dry. Along with visual inspection, unit weight tests can be performed to provide quality monitoring (Tennis, 2004). Testing and quality standards regarding pervious concrete are addressed later in this section.

After inspection and verification of proper mixing, the concrete can be placed. As just mentioned, a minimal distance between truck and placement location should be maintained. Placement should be continuous to maintain consistency throughout the slab. Concrete is placed within the formwork, and is leveled off with a screed, usually vibratory. Any low spots are filled and re-screeded. While manual screeds can be used, the stiff consistency may prevent adequate leveling and placement with such methods, as manual screeding does not have sufficient force to strike off the mix (NRMCA, 2006). The screed travels on the formwork to provide the level surface, with spacers on the top edge of the formwork. These spacers, usually ½ to ¾ inch thick wooden strips placed on top of the formwork, are removed after screed, and allow enough material compaction. The pervious concrete compaction is usually executed with a roller compactor, which spans the form, and allows the ½ to ¾ inch compaction, which prevents raveling and strengthens the slab strength. Although specifically designed roller screeds simplify the compaction process, vibratory tampers and hand tampers have been used to compact pervious concrete. If implementing a vibratory or hand tamper, experienced laborers should perform this step as to ensure a uniform finish. After compaction, joints should be placed in the pervious concrete. These joints should line up with existing joints in any adjacent concrete to prevent/reduce raveling. If no joints exist,

pervious concrete can be placed at distances greater than traditional, as this material shrinks less than traditional concrete. These joints can be placed with either a specialized joint roller, or can be saw cut. These joints should placed/cut to a depth of ¼ of the total slab thickness to prevent surface cracking (Tennis, 2004). Figure 4 depicts the screeding, compaction, and joint cutting phases of pervious concrete placement.

Figure 4: Sequence of Placing Pervious Concrete

Once the pervious concrete has been placed, screeded, compacted, and jointed, measures must be taken to cure the concrete soon after placement. Once properly placed, pervious concrete should be covered with plastic, and secured using rebar, lumber, or other non-granular medium, as slippage of the plastic cover may cause granular material to clog the void space. Because of the increased surface area, this material should be covered immediately after placement. In some instances, a fogging/misting is recommended to provide necessary moisture for curing. Also, in higher heat, lower humidity, and windier areas, greater measures should be emplaced to prevent loss of curing moisture. Curing/covering should take place constantly for seven days. Afterward the recommended seven days, pervious concrete may be open to traffic. (Tennis, 2004)

The following bulleted list summarizes the aforementioned processes for properly placing pervious concrete:

- Batching should consist of tight controls, utilizing computer-aided quantity control, with specific attention paid to the mix's water quantity.
- Transportation of pervious concrete should consider travel times and proper staging, considering the restricted working times associated with the material.
- Placing pervious concrete should be performed quickly, after visual inspection, using screeds/vibratory screeds, set on shimmed formwork, followed by proper compaction and jointing.
- Curing pervious concrete should immediately follow placement to ensure that moisture necessary to hydration is kept within the concrete cover for at least seven days following placement

2.2 Pervious Concrete Associations

Highlighting some of the various guidelines and specifications provided by different concrete associations provides insight to handling pervious concrete. Two examples of such associations/quality standard organizations include the American Concrete Institute (ACI), and the Portland Cement Pervious Association (PCPA). Both of these associations either focus strictly on quality standards, establishing testing methods, and creating quality standards, or have sectors within the organizations for establishing these criteria. While these are not the only organizations that have such roles, they provide two examples of the current state of such functions.

According to the ACI website, the American Concrete Institute is a "technical and educational society organized in 1904 to represent the user interests in the concrete field" (ACI, 2007). "ACI is a forum for

the discussion of all matters related to concrete and the development of solutions to problems." (ACI, 2007) This organization conducts meetings, produces various technical journals relating to different applications of concrete, and develops committees for specific areas relating to concrete by incorporating individuals throughout the concrete industry. The ACI, through ACI Committee 522, has developed a board of individuals for developing and reporting information on pervious concrete. While the goals of this committee change depending on the industry requirements/status of pervious concrete, the current goals of this committee is to revise certain pervious concrete documents, as well as to complete specifications for pervious concrete pavements (ACI2, 2007). The documents being revised include 522R-06, which provides information on the general aspects of pervious concrete, like those found in the introduction section of this report, as well as within this background section. The other includes the specifications for pervious concrete, which has not yet been published.

Another organization for the advancement of pervious concrete is the Portland Cement Pervious Association (PCPA). The information for this association was provided by a pervious contractor, and has will be available on the internet as of August 2007. According to the "Standards and Recommendations for Design Criteria, Testing, Inspections, Certifications, and Specifications" document, the PCPA is a "professional organization comprised of design professionals, researchers, academicians, environmentalists and Certified Installation Professionals." (PCPA, 2005) Like the ACI 522 committee, the PCPA's mission is to promote the appropriate use of pervious concrete, specifically concerning the establishment of standards, specifications, and certifications. With regard to specifications for pervious concrete, the aforementioned placing considerations are covered, but more in-depth. Many of these guidelines are specified in the appendixes, within the contractor interviews, and are addressed in the results section of this report.

2.3 Pervious Contractor Certification

Along with organizational standards for quality and mix design, there is also another standard for certifying contractors to install pervious concrete. This certification process, implemented by the NRMCA, is the called the pervious concrete contractor certification program. Within this program, there are two levels of certification, the pervious concrete technician, and the pervious concrete craftsman. The requirements for technician include attending a seminar and passing a written exam, while craftsman also require the same requirements with additional work experience, with 3000 hours experience in all aspects of placing pervious concrete, or 1500 documented hours with the completion of the NRMCA performance examination. With experience being the main difference, the baseline for these two certifications include basic concrete knowledge, pervious concrete and mixing proportions, proper use of tools and equipment, general design principles of pervious concrete pavement, pervious concrete construction, and maintenance and troubleshooting. With the pervious concrete contractor certification program, NRMCA has established a standard for pervious concrete contractors.

Now having described the various steps in handling pervious concrete, from batching to ultimate use, along with pervious concrete organizations and certification standards, this report can focus on specific case studies that have been performed on utilizing this material on various sites. Although reputable concrete contractors have successfully placed pervious concrete, these studies outline how the lack of familiarity with this material can affect the outcomes of a pervious concrete pour, and help to outline the unforgiving nature of this material.

2.4 Villanova Pervious Concrete Case Study

Through studying the Villanova case study of a test pour on their campus, issues related to pervious concrete were clearly addressed. These issues primarily involved the speed of placement, finishing, and curing, which are addressed below in a brief summary of the case study. (Villanova, 2006)

The Villanova pervious 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. Figure 5 outlines the Villanova pervious concrete site. The site consisted of 50,000 square feet of impervious surfaces, including rooftops, existing walkways, and compacted soil. As for the specific area of pervious concrete, an estimated 17,000-20,000 square feet of concrete were poured, based on a visual estimated of available pictures. During the construction process for the pervious 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)

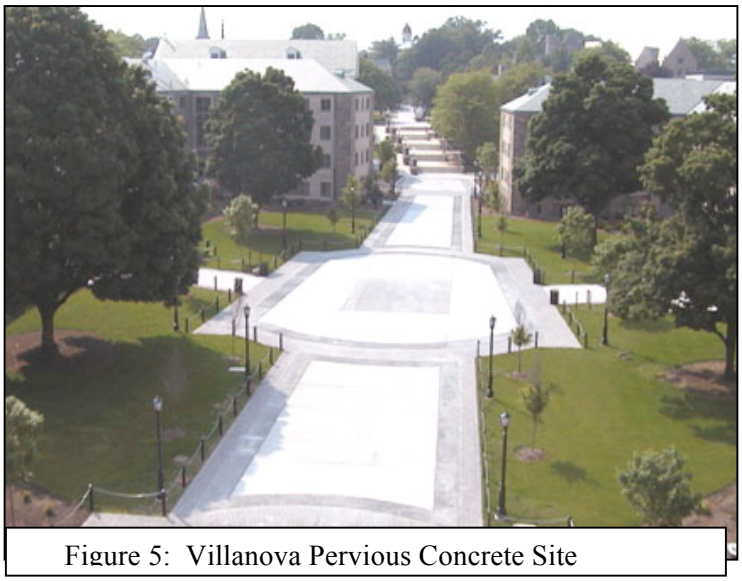

Figure 5: Villanova Pervious Concrete Site

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 pervious concrete at the Villanova site was placed and finished, plastic was placed over the slab to promote curing. Despite covering with plastic, the pervious 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 pervious 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 pervious 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-feet 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 pervious 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 2 provides a summary of the issues and solutions related to pervious concrete.

Table 2: Villanova Pervious 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 pervious concrete. For the original case study on the Villanova project, please refer to the bibliography for information on the original article.

2.5 Pervious Concrete Test Pour

In addition to the case study originating from the Villanova campus, this author has performed test pours of pervious concrete to explore the basic workability of this material and characteristics associated with this product. The next few paragraphs describe the basic recommended and actual mix designs used for the described test pour, as well as the findings from the trial run. Table 3 describes the mixes utilized for this test.

Table 3: Pervious Concrete Batch Designs

Initial Batch Design (per CY)			
Material	#8 Stone	Cement	Water
Amount	2500 lbs.	400-600 lbs.	~ 24 gal.

Revised Batch Design (per CY)					
Material	#8 Stone	Sand	Cement	Fly Ash	Water
Amount	2228 lbs.	222 lbs.	486 lbs.	114 lbs.	22 gal.

