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Investigation of the Effects of Aggregate Properties and Gradation on Pervious Concrete Mixtures

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INVESTIGATION OF THE EFFECTS OF AGGREGATE PROPERTIES AND GRADATION ON PERVIOUS CONCRETE MIXTURES

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ABSTRACT

Pervious concrete is a concrete mixture prepared from cement, aggregates, water, little or no fines and in some cases admixtures. It has been considered a Best Management Practice by the EPA because of its ability to reduce storm water runoff and to initiate the filtering of pollutants. Because the hydrologic properties of pervious concrete has been the primary reason for its reappearance in construction, the focus of previous research has been on maximizing the drainage properties of the mix with single-sized aggregates. This research, however, investigates the effects of aggregate properties and gradation on the strength, as well as hydrologic properties of pervious concrete mixtures.

The aggregates were retrieved from two sources and Type I cement was used to prepare the eight (8) batches of pervious concrete mixes for each source. An additional seven (7) batches were prepared with aggregate gradations derived from new uniformity coefficients (C_u). Each batch consisted of fifteen 3 × 6 in. cylinders and five 3 × 3 × 12 in. prisms. The water/cement ratio was held constant at 0.29 before factoring in absorption and the cement/aggregate ratio was 0.22. The design unit weight of the fresh concrete mixtures was 125 lb/ft^3. The specimens were stored in a wet curing room for 28 days. The compressive, split-tensile, and flexural strengths were tested on 5 specimens each, along with the maximum specific gravity test that was conducted on loose cured concrete mixtures. The bulk and apparent specific gravity, the air voids and porosity, and permeability were all tested. Gradations were categorized according to nominal maximum aggregate sizes of ⅜, ½, and ¾ in. and in order of their C_u values.

The results were analyzed to evaluate the effects of properties, gradation and size. Strengths decreased as air voids increased, porosity increased with air voids, and permeability increased as air voids increased. The highest compressive strength was generated from the blended gradations with higher C_u values. In general, the single-sized mixes were on the lower end of the strength scale but on the higher end for air voids, porosity and permeability. However, blended mixes produced a relatively suitable strength and permeability. It was observed that compressive strength increased with C_u to a point after which there was a decrease in strength. Permeability decreased with the increase in C_u to a point after which it increased.

DEDICATION

I wish to dedicate this thesis to my mother, Voltina Neptune, and my father, Wilmus Neptune. They are the ones worthy of this degree, because of the way they lovingly and sacrificially supported me. My parent's steadfastness in prayer, words of encouragement and financial dedication to my schooling, have given me the privilege of achieving this goal, which would not have been saved for their selfless lives. Because of their example and guidance, I was able stay focus on the tasks before me. I praise my God for them, and thank them for all the love and care they have poured into my life.

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CHAPTER I

INTRODUCTION

The US Environmental Protection Agency (EPA) and the passing of the Federal Clean Water Act of 1972 inspired a change to the way the construction process is approached (EPA, 2008). No longer is it a matter of giving attention simply to functional capability or performance, but now attention is also given to sustainability. The fundamental cause for this new approach to construction stemmed from the depletion of natural resources. To regulate the consumption of natural resources, a decision was made by the EPA to encourage sustainable construction. Sustainable construction refers to "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles" (Hui and Cheung, 2002). This concept focuses on the use of renewable and non-renewable resources and the impact construction has on the natural environment (Khalfan, 2002).

One aspect of sustainable construction that mitigates the negative impact of pollutants on the environment rests in the utilization of a concrete mix that consists of coarse aggregate, cement, water and in many instances admixtures. This modified concrete mix that includes no fine aggregate was developed in Europe in 1852 as structural insulation (Tennis et al, 2004). It was referred to as Portland cement pervious concrete, and it soon had a shift in function to that of a paving material (Dell, 2005). Although it was in existence for quite some time, it was not until the 1980's that it emerged in the United States as a possible solution to a growing environmental concern (Yang and Jiang, 2003). Pervious concrete has continued to grow in popularity among civil engineers. Some of the reasons behind its growth relate to the problem of excess storm water runoff. One issue that arises from the development of natural areas, that experience a substantial amount of precipitation, is the routing and controlling of runoff. Since the natural vegetation and soils which act as interceptors of the water flow, are replaced with impervious surfaces, drastically increased quantities of water enter rivers and water sources resulting in erosion of banks, sedimentation, flooding and the introduction of pollutants.

To help preserve good quality water, pervious concrete has been considered a Best Management Practice (BMP) because of its ability to reduce excessive runoff (Bury et al, 2006). Its porous structure allows both water and air to percolate through its matrix into the subsoils beneath. Because of the interconnected pores, pervious concrete reduces runoff but also performs the role of a filter by the degradation and entrapment of contaminants (e.g., oils and debris) on and within the pervious concrete structure (Schaefer et al, 2006). The size of these pores is affected by the gradation and type of the aggregate in the mix, the quantity of water and cement added, and the level of compaction.

Studies conducted on pervious concrete have placed an emphasis on examining primarily single-sized aggregate. Although the greatest concern with regards to pervious concrete is permeability, which is maximized with the use of single-sized aggregate, the strength of the structure cannot be slighted. The use of pervious concrete is application specific; some cases would require high permeability mixes depending on the rain intensity in the area, while others would be strength driven. In this study, the focus was directed to the effects of aggregate properties and gradation on both hydrologic and strength properties in pervious concrete mixtures. It is an accepted fact that pervious concrete is lower in strength compared with conventional concrete mixes hence the reason for its application in low traffic roads, parking lots, driveways and sidewalks (Tennis et al, 2004). However, durability tests done on pervious concrete specimens have shown that the addition of 7% fine aggregate to the mix improved strength by 57 to 84% but reduced void ratios by 6 to 8% (Kevern et al, 2005). With consideration given to these results and others alike, it may be necessary to use both distributed sizes and singled-sized aggregate to prepare the pervious concrete batches in an effort to help engineers design gradations that will optimize both hydrologic and strength properties.

Problem Statement and Research Significance

Based on the literature review conducted (Chapter II), it was realized that previous research done on pervious concrete mixtures has focused primarily on optimizing the hydrologic properties of pervious concrete mixes. This led to the use of singled-sized aggregates such as the ⅜ and ¾ inch sizes. In the event that aggregate gradations were investigated, the variations were quite limited (Ghafoori, 1995). Although permeability may be of greatest concern in one application because of high rainfall intensities, another application may place greater emphasis on strength, and another may consider rideability or sound absorption as the primary concern. Other porous construction materials, for instance porous asphalt, rely on a distribution of aggregate sizes for strength while providing adequate drainage properties (Kandhal, 2002). The design of each pervious concrete mixture is unique based on performance requirements. Therefore, the main objective of this study was to investigate the effects of aggregate properties and gradation on the performance of pervious concrete mixtures. The results of this study would lead to a better understanding of the manner in which aggregate gradation can be used to optimize a pervious concrete mixture depending on project or site-specific requirements.

Objectives

The main objective of this research project was to understand the effects of aggregate properties and aggregate gradation in pervious concrete mixtures. The following is an outline of the specific objectives of this research:

1. To determine the effects of aggregate source properties on pervious concrete mixtures (Phase I).
2. To determine the effects of aggregate size and gradation on pervious concrete mixtures (Phase II).

Scope of Research

The objectives of this research were accomplished through the completion of the following tasks:

1. Conducting a literature review on the preparation and performance of pervious concrete mixes. Further review was focused on aggregate properties and gradation.
2. Determining aggregate properties (L.A. abrasion, specific gravity [bulk, SSD and apparent] and absorption and the dry rodded unit weight).
3. Preparing mixes using eight (8) different aggregate gradations from two (2) different aggregate sources in Phase I and seven (7) additional aggregate gradations from one of the aggregate sources for Phase II.
4. Evaluating pervious concrete specimen properties (compressive strength, split-tensile strength, flexural strength, density, porosity, and permeability).
    a. From each pervious concrete batch 5 specimens were prepared for each destructive test and one set of 5 for the non-destructive tests.
    b. Specimens were cured for a period of 28-days.
    c. Conduct tests on specimens to evaluate properties.

5. Performing statistical analysis to quantify the effects of aggregate source and gradation on the properties of pervious concrete.

Organization of Thesis

Chapter II presents a literature review that relates to this research. This review provides background information of Portland cement pervious concrete, the benefits and applications, the physical, hydrologic, and strength properties, mix proportioning and design, and the construction and maintenance of pervious concrete. Chapter III documents the materials and experimental procedures used in this study. The experimental results along with discussions are included in Chapter IV. Finally, Chapter V gives a summary of the research, presents conclusions, and provides recommendations based on this research.

CHAPTER II

LITERATURE REVIEW

In recent years, pervious concrete has been reintroduced to the construction world in an effort to meet the regulatory demands regarding environmental issues. It involves the application of a low slump, high porosity concrete mix that has received growing recognition as a solution to the problems arising from the excessive flow of storm water above the ground surface. What this pervious system does is redirect the flow of water through its interconnected pores and into the subbase and subgrade. It is typically used in the construction of low traffic pavements, pedestrian walkways, greenhouses and parking lots, chiefly to reduce storm water runoff and to trap contaminants in these discharges as it functions as a filter. Pervious concrete has since been regarded by the U.S. Environmental Protection Agency (EPA) as one of the Best Management Practices (BMP) for the control of storm water runoff and its contaminants (Bury et al, 2006).

Pervious concrete is a combination of Portland cement, controlled amounts of water, coarse aggregate and little or no sand. The thick cement paste bonds the coarse aggregate together but allows adequate void formation of approximately 15% to 25%. The rate at which the water flows through pervious concrete is "typically around 480 in./hr (0.34 cm/s which is 5 gal/ft^2/min or 200 L/m^2/min)" (Tennis et al, 2004).

Environmental Benefits

The EPA Storm Water Phase II Final Rule has regulations to manage the quantity of pollutants entering bodies of water (Tennis et al, 2004). Contaminants may include oils, grease, sediment, anti-freeze, fertilizers, and pesticides. The partially filtered water is able to percolate into the soil and be further filtered by the soil structure, and in turn recharge the ground water table and readily water the surrounding plants. With pervious concrete, the need for management systems to control excess water flow is minimized. Along with these environmental benefits are safety concerns that are eliminated such as pooling, spraying and hydroplaning (Tennis et al, 2004).

Pervious concrete now has the potential of being certified for construction projects by the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Green Building Rating System, because of its environmental benefits along with the capability of lowering the heat island effect (Tennis et al, 2004). Urban areas tend to enclose large numbers of impervious pavements which add to the level of heat. The concentrated heat wave can be reduced by the open structure of pervious concrete that allows air to flow through it. Additionally, the roots of plants and trees adjacent to these pavements not only experience watering but also aeration (Tennis et al, 2004).

Economic Benefits

Economic concerns and regulations have rekindled an interest in pervious concrete. Regulations such as storm water impact fees are increasing the cost of developing real estate because of the size and cost of required drainage systems (Tennis et al, 2004). The labor, construction, and maintenance cost of implementing storm water management systems, such as retention ponds, pumps, swales, and storm sewers can be substantially reduced or even eliminated with the proper construction of pervious concrete pavements. Land developers who have installed these pavements have been rewarded with more available building area.

Another economical benefit of pervious concrete presents itself to local concrete companies. Because of the low slump property of pervious concrete, the delivery time is relatively short and would create issues for contractors and owners, but for companies that operate close to the construction site, they would have the advantage over their competitors who are further away. Finally, pervious concrete has a lower maintenance cost over its life-cycle due to its durability and strength in comparison to asphalt pavements (Tennis et al, 2004).

Physical Benefits

The surface of pervious concrete possesses a peculiar texture, because its mix is comprised of gravel or crushed stone and little or no fines. The coarse aggregate texture of the pervious pavement surface improves skid resistance by removing excess precipitation during rainy days and causes snow to melt faster (Schaefer et al, 2006). The surface of pervious concrete pavements experiences some raveling which only last during the early weeks after placement (Tennis et al, 2004). Proper compaction and curing methods greatly reduce this defect. Compressive strengths range from 1000 to 4000 psi, and the possibility of drying shrinkage of the hardened concrete is lower than conventional concrete since there is less water in the fresh mix (Offenberg, 2005). Because cracking is not as prevalent in pervious concrete pavements, control joints are spaced further apart (i.e., around 20 feet from each other) (Tennis et al, 2004).

Performance and Applications

The quality and performance of pervious concrete depends on the quality of the subgrade, and the constructor's ability to correctly proportion, mix, place, finish and cure the mixture (Crouch et al, 2003). A vibrating screed is used to maximize the density and strength and a steel pipe roller is used for compaction. The pavement is immediately sealed with plastic sheeting which remains on the pavement for at least a week and the cured pervious concrete has the appearance of Rice Krispies treats (Tennis et al, 2004). The gradations of pervious concrete mixes can be adjusted to meet the desired performance requirements for a given application whether for pedestrians, vehicles, or sound absorption. The unique abilities of pervious concrete offer solutions to environmental issues, public agencies, and building owners, which allow for diverse applications in which it can be used successfully. Some of the applications for pervious concrete involve residential roads and driveways, sidewalks, parking lots, low water crossings, subbase for conventional concrete pavements, patios, artificial reefs, slope stabilization, hydraulic structures, well linings, noise barriers and many other applications exist (Tennis et al, 2004).

Fresh Concrete Properties

Fresh pervious concrete is characterized as having a very low slump of about ¾ inches; therefore, it cannot be pumped. Generally, the coated aggregates maintain a molded shape since the mix is quite sticky. With regards to achieving some level of quality control and quality assurance, unit weight measurements are the best means of doing so. A unit weight range of 100 to 125 lb/ft^3 is typical with a tolerance of $\pm$ 5% or 5 lb/ft^3. The mixing and placement time for pervious concrete is usually one hour, but it can be increased to one and one-half hours when retarders or hydration stabilizers are added (Tennis et al, 2004). Modifications to the mixing process of allowing the aggregate to rotate for 1 minute with 5% of the total cement has increased the 7-day strength of the specimens tested (Schaefer et al, 2006).

Hardened Concrete Properties

Density and Porosity

The factors affecting the density of pervious concrete relate to the aggregate properties, batching of the different components, and the compaction methods implemented. The density of the mix ranges from 100 to 125 lb/ft^3. The typical air voids reported for pervious concrete mixes in the United States range from 14 to 31% (Schaefer et al, 2006). "A pavement 5 inches (125 mm) thick with 20% voids will be able to store 1 inch (25 mm) of a sustained rainstorm in its voids, which covers the vast majority of rainfall events in the U.S. When placed on a 6-inch (150-mm) thick layer of open-graded gravel or crushed rock subbase, the storage capacity increases to as much as 3 inches (75 mm) of precipitation" (Tennis et al 2004). To measure the air content of hardened pervious concrete, a relatively new test procedure, developed for porous bituminous paving materials, has been introduced to determine the theoretical maximum and bulk specific gravity of pervious concrete, since these values are used to calculate the porosity and air voids. The instrument used is called the Instrotek Corelok System and it has been rated as the most effective means of determining the external volume of materials with surface accessible voids (Crouch et al, 2003).

Permeability

Materials and placing techniques have a significant effect on permeability. "Typical flow rates for water through pervious concrete are 3 gal/ft^2/min (288 in./hr, 120

$L/m^2/min$, or 0.2 cm/s) to 8 $gal/ft^2/min$ (770 in./hr, 320 $L/m^2/min$, or 0.54 cm/s)" (Tennis et al, 2004). Laboratory apparatus used for testing permeability are typically some form of falling head permeability set-up. This type of set-up typically includes placing a specimen in a membrane to prevent water from flowing around the sides of the specimen. Different levels of head have been tested depending on the amount of rainfall that the pervious concrete system is being designed to handle (Schaefer et al, 2006; Yang and Jiang, 2003; Neithalath et al, 2006). Figure 2.1 illustrates one example of a falling head permeability apparatus.

Figure 2.1 Falling head permeability apparatus for pervious concrete specimens (Schaefer et al, 2006)

Compressive Strength

Although the typical compressive strength of pervious concrete is approximately 2500 psi, the range of values of its strength falls within 500 to 4000 psi (Tennis et al, 2004). Drilled cores are the best means found for measuring pavement strengths in the field. However, cast cylinders have also provided adequate results in laboratory testing (Shaefer et al, 2006).

Flexural Strength

The degree of compaction, porosity and aggregate-to-cement ratio are all factors that affect the flexural strength of pervious concrete. The normal range is 150 to 550 psi (Tennis et al, 2004).

Shrinkage

The strain that develops due to the loss of water in the hardened pervious concrete occurs on a much smaller scale but at an earlier time than regular concrete. Some possible reasons for this phenomenon relate to the low volume of paste and fine aggregates. "Roughly 50 to 80% of shrinkage occurs in the first 10 days, compared to 20 to 30% in the same period for conventional concrete" (Tennis et al, 2004). Therefore, control joints may be limited or spaced further apart.

Durability

Freeze-Thaw Resistance

The level of saturation in the voids of a pervious concrete pavement is a major factor during a freeze-thaw cycle. Though it is expected that the free flow of water through the pavement would limit saturation from occurring, the possibility still exists for some level of saturation and this can lead to severe freeze-thaw damage. Tests done to resolve this problem have experienced difficulty in replicating the freeze-thaw conditions experienced in the field (e.g., the standardized ASTM 666 test). In an effort to solve the problem of damage to pervious concrete structures in cold environments, research has shown that the use of air–entraining admixtures can greatly reduce the level of damage. "In addition to the use of air-entraining agents in the cement paste, placing the pervious concrete on a minimum of 6 inches (150 mm), and often up to 12 (300 mm) or even 18 inches (450 mm) of a drainable rock base, such as 1-inch (25-mm) crushed stone is normally recommended" (Tennis et al, 2004). The addition of latex and/or up to 7% sand to the pervious concrete mix has shown improved resistance to freeze-thaw damage (Schaefer et al, 2006).

Major recommendations for the design of pervious concrete pavement in freeze-thaw areas should include factors which limit the degree of saturation, control the average maximum spacing factor, promote proper subbase layout which draws water away from the pavement and paste protection by means of air-entraining agents. An interesting observation made was that snow on pervious concrete pavements melts faster than on regular pavement because of the air voids. The National Ready Mix Concrete Association (NRMCA, 2004) submits that among the different types of freeze conditions (dry, hard dry, wet and hard wet), hard wet is the most critical of all since the ground remains frozen resulting in very low soil permeability.

Regions that experience extreme conditions can further improve drainage in the base layer with perforated PVC pipes. But for freeze-thaw areas where the ground water level rises to less than 3 feet from the surface, pervious concrete pavements are not recommended (Tennis et al, 2004).

Sulfate Resistance

Pervious concrete is quite susceptible to acid and sulfates in ground water because of the high porosity. Precautionary measures taken in such cases involve "placing the pervious concrete over a 6-inch (150-mm) layer of 1-inch (25-mm) maximum top size aggregate (Tennis et al, 2004). This subbase acts as "stormwater storage, and isolation" for pervious concrete. The other option is following the ACI 201 guidelines on w/c ratio and material quantities.

Abrasion Resistance

A well compacted and properly cured pervious concrete pavement has a reduced level of surface raveling. This breaking of weakly bonded aggregates generally occurs during the early weeks of use.

Aggregate Effects on Pervious Concrete

Research done in the past has focused on achieving the best porosities through the use of single-sized aggregate, usually ⅜ or ¾ in. or limited variations in aggregate gradations (Ghafoori, 1995). Research at Tennessee Technological University has shown that effective air voids, compressive strength and permeability are greatly influenced by aggregate (Crouch, 2007). The compressive strength is dependent on the size of the aggregate whereas the air voids depend on the gradation (Ghafoori, 1995). As the size of the aggregate decreases the area of contact increases and as a result improves the strength.