Through the test pour of pervious concrete for a residential patio application, various discoveries were made concerning the workability of pervious 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 pervious concrete. After pouring the 7'x20'x4" patio, the laborers determined that pervious 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, pervious concrete does not. Pervious 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 pervious 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 pervious 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

Figure 6: Placing Pervious Concrete

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. Figure 6 on the previous page shows an example of working in progress for the pervious concrete test pour.

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. 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—pervious 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 pervious concrete, the finished surface for this test pour ended up being somewhat uneven, with various spots having low spots. Figure 7 depicts the results of the finished pour. 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 pervious concrete applications, and would be a valuable investment for contractors who plan to adopt pervious concrete. A modified vibratory tamper could also achieve a desirable finish in the hands of an experienced laborer.

Figure 7: Finished Pervious 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. Table 4, which follows on the upcoming page, outlines the results of this pervious concrete trial pour.

Table 4: Pervious Concrete Trial Pour Results	
Pervious Concrete Characteristic	Findings
Workability	Zero-slump mix is more labor intensive
Porosity	Increased handling/working times decreases porosity
Finishing	Simpler than traditional concrete, less labor intensive
Yield	Calculated concrete amount did provide enough material to finish job

With the conclusion of the background section, this report has addressed various parts of the current state of pervious concrete. In this section, the report has addressed the various sequences and considerations for placing pervious concrete, quality standard organizations, pervious concrete certification requirements, and two case studies on the implementation of pervious concrete. Given the different parts of the background, especially the placement process outline and case studies, this report has hopefully illustrated the challenges of working with pervious concrete. Ample literature has been reviewed to provide the reader with a condensed summary of pervious concrete. In the following problem statement section, this report ties the introduction and background together to highlight the focus of the study performed by this report.

3 The Problem with Implementing Pervious Concrete

Given the information provided in both the introduction and background section of this report, evidence shows that either concrete associations or academic literature has generated an abundance of the present literature related to pervious concrete. While this literature provides superb recommendations and examples of everything related to pervious concrete, and should be reviewed by any person or contractor desiring to implement or use this material, information generated from the pervious concrete contractors perspective appears to be lacking. Given that these pervious contractors routinely work with this material, the current source of literature could benefit from information generated from this demographic. This is not to say that the current literature does not consult with pervious concrete contractors, but there lacks a "contractors only" resource, unfiltered by various parties. With these ideas, there is clearly a "problem" that, when addressed, creates specific outcomes that benefit the pervious concrete community.

In order to support the problem statement, reference to specific examples in both the introduction and background sections of this report need to be addressed. From section 1.3 of this report, mix design, information shows that mix designs for pervious concrete are more specific than traditional concrete, and batching "recipes" have fewer deviations than one could experience with traditional concrete. This highlights that pervious concrete must be handled/batched to more stringent standards. Section 2.1 outlines the process of handling and placing pervious concrete, and supports that the material must be handled differently than traditional concrete. There are different skill sets a contractor must possess when placing pervious concrete as apposed to those needed to place traditional. Supporting arguments for this statement can be found in sections 2.4 and 2.5, where actual pervious concrete pours highlighted the differences/difficulties in placing the material, and that traditional concrete approaches were not beneficial. In summation, the previous sections provide support that pervious concrete contractors, having utilized the material successfully, can provide information to avoid the pitfalls of adopting this material.

3.1 Problem Statement

While there is ample literature on the proper procedures and recommendations for utilizing and placing pervious concrete, primarily from the industry/product associations, as well as academic literature, there exists an absence of literature on handling/placing pervious concrete from a contractor's standpoint. Because experienced pervious concrete contractors regularly utilize this material, it is hypothesized that they have developed different/unique methods in handling and implementing pervious concrete, and can thus benefit the current literature on placing pervious concrete by improving/revising/honing the ways in which it is handled/placed.

3.2 Objectives of the Report

The problem is that the current literature does not necessarily take into consideration pervious concrete contractors advice for placing the material, and therefore, the objectives are:

- Generate a list of experienced pervious concrete contractors
- Develop questions that relate to the current handling/placement of pervious concrete
- Interview pervious contractors to determine factors they feel are most critical to proper pervious concrete placement.
- Create a "lessons learned" approach that budding pervious contractors can use to successfully implement this material more quickly.

4 Methodology

Having stated the problem and outcomes associated with pervious concrete, this report must now develop a methodology to gather information to address the problem and create the desired outcomes. For this, there are certain factors that must be generated to address the problem. Since this report depends on contractors for information, it must first determine the concrete/pervious concrete contractors present in the United States. Once the overall population is addressed, this report must then focus on what percentage of the population is skilled using pervious concrete, as well as determine what qualifies a contractor as being qualified. From there, the report can focus on what questions need to be asked to determine how pervious contractors handle/place this unique material, and how these questions relate to the current methods for placing pervious concrete. Finally, the pervious concrete contractors that have been developed by the contractor population generation can be interviewed, and information can be collected through interviews.

4.1 Generation of Contractor Population

The contractor population generation proved to be relatively straightforward. Considering the vast number of concrete contractors that work within the United States, generating a list of all the concrete contractors would be extremely labor intensive, and likely be difficult to create an exhaustive list, and perhaps not benefit this report. Instead of generating a list of all concrete contractors, this report instead focused only on concrete contractors that use pervious concrete. In order to generate such a list, and to find contractors to interview, internet searches were performed for different regions of the United States. During this contractor search, a "Pervious Contractors Database", issued by the NRMCA, was discovered, and provided a comprehensive list of contractors that were certified through NRMCA by the guidelines listed in the background section of this report. These contractors were considered for the report, and the database alleviated a lengthy internet search, as well as provided a baseline for pervious concrete contractors. Once the database was discovered, the report established what type of contractors would be beneficial, based on certain certifications, as well as focusing on different climatic/rainfall areas of the United States. These regions were used to consider the amount of rainfall that pervious concrete experiences, and if different design considerations are utilized depending on rainfall amount. Figure 8 depicts the rainfall regions used for the study provided by the Oregon Climate Service. While there are 17 different rainfall gradations depicted by the rainfall map, this study simplifies the 17 regions into 4 different regions. The four gradations for this study include less than 5 inches to 20, 20 inches to 40, 40 to 80, and 80+. For this study, a group of contractors from each region would be needed to provide information to ensure that the gathered information was consistent, and that a certain contractors did not prove to be anomalies. Need to show distribution of interviewees! Where's the contractor list?

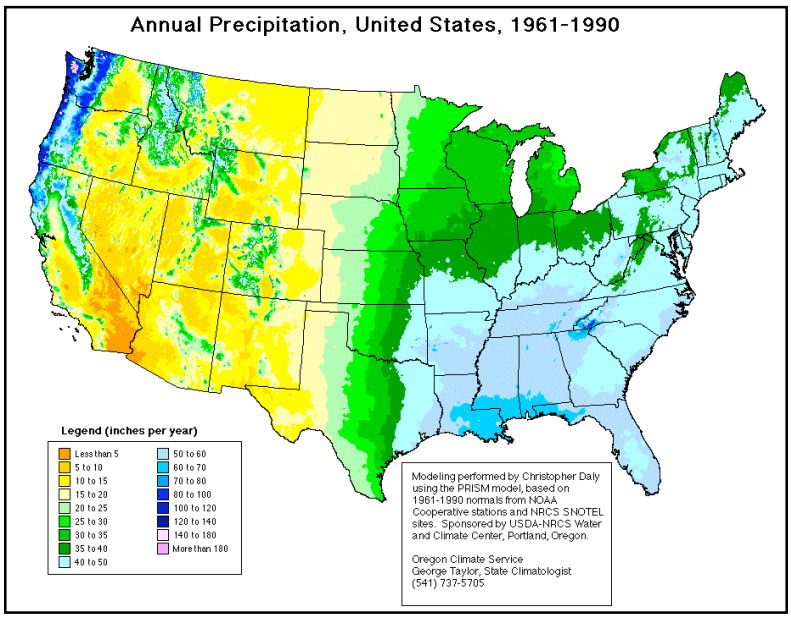

Figure 8: Rainfall Region Map

4.2 Justification of Population Used for Study

Considering the "Pervious Contractors Database" and the rainfall gradation to determine the population, the report must now justify an appropriate population to use for the contractor interviews. Given the format of the database, which segregates pervious concrete technicians from pervious concrete craftsmen, and further defines based on in which state they work, we find that there are 4 certified craftsmen throughout the United States, while there are approximately 850 certified pervious concrete technicians. At the start of this report, an older version of the database was in publication, which only consisted of approximately 250 pervious concrete technicians. Therefore, during this study, the amount of pervious concrete technicians increased nearly three-fold, which was not accounted for when determining our population. Despite this large increase in the number of pervious technicians, this report still manages to generate a list able to represent pervious concrete contractors. As defined in the background section, the difference between technicians and craftsman is 3000 hours of pervious concrete work, and the number of certified craftsmen did not increase between the publications of the two databases. Therefore, this report aims to interview (tense!) all of the certified craftsmen, which would yield information from over 12000 hours or experience in handling/placing pervious concrete, as well as 3 certified technicians from each of the defined rainfall regions. Because the certified craftsmen are all located within Florida, their information suffices for the 40" to 80" inch area, and therefore, only 9 other contractors are needed—3 from the remaining rainfall regions. While only 12 contractors are to be interviewed, which only accounts for 5% or the pervious certified population, the weight of the certified craftsmen should compensate for the lack of numbers in this qualitative research. Mention and address triangulation

4.3 Required Information

In order to provide beneficial information to contractors intending to implement pervious concrete, various questions must be asked. Since this report focuses on handling/placement of pervious concrete, it focuses on questions related to such considerations within the various steps of handling and placing. Given the information pertaining to pervious concrete handling/placing contained in the background, information for this report also follows the same outline. Therefore, our questions for the pervious concrete contractors' focus on batching/mixing, transportation, placement techniques, and finishing/curing. This information not only addresses the aforementioned sequence, but also aims to address the difficulties outlined in the other various sections of the background. By accessing this required information, this report is able to develop questions related to current handling/placing techniques of pervious concrete.