An understanding of cement paste requirement and the significance of aggregate proportion in conventional concrete can improve the understanding of paste requirements in pervious concrete. In conventional concrete, the cement paste fills the voids and coats the aggregate, whereas in pervious concrete sufficient paste is needed to just coat the aggregate and to leave the voids open, therefore the cement amount is crucial to the mix. The investigation of variations in aggregate gradation, quantity and size would clarify some of the understanding of paste requirements for pervious mix (Crouch et al, 2007).

It has been observed that the pervious concrete matrix has a tendency of failing at the cement binder layer between the aggregates. This issue is related to load transfer through relatively weak cement paste in comparison to the aggregate strength and the thickness of the layer of cement paste binder. To improve the strength of pervious concrete, the cement paste binder area has to be increased or the strength of the cement paste enhanced. Cement paste binder area can be increased by the use of smaller sized aggregate in the mix. This increases the specific surface area of the aggregate and the binder. The mature cement paste of pervious concrete has pores and microcracks within its structure. These defects are a greater concern when present in the interfacial transition zone (ITZ) which leads to much lower strengths. To remedy this problem, fine mineral admixtures and organic intensifiers are added to mix. The fine mineral admixtures reduce the size of the pores in the paste from a range of 5 to 50 μm to 0.1 to 0.2 μm and also reduce the thickness of the ITZ. The organic intensifiers improve the bond property of the cement paste and the aggregate. Mixes consisting of aggregate sizes ranging from 5 to 10 mm and 3 to 5 mm were prepared and tested in this research. Compressive test showed a strength increase with the combination of silica fume and superplasticizer when compared with only one admixture in a mix at a time. For mixes with aggregate sizes of 3 to 5 mm (#8 to #4), the compressive strengths increased from 26.7 MPa to 57.2 MPa for a compaction increase of 1.0 MPa to 2.0 MPa and hydraulic conductivity reduced from 2.9 mm/s to 1.7 mm/s (411 in./hr to 241 in./hr) (Yang and Jiang, 2002).

Mix Design and Materials

The materials used to prepare pervious concrete mixes are typical of concrete but with the exception of little or no fine aggregate added to the mix. The coarse aggregate typically follows a uniform grain distribution to achieve a void ratio that allows easy access of water to the ground (Tennis et al, 2004). The mixing process is monitored closely since deviating from the required specifications can cause undesirable results which are generally difficult to fix. The materials typically included in a pervious concrete mix design include:

- Cementitious Materials

  Portland cement, blended cement, admixtures and pozzolans (fly ash, blast furnace slag, pozzolans and silica fume) may be used in the production of pervious concrete to boost its performance (strength, and durability).

- Aggregate

  Commonly-used gradations of coarse aggregate include ASTM C 33 No. 67 (¾ in. to No. 4), No. 8 (⅜ in. to No. 16), and No. 89 (⅜ in. to No. 50) sieves (Tennis et al, 2004). Pervious concrete produced from rounded aggregate tend to possess higher strength capacities than mixtures from angular aggregate. The aggregates should generally be exposed to SSD conditions or their free water should be taken into accounted. Excess water increases slump whereas the loss of water to the aggregate during mixing can cause the mixture to be dry making it difficult to place.

- Water

  Generally a w/c ratio of 0.27 to 0.31 is used and in some instances ratios reaching 0.40 have been used successfully. There is difficulty in coming up with a distinct relationship between strength and w/c ratio since the volume of the cement paste is less than the volume of the voids. As a result, a stronger paste does not necessarily mean an increase in ultimate strength (Tennis et al, 2004).

- Admixtures

  Chemical admixtures used in the preparation of pervious concrete are retarders (ASTM C 494) and air-entraining admixtures (ASTM C 260). Because of the early set tendencies of pervious concrete and the possibility of damage caused by freeze-thaw cycles in cold climates, these admixtures are recommended. Retarders are known to increase the set time by as much as 1.5 hours (Tennis et al, 2004). Table 2.1 shows some of the typical ranges of material proportions in pervious concrete.

Table 2.1 Typical ranges of material proportions in pervious concrete (Tennis et al, 2004).

Mix Component	Proportions (lb/yd^3)	Proportions (kg/m^3)
Cementitious materials	450 to 700	270 to 415
Aggregate	2000 to 2500	1190 to 1480
Water/cement ratio (by mass)	0.27 to 0.34	0.27 to 0.34
Aggregate/cement ratio (by mass)	4 to 4.5:1	4 to 4.5:1
Fine/coarse aggregate ratio (by mass)	0 to 1:1	0 to 1:1

CHAPTER III

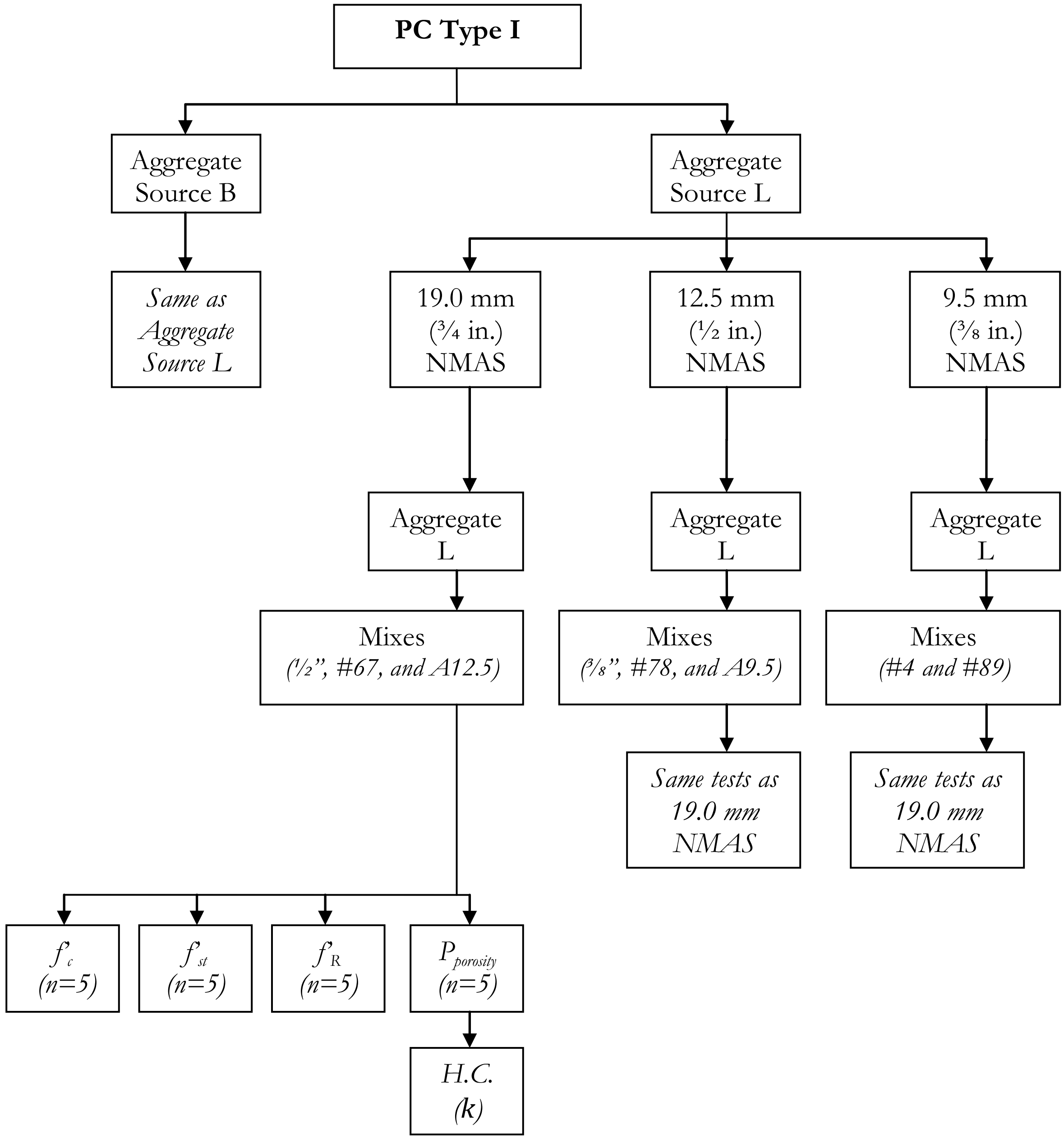
MATERIALS AND EXPERIMENTAL PROCEDURES

This Chapter provides descriptive information about the materials and procedures used to achieve the objectives of this study. Pervious concrete mixtures require careful analysis of aggregate size distribution and properties for a pavement to be capable of bearing expected loads and allowing water to drain through its matrix at a suitable rate. Another function of pervious concrete pavements relates to its filtering capabilities and the time period for which it effectively performs before it clogs with silt or debris. With these variables being considered, it was necessary to take the approach illustrated in Figure 3.1 and 3.2. This approach examined two aggregate types, from which multiple mixes of varying aggregate sizes and gradations were prepared.

Materials

Aggregate

Two aggregate types from two quarries in South Carolina were used in this study. The rock types were marble schist, aggregate B, and micaceous granite, aggregate L. Aggregate B was retrieved in sizes that are typical of dry screening sand, manufactured sand, #89M, #78 and #67. Aggregate L corresponded to sizes depicting manufactured sand, #89M, #789, and #67. The gradation specifications used in this research project followed the guidelines of ASTM C 33, ASTM D 448 and also two additional specifications A-9.5 and A-12.5 (GDOT, 2003).



where f'_c = compressive strength, (psi)
f'_{st} = split-tensile strength, (psi)
f'_R = flexural strength, (psi)
$P_{porosity}$ = effective porosity, (%) and
$H.C.$ = hydraulic conductivity, (in/hr)

Figure 3.1 Experimental Design for Phase I.

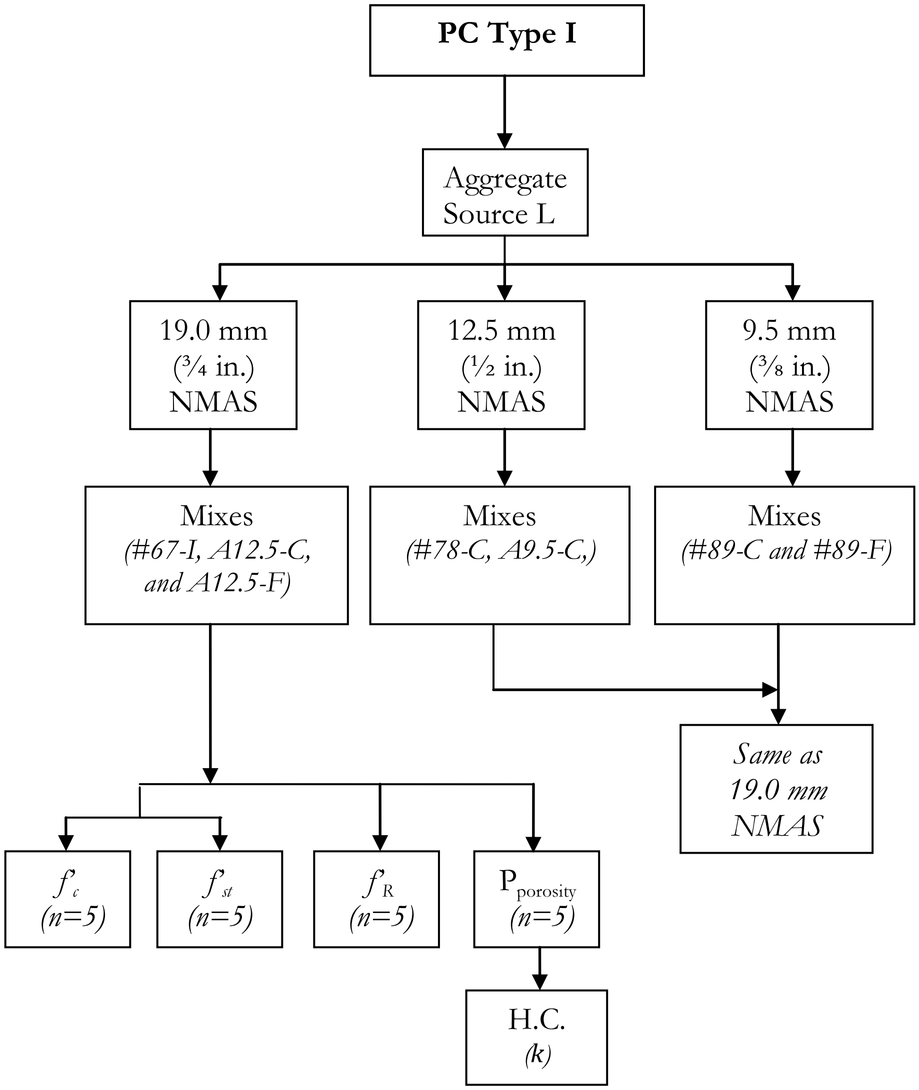


Figure 3.2 Experimental Design for Phase II.

Before the majority of the tests in this research were performed, the aggregates were oven dried and separated with a mechanical sieve machine into single-sized aggregates retained on the ½ in., ⅜ in., #4, #8, and #16 sieves. Some of the early tests conducted involved the determination of the percent finer than the 75 μm (#200) sieve (ASTM C 117), sieve analyses (ASTM C 136), specific gravity and absorption of coarse and fine aggregate (ASTM C 127 & C 128), and the L.A. abrasion test (ASTM C 131). These graduation tests were conducted to verify aggregate characterization against those provided by the suppliers. These results are shown in Table 3.1.

Table 3.1 Summary of aggregate properties.

Test Description	**ASTM Designation**	**Aggregate Source**	
		Aggregate B (Coarse)	**Aggregate L (Coarse)**
Absorption (%)	C 127	0.4	0.6
LA Abrasion (% loss)	C 131 (Grade B)	27.8	51.9
Specific Gravity (Bulk)	C 127	2.80	2.65
Specific Gravity (SSD)	C 127	2.81	2.66
Specific Gravity (App.)	C 127	2.83	2.69

Table 3.1 shows that aggregate B had a lower absorption capacity compared with aggregate L. It is also realized, based on the L.A. Abrasion test, that the aggregate from source B was significantly tougher than the aggregate from source L. Additionally, aggregate B has a greater specific gravity than that from source L.

Cement

The cement used in this project was general purpose Type I Portland cement. It was manufactured by LaFarge Building Materials Inc. of Harleyville, South Carolina to meet the requirements of ASTM C150. The typical chemical and oxide composition and chemical and physical properties of the cement used for all of the pervious concrete samples are given in Table 3.2.

Table 3.2 Chemical and oxide composition and properties of the Type I Portland cement used (LaFarge North America, 2004).

Chemical Composition/Properties		Oxide Composition	
Chemical	**Weight Percent**	**Oxide**	**Weight Percent**
C_3S	63.0	CaO	62.5
C_2S	11.0	SiO_2	20.6
C_3A	7.0	Al_2O_3	5.0
C_4AF	10.0	Fe_2O_3	3.4
Autoclave Expansion	0.08	MgO	1.2
Insoluble Residue	0.17	SO_3	2.8
Loss on Ignition	1.3	Na_2O eq.	0.29

Methods

Mix Design

The mix design for each pervious concrete batch had a target unit weight of 125 lb/ft^3 (2002 kg/m^3) and a cement-to-aggregate ratio of 0.22 as recommended from the literature review (Tennis et al, 2004). A water-to-cement ratio of 0.29 (exclusive of aggregate absorption) was determined by performing an experimentation mix with #89 aggregate from source B. The water-to-cement ratio was kept constant throughout this research project, which led to the assumption that a mixture that was pasty in nature was an indication of lower water demand. This was observed in aggregate gradations that consisted of a higher proportion of coarse aggregate. Because the maximum specific gravity test (ASTM D 2041) needed to be conducted for each batch of the pervious concrete mix, an additional 3,000 g (6.61 lb.) of mix was included in the calculation along with 10% of the total mass of the concrete as specified in the standards for making and curing concrete, ASTM C 192. The total mass of the aggregate in each mixture was calculated based on a block diagram deduction. Typically, aggregates occupy 70 to 80% of the volume of conventional concrete, but for the pervious concrete mixes, it was found to occupy 56 to 59% of the volume (Mindess et al, 2003). Because aggregate L had a lower specific gravity compared to aggregate B, it occupied a greater volume of the mix. All volumetric and weight proportions of each pervious concrete component are shown in Table 3.3.

Table 3.3 Proportions of the components in the pervious concrete mixes. *(Water-cement ratio was 0.29 and cement-aggregate ratio was 0.22)*

Pervious Concrete Components	**Volume (ft^3 or m^3)**		**Weight Density**	**Mass Density**
	Source B	**Source L**	**(lb/ft^3)**	**(kg/m^3)**
Air	0.24	0.21	0	0
Water	0.10	0.10	6	96
Cement	0.11	0.11	22	352
Aggregate	0.56	0.59	97	1554
Total	1.00	1.00	125	2002

Aggregate Proportioning

This research project was conducted in two (2) phases. The first phase (Phase I) examined the two (2) different aggregate types (B and L) by preparing a set of eight (8) mixes for each source. The second phase (Phase II) examined the aggregate gradations of one aggregate type, aggregate L, with gradations that were different from the Phase I but comparisons were made with the gradations from Phase I that consisted of aggregate L. Phase I aggregates were proportioned according to the intermediate aggregate specification that corresponded with the selected aggregate gradations. These aggregate gradations fit the specifications of the single-sized ½ inch, #67, A12.5, single-sized ⅜ in., A9.5, #78, single-sized #4, and #89 but with no material passing the #16 sieve. Aggregates from different sources were never blended in this study. But an examination of different gradations revealed that the uniformity coefficient (C_u) dominated the effects of aggregate gradation where this parameter is defined as

$$C_u = \frac{D_{60}}{D_{10}} \tag{3.1}$$

where D_{60} = the diameter of aggregate corresponding to 60% finer and
D_{10} = the diameter of aggregate corresponding to 10% finer.

New C_u values were used as a basis for proportioning aggregate L in Phase II. The new gradations were designed using those in Phase I as a guide, but provided different C_u values, across a wide range. The aggregate gradations that resulted in new C_u values along with the gradations from Phase I were all categorized in three (3) groups based on common nominal maximum aggregate sizes (NMAS). The NMAS used in this study was defined in accordance to asphalt standards as one size larger than the first sieve to have less than 90%

passing (Asphalt Institute, 2001). The aggregate gradations were all categorized based on their nominal maximum aggregate size and their coefficient of uniformity, D_{10}, D_{60} as well as their dry unit weight values are shown in Tables 3.4 through 3.6. The dry rodded unit weight test (ASTM C 29) measures the density of the aggregates and also presents an opportunity to compare voids loss due to the cement paste coating the aggregate. It is quite noticeable that the dry rodded unit weights followed the expected trend of being greater for the aggregates from source B than those from source L, since they were a denser rock. Figures 3.3 through 3.5, illustrate the gradation of each aggregate mix.

Table 3.4 Categorization of aggregate gradations and proportions according to a NMAS of ⅜ in. *(DRUW = dry rodded unit weight)*

Sieve Size	(mm)	#4 Percent passing (%)	#89-C Percent passing (%)	#89 Percent passing (%)	#89-F Percent passing (%)
1"	(25.4)	100	100	100	100
¾"	(19.05)	100	100	100	100
½"	(12.7)	100	100	100	100
⅜"	(9.5)	100	90	95	100
#4	(4.75)	0	20	34	53
#8	(2.36)	0	5	13	26
#16	(1.18)	0	0	0	0
D_{10} (mm)		5.1	3.0	2.0	1.6
D_{60} (mm)		7.2	7.0	6.4	5.3
C_u		1.41	2.34	3.20	3.28
DRUW	Source B	101	-----	106	-----
(lb/ft^3)	Source L	96	100	102	99

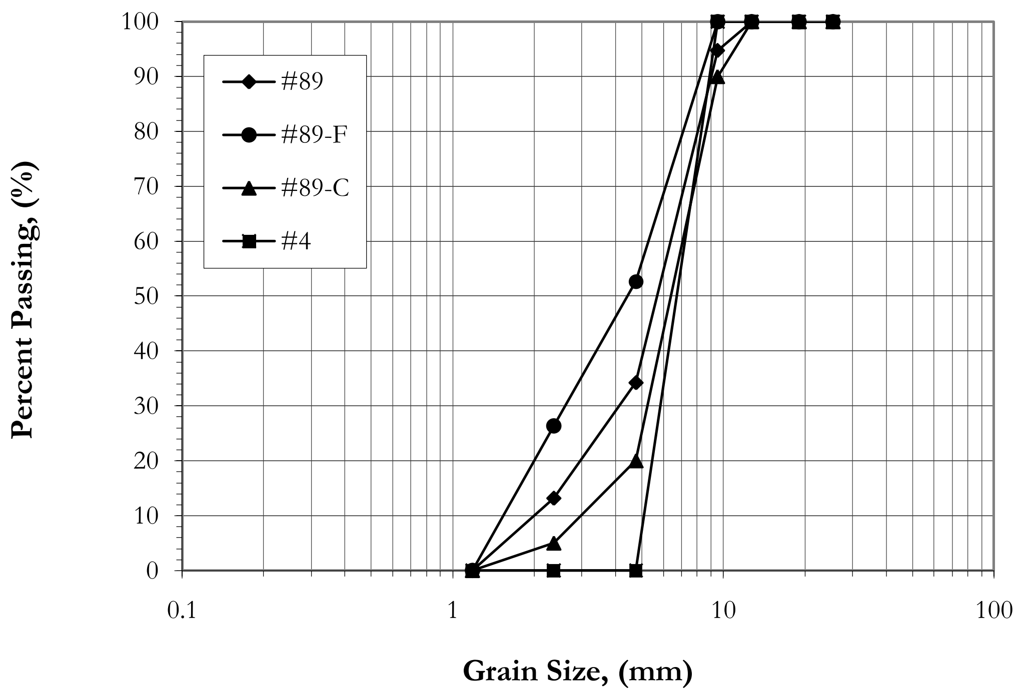


Figure 3.3 Sieve analyses for aggregate gradations with a NMAS of **⅜ in**.

Table 3.5 Categorization of aggregate gradations and proportions according to a NMAS of ½ in. *(DRUW = dry rodded unit weight)*

Sieve Size	(mm)	⅜ in. Percent passing (%)	#78-C Percent passing (%)	A9.5-C Percent passing (%)	A9.5 Percent passing (%)	#78 Percent passing (%)
1"	(25.4)	100	100	100	100	100
¾"	(19.05)	100	100	100	100	100
½"	(12.7)	100	95	100	100	95
⅜"	(9.5)	0	58	85	93	58
#4	(4.75)	0	15	20	30	15
#8	(2.36)	0	5	5	7	5
#16	(1.18)	0	0	0	0	0
D_{10} (mm)		9.8	5.3	3.0	2.6	3.4
D_{60} (mm)		11.8	10.9	7.3	6.6	9.7
C_u		1.20	2.07	2.43	2.53	2.83
DRUW	Source B	102	-----	-----	105	108
(lb/ft^3)	Source L	99	101	102	102	102

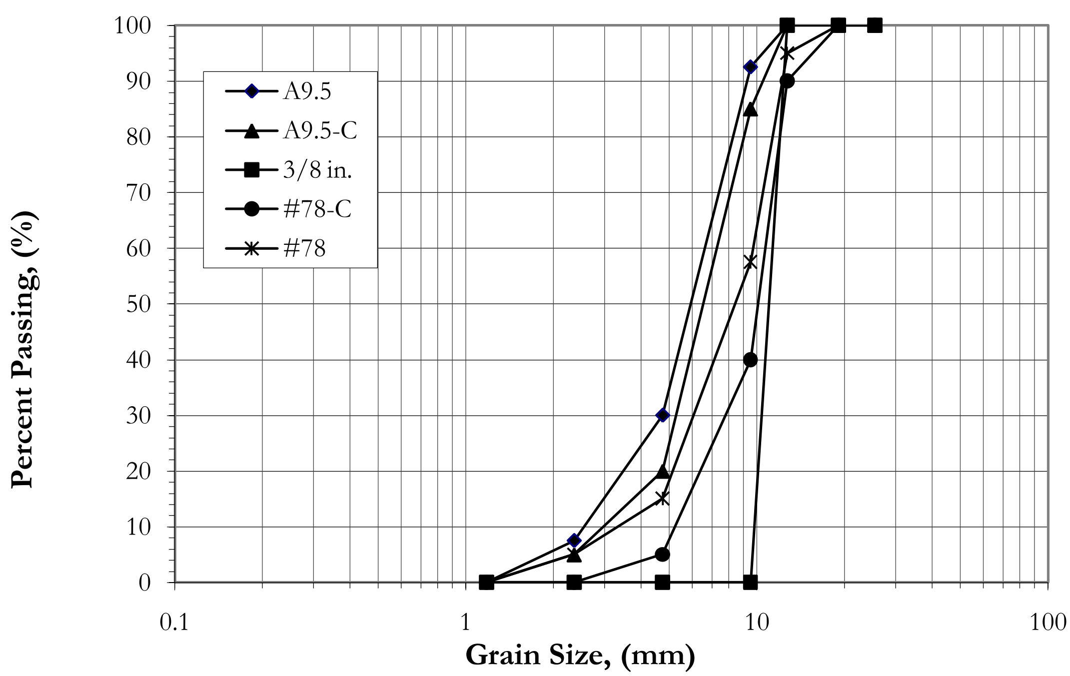


Figure 3.4 Sieve analyses for aggregate gradations with a NMAS of ½ in..

Table 3.6 Categorization of aggregate gradations and proportions according to a NMAS of ¾ in. *(DRUW = dry rodded unit weight)*

Sieve Size	(mm)	½ in. Percent passing (%)	#67-I Percent passing (%)	#67 Percent passing (%)	A12.5-C Percent passing (%)	A12.5 Percent passing (%)	A12.5-F Percent passing (%)
1"	(25.4)	100.0	100.0	100.0	100.0	100.0	100.0
¾"	(19.05)	100.0	100.0	100.0	100.0	100.0	100.0
½"	(12.7)	0.0	77.0	66.0	85.0	92.0	100.0
⅜"	(9.5)	0.0	55.0	38.0	55.0	65.0	75.0
#4	(4.75)	0.0	0.0	5.0	15.0	20.0	25.0
#8	(2.36)	0.0	0.0	3.0	5.0	8.0	10.0
#16	(1.18)	0.0	0.0	0.0	0.0	0.0	0.0
D_{10} (mm)		14.0	5.4	5.3	3.5	2.8	2.4
D_{60} (mm)		16.9	10.1	12.6	10.0	8.8	7.8
C_u		1.20	1.87	2.36	2.89	3.18	3.23
DRUW	Source B	101	-----	106	-----	109	-----
(lb/ft^3)	Source L	100	101	103	103	104	102

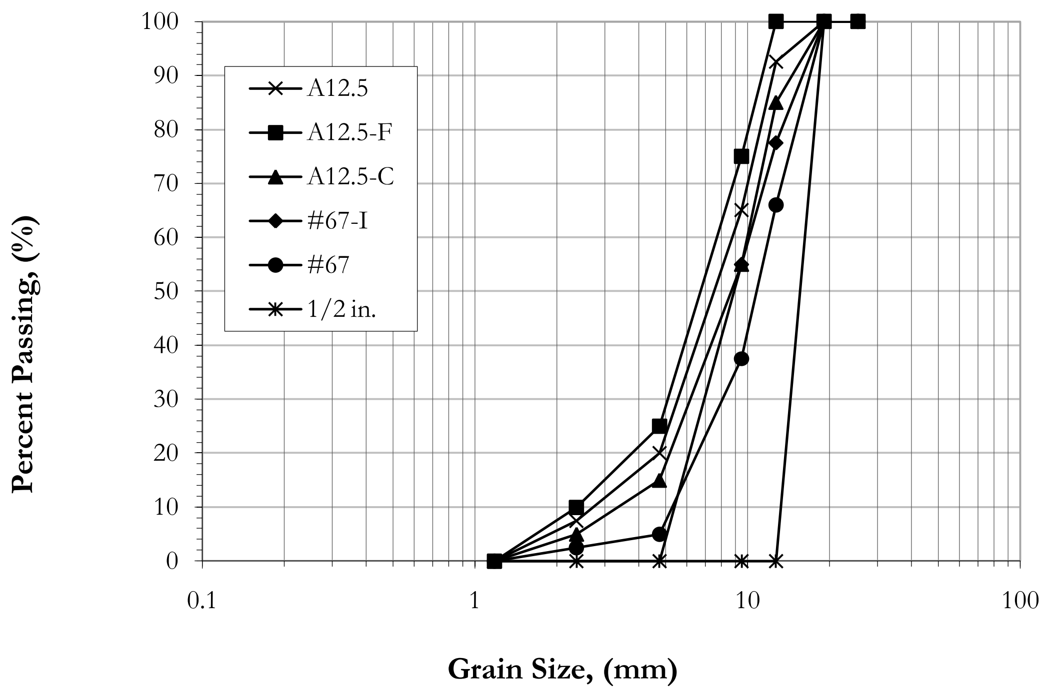


Figure 3.5 Sieve analyses for aggregate gradations with a NMAS of ¾ **in**.

Mixing and Curing Techniques

The mixing and curing procedures were done in accordance to ASTM C 192, but with one adjustment. This adjustment included the addition of approximately 5% of the cement to the aggregate which was allowed to rotate for one minute to initiate the coating of the aggregate with cement and improve bonding (Schaefer et al, 2006). Each pervious concrete batch size was approximately 0.83 ft^3 (0.03 yd^3) and it was prepared in a concrete mixer capable of mixing 1.5 ft^3 of concrete per batch. The first set of batches was prepared from aggregate B, then from aggregate L, which was prepared with identical gradations as aggregate B. The final set was prepared from aggregate L but with new uniformity coefficients to the others made prior it.

A total of 460 specimens were made for this research project, not including those prepared for preliminary studies. Of these 460 specimens, 345 were cylinders 3 in. in diameter × 6 in. tall (75 × 150 mm), and 115 were prisms 3 in. × 3 in. × 12 in. (150 × 150 × 300 mm). These specimens were consolidated by rodding and also by means of a vibrating table (for a period of 10 seconds) after placing each of the two layers within the molds. When consolidation was complete, the remaining concrete was placed in two (2) plastic tubs and cured until 28 days before the maximum specific gravity (ASTM D 2041) of the mix was determined. The concrete specimens were covered with plastic and placed in a wet curing room equipped with a sprinkler that generated a constant mist and maintained a temperature of approximately 23.7 °C (73.4 °F). At some time just prior to final set, the pervious concrete in the plastic tubs was stirred and separated into individually coated aggregate particles and left to cure. After 24 ± 8 hours, the specimens were removed from their molds and they were kept in the curing room until 28-days before testing.

Specimen Testing

Strength Test

A variety of tests were performed on the specimens to account for strength, density, air voids, porosity and permeability. The standard compressive, split-tensile and flexural strength tests were performed on the relevant specimens as documented in ASTM C 39, ASTM C 496 and ASTM C 78, respectively. A total of twenty (20) specimens were made of each specific aggregate gradation. Of the twenty specimens, five (5) were 3 × 3 × 12 in. beams for the flexural strength and the remainder were 3 × 6 in. cylinders. The top ends of the cylindrical specimens were leveled for testing by sawing off ¼ inch. The new heights along with the diameters of the cylinder were measured and recorded for computational purposes.

Density, Air Voids, and Porosity Test

The density tests consisted of three primary test procedures: the unit weight (ASTM C 138), the maximum specific gravity test (ASTM D 2041) and the Corelok automatic vacuum sealing test (ASTM D 6752 and D 7063). The fresh unit weight test was performed on the pervious concrete immediately after mixing and the actual density of the mixture was determined which normally has a tolerance of plus or minus 5 lb/ft^3 (80 kg/m^3)of the designed unit weight based on the literature (NRMCA, 2004). The maximum specific gravity test, ASTM D 2041 (Rice Test), although specified for bituminous paving mixtures according to the ASTM standard, was deemed valid since pervious concrete is a relatively new concept for which specific standards are still being tested and developed. Also, loose matured cement coated pervious concrete aggregate is similar in form as loose porous asphalt or a bituminous paving mixture which is essentially loose aggregate coated with binder which compares to the loose aggregate coated with cement paste. The loose cement coated aggregate was oven-dried and a minimum mass of 1500 g (each was placed in two (2) metal bowls. The sample weights were taken and water with a temperature of approximately 25 °C (77 °F) was added to the bowls to completely cover the samples. The two bowls were placed on the mechanical agitation device and the air trapped in the sample was removed and later the bowl and sample submerged weight were recorded as documented in the ASTM D 2041 standard, Section 9.4 through 9.5.1. Calculations for the maximum specific gravity were conducted based on the bowls used under water determination:

$$G_{mm} = \frac{A}{A-(C-B)} \tag{3.2}$$

where G_{mm} = maximum specific gravity of the mixture,
A = mass of the dry sample in air, g,
B = mass of bowl under water, g, and
C = mass of bowl and sample under water, g.

The effective porosity test is another test that is specified for bituminous paving mixtures but similar reasoning was applied in validating this test for the pervious concrete samples (ASTM D 7063)). The effective porosity of a specimen is the total amount of interconnected voids that allows water to saturate the specimen from its surfaces (ASTM D 7063). The pervious concrete specimens were oven-dried prior to testing. Their dry weights were measured and recorded and the weights of the plastic bags in which the specimens were to be sealed were also recorded. The bagged specimens were then placed in the Corelok vacuum chamber to be sealed. The sealed specimens were inspected to confirm proper vacuuming. The submerged weights of the sealed specimens were measured by placing them in the water bath equipped with a scale. The calculations involved in computing the percent porosity involves the calculation of the bulk specific gravity and the apparent specific gravity as follows:

$$BSG = \frac{A}{B - E - \frac{B - A}{F_T}} \tag{3.3}$$

where BSG = bulk specific gravity
A = mass of dry specimen in air, g,
B = mass of dry sealed specimen, g,
E = mass of sealed specimen underwater, g, and
F_T = apparent specific gravity of plastic sealing material at 25 ± 1°C (77 ± 2°F), when sealed, provided by the manufacture.

$$ASG = \frac{A}{B - C - \frac{B - A}{F_{T1}}} \tag{3.4}$$

where ASG = apparent specific gravity
C = mass of unsealed specimen underwater, g, and
F_T = apparent specific gravity of plastic sealing material at 25 ± 1°C (77 ± 2°F), when opened under water, provided by the manufacture
.

$$\%\ Porosity = \frac{ASG - BSG}{ASG} \times 100 \tag{3.5}$$

The % air voids within the specimen were also calculated based on the maximum specific gravity test and the bulk specific gravity calculated from performing the Corelok test in the form

$$\%\ Air\ Voids = \left(1 - \frac{BSG}{G_{mm}}\right) \times 100 \tag{3.6}$$

where G_{mm} = maximum specific gravity.

Permeability Test

One of the most crucial tests used in the selection of an aggregate gradation that qualifies for pervious concrete mixes is the permeability test. Again, the lack of specifications has left allowance for innovative techniques for measuring this criterion. The literature review has revealed that it was common practice to use a falling-head apparatus to measure hydraulic conductivity (Kevern et al, 2005). An arrangement of the falling-head permeability test used in this research is shown in Figure 3.6.

The preparation of each specimen for the permeability test first involved sawing off of ¾ in. on each end of the specimen, resulting in a total height of 4.5 inches. Then the sides of the specimen were sealed off with petroleum jelly to prevent water from flowing down the sides. The specimens were then slid into a rubber membrane and rubber bands were used on the outside of this membrane at the bottom, middle, and at the top to prevent slippage and probable leaks along the sides. The sealed sample was placed into the specimen holder at the bottom of the standpipe. The standpipe was attached to the specimen holder by a rubber pipe coupling. The standpipe had a diameter of 3 in. (75 mm) and had 3 in. divisions marked down the front, beginning at a head level of 15 in. (380 mm) to 3 in. above the specimen. These different head levels were included to better predict the permeability of a specific pervious concrete gradation for a wide range of rainfall intensities. Water was then pumped into the bottom chamber and allowed to saturate the pervious concrete specimen to a level above the specimen, after which the side valve was closed and the stand pipe was filled. The water was allowed to flow through the specimen by opening the bottom valve and at the initial head difference of 15 inches above the specimen the timer was started and recorded at every 3 inch interval until it came to the final 3 inch head difference. This process was repeated four (4) times for each specimen to allow the flushing of the specimen pores. The hydraulic conductivity (k) of the specimens was calculated for the head differences of 12 in., 9 in., 6 in., and 3 in. by the following equation (Das, 2002):

$$k = \frac{aL}{At} \log_e \frac{h_1}{h_2} \tag{3.6}$$

where k = hydraulic conductivity
a = cross-sectional area of the standpipe
L = length of the specimen
A = cross-sectional area of the pervious concrete specimen
t = duration of flow
h_1= initial head difference
h_2= final head difference

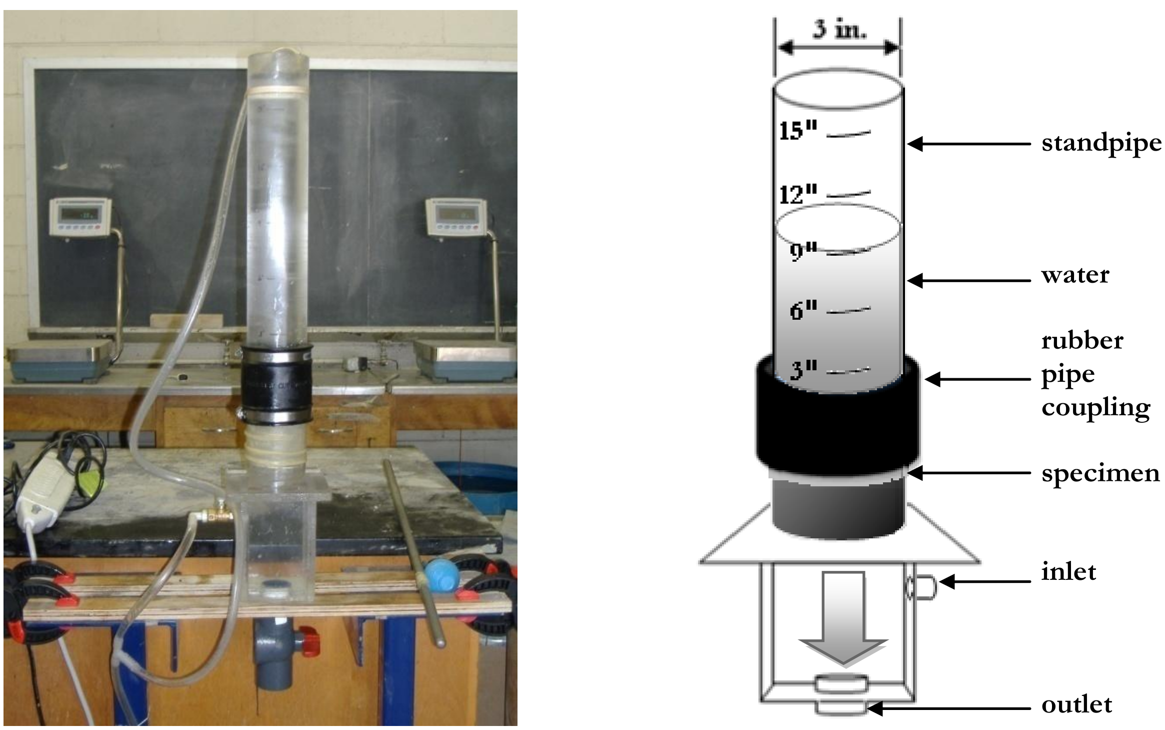


Figure 3.6 Falling-head permeability test setup: (a) photograph and (b) schematic.