4.4 Question Development/Justification

Knowing what information this report is seeking, which was just addressed in the previous section, the report can begin to develop questions. The questions that have been used for the contractor interviews in this report, as well as the justifications for these questions, can be found in the appendix section. While the original/long documents can be found in the appendix, this section highlights question development and justification of the various stages of in the report. The following few paragraphs overview questions related to contractor information, applications, mix, transportation, placement, results, and maintenance.
Show questions in a table here
While contractor information is not necessarily pertinent to placing pervious concrete, it is important to establishing the credibility of the pervious concrete contractor. The amount of pervious concrete that a contractor pours can indicate how much experience that contractor has working with the material, and the number of years a contractor has been placing this material also sheds light on experience with the

material. The application set of questions addresses the size of pours, as well as the thickness, in order to see if any correlation arises for strength in concrete depending on thickness, and pour size may shed light on any unique considerations that may be necessary in pour planning. Since this report only focuses on slab/pavement applications, any information on other type of application is not critical for this report, but may be beneficial to learn of other applications as a whole. The next set of questions addresses mix considerations for pervious concrete, such as mix designs, aggregates and fines used, admixtures, batching sequence, and other components. After the concrete mix questions, there are the pour process questions, which include questions pertinent to transportation, site preparation, subbase, formwork, placement, compaction, finishing, and curing. These sets of questions are intended to address any issues or considerations when actually handling and placing pervious concrete—the main focus of this report. With these questions, issues highlighted in the background section can be addressed, and hopefully produce recommendations and procedures that are beneficial to the pervious concrete community. The last set of questions asked is the results and maintenance questions. These questions also relate to the success of the pervious contractor, in terms of how long their product lasts, and maintenance is intended to address any considerations that pervious concrete contractors must be aware of ensuring their product continues to function properly through the life of the material.

4.5 Interview Plan

Now that the contractor population has been outlined and question/justification has been performed, this report moves on to generate an interview plan in order to gather the necessary information from the contractors. Given the population in the population generation subsection, the author can contact the concrete contractors in each of the rainfall areas, including the 3-4 pervious craftsmen. While it is necessary to contact the craftsmen because of their ample experience, there is more leeway in contacting the certified technicians. Various contractors can be contacted, who are technicians, from the respective areas, until enough contractors have been interviewed to supply the three contractors per region quota.

In terms of conducting the interview, they can either be administered by phone, or sent via email to the pervious concrete contractor. When given a phone interview, the contractors' responses are recorded by hand, and are then typed up in a logical manner immediately after the interview. If the contractors choose to have the interview emailed to them, they can fill out the answers to the questions, and send back the completed interview to the author. Who did which? Again, the interview questions can be found in the appendix section of this report. "Question Outline II" is the format that used for the interview, where "Question Outline I" was the initial generation of interview questions.

Once interview responses have been written, they are sent to the respective contractors to validate the information, and to ensure that no mistakes have been made. If the response has not been responded to after 1 week, then it is assumed there were no problems with the information provided. Tense. How many total were interviewed? How many were approached in total? Response rate?

5 Discussion of Contractor Interviews

Having outlined the methodology, the report was able to collect the necessary information for placing and handling pervious concrete outlined by contractors. These interviews were performed from March 19, 2007, to April 13, 2007, and the interview data/notes are found in the appendix section of this report. As stated in the methodology, these interviews were administered via telephone conversation and email, with the majority of the interviews conducted by phone.

During interview conduction, the actual methodology of selecting contractors to interview changed slightly. Of the four certified craftsmen, three were contacted, and thus completed one of the rainfall regions. However, instead of going strictly by the pervious contractors database, interviewed contractors were asked to recommend other contractors that may be willing to answer questions. Thus, a "snowball" type methodology was used to select interviewees, as well as the contractor database. This also helped by including pervious contractors who were not on the NRMCA list, but were certified by other organizations. Along with gathering information from non-NRMCA certified contractors, this "snowball" approach also saved time involved with cold-calling contractors. While cold-calling was used in this study, it proved to be time consuming, and require many calls in certain locations to gather the desired number of contractors.

With the slight variation from the prescribed methodology, there was also some deviation within the interviews themselves. While there is an actual list questions, found in the appendix, these questions were not asked specifically. Instead, discussion took place instead of a strict interview – this is called a semi-structured interview. During the interviews, the interviewer ensured that the questions from the list were being answered, however, documented additional data. Later, the answers were written in the question list. By performing the information in such a manner, not only were the questions answered, but also far more insight was gained into the characteristics of pervious concrete. Therefore, the results section address just the questions outlined in the methodology/appendix—the specific data this report has sought out.

Instead of providing strictly raw data in the form of a question/answer table, more specific data can be addressed through the discussion of the interviews. This discussions section is derived from the contractor interview notes, where tabular question/answer list can be found in the appendix. For this discussion, instead of addressing each specific question, the report groups the results into contractor information and applications, mix considerations, and placing process. All the questions, and their respective answers, can be addressed by this grouping.

Through the contractor interview questions, this report was able to determine the level of experience the contractors we were interviewing possessed. Of the contractors interviewed, the range of experience spanned from one year to twenty years. While this is quite a wide range, the average experience these contractors possessed was just 13.5 years. The low outlier of one-year experience was removed. With respect to the amount of pervious concrete the interviewed contractors poured, the responses were either provided in the amount of square feet of pervious concrete pavement poured throughout their career, or the average square feet of pervious pavement they poured per year. The contractors that responded with amount of pervious concrete pavement throughout their career averaged 3.3 million ft^2, while contractors that responded with yearly average amounts of pervious concrete pavement averaged approximately 100,000 ft^2, with placement amounts increasing yearly. Not only was this report able to determine

contractor experience, but also the typical thickness of placed pervious concrete, ranging, typically, from 4-8 inches. Be more specific with actual data – don't provide just averages here!

Moving on to mix considerations, pervious concrete contractors responded on topics such as mix design, aggregates and fines, admixtures, mix sequencing, and temperature considerations. In regards to mix design, all of the contractors interviewed prescribed to the NRMCA mix outlined in figure 2, containing cement, water, large aggregate, and admixtures, with the exclusion of fine aggregate. Their mixes were very similar the first mix outlined in table 3, and predominately contained #87 stone, cement, and water, with various hydration stabilizing and retarding admixtures; however, the size of aggregates and proportions would vary depending on the job. Throughout the various interviews, contractors did not use any fines, as they either were comfortable with the mixes they created that did not use fines, or they felt that fines reduced the integrity of their mix. Therefore, in regard to fine aggregates, the pervious contractors did not utilize these components for their pervious concrete mixes. Admixtures, as cited by the contractors, were vital for providing workability and increased placement times to the concrete mix, and were used in accordance their labeling. A discussion regarding various admixtures is provided in the conclusions section of this report, and expands on various considerations when choosing admixtures. Mix sequencing, while not highlighted in the earlier sections of this report or addressed from previous data, is important in providing consistent pervious mixes. When batching pervious concrete, most contractors stated that admixtures could not be added last in the process, as they will not mix thoroughly in the drum. Fins within the mixing drums must also be clean to prevent the mix from sticking, and other contractors recommended to mix less than a full truckload, as the mix is "fluffy" and needs additional room within the drum to mix thoroughly. Lastly, as with already available literature, contractors recommended that pervious concrete batches be altered slightly to account for fluctuations in temperature. The knowledge to adjust pervious mixes is gained through experience; however, the contractors stated that adjustments should be made through by reducing water in lower temperature, and adding admixture in warmer weather.

Organize this section specifically by question. It kind of rolls together as it is now. Flesh it out with anecdotes/quotes from your interviews.

Having addressed questions related to experience and mix considerations, contractors were then asked to elaborate on the pervious concrete pour process. Contractors were asked questions related to the challenges of placing pervious concrete, steps in the placement process, tools implemented, and maintenance procedures. Much like the product association literature, the interviewed contractors stated that planning, timing, and experience were the most critical factors when placing pervious concrete. One difference arose with the placement of pervious concrete joints, where the present literature says the joints can be placed further apart in traditional concrete, the contractors stated that joints should be placed similarly to that of traditional concrete. They could not stress enough how important a well-planned placement sequence was for the success of a pervious concrete job. Contractors must have the site prepared for the concrete, and must be able to begin placement once the truck arrives on-site. This is due to the unforgiving nature of the pervious concrete mix, and the low working times associated with the material. While literature states that pervious concrete working times can span from 1-1.5 hours, all of the contractors stated that they only allow a maximum of 45 minutes to place the material, with quicker placement times being more desirable. The placement processes were similar to those descried in the background section 2.1. Interviewed contractors utilized similar tools as described in section 2.1, and implemented vibratory screeds, rolling compactors, and preferred rolling jointers over saw-cut joints, as saw cut joints may create debris that could fill void space. Contractors also used plastic/poly covers to cure the concrete, which are immediately placed over the concrete after compaction and secured with either timber or scrap rebar. In regards to maintenance, contractors recommended minimal maintenance,

either utilizing site/pavement design to reduce debris from entering the void space, or having routine maintenance for vacuuming debris from the surface. Power washing is not recommended, as this may drive debris further into the void space and reduce porosity. Table 5 provides a results summary based on contractor responses.

Table 5: Contractor Response Summary

Category	Response
Contractor Information	▫ 13.5 years average experience ▫ 3.3 million ft^2 career pervious placement experience (average?) ▫ 100,000 ft^2 yearly pervious placement experience (average?)
Mix Consideration	▫ Similar to mixes described in product association literature ▫ No fine aggregate used in pervious mix ▫ Admixtures vital for providing workability and increased work time ▫ Mix sequencing, with admixtures presented early in batching, are important for providing consistent homogeneous batch ▫ Using smaller batches in larger concrete trucks to facilitate thorough mixing of "fluffy" pervious mix ▫ Adjust water or admixture depending on cooler or warmer weather, respectively
Placing Process	▫ Similar to process described in product association and academic literature ▫ Experience and thorough planning vital to successful placement of unforgiving pervious concrete mix ▫ Maximum recommended placement time of 45 minutes ▫ Vibratory screed, roller compactor, rolling jointer, and plastic cover necessary for proper placement, finishing, and curing ▫ Slab surface should be designed to prevent debris from entering void space, and maintenance should consist of routine vacuuming

While the previous information provided answers and insight into the specific questions, interviewed pervious concrete contractors provided additional information throughout the conversational interviews. This information addresses questions that were not necessarily brought up in the methodology, or delves into more specific information than in previously addressed sections. In the following paragraphs, the discussion section of this report focuses on some of outstanding and interesting main findings of the contractor interviews that are more in-depth than the original questions. This discussion addresses the topics related to the necessity of experience, stances on product association information, admixture details, composition of large aggregate, the affect of fine aggregates, and quality control.

Subheading?

Of the contractors interviewed, the individuals that were certified concrete craftsman, thus having an abundance of experience, provided information pertaining the necessity of experience. Issues related to experience that were addressed include product association certification, low quality finished products, and banned material usage in certain locals. Contractors stated that certification has lowered the standards by allowing contractors to have credentials without actually having placed pervious concrete. Such a statement was correlated to that of a pilot receiving a license without actually having flown a

plane. Contractors stated that hands-on experience was necessary, as pervious concrete is a mix that is unlike traditional concrete—zero slump, unforgiving, strict working times, and unique handling—and traditional approaches cannot be taken on this untraditional material. Interviewed contractors utilized dedicated pervious crews, usually with each crewmember performing a specific task, and certain contractors stated that necessary experience was gained after 6-months of routine pervious concrete work. With respect to pervious concrete's finished quality, inexperienced contractors predominately have inferior quality. While quality would likely increase with experience, inferior quality has already affected the pervious industry, as various locals have banned the implementation of this material. Quality standards and specifications are being developed and refined to address such issues.

I'd like to see specifics of how many of your population had these kinds of comments. It's unclear whether they all did these things or only some of them.

Another issue of contention addressed by interviewed contractors is that of information provided by the product associations. Addressing this topic is somewhat touchy, as these statements may not be taken well by the product associations. Contractors have stated that product associations have provided misinformation, while not intentionally, on certain aspects of pervious concrete. This includes the ease of placing the material, fine aggregates, placing tools/procedures, and the mission of the product association. When addressing the product association's statement on that pervious concrete is easy to place, but unlike traditional concrete, contractors agreed to the fact that pervious is unlike traditional, but stated that ease came only with experience, thus relating this statement to the previous paragraph. The fine aggregate issue is addressed in the next few paragraphs. ? Are we talking about your document or some other document? In regards to placing tools, some literature has stated that manual and roller screeds are acceptable for striking off pervious concrete. Pervious contractors insist on vibratory screeds, as a manual screed may be too difficult to level pervious concrete, and roller screeds may reduce porosity and consolidate the surface in the final slab. Lastly is the somewhat political view of the product associations, in that they are interested in pushing a product to market, as well as promoting certain placement tools and mix designs because of partnerships with associated industry. This is not addressed because of the certain arguments that could occur.

Moving on, contractors provided specific information on admixtures. All of the contractors interviewed used hydration stabilizers and retarders, and some went into great detail concerning their use. While some contractors stated that any such admixture could be used in pervious concrete mixes in accordance to their labeling, others described the properties associated with admixture constituents. These properties include the various chemical constituents of the admixtures, specifically either acid- or sucrose-based hydration retarders. According to certain contractors, acid-based retarders do not add the needed workability for the zero-slump pervious concrete mix, and therefore sucrose-based retarders are used. Even with this, there is discussion amongst contactors pertaining to admixtures, and the decision ultimately comes down to either the contractor or batch plant preferences. There are also various proprietary admixtures that have been used, but such batch components can significantly increase the price per cubic yard. Also, when implementing a different brand of admixture, trial batches should be tested to determine how the change has affected the mix's characteristics.

The contractors interviewed also provided information on the affects certain large aggregate characteristics have on the mix and final product, such as for porosity, mix water, and slab strength. With respect to the composition of aggregate, differences between lime and granite based large aggregate affected both mix water and void space, with the chemical make-up of lime potentially more absorptive than granite. While water absorption may be more likely in lime than granite aggregate, both should be

moistened to prevent any loss of mix water necessary for hydration. I thought you said earlier they had to be dry! When do they get moistened?. In terms of void space, granite-based aggregates typically provide an 11-16% void space, where as lime-based aggregates provide a 22% void space. While larger void space allows more fluid transmission through the slab, increased voids may also lead to a weaker slab. Also related to void space is the shape of the aggregate, with more jagged/irregular surfaces providing more void space when compared to aggregate with rounded edges.

Like large aggregates, small aggregate, or fines, also affect the mix and finished slab of pervious concrete. In the results sections, all of the contractors interviewed did not use fine aggregate, citing the affects they had on the mix/finished slab. Fine aggregates such as fly ash and slag are hydrophobic and cationic. Hydrophobic constituents attach to sand and then react with calcium in the cement. These constituents will float on the water and act as filler, not thoroughly mixing with the concrete. Also, when fly ash is introduced into the mix, it can promote "popping" in areas characterized by freeze/thaw conditions. Also, since fly ash is loose and does not bond with the concrete, it may have a tendency percolate through the slab and pollute the subsurface/groundwater. Some contractors felt that fines were contaminates, and were an issue of contention with the product associations promoting them. The product associations stated they would strengthen pervious mixes, like they do in traditional mixes; however, certain contractors felt otherwise, stating that they actually weaken the mix.

The last outstanding information provided by the interviewed contractors is that of quality control for pervious concrete. Because of previously mentioned information pertaining to banning pervious concrete in certain locals (should be "locales"), as well as non-hands-on pervious concrete certifications, there is a push to develop standards for this material. ACI is currently drafting standards and specifications for batching and placing pervious concrete, and the PCPA currently has established standards, with some companies striving for less than 2% surface raveling and consolidation. While quality standards would establish a minimal performance level, one difficulty with quality standards is that of testing pervious concrete. Tests established for traditional concrete, such as slump tests, do not accurately describe pervious concrete characteristics. Pervious concrete relies on experienced contractors to visually inspect each batch to determine the properties, and additional, less subjective tests need to be established to ensure uniform standards. Table 6 outlines information addressed in the conclusion section.

Table 6: Conclusions Summary

Contractor Issues Addressed	Findings
Necessity of Experience	Contractors advise hands-on experience vital to learning pervious—revise training requirements
Product Associations	Contractors believe product associations should focus on promoting a well-researched product with accurate information
Admixtures	Test admixtures prior to pour, sucrose-based admixtures may promote workability
Large Aggregate	Differences between aggregate constituents and shape on porosity and strength
Fine Aggregate	Such components may contaminate pervious mix
Quality Control	Non-subjective standards needed to test pervious concrete properties

6 Conclusions

Given the results in the previous section, this report can now make conclusions regarding the problem section of this report. In the problem statement, there were four objectives to develop for this report, including the development of a contractor list, developing questions, interviewing pervious concrete contractors, and creating a lessons learned document from the contractors. This conclusion addresses the four objectives from the standpoint of the data, as well as elaborates on various contractor responses.

Considering that the pervious concrete contractors list already existed, this objective proved to be unneeded. The National Ready Mixed Concrete Association has already created a database of over 850 certified pervious concrete technicians that have passed written exams to show their knowledge in various aspects of pervious concrete. This database can be contacted through the NRMCA website. While other contractors exist outside of the database, there are also certifying organizations related to pervious concrete, such as the ACI and PCPA (website to come in August), which have lists of their own certified pervious contractors. Therefore, there are ample resources to find pervious concrete contractors, and when choosing a pervious concrete contractor for a job, ensure that they are certified.

In terms of question development, a list of questions has been created within the methodology to determine certain factors, and can be seen in the methodology section 4.4/appendix. These questions have been justified through the different steps required in handling and placing pervious concrete outlined in numerous articles, with the contractors answers and recommendations found in the results section. By asking these questions, insight has been gained from the pervious contractors that regularly use this material. While there are likely additional questions that could have been raised, these questions focus on the handling and placement of pervious concrete.