CHAPTER IV

EXPERIMENTAL RESULTS AND DISCUSSION

In this Chapter, the experimental results are presented with discussions that provide an interpretation of the results. Statistical analyses of the results were tabularized to aid in understanding the extent of variance revealed in the pervious concrete mixtures when various properties were tested. These properties involved the density, strength, percent air voids and porosity, and permeability.

The experimental design for this study featured two Phases, with Phase I investigating the effects on pervious concrete mixtures based on the two aggregate sources, referred to as B and L, and with Phase II focusing on the effects of additional aggregate gradations of a single source (aggregate L). In this Chapter, both phases were consolidated for simplicity. Therefore, the effects of the eight (8) mixes prepared from aggregate B were compared and contrasted with the effects of the fifteen (15) mixes prepared from aggregate L. Aggregate L was used to prepare eight pervious concrete mixes of identical gradation as aggregate B, and seven additional mixes that were based off of new uniformity coefficients. The impact that the aggregate properties and gradation have on pervious concrete mixes will be examined in the results presented.

Pervious Concrete Unit Weight

One of the key factors of a pervious concrete mix is unit weight. Since there has been limited research conducted on pervious concrete, there is no officially standardized test procedure to measure unit weight, except those published by individual researchers.

However, one of best measures for quality control of pervious concrete mixtures is the unit weight test. The guidelines for determining whether a mix should be accepted or not, rest on a tolerance factor of ± 5% or 5 lb/ft^3 (80 kg/m^3) of the design unit weight (Tennis et al, 2004). As a result of the emphasis placed on the unit weight, the common compaction process, along with another possible method were analyzed when performing the unit weight test for fresh pervious concrete mixes in this study.

Fresh Concrete Unit Weight Determined by Jigging and Rodding

There are different methods of compacting concrete for the standard unit weight test. Although it is a regular practice to compact pervious concrete by the jigging method in ASTM C 29 (NRMCA, 2004), an alternative method of compaction, rodding, was investigated to see why it is not used in testing the unit weight of pervious concrete. ASTM C 138 recommends rodding for concrete with slumps of 3 in. (75 mm) or greater and vibration for concrete with slumps less than 1 in. (25 mm). The fact that pervious concrete is not considered to have a slump and its composition is different from regular concrete (i.e. no fines) can factor in why rodding is not practiced for the pervious concrete unit weight test. ASTM C 29 recommends jigging to compact aggregates with a nominal maximum size greater than 1½ in. (37.5 mm) but not greater than 5 in. (125 mm). Neither recommendation makes it clear as to why the jigging method is more suited for pervious concrete unit weight testing, but it can be assumed from ASTM C 29 that jigging applies greater impact on the mix since it is recommended for larger aggregate sizes. Although each method of compaction was done once and not three times as is standardized for validity, the trends observed suggested reasons why jigging is preferred over rodding for pervious concrete mixtures.

At first, it was observed that there was little difference in the results generated by the two methods of compaction. The results of unit weights performed by jigging and rodding are shown in Table 4.1. Figure 4.1 shows how the two methods compare with each other in relation to a design unit weight of 125 lb/ft^3. It was realized that the gradations with finer aggregate (4.75 mm and smaller), were less affected by the type of compaction method used. Other factors such as the type of gradation (well graded, or not well graded), the shape of the aggregate (rounded or flat), and the time span between completion of mixing and compaction (pervious concrete sets earlier than conventional concrete) can affect normal trends. Jigging resulted in higher unit weight for mixes with gradations of lower nominal maximum aggregate sizes (NMAS), such as the #89 and the #4 gradations, whereas rodding produced higher unit weights for the higher NMAS mixes, such as the ½ in. and the ⅜ in. gradations. From the sieve analyses presented in Chapter II, the A12.5 mix bears the characteristics of a relatively well graded mix. As a result of it being well graded, it was compacted beyond the target unit weight when jigged. This led to the assumption that jigging performs well for aggregate gradations that are not well graded; hence it is a common practice to use the jigging method in performing the unit weight test for pervious concrete, which is in most cases not prepared from a well graded distribution of aggregate sizes. Overall, the jigging method resulted in unit weights that were closer to the design unit weight than rodding. Rodding did, however, generate results that were closer to the target unit weight for gradations consisting of higher proportions of coarse aggregates.

Table 4.1 Summary of unit weights for pervious concrete mixes each determined by both jigging and rodding.

NMAS	Mix	C_u	Unit Weight Jigging (lb/ft³)	Unit Weight Rodding (lb/ft³)
⅜ in.	#4	1.41	120	119
	#89-C	2.34	121	119
	#89	3.20	126	123
	#89-F	3.28	119	118
½ in.	⅜ in.	1.20	122	124
	#78-C	2.07	121	124
	A-9.5C	2.43	123	120
	A9.5	2.53	125	125
	#78	2.83	125	126
¾ in.	½ in.	1.20	118	121
	#67-I	1.83	123	125
	#67	2.36	126	126
	A-12.5C	2.89	125	124
	A12.5	3.18	129	127
	A-12.5F	3.23	125	124

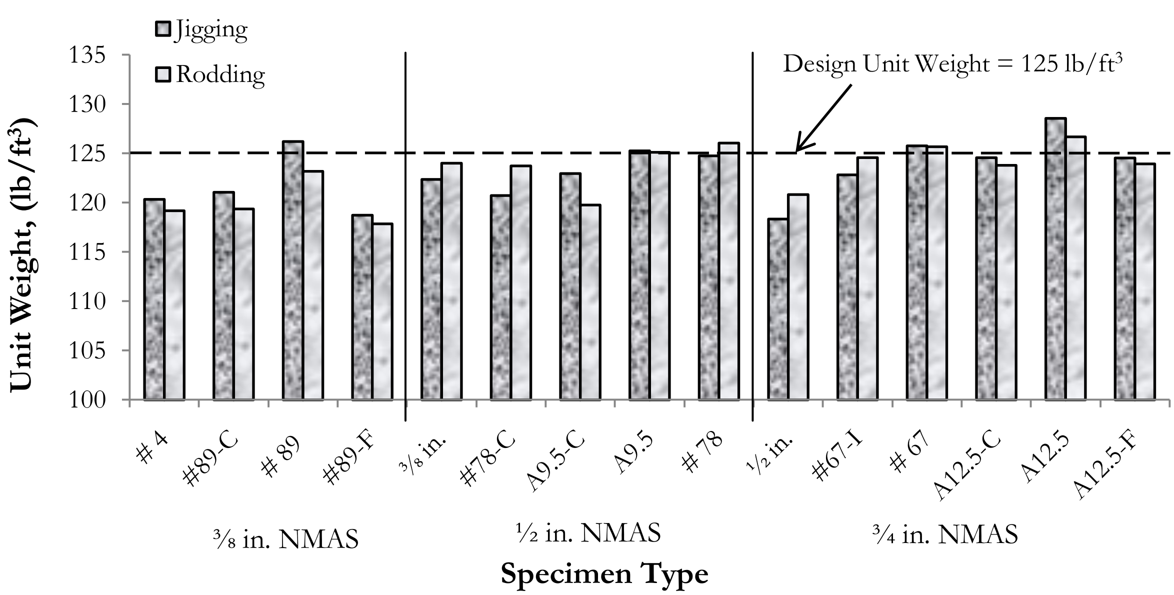


Figure 4.1 Comparison of unit weight tests that were conducted by the rodding and jigging methods for pervious mixtures prepared from aggregate B and L.

Aggregate Dry Rodded Unit Weight and Fresh Concrete Mix Unit Weight

The dry rodded unit weights of the aggregates and fresh mix unit weights of each pervious concrete mixture from both sources, B and L, were plotted in Figure 4.2. As expected, the unit weight of the fresh concrete increased as the dry rodded unit weight of the aggregate increased. Also, the dry rodded unit weight of aggregate B was higher than aggregate L, which had a lower bulk specific gravity. The correlation between the unit weights for aggregate B was very weak, whereas aggregate L had a stronger correlation that would give a more accurate prediction of the unit weight based on a known dry rodded unit weight and aggregate gradation. A deduction that can be made from the unit weight correlation relates to the percent of air voids lost to the addition of the other ingredients to the pervious concrete mix, such as cement and water. The trend established when both aggregate sources were treated as a single source was true to the fact that as the dry rodded unit weight increase so did the fresh concrete unit weight.

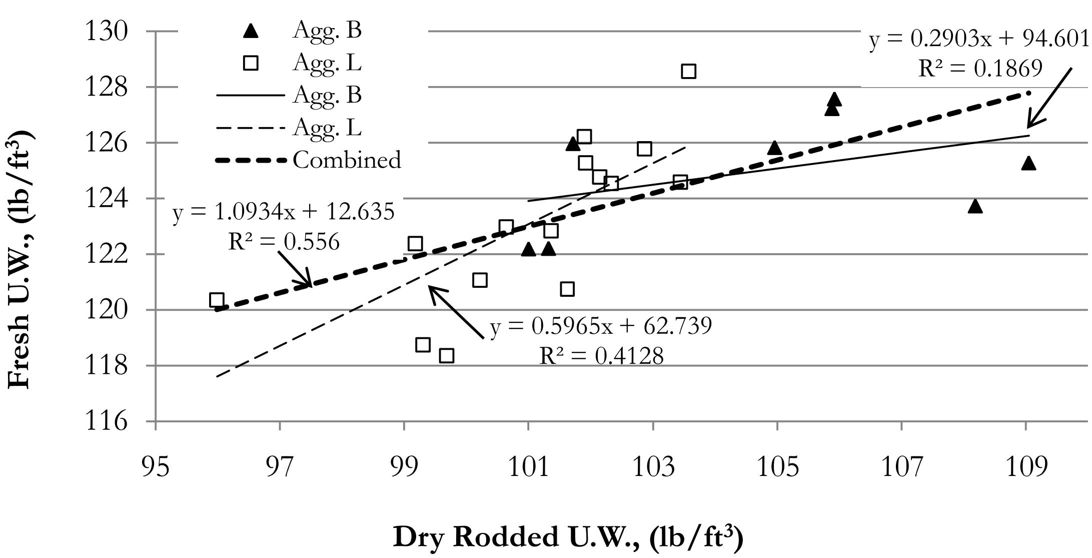


Figure 4.2 Correlation between aggregate dry rodded unit weight and fresh unit weight for pervious mixtures prepared from aggregates B and L.

Pervious Concrete Strength Analysis

The pervious concrete strength tests conducted in this research involved the compression, split-tensile and the flexural strength tests. A total of eight (8) mixes prepared from aggregate B were tested along with a total of fifteen (15) mixes prepared from aggregate L. The specimens tested had dimensions of 3 × 6 in. for cylinders and 3 × 3 × 12 in. for beams. The specimens were placed in a wet curing room for a 28-day period before strength tests were conducted as specified in ASTM C 39. When the specimens were examined after they were broken, it was found that the majority of the failures occurred because of the aggregates and not because of the cement paste. The mixes are categorized according to NMAS, which was defined in Chapter III. Column and scatter plots are used to present the results.

Compressive Strength Analysis

The compressive tests were conducted on five (5) specimens from each pervious concrete mix. The results of the compressive tests are shown in Table 4.2. Figure 4.3 illustrates the compressive strength trends and categorizes the specimens into groups according to the NMAS. The specimens prepared from aggregate B were prepared first and it was observed that the mix with the greatest proportion of finer aggregate, such as the #89 mix, generated the highest compressive strength which was 2258 psi (16 MPa). The single-sized aggregates, such as the ½ in., ⅜ in., and the #4 gradation mix were on the lower end of the compressive strength scale. The blended or mix graded specimens had higher strengths, as expected since there is a general tendency for gradations with wider distribution of aggregate sizes to increase in area of contact and to improve bonding between the cement paste and the aggregate.

A series of batches were prepared from aggregate L which had the identical gradation as aggregate B, followed by an additional seven mixes that were prepared based on new uniformity coefficients. When the specimens from those mixes were tested, a lower compressive strength was expected but the opposite was observed. Aggregate L was not as tough as aggregate B based on the LA abrasion test (B = 28% loss, L = 52% loss), but its strengths were higher than those of aggregate B. Possible reasons for this related to the lower air content of the mix as determined in Chapter III, the more cubical shape of the aggregate L particles or over consolidation. Although the strengths were higher, the trends were similar to aggregate B. Based on equal weights of aggregates B and L, L generally produced higher compressive strengths. This is likely due to the difference in the volume proportions of the mixtures resulting from the difference in the specific gravity of each aggregate. Another series of concrete batches were made from aggregate L with new gradations developed from new uniformity coefficients. From those final mixes, the specimens that produced the higher compressive strengths were those made from the relatively well graded gradations within the highest NMAS (¾ in.), such as the A12.5-C and A12.5-F. It was also observed that the compressive strength increased with the uniformity coefficient to a point after which a decrease in strength was observed. This could indicate the presence of an optimum C_u for compressive strength.

Table 4.2 Summary of compressive strengths for pervious concrete specimens B and L.

NMAS	Mix	C_u	Compressive Strength B (psi)	Standard Deviation (psi)	Compressive Strength L (psi)	Standard Deviation (psi)
⅜ in.	#4	1.41	1339	160	1957	253
	#89-C*	2.34	---	---	1659	171
	#89	3.20	2258	77	2943	321
	#89-F*	3.28	---	---	1975	35
½ in.	⅜ in.	1.20	1683	251	1938	210
	#78-C	2.07	---	---	1813	101
	A-9.5C	2.43	---	---	1961	97
	A9.5	2.53	1797	182	2701	544
	#78	2.83	1693	153	2497	38
¾ in.	½ in.	1.20	1218	221	1896	324
	#67-I*	1.83	---	---	1886	241
	#67	2.36	1780	243	2054	277
	A-12.5C	2.89	---	---	2132	263
	A12.5	3.18	2108	132	2608	72
	A-12.5F	3.23	---	---	2051	195

*The 'C', 'F's and the 'I' behind the mixes represent gradation generated from the coarser or finer boundaries or across the aggregate specification range.

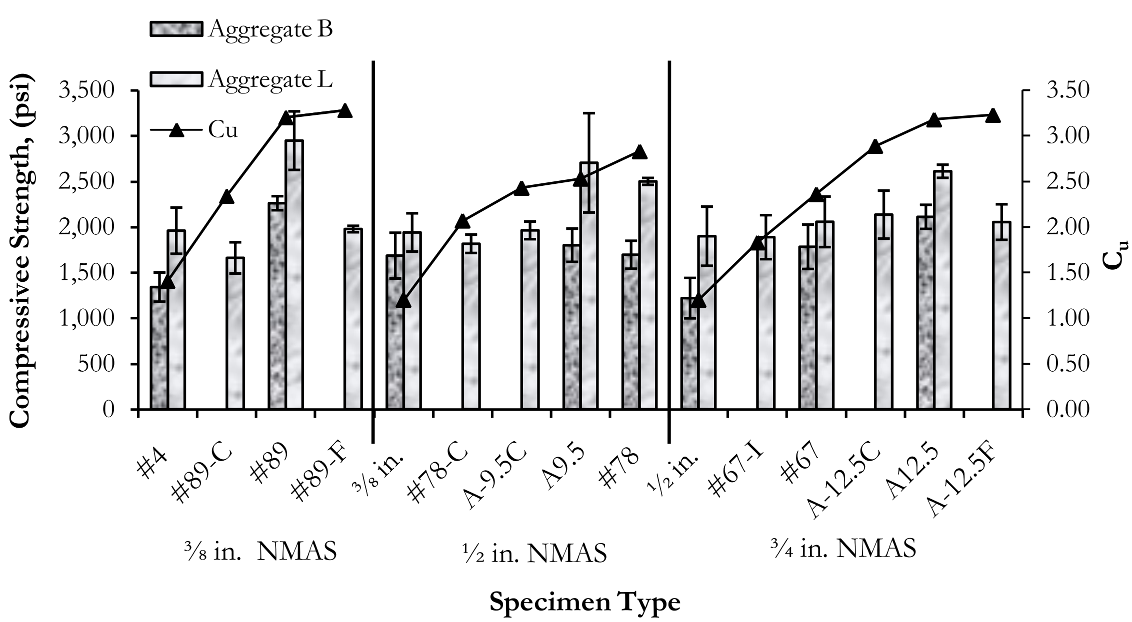


Figure 4.3 Compressive strength for pervious concrete spencimens prepared from aggregate B and L and separated based on NMAS.

Statistical Analysis for Compressive Strengths

The comparison of compressive strengths for each aggregate source within a common gradation revealed significant differences as shown in Table 4.3. The compressive strengths for the specimens prepared from aggregate L, with the same aggregate gradation as aggregate B, were all higher than those of aggregate B. Since the bulk specific gravity and toughness of the aggregates from source L were lower than those of aggregate B, the strengths were expected to be lower. The final series of batches were prepared with aggregate L and the gradations were either on the coarser or finer boundaries of the aggregate specifications and even across the specified aggregate range for concrete, to match desired uniformity coefficient. The first set of mixes from aggregate L possessed gradations that matched the intermediate section of the specifications. The strengths of particular mixes with gradations that were derived along the coarse and fine specification boundaries were examined to find the compressive strengths of the intermediate mixes surpassing their boundary mixes. In the case of the L #89, it produced a compressive strength of 2943 psi (20 MPa) whereas the L #89-C (coarse boundary gradation) produced 1659 psi (11 MPa) and the fine L #89-F produced 1975 psi (14 MPa). Another example of this was found in the ¾ in. NMAS grouping where the L A12.5 produced a compressive strength of 2608 psi (18 MPa), the L A12.5-C produced 2132 psi (15 MPa) and the L A12.5-F, 2051 psi (14 MPa). From these examinations, came some indication that the results had been affected by some element of the making, casting and curing process.

The mixes were also analyzed within the NMAS and within their individual sources to identify the mix that exemplified an effective gradation with regard to compressive strength. Another significant aspect of this analysis is to assist in the design of pervious concrete mixes when a substitute aggregate gradation has to be used to meet a required performance. This analysis was based on compressive strengths, the NMAS, and t-test groupings. For the NMAS of ⅜ in., aggregate B #89 exhibited the highest compressive strength and the single-sized #4 the lower strength. The aggregate L #89 produced the highest strength and #89-C the lowest strength. The NMAS of ½ in. had the aggregate B mix A9.5 with the highest strength and the single-sized ⅜ in. mix the lowest strength. The same NMAS revealed for source L the highest strength from mix A9.5 and the lowest from mix #78-C. The NMAS of ¾ in. indicated that aggregate B had the highest compressive strength from the A12.5 mix and the lowest strength from the single-sized ½ in. mix. Aggregate L had the same gradation with the highest strength, A12.5, but a different gradation for the lowest strength, #67-I. It was observed that this mix was not statistically significantly different to the ½ in. with regards to compressive strength properties. Generally, both sources had the same aggregate gradations producing the highest compressive strength while on the lower end it varied. The highest overall compressive strength was produced by aggregate L mix #89 of 2943 psi (20 MPa).

Finally, the statistical compressive strength data for gradations with similar uniformity coefficients and changes in their NMAS were compared. The aggregate B #89 and the B A12.5 and the aggregate L ⅜ and ½ in. had non-significant differences. It was found that the single-sized aggregate gradation decreased in strength as the NMAS increased. The general trend for the blended gradations was a decrease in compressive strength as the NMAS increased.

Table 4.3 Statistical analysis of compressive strengths for specimens prepared from aggregate B and L.