As for the “lessons learned” deliverable, conversations with contractors revealed that such a document, while it would provide insight to various aspects of pervious concrete, is not needed in the industry. Contractors stated that an increase in hands-on learning and training to build experience were necessary for teaching budding pervious concrete contractors the proper methods for utilizing this material, and that a thorough informational document could not replace proper experience/hands-on training. Along with the aforementioned remark on a “lessons learned” document, the contractors provided beneficial information on the various nuances associated with their product that would likely have been left unaddressed if the conversational interview format were not taken. Through conversations, much insight was gained from contractors, and is provided in this conclusion section.

While a concise “lessons learned” document has not been created, this report can provide insight into handling and placing pervious concrete. The main area where this report has added to the depth of knowledge with pervious concrete is mix considerations, instead of the originally desired placing of pervious concrete. While there were slight differences and recommendations for placing pervious concrete, the main issues addressed for that aspect of the material were emphasis on preparedness and short working times. However, much more insight to the pervious mix, including affects of admixtures, course aggregate, fine aggregate, and quality standards, was provided, which did not exist in the present product association literature. In conclusion, this report has not necessarily created anything new information about pervious concrete, but has uncovered vital information that is necessary to successful pervious concrete handling that is not present in literature utilized by (would be better to say “available to”) budding pervious concrete contractors. This is not a strong way to end your conclusions.

7 Recommendations for Pervious Concrete

This report has provided background information pertaining to pervious concrete and its basic characteristics, as well as information related to difficulties with batching and placing the material. Through various resources, this report was able to highlight information on the difficulties with this material, and able to address that the majority of literature is either academic or product association based. I don't think your literature review established this fact. While contractors are likely included in these sources, there lacked a strictly unfiltered contractor source. Based on the existing literature, this report addressed the problem of a lack of contractor information, and developed a methodology to find out how contractors handled and placed pervious concrete. This report was able to define questions based on previous pour procedure, which were then used to interview pervious concrete contractors, where upon they provided ample information in the form of conversational interviews. A population of contractors was based on already existing pervious contractor databases, and experienced pervious contractors were contacted and their information was gathered. In the results and conclusion section, the information from the interviews is shown, and unique information, some dissimilar to present literature, is provided.

While this report provides a suitable product for initial insight into the contractor side of pervious concrete, it has also brought up other issues. As with many reports and recommendations, further research is prescribed. This report could be strengthened to provide a broader population and more pervious contractors, as well as a strengthened methodology and more refined questions. Despite those recommendations, this report has found information that was not readily present in the current pervious concrete literature employed by a vast majority (not sure you can claim this!) of contractors. In terms of further research, topics presented in the contractor discussion section can be developed to address their affects on pervious concrete.

In general, my main recommendation for pervious concrete is to experience it first-hand. No amount of literature is going to replace training from an experienced pervious contractor. Also, set aside preconceived notions and biases towards the material, and approach it as a new material—it's different, and one cannot use traditional approaches for this product. Contact individuals that have used this product—they're friendly, approachable, and would rather speak with someone on developing a superior pervious concrete product than try to bolster a product tainted by inexperienced hands. Besides first-hand experience, product associations are recommended to provide additional information such as that uncovered in this report so that would-be contractors consider the minute details when implementing this material.

8 Appendices/References

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Citation needed for Ghafoori and Dutta, 1995
Citation needed for University of Central FL Cost analysis
http://everything2.com/index.pl?node_id=1266592
Need citation for CIP-38
ACI citation needed
Aci2 citation needed
PCAC cite needed

Note that none of these appear to be from refereed academic journals!

Ref #	Annotation	Ref #	Annotation	Ref #	Annotation	Ref #	Annotation
1	Pearce, 2006	6	Villanova, 2006	11	NRMCA2, 2006	16	Tennis, 2004
2	Charger, 2005	7	CNCPC, 2006	12	PCA, 2007	17	Peterson
3	GCPA,2006	8	NRMCA1, 2004	13	NRMCA2, 2004	18	SCM, 2006
4	NRMCA, 2007	9	RMC, 2007	14	PCA, 2004	19	Granitrock, 2006
5	CS, 2005	10	NRMCA1, 2006	15	PCA, 2003	20	

8.2 References/Acknowledgments

While the aforementioned bibliography section tracks articles used for the literature part of this section, the references/acknowledgements section lists the contact information for various resources that would be beneficial for implementing pervious concrete, as well as some of the contact information of companies and associations contacted for this report.

Magruder Constrution
Petrus, UTS
Rinker Materials
PCI, Inc
Burns and Sons Concrete
Carrera Construction
Thomas Bly Landscapes
NRMCA
State Concrete Association Directory
Pervious Concrete Contractors Database

8.3 Appendix I: Question Outline and Relevance

8.3.1 Question Outline I

Category	Question	Relevance
Contractor	How many years have you/your company been placing Pervious Concrete	Denotes how successful company is and ability to provide useful information
	How many yards/jobs/$ poured a year	Denotes size of company
	What is the size of your company	Ability to relate to like companies
Applications	What type of surfaces do you offer to apply pervious concrete and why	Shows ability to use concrete and market options
	How large of an area can you apply pervious concrete/what is your largest pour?	Dictates pour planning
	How thick are your surface applications	Water Retention/durability
Mix Design	Would you be willing to share mix designs	Home-made or recommended
	Are your mixes similar to outlined mixes	Variability of mix
	Have you had yield problems with your mix	Workability issues
Pour Process		
	What is the thickness of your base	
Subbase prep	What are the typical site characteristics of your pervious pours	
	What type of forms do you use	
Batch handling/	How do you transport pervious concrete (dry)	Material handling

Transportation	What type of spacing do you have for delivery	Constructability/urban/rural
	Are you in an urban/rural environment	
	Temperature restrictions for pervious concrete	
	Can you alternate pours	Dictates pour planning
Placement	What is the typical pour process	
	Is your crew make-up different than traditional pours	Placing considerations
	What are the essential tools you use to effectively place? Are there any "pervious specific" tools you use or have implemented?	Placing considerations
	What working times do you allow during placing (can denote hydration)	Staging and planning issues
	What are your average size pours	Staging and planning issues
Finishing/ Curing	How do you compact the placed concrete	
	What are the typical measures for curing?	
Pour Results	What type of maintenance do you recommend	Product information
	Is there any history of pours deteriorating or freeze thaw problems?	Quality of pour/material
	What effects does snow removal have on the longevity of pervious	Durability of concrete

8.3.2 Question Outline II

This is the list of questions for Pervious Concrete Contractors. Feel free to take as much space as you like. Thank you for taking the time to share your knowledge.

Questions		Answer
	Contractor Information	
1	This set of questions is to establish your familiarity with pervious concrete.	
2	How many years experience do you have with pervious concrete?	
3	How many yards of pervious concrete have you poured in your career?	
4	On average, how many yards do you pour a year?	
	Application	

5	What is the largest pervious concrete pour you have performed?	
6	Do you only install slab-type applications with pervious concrete?	
7	How does the thickness of pervious concrete vary depending on the intended use of the slab?	
	Mix	
8	Can you elaborate on your pervious concrete mix?	
9	What type of aggregate do you use? Do you use any fines?	
10	What type of admixtures do you use?	
11	If you are willing to share, what is your basic mix design?	
12	Is there a certain sequence in which the concrete components must be batched/mixed?	
13	How do you alter the mix for temperature fluctuations?	
	Pervious Concrete Placement	
14	What is the biggest challenge in placing this material?	
15	How much time do you allow to place each batch/truck?	
16	What type of tools do you utilize during placement/finishing/curing?	
	Maintenance	
17	Do you recommend any sort of maintenance to maintain open voids?	

8.3.3 Question Relevance

By asking a set of questions related to the overlying question, which will uncover the variables in implementing and employing pervious concrete considered by current pervious concrete contractors, this report develops a "lessons learned" list that concrete contractors desiring to implement pervious concrete may use to reduce initial mistakes when implementing the product, offer a quality product quicker, and become an experienced pervious concrete placing contractor quicker than with out it. In general, speed up the learning curve and offer a successful product (previous success breeds success)

A set of four question categories has been established that act as variables for the success of the company. This "Contractor" set of questions establishes the experience/success/and relevance of the contractors/businesses answering these questions. The answers to these questions set up a sort of qualitative aspect to the answers. If a contractor is more experienced, they would be better qualified to answer these questions. These questions basically set the credibility of the contractor to answer the questions. These questions could also serve as a progression of the contractors. A contractor earlier in the business of pervious may have fresh mistakes in mind. In general, these questions give credibility, experience, and successfulness to the contractors participating in the interview.

The report then moves on to discuss the applications of the material. This set of questions aims to inform would-be pervious concrete contractors the various ways one can apply the material. By having these questions answered, contractors thinking of implementing pervious concrete would know what applications to avoid to save time, money, and heartache. These questions may also throw caution toward contractors that wish to apply this material differently, so the contractor may take more time in planning or consideration when applying the material. Along with other categories, that will mentioned momentarily, asking questions about application can help dictate pour planning.

The mix design questions are asked to determine the pervious concrete mix characteristics used by current concrete contractors. These questions will help new pervious concrete contractors by indicating what to expect out of a pervious mix. These questions will tell would-be contractors what to expect in terms of strength, workability, and placing/curing. Hopefully, these questions will also generate a list of pervious mixes that concrete suppliers could base future mixes off of.

Lastly are the pour process questions. This set of questions mainly sets out to answer/remedy issues with placing pervious concrete. Case studies primarily cite pouring processes as the most troublesome issues, whether with premature hydration, concrete consolidation, etc. This is likely the set of questions that experienced contractors can have the most influence towards new pervious concrete contractors. By prescribing advise and offering placement methods and tool consideration, experienced contractors can help inexperienced contractors avoid mistakes, thus bringing success to inexperienced contractors quicker.