NMAS	Mix	C_u	Compressive Strength (psi)				
			B	t Grouping	Strength Difference*	L	t Grouping
⅜ in.	#4	1.41	1339	B	S	1957	BC
	#89-C	2.34	---			1659	C
	#89	3.20	2258	A	S	2943	A
	#89-F	3.28	---			1975	B
½ in.	⅜ in.	1.20	1683	A	S	1938	CD
	#78-C	2.07	---			1813	D
	A-9.5C	2.43	---			1961	C
	A9.5	2.53	1797	A	S	2701	A
	#78	2.83	1693	A	S	2497	B
¾ in.	½ in.	1.20	1218	C	S	1896	C
	#67-I	1.83	---			1886	C
	#67	2.36	1780	B	S	2054	BC
	A-12.5C	2.89	---			2132	B
	A12.5	3.18	2108	A	S	2608	A
	A-12.5F	3.23	---			2051	BC

*S = Significant differences and NS = non-significant differences.
Aggregate strengths with the same letter are not significantly different.

Split-Tensile Strength Analysis

The split-tensile strength test was conducted on five (5) cylinders from each mixture and the results are shown in Table 4.4. A column plot was used to illustrate the comparisons and correlations of the split-tensile strengths to their uniformity coefficients in Figure 4.4. The #89 mix, was the strongest gradation for the split-tensile strength test within the aggregate B mixes. It was also the strongest mix for the compressive strength tests for both B and L. Aggregate L, had the A12.5 (relatively well graded) as the mix with the highest split-tensile strength. The specimens prepared from aggregate B, the tougher aggragate, appeared to rely more on the toughness of the aggregate for the split-tensile strength test whereas aggrgate L seemed to rely more on the level of compaction and aggregate size. Based on the results, it can be stated that weaker aggregates would need better compaction or a more well graded aggregate gradation to maximize the split-tensile strength.

The specimens with a NMAS of ½ in. were found to have had a reduction in split-tensile strength between C_u values of 2.53 and 2.83 for both aggregate sources. But the specimens with the NMAS of ¾ in. had a higher C_u range of 3.18 to 3.23 between which their split-tensile strength was reduced.

Table 4.4 Summary of split-tensile strengths for pervious concrete specimens B and L.

NMAS	Mix	C_u	Split-Tensile Strength B (psi)	Standard Deviation (psi)	Split-Tensile Strength L (psi)	Standard Deviation (psi)
⅜ in.	#4	1.41	239	31	275	29
	#89-C	2.34	---	---	243	35
	#89	3.20	384	24	373	15
	#89-F	3.28	---	---	285	15
½ in.	⅜ in.	1.20	301	38	263	23
	#78-C	2.07	---	---	277	20
	A-9.5C	2.43	---	---	275	41
	A9.5	2.53	369	22	367	1
	#78	2.83	337	47	306	30
¾ in.	½ in.	1.20	209	17	244	25
	#67-I	1.83	---	---	284	48
	#67	2.36	320	56	303	29
	A-12.5C	2.89	---	---	307	27
	A12.5	3.18	338	19	423	17
	A-12.5F	3.23	---	---	341	24

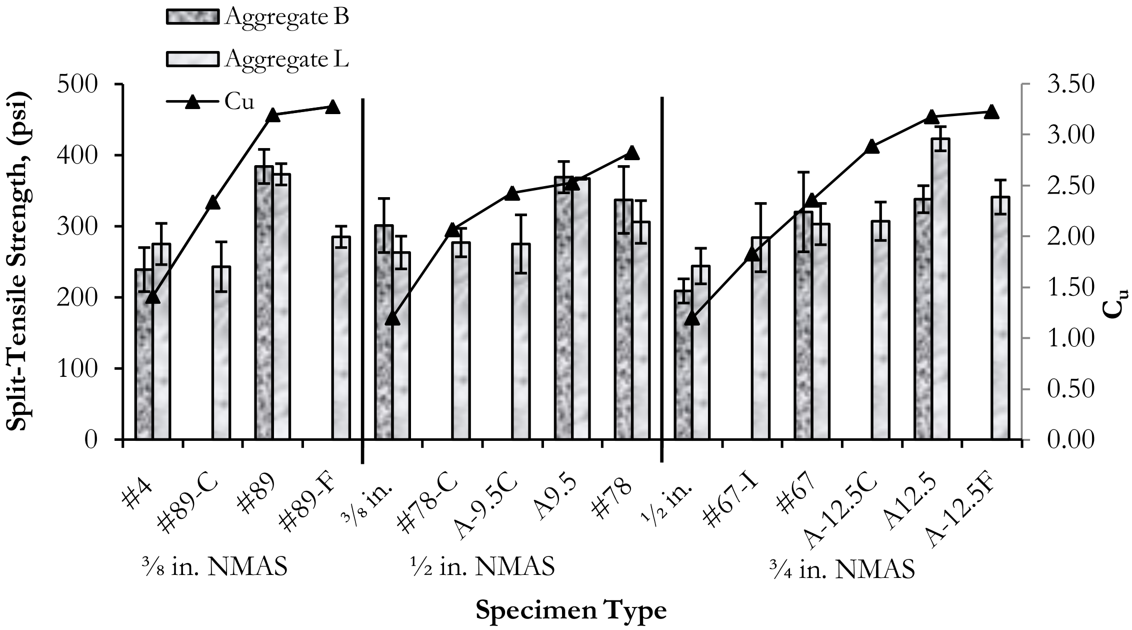


Figure 4.4 Range of split-tensile strengths for pervious concrete specimens prepared from aggregate B and L categorized according to NMAS.

Statistical Analysis for Split-Tensile Strengths

The comparison of split-tensile strengths for each aggregate source within a common gradation produced significant differences in all cases, except for the A9.5 which was quite similar in strength for both sources as shown in Table 4.5. The split-tensile strengths for the specimens prepared with the same aggregate gradation for both sources were in most cases higher for aggregate B mixes than for aggregate L, the ratio being approximately 5:3. Within the NMAS of ½ in, the split-tensile strength of the aggregate B mixes were all higher than the aggregate L mixes but for the other NMAS, the strength varied between the sources. The majority of the higher split-tensile strengths of the single-sized gradations were in the specimens prepared with aggregate B.

The mixes were analyzed as mentioned in the compressive statistical section. For the NMAS of ⅜ in., aggregate B # 89 exhibited the highest split-tensile strength and the single-sized #4 the lower strength. The aggregate L #89 produced the highest strength and #89-C the lowest strength. The NMAS of ½ in. had the aggregate B mix, A9.5, with the highest strength and the single-sized ⅜ in. mix with the lowest strength. The same NMAS revealed that mix A9.5 produced the highest strength for source L and the lowest strength was from the singled-sized ⅜ in. mix. The NMAS of ¾ in. indicated that aggregate B had the highest split-tensile strength from the A12.5 and the lowest strength from the single-sized ½ in. mix. Aggregate L had the same gradation with highest strength, A12.5, and the single-sized ½ in. mix with the lowest strength. Within NMAS of ½ in., it was observed that the 78-C and the A9.5-C produced similar split-tensile strength values and they may probably work as substitutes. The gradations that produced the highest and the lowest strengths were the same for both aggregate sources. The highest overall split-tensile strength was generated by aggregate L mix A12.5 of 423 psi (3 MPa).

Finally, the statistical split-tensile strength data for gradations with similar uniformity coefficients and changes in their NMAS were compared. The aggregate L #78 and the L A12.5-C had non-significant differences. It was found that the single-sized aggregate gradation decreased in strength as the NMAS increased. . The general trend for the blended gradations was a decrease in flexural strength for aggregate B and an increase in flexural strength for aggregate L as the NMAS increased to an optimum point which was followed by a drop in strength.

Table 4.5 Statistical analysis of split-tensile strengths for specimens prepared from aggregate B and L.

NMAS	Mix	C_u	Split-Tensile Strength (psi)				
			B	t Grouping	Strength Differences*	L	t Grouping
⅜ in.	#4	1.41	239	B	S	275	BC
	#89-C	2.34	---			243	C
	#89	3.20	384	A	S	373	A
	#89-F	3.28	---			285	B
½ in.	⅜ in.	1.20	301	B	S	263	C
	#78-C	2.07	---			277	BC
	A-9.5C	2.43	---			275	BC
	A9.5	2.53	369	A	NS	367	A
	#78	2.83	337	AB	S	306	B
¾ in.	½ in.	1.20	209	B	S	244	D
	#67-I	1.83	---			284	C
	#67	2.36	320	A	S	303	C
	A-12.5C	2.89	---			307	BC
	A12.5	3.18	338	A	S	423	A
	A-12.5F	3.23	---			341	B

*S = Significant differences and NS = non-significant differences.
Aggregate strengths with the same letter are not significantly different.

Flexural Strength Analysis

The flexural strength test was conducted on groups of five (5) beams from each mix with their results shown in Table 4.6. A column plot was also used to illustrate the comparisons and correlations of the flexural strength test to their uniformity coefficients in Figure 4.5. The #89 mix was found to be the strongest gradation for the flexural strength test within the aggregate B mixes as it was for the other strength tests. The highest flexural strength for the aggregate L mixes came from the same mix that generated the highest split-tensile strength, A12.5. For the flexural strength results, similar oberservations were made as compared to the split-tensile strength results, which supported better compaction or a more well graded aggregate gradation as a means of maximizing the flexural strength of weaker aggregates, and aggregate B seemed to rely on its toughness whereas L seemed to rely on compaction and aggregate size.

The specimens with a NMAS of ½ in. were again found to have had a reduction in flexural strength between their upper C_u values for both aggregate sources. But the specimens with the NMAS of ¾ in. had a higher C_u range similar to the slit-tensile results between which their flexural strength was reduced. In most cases, the flexural strength results were higher than the split-tensile but the standard deviations were quite similar between the two mixes.

Table 4.6 Summary table of flexural strengths for pervious concrete specimens B and L.

NMAS	Mix	C_u	Flexural Strength B (psi)	Standard Deviation (psi)	Flexural Strength L (psi)	Standard Deviation (psi)
⅜ in.	**#4**	1.41	331	27	347	24
	#89-C	2.34	---	---	287	41
	#89	3.20	396	41	337	22
	#89-F	3.28	---	---	261	16
½ in.	**⅜ in.**	1.20	330	38	319	52
	#78-C	2.07	---	---	304	23
	A-9.5C	2.43	---	---	285	31
	A9.5	2.53	374	19	383	33
	#78	2.83	329	43	362	40
¾ in.	**½ in.**	1.20	272	59	306	13
	#67-I	1.83	---	---	314	51
	#67	2.36	358	50	349	30
	A-12.5C	2.89	---	---	357	44
	A12.5	3.18	362	32	385	49
	A-12.5F	3.23	---	---	324	60

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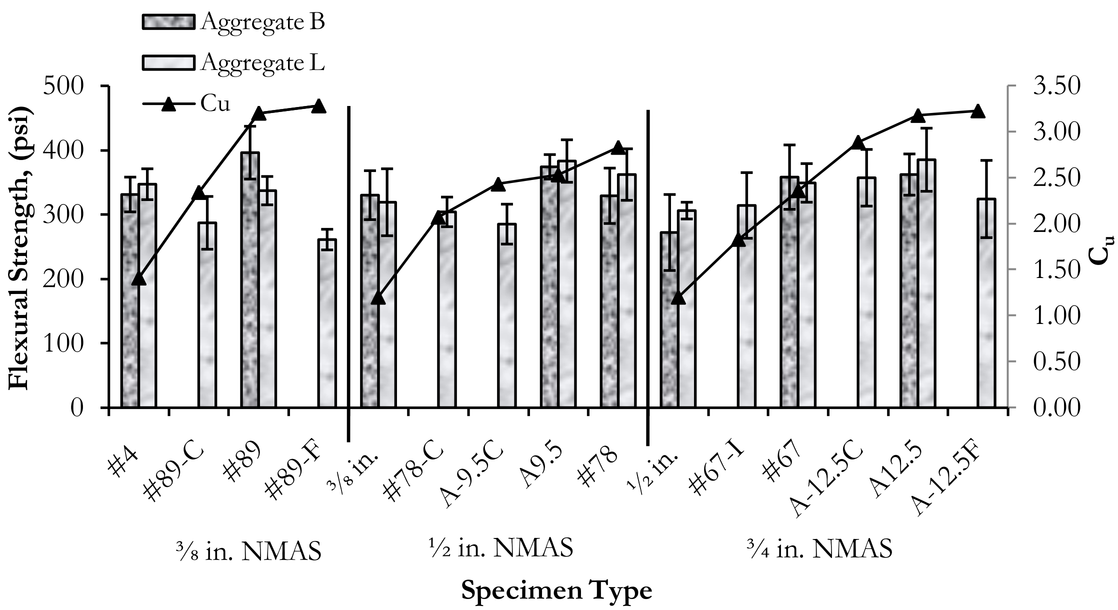

Figure 4.5 Range of flexural strengths for pervious concrete specimens prepared from aggregate B and L categorized according to NMAS.

Statistical Analysis for Flexural Strengths

The flexural strengths for each aggregate source within a common gradation produced significant differences in all cases as shown in Table 4.7. The flexural strengths for the specimens prepared with the same aggregate gradation from both sources were higher for most of aggregate L mixes. The aggregate source with the highest flexural strength varied throughout all of the NMAS categories. The majority of higher flexural strengths for the single-sized gradations were produced by the specimens prepared with aggregate B which was the opposite for split-tensile.

For the NMAS of ⅜ in., aggregate B # 89 exhibited the highest flexural strength and for the single-sized, the #4 produced the lowest. The aggregate L #4 produced the highest strength and #89-F the lowest strength. The NMAS of ½ in. had the aggregate B mix, A9.5, with the highest strength and the #78 the lowest strength but was extremely close to the single-sized ⅜ in. mix. The same NMAS revealed that source L had the highest strength from mix A9.5 and the lowest from the A9.5-C mix. The NMAS of ¾ in. indicated that aggregate B had the highest strength from the A12.5 mix which was close to the strength of #67, and the lowest strength from the single-sized ½ in. mix. The L aggregate had the same gradation with highest strength, A12.5, and the single-sized ½ in. mix with the lowest strength. Within NMAS of ⅜ in., it was observed that the #4 and the #89 produced similar flexural strengths. The gradation that produced the highest flexural strength was the aggregate B #89 mix of 396 psi (3 MPa).

Finally, the statistical flexural strength data for gradations with similar uniformity coefficients and changes in their NMAS were compared. The aggregate were all significantly different. It was found that the single-sized aggregate gradation decreased in strength as the NMAS increased as it did for both compressive and split-tensile statistical analysis. The general trend for the blended gradations was a decrease in flexural strength for aggregate B and an increase in flexural strength for aggregate L as the NMAS increased to an optimum point which was followed by a drop in strength.

Table 4.7 Statistical analysis of flexural strengths for specimens prepared from aggregate B and L.

NMAS	Mix	C_u	Flexural Strength (psi)				
			B	t Grouping	Strength Differences*	L	t Grouping
⅜ in.	#4	1.41	331	B	S	347	A
	#89-C	2.34	---			287	B
	#89	3.20	396	A	S	337	A
	#89-F	3.28	---			261	B
½ in.	⅜ in.	1.20	330	A	S	319	BC
	#78-C	2.07	---			304	C
	A-9.5C	2.43	---			285	C
	A9.5	2.53	374	A	S	383	A
	#78	2.83	329	A	S	362	AB
¾ in.	½ in.	1.20	272	B	S	306	C
	#67-I	1.83	---			314	C
	#67	2.36	358	A	S	349	B
	A-12.5C	2.89	---			357	AB
	A12.5	3.18	362	A	S	385	A
	A-12.5F	3.23	---			324	BC

*S = Significant differences and NS = non-significant differences.
Aggregate strengths with the same letter are not significantly different.

Compressive and Flexural Strength Correlation

A correlation exists between the compressive strength of a material and its flexural strength (Mindess, 2003). This correlation is important in the estimation of the flexural strength of a concrete mixture, especially in the field when only cylinders are available for compression testing. The expected trend of flexural strength increasing as compressive strength increased was established in the results. Figure 4.6 shows the correlations that exist between the compressive and flexural strengths of the specimens prepared from aggregates B and L. A much stronger correlation was found to exist between the two strength tests for aggregate B specimens when compared to aggregate L. The rate at which the flexural strength increased for mixes with aggregate L was slightly lower than mixes with aggregate B. The relationships between 28-day flexural strength (R) and the compressive strength (f'_c) of the pervious concrete mixtures from aggregate B and L were developed from trendlines of the scatter plot:

$$R_B = 9.28(f'_c)^{0.5} \tag{4.1}$$

$$R_L = 8.73(f'_c)^{0.5} \tag{4.2}$$

where R_B = flexural strength of aggregate B,
R_L = flexural strength of aggregate L and
f'_c = compressive strength of the specimen.

The relationships were quite similar to the relationship between flexural and compressive strength for conventional concrete (Mindess, 2003):

$$R = 7.5(f'_c)^{0.5} \tag{4.3}$$

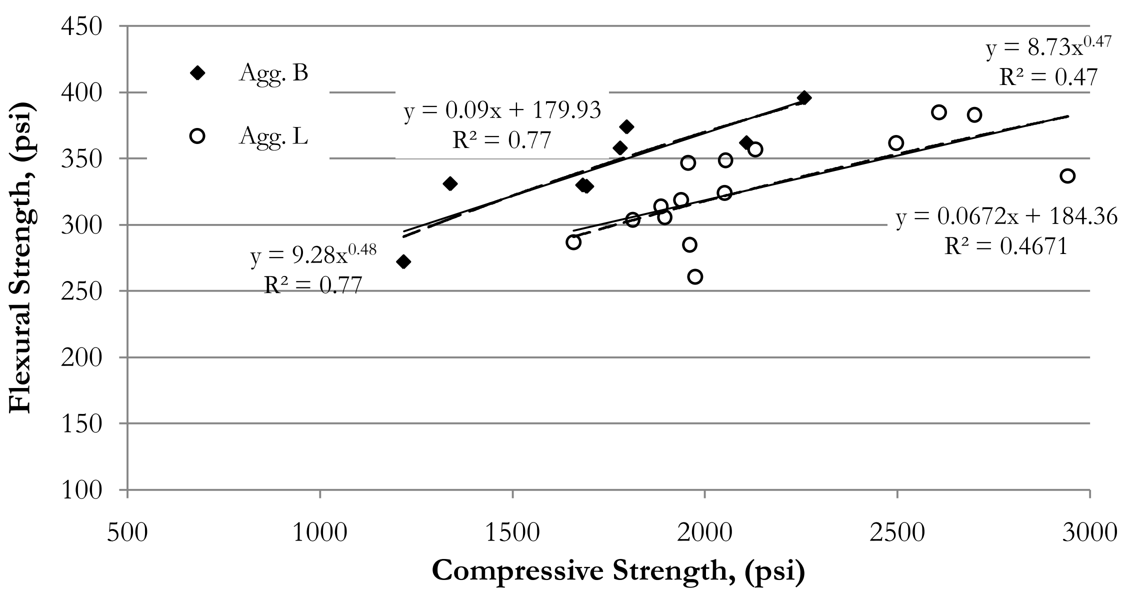

Figure 4.6 Correlation between compressive strength and flexural strength for specimens prepared from aggregate B and L.

Normalization of Compressive Strength

In an effort to quantify the relationships that existed among the blended and single-sized aggregate mixes and at the same time making reference to their uniformity coefficients, the compressive strength and permeability (presented in a later section) of the blended mixes were normalized with the single-sized mixes. Table 4.8 shows the normalized compressive strength and the respective uniformity coefficients for the pervious concrete mixes prepared from both aggregate sources. Figure 4.7 illustrates the trend that resulted from the compressive strength ratio and the increase in the uniformity coefficient. An increase in C_u values defines a decrease in uniformity.