8.4 Appendix II: Contractor Responses

8.4.1 Contractor A

approximately 20 years experience working with pervious concrete, and is a member of the ACI board.

Contractor A said that you cannot be a pervious contractor and offer a quality product just by reading a book and specifications. He equated it to a pilot training, where you have to have a certain number of training hours to actually know what you're doing. The whole of the concrete industry, minus a few contractors, have low standards when dealing with previous concrete. Contractor A's concern was with the pervious concrete certification process, and that someone could become a certified technician just by attending a course and taking a test. This would release someone with a "qualification" without any actual experience.

Contractor A also mentioned that about half of the contractors interested in pervious concrete are actually just interested in making money off of the product, and not promoting a quality product. Some of the contracting companies are either on the verge of bankruptcy and searching for a product that can get them "out of the hole", or are just interested in offering the product without understanding the unique characteristics of the material. One example Contractor A gave was that there was a big push in the mid 90's to adopt this product, but the rapid initial utilization of this product, without understanding its characteristics, led to inferior quality and resulted in unsatisfied customers.

Contractor A experimented and tested pervious concrete between 1986-87, with out-of-pocket resources to understand its properties before offering the product commercially.

Contractor A also mentioned that you must place joints in pervious concrete, unlike some literature that says you do not need joints. Some of the literature also says that joints can be placed further apart than traditional concrete; say up to 60' apart, which is also not true. Joints must be determined depending on the specific job, and most likely should be placed like traditional concrete joints.

According to Contractor A, there are inherent issues with the various concrete and cement associations and pervious concrete. These myriad institutions are interested in product promotion and "getting it out" of the door and into market without necessarily taking into consideration the unique characteristics. While this is not to say that they are trying to promote a product without understanding it, there seems to be a conflict of interest with marketing and with completely understanding the product. Also, there are problems with the certification process these institutions offer for pervious concrete contractors. Contractors cannot simply take a test in a weekend and understand the product. They must work with it.

Pervious concrete is a difficult product to work with, and most concrete contractors are unable to work with it. This is because of the general attitude of the laborers, and that they want to treat this product like traditional concrete. When asked what makes a good pervious concrete contractor, Contractor A replied with time and attitude. With the proper contractor, one with the ability to learn a new product, a good contractor could be turned out in 6 months pour experience. The contractor needs to posses skill with traditional concrete, and have the mental ability to overcome bad experiences with pervious concrete and learn from mistakes.

In regards to the pour process of pervious concrete, with relation to the majority of concrete contractors, 90% of them are not ready for the pour when the first concrete truck arrives. This is detrimental to pervious concrete, as time is of the essence. Pervious concrete is unforgiving, and contractors cannot afford mistakes in the planning process. The installation of this process must be smooth and flow seamlessly between concrete trucks. Site access is critical, as each truck must be placed within 30-45 minutes of delivery.

Yet another issue addressed is that of the product in regards to installation and contractors. Usually, inexperienced contractors offer a cheaper product than experienced contractors because they treat the pervious concrete like traditional concrete, and work in the same manner. This product, while it may have the same appearance of pervious concrete, doesn't function the same. The customer doesn't know that it differs, and thinks they have received a bargain, yet when it doesn't perform, are disappointed with the product, and pervious gets a bad reputation.

Contractor A, with his 20 years of experience, has an estimated pour experience of pervious concrete of 5million square feet, while many of his crew members have 7-10 years minimum experience with handling pervious concrete. The construction company Contractor A works for, X construction, does all type of concrete work, and Contractor A is the in-house expert on pervious concrete. While Contractor A does well with pervious concrete, he much rather pour traditional concrete.

When pouring pervious concrete, you need consistency, both in the batches/trucks, as well as in the pour process itself. As soon as you pour, you need to cover the concrete to facilitate hydration. If not done immediately, the integrity of the concrete can be compromised.

In regards to pervious concrete maintenance, the best maintenance is prevention. While there has been literature published that one can pressure wash or use a street sweeper/vacuum to clean the concrete, these recommendations have not been proven. Pressure washing can cause raveling, and potentially force debris into the void space, while vacuuming only cleans approximately the first .25 inches, as the suction acts horizontally. It appears to "clean" the concrete, because water that is poured on it, while it doesn't percolate, spreads horizontally through the void space. Dirty concrete does not have the same storage capacity of clean concrete. Void space that is filled with debris such as sand can still function, only with a reduced infiltration rate. Voids filled with clay should be removed and replaced to maintain void space. Do not get the concrete too dirty—prevention is the best solution.

Be organized when using pervious concrete--complete planning and anticipating every step is crucial. Planning and executing according to plan are critical.

Contractor A/ X concrete have implemented various tools in regards to installing and finishing pervious concrete. X implements vibratory screeds when placing pervious, as roller screeds have a higher possibility to consolidate the surface. They remove shims placed on the formwork during screeding (1/4in shims), and then roll compact the surface parallel to the pour. X also implements a roller/creaser (pizza cutter) to install joints into the concrete, which, unlike present literature says, must be placed more in line with traditional concrete. Joints cannot be excluded from pervious, and should not be placed 60' apart. Contractor A also stated that one of the main reasons roller screeds were being utilized for pervious concrete was because the manufacturers of such tools were pushing contractors to use them for pervious placement.

Only certain types of admixtures, and certain brands/chemical make-up should be used when batching pervious concrete. The main admixtures that are implemented in pervious mixes are hydration retarders and hydration stabilizers. The different chemical make-ups of the admixtures can also alter the consistency of the cement paste and the ability of it to coat the aggregate. When comparing acid-based to sucrose-based retarders, acid-based retarders do not add workability to the low-zero slump mix. Admixtures that improve the workability of the pervious mix must be used, as this is an unforgiving/temperamental mix. Retarders should even be used in cold weather pours for consistency within the mix, and consistency within pervious mixes cannot be obtained without admixtures.

Planning is once again crucial when contracted to place pervious concrete in other parts of the country. When using another concrete batch plant across country (or even changing suppliers in your local area), pervious concrete contractors must account for the differences in aggregate, as well as insure the supplier has the proper admixtures. The origin of the aggregate, such as granite or limestone, can affect the mix because of differences in structural make-up, water retention ability, and chemical composition (with

water retention being most critical), as well as the aggregate volume and gradation. The origin of the cement/cement manufacturer, may also impact the mix, due to its chemical constituents, as well as the brand and components of the different admixtures, as previously stated.

Not only will the aforementioned factors affect the characteristics of the pervious concrete mix, but when the components are introduced into the mix will also affect the consistency of the mix. For example, admixtures should not be introduced last in the batch, as they will not be able to thoroughly mix with the other components and the batch will not be consistent, with the first part of the batch being too fluid/plastic.

Continuing with the batching theme, the amount of concrete that is batched in a truck is also important. The consistency of pervious concrete is "fluffy and puffy", and tends to take up more volume than traditional concrete. In order to insure the batch is thoroughly mixed, two yards of concrete should be subtracted from the total capacity of the concrete truck. Therefore, if using a 10 yard truck, only 8 yards of concrete should be shipped. By doing so, the concrete has extra room to mix, and thus overcome the "fluffy" mix.

One example of work placed by Contractor A was a Home Depot parking lot in northern Florida, placed in 1990. The parking lot has performed well, with infiltration only becoming somewhat slower. There have been no callbacks for repair. The only detractor is the wear patterns from tires and oil marks, which still happens on traditional pavements.

8.4.2 Contractor B

Contractor B was contacted after Contractor A recommended that I speak with him for this report. The phone conversation was relatively short, as this contractor directed me to his website. While this is not an interview, per say, the website did provide ample information to address the questions for the study. The answers that exist for this contractor were gathered primarily from the recommend website (www.perviousconcrete.info), or from the contractor himself.

8.4.3 Contractor C

10 years experience

The first person I spoke with was Contractor C, vice president of Company y. Company y not only places pervious concrete, but also other stormwater management systems. The conversation with Contractor C was somewhat random/unstructured, with various bits and pieces of information.

Contractor C began the conversation by stating how the trade associations "promote contaminates" for pervious concrete mixes through flag and fly ash additives. Slag apparently promotes electrolysis within the batch, and can weaken the structural integrity of placed pervious concrete. Pervious concrete mixes should not have any fines in it. No sand, fly ash, or slag. The only components of the mix should be aggregate/stone, cement, water, and admixture.

Pervious contractors need to be able to adjust both mixes and working strategies to environmental conditions, and constant adjustment is needed, depending on humidity, temperature, and characteristics of the different batches/trucks. Every truckload of pervious concrete must be inspected to insure proper

consistency and characteristics. Also, pervious concrete must be placed within an hour of batching, otherwise, the mix will begin to stiffen and set. Placing and finishing pervious concrete is counterintuitive to traditional concrete finishers, as the cement does not need to be floated.

Company y utilizes a specially made hoe that confirms to the curvature of the concrete to facilitate pervious placement.

Company y uses specially designed rollers for concrete compaction.

Different admixtures vary/alter the batches, and only 2-3 admixtures can be used for pervious concrete applications. Some admixtures may dry pervious concrete.

Company y contracted a 1999 pervious concrete pour for a garbage truck unloading area, which is still functioning properly.

The different trade associations "dumb down" the product (pervious concrete) and politics get involved with the associations.

Visual inspection is utilized to "test" the finished pervious concrete product. Less than 2% raveling or consolidation is acceptable.

There is 25% storage in a slab with half inch aggregate, while 30% storage exists with ¾ inch aggregate.

A light roller compaction is used to finish the surface, and a vibratory screed is used with a ¼ inch shim to facilitate subtle compaction.

Compnay y is the primary distributor for "Invisible Products" stormwater management in the southeast, and works throughout GA, AL, and SC

After speaking with Contractor C, I was able to contact Contractor D, President of Company y

8.4.4 Contractor D

years experence

Contractor D is one of/the most recognized experts for pervious concrete in the South East

She works closely with Bruce Furgeson, author of the Pervious Pavement.

In regards to pervious concrete crews, each crewmember has a specific task that they are responsible for, and do not perform various jobs.

Pervious concrete has been banned from certain municipalities because of improper installation and poor performance. This is likely caused by the product being implemented by inexperienced contractors, who were likely contracted because of a lower price caused by treating this product like traditional concrete.

In the long run, pervious concrete is cheaper than traditional paving systems. Traditional paving systems must properly grade, install pipe and retention areas, which are not usually incorporated into the cost of the paving.

Pervious concrete is also advantageous for trees in parking areas, as it allows water to infiltrate into the roots. Trees can also absorb large quantities of groundwater.

Fly ash is bad in the mix

Street sweepers/lawn vacuums can be utilized for routine maintenance

Most of the business Company y has is through return customers

20000 to 60000 square-foot jobs

Sam's clubs and Wal-marts have been good at implementing non-traditional paving and stormwater management systems. Parking lots can take the last ring/outer ring of parking and install a grass pave/pervious infiltration system to reduce the need for stormwater retention areas.

Pervious concrete is a field-type of material, and you must work with the product in order to understand how it behaves. This product is 180 degrees out of phase of traditional concrete.

Contractor D has taught classes on pervious concrete

Contractors have to know the origin or manufacturer of the cement in order to understand intrinsic chemical properties of the cement

Contractor Dadvises more people to not use pervious concrete than to use. Pervious is not the best paving system for all areas, and its properties must be taken into consideration in the area it is being used.

Company y is PCPA certified and believes that, in order for the product to maintain integrity, more contractors should become certified through this association.

For maintenance, pervious should have a routine maintenance program, where surface debris is removed before it has the opportunity to migrate into the void space and prevent infiltration.

Pervious is a good product for institutional space where there is already a maintenance plan in place.

Pervious is also acceptable for road traffic/light load traffic such as subdivisions, where there is less than a 35mph speed limit.

Company y aims for <2% raveling and consolidations, where most of the inexperienced competitors best is 20% raveling/consolidation. This percentage is over the total surface area.

Pervious allows recharge to subsurface water, not necessarily groundwater. By recharging subsurface water, heat pollution associated with other retention systems is eliminated. Heat pollution is very detrimental to aquatic ecosystems.

Mindsets are the worst thing in pervious concrete. Pervious concrete cannot be treated like traditional concrete. There are hardly any lab tests for this material. The only laboratory tests are for void space. Green rotting is not an acceptable test.

John Sansalone at UF has used CAT scan for void space, and has created formulas for interconnected void space.

Asphalt collects heavy metals, where concrete doe snot

In regards to aggregate characteristics, 11-16% void structure for granite, where there is a 22% void space for lime. Larger voids and more water conveyance are achieved through lime rock; however, larger void percentages may lead to weaker slab surfaces.

Sharp/jagged rock is better to use than rounded rock, as jagged rock facilitates void space.

If using a new concrete supplier, visit the batch plant prior to use in order to insure they utilize concrete components that are suitable for pervious concrete

Fly ash and Slag are cationic and hydrophobic. Hydrophobic constituents attach to sand and then react with calcium in the cement. Hydrophobic "contaminants will float on the water, and act as a filler. Also, when fly ash is introduced into the mix, it can promote "popping" in areas characterized by freeze/thaw conditions. Also, since fly ash is loose and does not bond with the concrete, it may have a tendency percolate and pollute the groundwater.

The base pervious concrete mix is ~20gal water, 611 lb cement, 2445lb #87 stone, 6oz retarder

6 mil poly and rebar are used to cover the finished concrete. It is vital that no air pockets are under the poly, as that may affect curing/strength.

Joints are placed just like regular concrete. 2 -inch joint with a ½ inch radius are utilized.

Compaction is done using a 30-inch-wide, 70lb roller, which is run transverse/perpendicular to placed pervious concrete.

One use for pervious concrete is for poll deck applications, where a terrazzo grinder used to finish the hydrated concrete surface.

When using pervious concrete in cooler weather, reduce the water content instead of reducing admixtures vital to workability

Company y place, on average, 100,000 square feet of pervious concrete a year

The deeper the pervious concrete slab, the stronger the slab. 4" foot traffic, 6" car, 8" truck

Snow will melt quicker, in comparison to traditional impervious concrete, off of pervious concrete. This is due to warmer sub-surface air rising up through the voids and melting the snow/ice.

The mixing fins of a concrete truck must be cleaned before pervious can be mixed in the truck. If fins are not cleaned, they may cause pervious concrete to adhere to the inside of the drum.

Company y takes other factors in for sustainability when placing pervious. Peanut or soy oils are used for form release, and shorter lengths of lumber are used, because longer lengths are harvested from old growth trees.

Consistency is obtained through computer batching, and therefore, water is added at the plant. Batches are not transported dry.

8.4.5 Contractor E

The phone conversation started off with a poor connection, however, we were able to later connect using a landline.

Contractor E has been installing pervious concrete for over 18 years. Pervious concrete is an ideal application for areas that experience flooding, or regions that have a high water table. Pervious concrete that was applied when the company initially started offering pervious concrete is still functioning and remains to be a lasting product. This contractor is certified through the ACI and NRMCA.

In terms of mix design, pervious concrete normally contains pea rock gravel with no sand. The preferred pea rock gravel is limestone, however, granite-type gravel may also be used. The gravel used for batching pervious concrete should be saturated so that the already low-water mix does not lose any water necessary for cement hydration through absorption by dry aggregate. Typical mixes only contain 20-25 lbs of water per cubic yard, and too much water can cause paste to migrate to the bottom of the drum, as well as to the bottom of the slab application, thus preventing stormwater from migrating into subsurface water. Regarding retarders, the proper amount to add to a batch of pervious concrete is that of what is recommend on the product packaging for the amount of cement contained in the mix. When asked about the affect of different based retarders, such as acid or sucrose based, there was no difference between the workability or changes in the final pervious mix. When asked about fly ash or slag, this contractor stated that it could be used, however does not prefer to use such additives. This contractor has successfully been applying pervious concrete for a number of years, and has had success without these additives, and prefers not to “mess with a good thing”. These additives would affect workability and structural properties of the concrete.

When asked about tools and applications of pervious concrete, this contractor stated that proper equipment must be used when applying this material to prevent raveling or compaction. These tools include a vibratory screed, as well as a roller compactor (1900 lb roller), as well as immediate coverage of placed concrete with 6-mil poly for 7 days. In lighter traffic applications, pervious concrete can be utilized in as little as three days..

Handling and placing pervious concrete is dependent on the weather, as temperature and humidity/precipitation can affect the workability and placing times associated with pervious concrete, and should be altered and inspected depending on climatic changes. Each truckload that arrives on-site, like traditional concrete, should be inspected for workability and consistency. This is important, as each batch

must be blended slowly and properly in the concrete trucks to ensure thorough coating/mixing Typically, a pervious concrete truck can be unloaded and placed in 15 minutes by an experienced crew. The crew utilized for pervious concrete placement by this contractor has 12 years experience with the material, and places approximately 2 million feet of pervious concrete yearly. Not only does this contractor install new pervious concrete, but also installs pervious where other contractors have installed an inferior pervious concrete product.
In regards to care and maintenance of pervious concrete, this contractor stated that maintenance can be performed, however, proper design is more important to ensuring properly functioning pervious concrete than anything. Power vacuums can be utilized to clean the surface of debris, yet this is not usually done. Pervious concrete installed by this contractor is designed to keep the void space free of debris. Proper design includes predominately flat surfaces, with proper curbs and entrances that can reduce dirt/debris on vehicle tires. Landscaped areas should not drain onto pervious concrete during storm events, and certain types of vegetation and landscaping procedures should not be used around this material.

Pervious concrete proves to be a strong material. Slab applications ranging in thickness can be utilized from light use to heavy industrial use. Normally, the heavier industrial applications use 8-inch slab thicknesses, and are ideal for tractor-trailer type loads, or vehicles with larger surface area tires. Heavy, concentrated loads, such as those by forklift tires, are the most detrimental to the wear of pervious concrete. In terms of subbase and strength, stone is important for a good foundation and stormwater storage capacity, although pervious has been placed on sand without any structural damage. Pervious is also ideal for freeze/thaw locations, and the mix varies insignificantly with these applications. The most important considerations for these type of areas are subbase and drainage capacities, so that the pervious slab is free of water/precipitation so that water does not freeze and crack the concrete.

8.4.6 Contractor F

contacted after their information was found through an internet search of pervious concrete providers in the State of Oregon. Contractor F returned my phone call after making initial contact. The interview with Contractor F remained short, as his company has not made any pervious concrete pours. Contractor F stated that pervious concrete was a relatively new material to the Portland area, and has not “taken off” yet. When asked how his company learned about pervious concrete, he stated that they were approached by the Oregon Concrete and Aggregates Producers Association to gain certification through the NRMCA for pervious concrete applications.