A general trend was observed that as uniformity of the aggregates in each mix decreased (increasing C_u values), the compressive strengths increased but to particular C_u values that varied according to the NMAS. The NMAS of ⅜ in. and ¾ in. for aggregate B mixes did not fully show that trend because they had insufficient reference points within their categories. But the NMAS of ½ in. for aggregate B had sufficient points to illustrate that drop off in strength above a C_u of 2.5. The C_u values that represented the drop off in strength were found to be quite similar for mixes within the same NMAS regardless of their source. The NMAS of ⅜ in. and the ¾ in. categories had similar drop off values that were approximately 3.2, but they were higher than the NMAS of ½ in. which was approximately 2.5. Pervious mixes prepared from aggregate B produced higher normalized values for NMAS of ½ and ¾ in. as compared to mixes from aggregate L. The goal of establishing this relationship was to potentially aid in predicting the mix gradation that gives the best strength that meets the requirements.

Table 4.8 Normalized compressive strengths and the related uniformity coefficients used to determine the correlations for mixes from both aggregate sources.

NMAS	Mix	C_u	*f'_c blend/f'_c single*	
			L	B
⅜ in.	#4	1.41	100	100
	#89-C	2.34	85	---
	#89	3.20	150	169
	#89-F	3.28	101	
½ in.	⅜ in.	1.20	100	100
	#78-C	2.07	94	---
	A9.5-C	2.43	101	---
	A9.5	2.53	139	107
	#78	2.83	129	101
¾ in.	½ in.	1.20	100	100
	#67-I	1.87	99	---
	#67	2.36	108	146
	A12.5-C	2.89	112	---
	A12.5	3.18	138	173
	A12.5-F	3.23	108	---

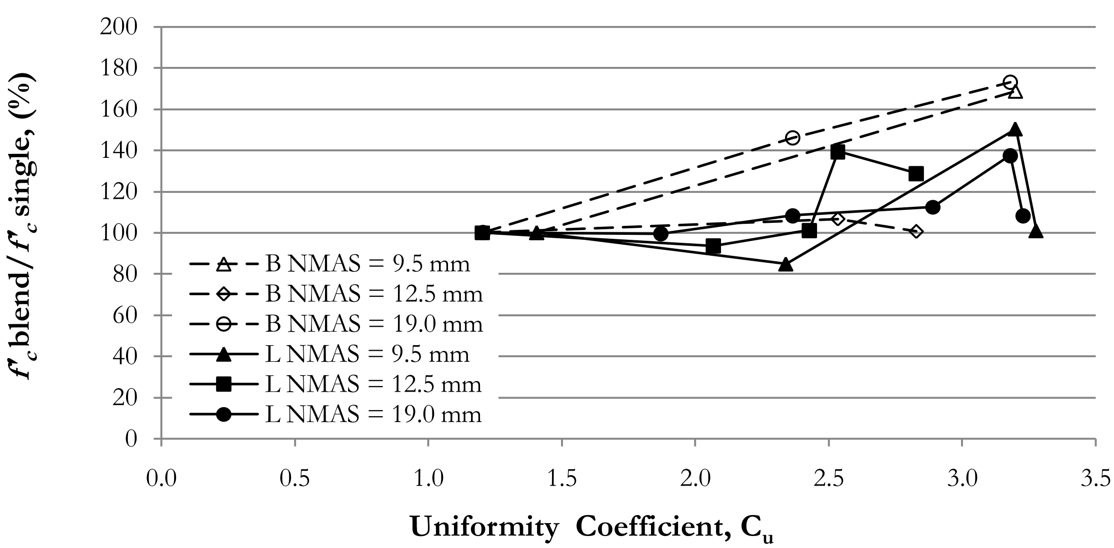

Figure 4.7 Comparison of *f'c* blend to *f'c* single ratio to uniformity coefficients of both aggregate B and L with NMAS of ⅜ in., ½ in., and ¾ in.

Specific Gravity Analysis

The maximum, bulk and apparent specific gravities were determined for the pervious concrete mixtures. Presently, there is no standardized procedure to test pervious concrete mixtures for these properties. Therefore, the standard test method for theoretical maximum specific gravity of bituminous paving mixtures was used to determine the maximum specific gravity (G_{mm}) (ASTM D 2041) and the density (i.e., bulk and apparent specific gravity), effective porosity and effective air voids of compacted pervious concrete materials were determined using ASTM D 7063.

Specific gravity is a ratio that relates the density of the coated aggregates or compacted specimen, as in this study, to the density of water (Mindess et al, 2003). A summary of the specific gravities determined for the cement coated aggregates and compacted specimens are shown in Table 4.9. Although the G_{mm} was expected to be the greatest of the three densities, it was found to be either the same or slightly lower than the apparent specific gravity (ASG) for the aggregate B mixes. Probable reasons for this include the fact that two distinct tests were conducted and the difficulties in completely separating cement coated aggregates, therefore, some aggregates were still bonded to each other. Another possible reason might be in the dimples formed by the bag around the specimen caused by the Corelok vacuum chamber as a result of the surface pores. This could reduce the volume of the air voids but when the bag is opened for the porosity determination, the water rushing in fills beyond the previous dimpled surface, the porosity volume is greater than the air voids. Figure 4.8 compares the maximum, bulk and apparent specific gravities for mixes prepared from aggregate B. The expected trend of there being a slight increase in the specific gravity as the NMAS increased was represented.

Table 4.9 Summary of specific gravities for aggregate B.

NMAS	Mix	Max. Specific Gravity	Bulk Specific Gravity	Apparent Specific Gravity
⅜ in.	**#4**	2.73	1.94	2.76
	#89	2.70	2.07	2.74
½ in.	**⅜ in.**	2.77	2.03	2.77
	A9.5	2.71	2.06	2.74
	#78	2.72	2.02	2.73
¾ in.	**½ in.**	2.75	2.05	2.77
	#67	2.72	2.07	2.74
	A12.5	2.75	2.07	2.76

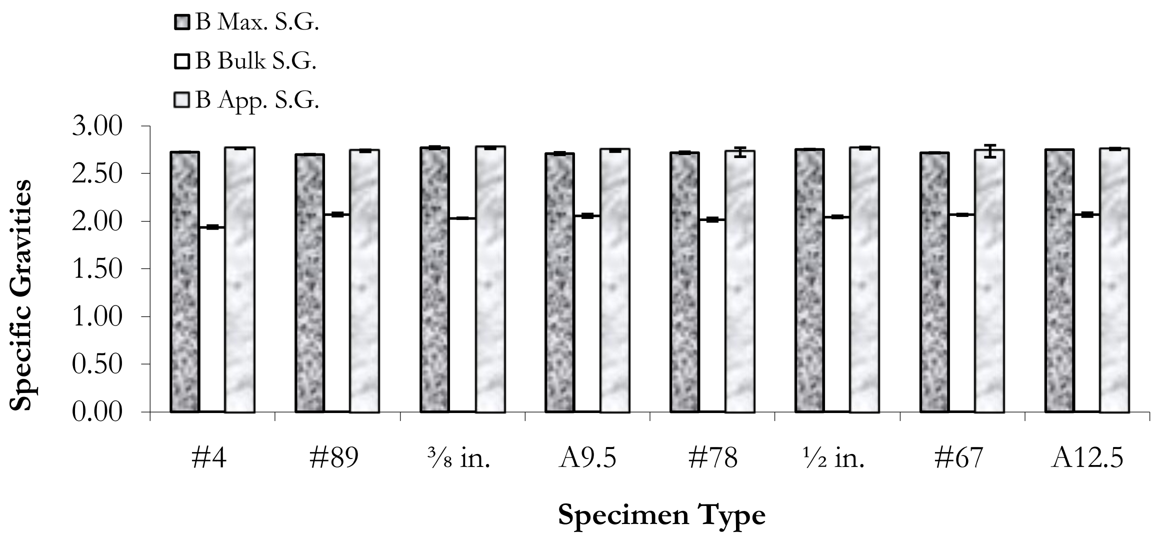

Figure 4.8 Comparison of the maximum, bulk and apparent specific gravities for mixes prepared from aggregate B.

The results of the maximum, bulk and apparent specific gravities for mixes prepared from aggregate L are given in Table 4.10. As expected, the specific gravities were lower for mixes with aggregate L as compared to mixes with aggregate B, which is a denser aggregate. The specific gravities for L did not follow the trend of increasing values with increasing NMAS as aggregate B did. Two factors that may have limited the occurrence of that trend was the percentage of coarse aggregates in some of the mixes and the number of mixes within the respective NMAS groups. Figure 4.9 illustrates the differences among the maximum, bulk and apparent specific gravities for mixes prepared with aggregate L.

Table 4.10 Summary of specific gravities for aggregate L.

NMAS	Mix	Max. Specific Gravity	Bulk Specific Gravity	Apparent Specific Gravity	MSG-ASG
⅜ in.	#4	2.60	1.91	2.60	0.000
	#89-C	2.52	1.91	2.63	0.078
	#89	2.50	2.02	2.62	0.085
	#89-F	2.62	1.88	2.64	0.014
½ in.	⅜ in.	2.59	1.96	2.68	0.064
	#78-C	2.64	1.94	2.63	0.007
	A-9.5C	2.52	1.94	2.60	0.057
	A9.5	2.62	2.02	2.52	0.071
	#78	2.59	2.02	2.62	0.021
¾ in.	½ in.	2.63	1.96	2.57	0.042
	#67-I	2.61	1.98	2.61	0.000
	#67	2.54	2.03	2.57	0.021
	A-12.5C	2.56	1.98	2.57	0.007
	A12.5	2.58	2.08	2.53	0.035
	A-12.5F	2.55	1.98	2.62	0.049

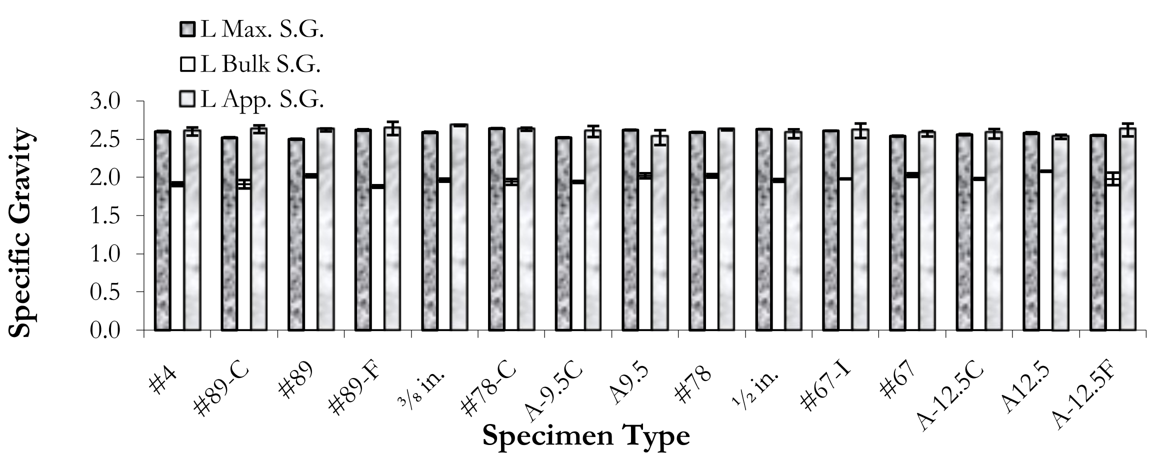

Figure 4.9 Comparison of the maximum, bulk and apparent specific gravities for mixes prepared from aggregate L.

Air Voids and Effective Porosity in Pervious Concrete Mixtures

Air Voids

The percent air voids in the pervious concrete specimens were determined using the Corelok vacuum chamber. Another method used to determine the percent air voids from calculations involving the fresh concrete unit weight is the gravimetric method. It takes the volume of each ingredient and deducts it from the entire volume to find the total air content. Figure 4.10 gives the relationships that existed between the gravimetric and Corelok methods for mixtures with both aggregate sources. Both sources generated trends that exhibited a directly proportional relationship. The mixes with aggregate L had a stronger correlation than the aggregate B mixes.

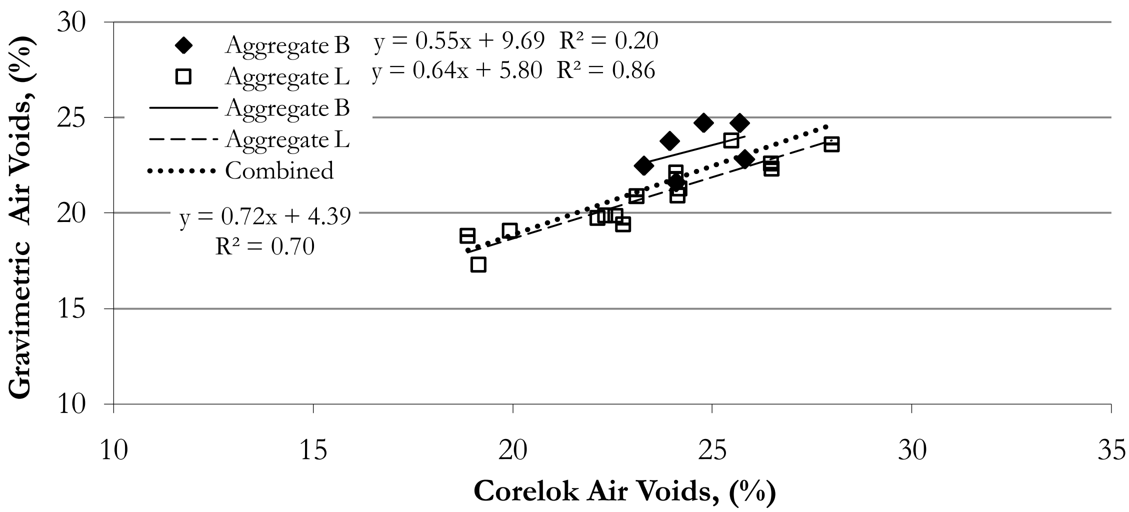

Figure 4.10 Comparison of the gravimetric test to the Corelok test for air voids in aggregate B and L specimens.

Statistical Analysis of Air Voids

The percent of air voids in pervious concrete is critical to the performance and as a result special care must be given the mix design and the method of compaction. Table 4.11 presents the percent air voids in specimens from both sources with the basic statistical relationships that exist among the mixes. There was no significant relationship observed between the values of one source to another. Aggregate B mixes had the higher air void content for all its mixes over the identical gradations used to prepare aggregate L. This was to be expected as the mix designs were based on an equal mass as opposed to equal volume and aggregate B has a significantly higher specific gravity than aggregate L (Table 3.3).

The comparison of each aggregate source within the NMAS of ⅜ in. resulted in the # 4 consisting of the highest volume of air voids for aggregate B and # 89 the lowest percentage. Aggregate L had the #89-F with the highest air voids, and like aggregate B, had the least amount. The next NMAS, ½ in., had the single-sized ⅜ in. mix with the highest air content for aggregate B and the A9.5 mix possessed the lowest air voids. Aggregate L had the #78-C mix with the highest air voids and the A9.5 with the lowest value. The NMAS of ¾ in. did not change the trend being set by aggregate B with the single-sized aggregate mixes containing the highest volume of voids. The ½ in. mix had the highest air voids and the #67 the lowest. For aggregate L the ½ in. mix also had the highest percent air void with the #67 representing the least air void content. The blended aggregate gradations produced the highest percent of air voids for aggregate L whereas the single-sized mixes promoted high air content levels for aggregate B. The highest air void percent of 28.6% came from the #4 mix for aggregate B.

Table 4.11 Statistical analysis of air voids for specimens prepared from aggregate B and L.

NMAS	Mix	C_u	Air Voids (%) B	t Grouping	Void Differences	L	t Grouping
⅜ in.	#4	1.41	28.6	A	S	26.9	A
	#89-C	2.34	---			24.1	B
	#89	3.20	23.7	B	S	19.7	C
	#89-F	3.28	---			28.0	A
½ in.	⅜ in.	1.20	26.0	A	S	24.2	B
	#78-C	2.07	---			26.5	A
	A-9.5C	2.43	---			23.1	BC
	A9.5	2.53	24.1	B	S	21.5	C
	#78	2.83	25.6	AB	S	23.8	B
¾ in.	½ in.	1.20	26.8	A	S	25.3	A
	#67-I	1.83	---			24.1	AB
	#67	2.36	23.4	B	S	20.4	B
	A-12.5C	2.89	---			22.6	B
	A12.5	3.18	23.8	B	S	20.8	B
	A-12.5F	3.23	---			22.3	B

*S = Significant differences and NS = non-significant differences.
Aggregate strengths with the same letter are not significantly different.

Compressive Strength and Air Voids

The percentage of air in pervious concrete is much greater than in regular concrete. The more air voids present in concrete, the weaker it is because of the reduction in support from surrounding particles. This reduces the general compressive strength of pervious concrete compared to conventional concrete. Figure 4.11 illustrates this by showing that an increase in air voids results in a decrease in the compressive strength of the pervious mix. The compressive strength of aggregate L specimens seemed to be somewhat less affected by the increase in air voids in comparison to specimens from aggregate B. Several of the L specimens produced much higher compressive strengths but had much lower air voids, which compared to the other specimens would indicate some degree of over consolidation during the casting process.

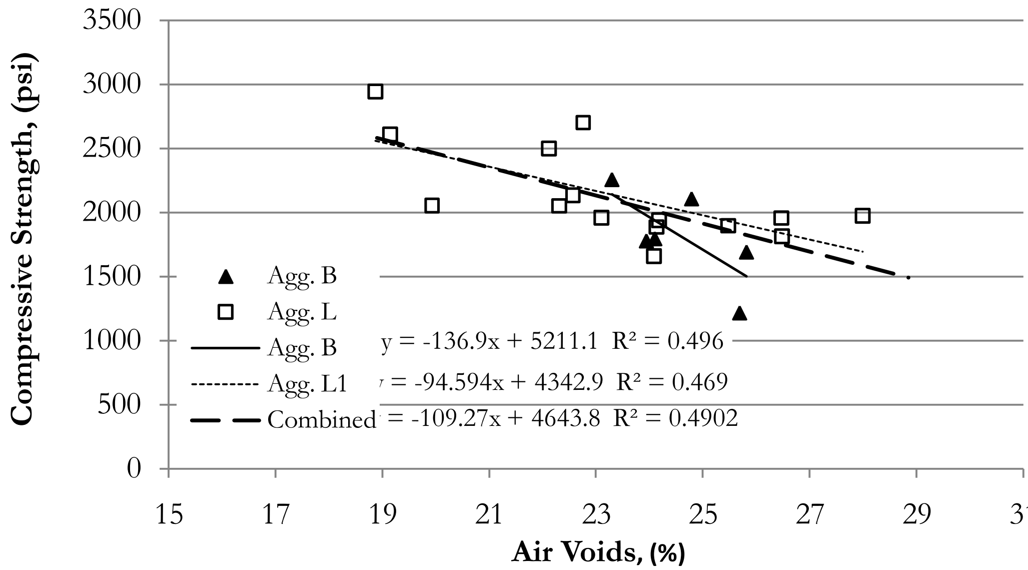

Figure 4.11 Comparison of compressive strength to air voids for specimens with aggregate B and L.

Split-Tensile Strength and Air Voids

The split-tensile strength test is used to determine the tensile capacity of a concrete mixture. The results from this test are use to obtain a conservative idea of what the flexural strength of the structure would be, were there a beam to be tested. The manner in which the results from this test were affected by the air voids in the pervious concrete specimens was plotted in Figure 4.12. It was observed, as expected, that the strength decreased as the air voids increased. Also, the split-tensile strengths of the specimens prepared from the denser aggregate mix, B, were generally higher at air voids of 23% and higher as compared to specimens made from aggregate L. It was found that specimens with aggregate L exhibited higher split-tensile strengths but much lower air void content which could be based on mix design.