8.4.7 Contractor G

Contractor G is a Pavement Design Engineer with Rinker Materials based out of southern Florida. Contractor G has worked with Rinker for 2 years, and prior to that worked in other aspects of of construction and engineering. He said that pervious concrete is ideal for parking stalls, as well as tree protection in parking lots, as pervious in not as compacted as other types of pavements, and allows stormwater to infiltrate into the subsurface water where it can reach the root systems of vegetation. While Mike is not necessarily a contractor working with pervious concrete at the delivery point, he is involved with designing pavement systems and possesses experience in properly designing myriad paving systems, and promotes the use of pervious concrete in suitable applications.

When asked about the size of pervious concrete jobs that he designs, most of the work consists of 20-35 thousand square feet, and the work is predominately parking areas. This contractor stated that one of the main reasons for implementing pervious concrete is for credit when construction LEED certified buildings or for stormwater management practices. While pervious concrete is ideal for stormwater management and gaining credits associated with various "Green" associations, there still remains a challenge to try and get water manager approval for pervious concrete, and is sometimes contributed to previous improper installation of pervious concrete.

In regards to properly designing pervious concrete applications, this contractor recommends that this building material be installed on well-training soil, which is overlaid with approximately 2-feet of clean rock/gravel. It is important to implement rock of appropriate size, as rock that is too small, such as limestone chips, would not allow enough void space or storage capacity to allow proper percolation during a storm event. Larger stone, such as #87 stone, is ideal for subbase fill of pervious concrete. Also, subbase should not be over compacted, as this will also inhibit the migration of stormwater into the subsurface water.

In a typical Florida pervious concrete mix, low range hydration retarders are used, as well as hydration stabilizers. Low range hydration reatrders are used, as apposed to high range retarders, as the high range retarders tend to over-plasticize pervious concrete and thus reduce void space necessary for the concrete to maintain porosity. This material provider does not use proprietary admixtures, as they can significantly increase the price per cubic yard of concrete. Grace water reducers and stabilizers are predominately used, as it helps with hot mixes, as well as warmer working temperatures. BASF viscosity modifier admixtures have also been used successfully to aid in the workability of pervious concrete. With such admixtures to a no-fines batch, and proper handling and placing procedures, properly designed pervious concrete applications can last many years.

When asked about placement phasing and site location/staging, this contractor stated that the contractor installing pervious concrete determines such factors, however, it is important to have a thorough plan because of the short working times associated with pervious. When Installing pervious concrete, most applications are placed at various lengths, usually 12-15 feet wide, depending on the screed and roller widths. While pervious cannot be pumped, it can be transported to the placement location through concrete conveyors. Also, unlike traditional concrete, the low slump and rough consistency of pervious concrete can cause increased wear on concrete trucks, and the low work times and necessity to quickly place pervious concrete may tie up equipment from other jobs.

In terms of costs comparison to traditional pavement systems, this contractor/material provider stated that little in-depth analysis has been performed to compare the true costs of total pavement systems with traditional pavements and pervious pavements. However, one study by the University of Central Florida estimated a cost saving of $1.15/sqft over asphalt systems when using pervious concrete. Such savings is obtained by the ability to omit more grading and drainage when implementing pervious concrete. When simple cost comparison of only the pavement material is performed, pervious concrete is approximately 15% higher than traditional pavements.

Maintenance for pervious pavement systems usually depends on the site, and will vary depending on usage and vegetation around the site. Maintenance requirements are determined on a site-by-site basis, and may require power vacuuming. Most maintenance plans/agreements are determined by the owner, and are recommended by design engineers. Besides maintenance to maintain void space, many

municipalities require a yearly inspection by an engineer to determine if the void space and porosity is properly maintained. This contractor also stated that proper design is more important to maintaining functioning void space than maintenance. Sites should be designed so that landscaping does not drain into pervious concrete, curbs should be used to prevent runoff from entering the system during a storm event, and that pervious pavement should be used in locations that have little access to dirt roads/dirty vehicles. If the permeability is les than 1.5 inches of water an hour, the system is in need of heavy maintenance. Also, characteristics of the material that clog void space in pervious concrete also affect the permeability. Sand may fill all the void space of a slab and still allow percolation, while clay may completely clog void space.

Local product associations, as well as national, are an important part of pervious concrete, as they create exposure for the material. Associations such as ACI and ASTM have various committees for promoting pervious concrete in terms of testing for strength, developing new testing methods, and quality control processes for this unique material.

8.5 Tabular Contractor Responses

The following tables are broken down by contractor, and help to outline the answers to the specific questions.

Questions		Answers		
	Contractor Information	Contractor A	Contractor B	Contractor C
1	How many years experience do you have with pervious concrete?	20	20	10
2	How many yards of pervious concrete have you poured in your career?	5 million ft^2	3 million ft^2	N/A
3	On average, how many yards do you pour a year?	N/A	N/A	100K ft^2
	Application			
4	What is the largest pervious concrete pour you have performed?	N/A	N/A	20-60K ft^2
5	Do you only install slab-type applications with pervious concrete?	yes	yes	yes
6	How does the thickness of pervious concrete vary depending on the intended use of the slab?	4-8 inches typically	4-8 inches typically	4-8 inches typically
	Mix			
7	Can you elaborate on your pervious concrete mix?	Similar to trade organization literature	Similar to trade organization literature	Water, cement, #87 stone, retarder
8	What type of aggregate do you use? Do you use any fines?	Typical to published literature	Typical to published literature	Lime or granite rock, no fines
9	What type of admixtures do you use?	Retarders/Stabilizer Acid-based	Retarders/Stabilizers Acid-based	Retarders/Stabilizers
10	Is there a certain sequence in which the concrete components must be batched/mixed?	Yes	Yes	Yes

11	How do you alter the mix for temperature fluctuations?	Addition of admixtures	Addition of admixtures	Addition of Admixtures, working times
	Pervious Concrete Placement			
12	What is the biggest challenge in placing this material?	Planning/preparedness	Planning/preparedness	Time/Preparedness/ Experience
13	How much time do you allow to place each batch/truck?	30-45 minutes	30-45 minutes	30-45 minutes, as quickly as possible
14	What type of tools do you utilize during placement/finishing/curing?	Vibrating Screed, roller compactor, joint roller, plastic cover	Vibrating Screed, roller compactor, joint roller, plastic cover	Vibrating Screed, roller compactor, joint roller, plastic cover
	Maintenance			
15	Do you recommend any sort of maintenance to maintain open voids?	Prevention of debris, possible suction	Prevention of debris, possible suction	Routine Maintenance/ Suction

Questions		Answers		
	Contractor Information	Contractor D	Contractor E	Contractor F
1	How many years experience do you have with pervious concrete?	10	18	No experience
2	How many yards of pervious concrete have you poured in your career?	N/A	N/A	
3	On average, how many yards do you pour a year?	100K ft^2	2 million ft^2	
	Application			
4	What is the largest pervious concrete pour you have performed?	20-60K ft^2	N/A	
5	Do you only install slab-type applications with pervious concrete?	yes	yes	

6	How does the thickness of pervious concrete vary depending on the intended use of the slab?	4-8 inches typically	4-8 inches	
	Mix			
7	Can you elaborate on your pervious concrete mix?	Water, cement, #87 stone, retarder	25 lb water, cement, aggregate, admixture	
8	What type of aggregate do you use? Do you use any fines?	Lime or granite rock, no fines	Pea rock limestone, no fines	
9	What type of admixtures do you use?	Retarders/Stabilizers	Hydration retarders/stabilizers	
10	Is there a certain sequence in which the concrete components must be batched/mixed?	Yes	No	
11	How do you alter the mix for temperature fluctuations?	Addition of Admixtures, working times	Speed up working times/ admixture addition	
	Pervious Concrete Placement			
12	What is the biggest challenge in placing this material?	Time/Preparedness/ Experience	Unforgiving mix	
13	How much time do you allow to place each batch/truck?	30-45 minutes, as quickly as possible	15 minutes average, up to 45	
14	What type of tools do you utilize during placement/finishing/curing?	Vibrating Screed, roller compactor, joint roller, plastic cover	Vibrating Screed, roller compactor, joint roller, plastic cover	
	Maintenance			
15	Do you recommend any sort of maintenance to maintain open voids?	Routine Maintenance/ Suction	Proper design to reduce debris from entering void space	

Questions		Answers		
	Contractor Information	Contractor G	Contractor H	Contractor I
1	How many years experience	2 years pervious		

	do you have with pervious concrete?			
2	How many yards of pervious concrete have you poured in your career?	N/A		
3	On average, how many yards do you pour a year?	N/A		
	Application			
4	What is the largest pervious concrete pour you have performed?	20-35K ft^2		
5	Do you only install slab-type applications with pervious concrete?	Yes		
6	How does the thickness of pervious concrete vary depending on the intended use of the slab?	4-8 inches		
	Mix			
7	Can you elaborate on your pervious concrete mix?	N/A		
8	What type of aggregate do you use? Do you use any fines?	No fines		
9	What type of admixtures do you use?	Low-range retarder		
10	Is there a certain sequence in which the concrete components must be batched/mixed?	No		
11	How do you alter the mix for temperature fluctuations?	Admixture/working time		
	Pervious Concrete Placement			
12	What is the biggest challenge in placing this material?	Short working times/ difficult mix		
13	How much time do you allow to place each	N/A		

	batch/truck?			
14	What type of tools do you utilize during placement/finishing/curing?	Vibrating Screed, roller compactor, joint roller, plastic cover		
	Maintenance			
15	Do you recommend any sort of maintenance to maintain open voids?	Prevention		