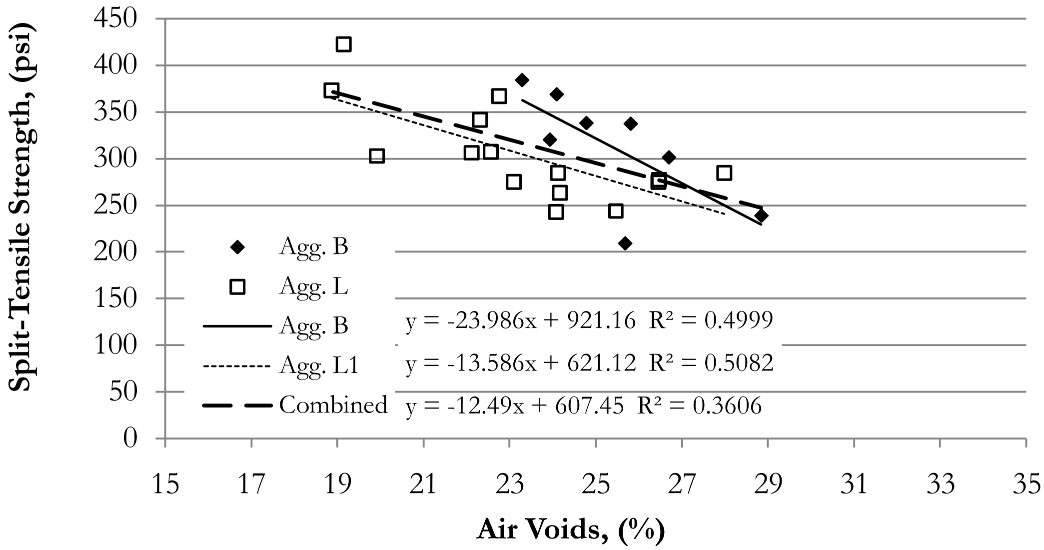

Figure 4.12 Comparison of split-tensile strength to air voids for specimens prepared from aggregate B and L.

Flexural Strength and Air Voids

The flexural strength is the bending capacity of the specimen being tested. As was observed before, the strength of the pervious concrete beams, prepared from both aggregate sources, decreased as the air voids increased. The specimens from aggregate B attained higher flexural strengths at higher air void contents in comparison to the specimens prepared from aggregate L. The over consolidated effect was again evident along with the other observations in Figure 4.13. The rate at which the flexural strength of the specimens decreased with the increase in air voids was quite similar.

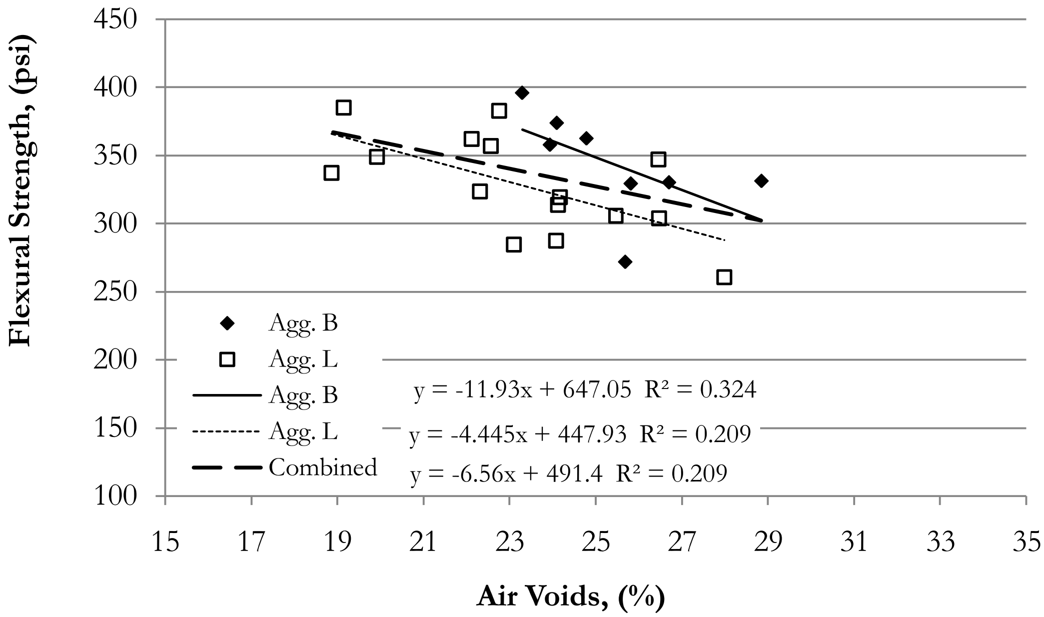

Figure 4.13 Comparison of flexural strength to air voids for specimens prepared from aggregate B and L.

Effective Porosity

Generally, the percentage of air voids in conventional concrete is not of much concern unless designing for cold climates with air-entraining agents. The mix design recommended, in Chapter II, for pervious concrete mixes revealed an air content by volume of 21 to 24%. Such significant increase to air content has made it an important factor to the development of proper pervious concrete mixes. The determination of the air voids in the concrete specimens was determined based on the ratio of bulk to maximum specific gravity. Along with the air voids, the effective porosity was found. The difference between the two lies in fact that the effective porosity is the percentage of air voids that can be accessed by water through interconnected pores to saturate a compacted specimen (ASTM D 7063). It is calculated based on the ratio of bulk and apparent specific gravity difference to the apparent specific gravity. Figure 4.14 gives the relationship that existed between the effective porosity and air voids. The correlation between the two parameters was stronger for the mixes with aggregate B, but there was an additional seven mixes to consider for aggregate L that reduced its correlation. The expected trend of effective porosity increasing as air voids increased, even independent of aggregate source was established in the results.

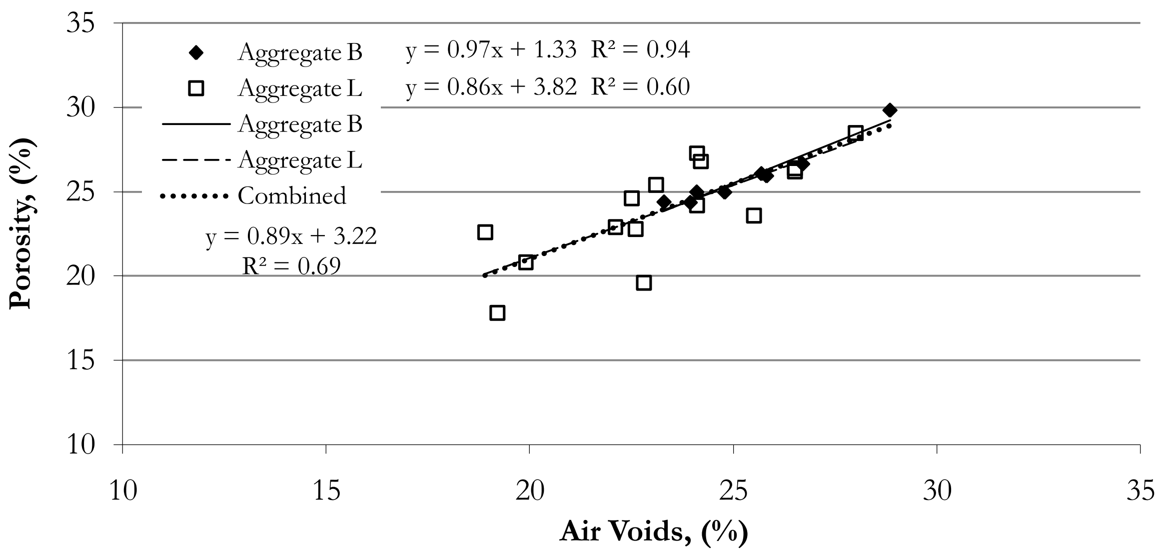

Figure 4.14 Comparison of porosity to air voids in specimens prepared from aggregate B and L.

Statistical Analysis for Effective Porosity

The effective porosity of the specimens ranged from 23.3 to 28.6% for aggregate B specimens and 16.0 to 28.5% for aggregate L specimens. Table 4.12 shows the results from the Corelok tests of effective porosity for both aggregate sources. The results showed that mixes with like gradations had a higher percent of porosity in favor of aggregate B mixes, a total of 7 out of 8. Some of the porosity values were similar between mixes B and L, such as the ½ in. and the #67. The NMAS of ⅜ in. and ½ in. seemed to have gradations that promoted much more variance to the porosity between sources.

The analysis of individual aggregate sources, it was found that the #4 had the higher porosity to the # 89 for source B within the NMAS of ⅜ in. Aggregate L for the same NMAS had the #89-F mix with the highest porosity and the #89 with the lowest. NMAS of ½ in. resulted in #78 mix having the highest porosity with and A9.5 the lowest for aggregate B. Within that same category, aggregate L had the ⅜ in. mix with the highest porosity and the A9.5 with the lowest which had the lowest value for B. The final NMAS of ¾ in. had for aggregate B the ½ in. mix with highest porosity and #67 with the lowest which was quite similar to the porosity of A12.5. Aggregate L top porosity for the NMAS of ¾ in. was from the ½ in. mix and the lowest from the A12.5 which was a very low value compared to the rest of porosity values. Aggregate B definitely showed signs of producing mixes with higher porosity with mix #4 producing the highest effective porosity of 28.6%.

Table 4.12 Statistical analysis of effective porosity for specimens prepared from aggregate B and L.

NMAS	Mix	C_u	Porosity (%) Source B	t Grouping	Porosity Differences*	Source L	t Grouping
⅜ in.	#4	1.41	28.6	A	S	27.1	A
	#89-C	2.34	---			27.3	A
	#89	3.20	24.8	B	S	22.6	B
	#89-F	3.28	---			28.5	A
½ in.	⅜ in.	1.20	25.0	AB	S	26.8	A
	#78-C	2.07	---			26.2	A
	A-9.5C	2.43	---			25.4	AB
	A9.5	2.53	23.3	B	S	21.6	C
	#78	2.83	26.5	A	S	24.1	B
¾ in.	½ in.	1.20	25.6	A	NS	25.2	A
	#67-I	1.83	---			24.2	B
	#67	2.36	23.5	A	NS	24.2	B
	A-12.5C	2.89	---			22.8	B
	A12.5	3.18	23.7	A	S	16.0	C
	A-12.5F	3.23	---			24.8	AB

*S = Significant differences and NS = non-significant differences.
Aggregate strengths with the same letter are not significantly different.

Hydraulic Conductivity of Pervious Concrete Mixes

The primary functions of pervious concrete mixtures are to construct a structure that can adequately support the required loads and manage excessive storm water discharge. The rate at which water flows through pervious concrete is the referred to as the permeability or hydraulic conductivity. The cylindrical specimens were tested with water of an initial head of 15 in. and a final head of 3 in. above the specimen with the time of flow taken for various head differences. The specimens were again classified according to their nominal maximum aggregate size (NMAS). The relationship between the hydraulic conductivity and head difference is illustrated in Figure 4.15.

The average hydraulic conductivity gradually increased as the total head decreased from 15 in. down to 3 in above the specimens. The pervious mixtures that were expected to possess the best hydraulic conductivity were those prepared from the single-sized aggregates. That was generally observed in all categories, with a minor exception to the ⅜ in. NMAS. The more well graded the mixes were, the lower the permeability was for mixes such as the A12.5 for both aggregate B and L. Other factors that reduced permeability included the water demand of the mix, the level of compaction, and the shape of the aggregate. Mixes that consisted of high proportion of coarser aggregates demanded less water because of less surface area but the water/cement ratio was keep constant for all mixes. Those mixes, such as the # 67, had the tendency to be more pasty which resulted in the reduction and clogging of pores.

Statistical Analysis of Hydraulic Conductivity

The hydraulic conductivity of pervious concrete mixtures is one of the primary concerns associated with the construction of pervious concrete mixtures. Since the main purpose of pervious mixtures is to reduce excess storm water runoff, a proper rate at which water flows through the pores of the structure is essential. The hydraulic conductivities of the specimens produced from both aggregate sources were calculated at different head differences and presented in Tables 4.13, 14, 15 and 16.

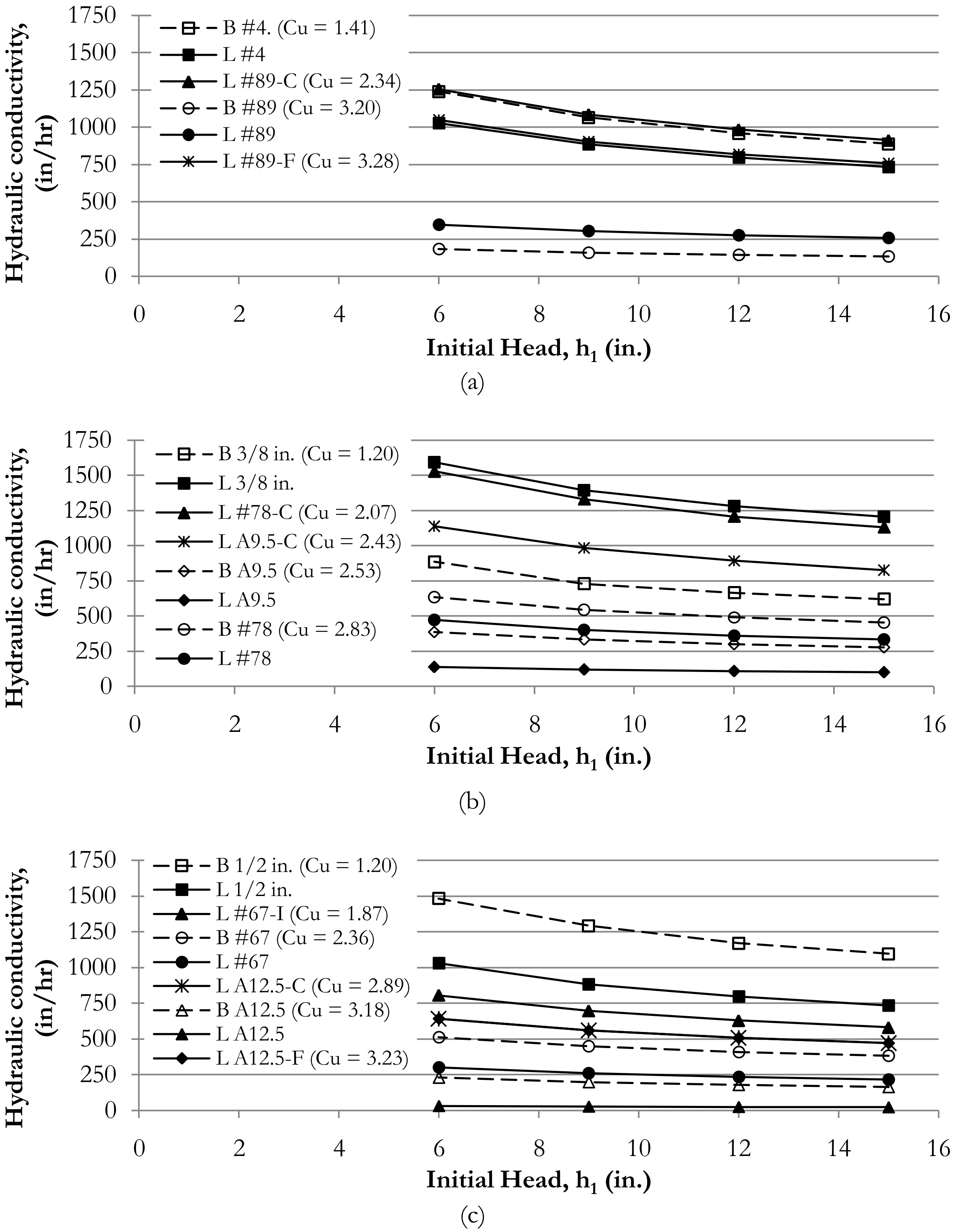

Figure 4.15 Comparison of the hydraulic conductivity of the specimens with a final head difference, h_2, of 3 in. and categorized based on (a) NMAS = ⅜ in., (b) NMAS =½ in. and (c) NMAS = ¾ in.

The four (4) head difference of 15 to 3 in., 12 to 3 in., 9 to 3 in. and 6 to 3 in. were examined and it was found that aggregate B had a higher hydraulic conductivity compared with aggregate L. This was expected, since aggregate B mixes proved to have higher air content with regards to the gradations tested. But this control of the hydraulic conductivity by aggregate B mixes was within the NMAS of ⅜ and ¾ in., it was not observed in the ½ in. category. Aggregate L mixes were the controlling gradation for the ½ in. NMAS.

The specimens prepared from aggregate B produced the highest hydraulic conductivity values from the single-sized aggregate gradations. Generally, the ½ in. mix produced the highest permeability values for aggregate B. The specimens prepared from aggregate L performed similarly to aggregate B with their highest permeability values being produced by single-sized aggregates of NMAS ½ and ¾ in. But for the lower NMAS of ⅜ in. the #89-C performed the best for aggregate L. The permeability of some of the specimens was closely related such as the #4 and the #89-F mixes for aggregate L. The highest hydraulic conductivity attained was 1592 in/hr. for the single-sized ⅜ in. mix from aggregate L for a head difference from 6 to 3 inches.

Table 4.13 Statistical analysis of permeability (15-3 in.) for specimens made from aggregate B and L.

NMAS	Mix	C_u	Permeability 15 - 3 in. (in./hr.)				
			B	t Grouping	Permeability Differences*	L	t Grouping
⅜ in.	#4	1.41	889	A	S	734	A
	#89-C	2.34	---			914	A
	#89	3.20	132	B	S	259	B
	#89-F	3.28	---			760	A
½ in.	⅜ in.	1.20	620	A	S	1204	A
	#78-C	2.07	---			1132	A
	A-9.5C	2.43	---			824	B
	A9.5	2.53	278	B	S	102	D
	#78	2.83	452	AB	S	334	C
¾ in.	½ in.	1.20	1096	A	S	734	A
	#67-I	1.83	---			581	AB
	#67	2.36	382	B	S	216	C
	A-12.5C	2.89	---			490	B
	A12.5	3.18	166	C	S	60	C
	A-12.5F	3.23	---			471	BC

Table 4.14 Statistical analysis of permeability (12 – 3 in.) for specimens made from aggregate B and L.

NMAS	Mix	C_u	Permeability 12 - 3 in. (in./hr.)				
			B	t Grouping	Permeability Differences*	L	t Grouping
⅜ in.	#4	1.41	960	A	S	797	A
	#89-C	2.34	---			985	A
	#89	3.20	144	B	S	278	B
	#89-F	3.28	---			820	A
½ in.	⅜ in.	1.20	666	A	S	1280	A
	#78-C	2.07	---			1209	A
	A-9.5C	2.43	---			891	B
	A9.5	2.53	300	B	S	110	D
	#78	2.83	490	B	S	362	C
¾ in.	½ in.	1.20	1170	A	S	797	A
	#67-I	1.83	---			629	AB
	#67	2.36	409	B	S	235	C
	A-12.5C	2.89	---			529	B
	A12.5	3.18	180	C	S	65	C
	A-12.5F	3.23	---			506	B

Table 4.15 Statistical analysis of permeability (9 – 3 in.) for specimens from B and L.

NMAS	Mix	C_u	Permeability 9 - 3 in. (in./hr.)				
			B	t Grouping	Permeability Differences*	L	t Grouping
⅜ in.	#4	1.41	1067	A	S	887	A
	#89-C	2.34	---			1086	A
	#89	3.20	159	B	S	304	B
	#89-F	3.28	---			906	A
½ in.	⅜ in.	1.20	730	A	S	1391	A
	#78-C	2.07	---			1332	A
	A-9.5C	2.43	---			983	B
	A9.5	2.53	333	B	S	121	D
	#78	2.83	545	AB	S	401	C
¾ in.	½ in.	1.20	1291	A	S	882	A
	#67-I	1.83	---			697	AB
	#67	2.36	447	B	S	261	C
	A-12.5C	2.89	---			585	B
	A12.5	3.18	199	C	S	71	C
	A-12.5F	3.23	---			558	B

Table 4.16 Statistical analysis of permeability (6 -3 in.)for specimens from aggregate B and L.

NMAS	Mix	C_u	Permeability 6 - 3 in. (in./hr.)				
			B	t Grouping	Permeability Differences*	L	t Grouping
⅜ in.	#4	1.41	1240	A	S	1028	A
	#89-C	2.34	---			1256	A
	#89	3.20	184	B	S	348	B
	#89-F	3.28	---			1050	A
½ in.	⅜ in.	1.20	886	A	S	1592	A
	#78-C	2.07	---			1529	A
	A-9.5C	2.43	---			1139	B
	A9.5	2.53	386	B	S	139	D
	#78	2.83	636	AB	S	472	C
¾ in.	½ in.	1.20	1482	A	S	1029	A
	#67-I	1.83	---			806	AB
	#67	2.36	512	B	S	302	C
	A-12.5C	2.89	---			677	B
	A12.5	3.18	230	C	S	81	C
	A-12.5F	3.23	---			641	B

*S = Significant differences and NS = non-significant differences.
Aggregate strengths with the same letter are not significantly different.

Normalization of Permeability

The process of normalizing the permeability values of the blended to the single-sized aggregate mixes was implemented to help quantify the trends that existed among the permeability values and the uniformity coefficients. Table 4.18 shows the normalized permeability values and the related uniformity coefficients used to determine the correlations for both aggregate sources. Figure 4.16 illustrates the trend that resulted from the permeability ratios and the increase in the uniformity coefficient.

The observation was made that permeability decreased as the C_u increased. But there were some jumps in the permeability trend followed by dips for mixes with aggregate L that were not observed in B. But a final change in the general trend was observed at similar points for like NMAS regardless of the aggregate source. The NMAS of ½ in. again, as in the compressive strength model, had a lower permeability jump point at a C_u of approximately 2.5 as compared to the NMAS of ⅜ and ¾ in. that had final permeability jump at a C_u value of approximately 3.2. The mixes prepared from aggregate B had the tendency to produce higher normalized permeability values as compared to mixes from aggregate L probably due to the fact that aggregate B had higher air content to L. The goal of this normalization was to aid in identifying the mix gradation that gives the best permeability to meet the requirements. It should be noted that more care has to be given to the consolidation process to optimize both strength and permeability.

Table 4.17 Normalized permeability values and the related uniformity coefficients used to determine the correlations for mixes from both aggregate sources.

NMAS	Mix	C_u	*k blend/k single*	
			L	B
⅜ in.	#4	1.41	100	100
	#89-C	2.34	124	---
	#89	3.20	35	15
	#89-F	3.28	103	---
½ in.	⅜ in.	1.20	100	100
	#78-C	2.07	94	---
	A9.5-C	2.43	70	---
	A9.5	2.53	9	45
	#78	2.83	28	74
¾ in.	½ in.	1.20	100	100
	#67-I	1.87	79	---
	#67	2.36	29	35
	A12.5-C	2.89	66	---
	A12.5	3.18	3	15
	A12.5-F	3.23	64	---

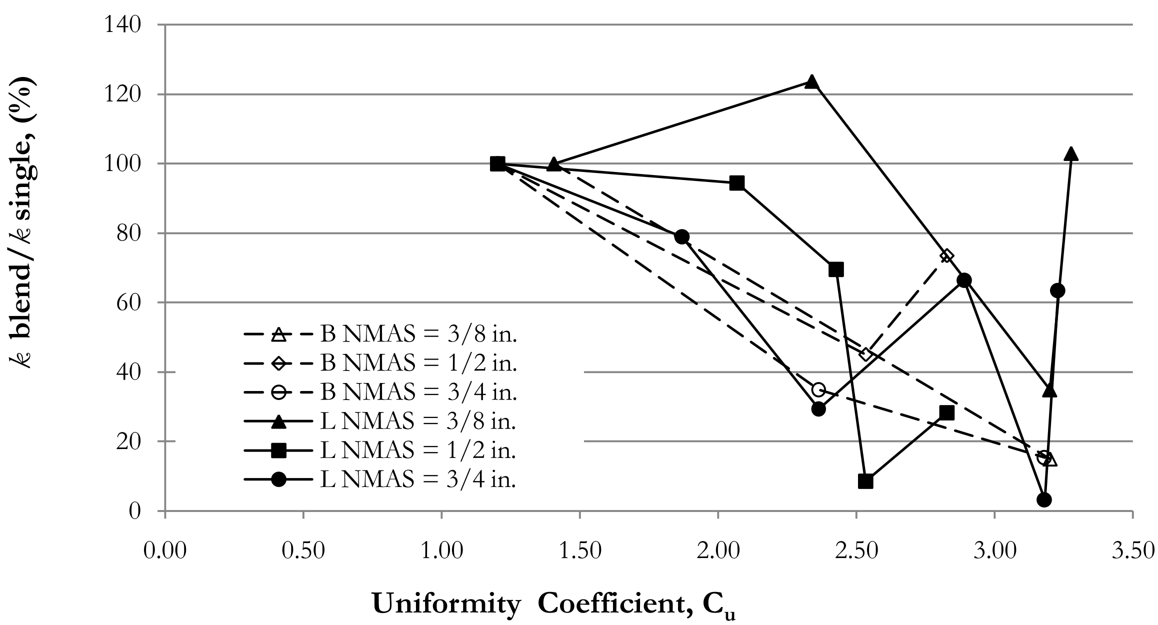

Figure 4.16 Comparison of *k* blend to *k* single ratio to uniformity coefficient of both aggregate B and L categorized based of C_u values with NMAS of ⅜ in., ½ in., and ¾ in..

Determination of Site-Specific Mix Gradations

The relationships among the primary properties of pervious concrete mixes, compressive strength, permeability, and uniformity coefficient, are illustrated in Figure 4.17. The point at which the compressive strength trend line for aggregate B crosses the permeability trend line corresponded to a compressive strength of approximately 1640 psi, a permeability of 655 in/hr and has a uniformity coefficient of 1.86. This point marks the region where further increase of one property will adversely affect the other property. For aggregate L, the point of intersection for compressive strength and permeability corresponds to a compressive strength of approximately 2000 psi, a permeability of 800 in/hr and the uniformity coefficient of 1.95. The aggregate gradation that fits the uniformity coefficients at the intersections would be the #67-I and the #78-C. The aggregate L gradation #67-I that has a C_u of 1.83 and a compressive strength of 1886 psi was the closest tested gradation to the intersection point for aggregate L.

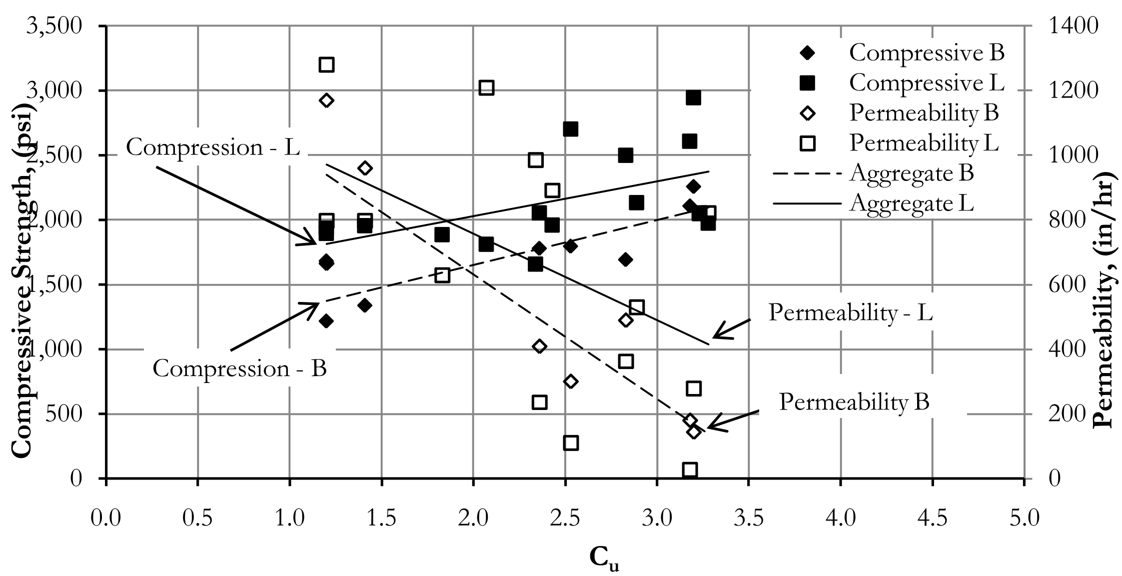

Figure 4.17 Correlation among compressive strength, permeability and uniformity coefficient.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Summary

Pervious concrete has been reintroduced in recent years to help reduce the excessive flow of storm water and to improve water quality. It has since received recognition as being compatible with the new focus on sustainable construction. Pervious concrete basically consists of coarse aggregate, cement, and water. Because of the omission of fine aggregate to the mix, pervious concrete has a much higher air content compared to conventional concrete. This gives it the ability to drain water through its porous structure and also filter pollutants. It is typically used for low traffic roads, parking lots, driveways and sidewalks. The strength of pervious concrete is lower than regular concrete because of its open structure. The quantity of research work done on pervious concrete is rapidly increasing and although the effects of aggregate gradation have been studied to some extent, there is still much to understand about the effects its properties and gradations have on pervious concrete mixtures.

In this research, twenty-three (23) batches of pervious concrete mixtures were prepared. The aggregates for the mixes were sourced from two quarries in South Carolina. Initial testing involved verification of aggregate properties provided by the supplier such as bulk and apparent specific gravity, LA abrasion, and absorption. The dry rodded unit weight of each aggregate gradation was also measured for each aggregate source. The aggregates were separated into single sizes and then proportioned by mass in gradations specific to the mix design. Two sets of eight (8) mixes had identical gradations while the other was prepared based on gradations derived from new uniformity coefficients. The gradations incorporated both single-sized and blended aggregate sizes.

The test conducted on the fresh concrete mix was to determine the unit weight. A total of twenty specimens were made from each batch, which consisted of fifteen 3 × 6 in. cylinders, five 3 × 3 × 3 in. prisms and some additional mix to be tested for maximum specific gravity. The pervious concrete mixtures were cured in a wet curing room for 28 days. At maturity, the specimens were tested for compressive, split-tensile, and flexural strength. The testing process continued with the maximum specific gravity test (Rice Test), the air voids content and porosity test, and falling head permeability test.

The dominating factor throughout this study was the uniformity coefficient of the aggregate gradation. The different gradations were categorized according to the NMAS of ⅜, ½, and ¾ inch. Relationships were found to exist between the aggregate dry rodded unit weight and the fresh concrete mix unit weight, compressive strength and the flexural strength, the air voids and the compressive, split-tensile and flexural strengths, permeability and initial head, normalized compressive strengths and uniformity coefficient, and normalized permeability and uniformity coefficient.

Statistical analyses were performed for selected pervious concrete properties such as strengths, air voids and porosity, and the permeability. These analyses were done along with the development of the relationships that existed between compressive strength and permeability with the uniformity coefficients of the aggregate gradations of B and L. From this, an effective mix gradation can be determined and designed to match the primary function that the pervious concrete mixture is to serve.

Conclusions

Based on the results from this laboratory investigation on pervious concrete mixtures, the following conclusions were made:

- The fresh concrete mix unit weight is directly related to the aggregate dry rodded unit weight. As the dry rodded unit weight of the aggregate increases the unit weight of the fresh concrete also increases.
- The compressive, split-tensile, and flexural strengths increased with the uniformity coefficient to points after which a decrease in strength was observed. This could indicate the presence of an optimum uniformity coefficient for compressive, split-tensile and flexural strength.
- The LA abrasion loss of the aggregate did not significantly affect the strength properties of the pervious concrete mixtures.
- The effective porosity of a pervious concrete mixture increases with air voids regardless of aggregate source.
- The compressive, split-tensile and flexural strengths are inversely related to air voids. As the air voids increase the strength properties of pervious concrete mixtures decreases.
- The hydraulic conductivity decreased as the uniformity coefficient increased to points after which an increase in permeability was observed. This could indicate the presence of a pessimum uniformity coefficient for hydraulic conductivity.
- The compressive, split-tensile, and flexural strengths of the single-sized aggregate gradations decreased as the nominal maximum aggregate size increased. The general trend of the blended aggregate gradations, however, did not follow consistent trends with respect to NMAS for each aggregates source.

Recommendations

Based on this evaluation of pervious concrete performance, the following recommendations are provided to generalize and to build upon the findings of this study:

Recommendation for Implementation

- A single-sized aggregate gradation (#4, ⅜ in., and ½ in.) can be used for applications that require high porosity because of high rainfall intensities and relatively low strength.
- Applications that require greater strength and rideability properties can use a blended gradation (i.e., higher C_u) consisting of higher proportions of aggregate sizes retained on the #8 and #16 sieves. Such requirements can be met with the #89 or A9.5 gradations used in this study.
- Applications that require fairly high strength and hydraulic properties can use a blended gradation consisting of higher proportions of the ⅜ in. and ½ in. aggregate sizes. Such requirements can be met with aggregate gradations similar to the #67 or #67-I used in this study.
- In addition, a figure similar to Figure 4.17 can be used as a guide in selecting pervious concrete gradations that are suitable for specific application requirements based on uniformity coefficients for a specific aggregate source. See the design example in Appendix F.

Recommendation for Future Research

- Measure the performance of pervious concrete mixtures prepared using variations in the water/cement ratio to determine effective dosages of water for specific aggregate gradations.
- Measure the performance of pervious concrete mixtures prepared using variations in the cement/aggregate ratio to determine effective cement content for specific aggregate gradations.
- Develop relationships to aid in predicting compressive, split-tensile, flexural strengths and permeability based on uniformity coefficients.
- Investigate the effects of fines on the durability and permeability of pervious concrete mixtures
- Investigate the effects of fibers and crumb rubber in pervious concrete mixtures.

APPENDICES

Appendix A

Compressive Strength Experimental Data

Aggregate B

Table A.1 Compressive strength of PCPC cylinders of aggregate B for #4.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Maxi. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.030	5.752	9,639	1,337	2
2	2.999	5.755	8,209	1,162	2
3	2.999	5.783	8,980	1,271	2/4
4	3.029	5.785	11,509	1,597	2
5	3.017	5.790	9,494	1,328	2
Mean	3.015	5.773	**9,566**	**1,339**	
Standard Deviation	0.015	0.018	**1,222**	**160**	
Coefficient of Variation	0.51%	0.31%	**12.77%**	**11.96%**	

Table A.2 Compressive strength of PCPC cylinders of aggregate B #89.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.004	5.844	15,418	2,176	2
2	2.999	5.841	16,243	2,299	2
3	3.007	5.788	15,719	2,214	5
4	3.011	5.828	16,685	2,344	5
Mean	3.006	5.829	**16,016**	**2,258**	
Standard Deviation	0.004	0.024	**561**	**77**	
Coefficient of Variation	0.15%	0.41%	**3.50%**	**3.41%**	

Table A.3 Compressive strength of PCPC cylinders of aggregate B for ⅜ in.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.009	5.793	13,339	1,876	2
2	3.021	5.767	11,776	1,643	4
3	3.008	5.802	9,266	1,304	1/5
4	3.006	5.7825	13,804	1,946	2
5	3.014	5.7535	11,752	1,648	2
Mean	**3.011**	**5.780**	**11,987**	**1,683**	
Standard Deviation	**0.006**	**0.020**	**1,777**	**251**	
Coefficient of Variation	**0.20%**	**0.34%**	**14.82%**	**14.93%**	

Table A.4 Compressive strength of PCPC cylinders of aggregate B for A9.5.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.003	5.8385	11,633	1,642	2L
2	2.995	5.8145	14,530	2,063	2
3	3.003	5.8188	11,672	1,648	2
4	3.001	5.8275	12,224	1,728	2
5	3.006	5.8005	13,495	1,902	2
Mean	3.001	5.820	**12,711**	**1,797**	
Standard Deviation	0.004	0.014	**1,265**	**182**	
Coefficient of Variation	0.14%	0.24%	**9.95%**	**10.14%**	

Table A.5 Compressive strength of PCPC cylinders of aggregate B for #78.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.024	5.812	12,027	1,675	2
2	3.000	5.7535	12,193	1,725	2
3	3.006	5.781	13,715	1,933	4
4	3.008	5.8145	10,895	1,533	2
5	3.011	5.7885	11,384	1,599	2
Mean	3.010	5.790	**12,043**	**1,693**	
Standard Deviation	0.009	0.025	**1,069**	**153**	
Coefficient of Variation	0.30%	0.43%	**8.88%**	**9.03%**	

Table A.6 Compressive strength of PCPC cylinders of aggregate B for ½ in.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
Retested 1	2.995	5.783	8,373	1,188	2
2	3.010	5.777	6,764	950	2/3
3	2.989	5.755	8,041	1,146	2
4	2.997	5.762	10,997	1,559	3
Retested 5	3.002	5.8	8,821	1,246	2/3
Mean	**2.999**	**5.775**	**8,599**	**1,218**	
Standard Deviation	**0.008**	**0.018**	**1,543**	**221**	
Coefficient of Variation	**0.26%**	**0.31%**	**17.95%**	**18.11%**	

Table A.7 Compressive strength of PCPC cylinders of aggregate B for #67.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.017	5.7863	12,968	1,815	4/2
2	3.019	5.763	10,326	1,442	2
3	2.990	5.767	12,351	1,759	2
4	3.012	5.759	12,519	1,757	2
5	3.013	5.779	15,154	2,126	2
Mean	3.010	5.771	**12,664**	**1,780**	
Standard Deviation	0.012	0.011	**1,723**	**243**	
Coefficient of Variation	0.38%	0.20%	**13.61%**	**13.64%**	

Table A.8 Compressive strength of PCPC cylinders of aggregate B for A12.5.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.009	5.8715	15,596	2,194	2/4
2	3.003	5.7995	13,788	1,947	4
3	3.012	5.782	0	0	5
4	3.010	5.7975	15,919	2,237	2
5	3.006	5.8205	14,585	2,055	5
Mean	**3.008**	**5.814**	**14,972**	**2,108**	
Standard Deviation	**0.004**	**0.035**	**973**	**132**	
Coefficient of Variation	**0.12%**	**0.60%**	**6.50%**	**6.28%**	

Aggregate L

Table A.9 Compressive strength of PCPC cylinders of aggregate L for #4.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	2.999	5.75	11,926	1,689	2
2	3.011	5.724	15,198	2,134	4
3	3.018	5.777	12,460	1,742	3 side
4	3.009	5.786	13,762	1,935	
5	3.004	5.773	16,184.	2,283	
Mean	3.008	5.762	**13,906**	**1,957**	
Standard Deviation	0.007	0.025	**1,795**	**253**	
Coefficient of Variation	0.24%	0.44%	**12.91%**	**12.95%**	

Table A.10 Compressive strength of PCPC cylinders of aggregate L for #89-C.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.016	5.814	10,776	1,509	
2	3.009	5.791	10,906	1,533	
3	3.013	5.807	11,187	1,569	
4	3.011	5.761	12,798	1,798	
5	3.010	5.799	13,409	1,885	
Mean	3.012	5.794	**11,815**	**1,659**	
Standard Deviation	0.003	0.020	**1,205**	**171**	
Coefficient of Variation	0.09%	0.35%	**10.20%**	**10.29%**	

Table A.11 Compressive strength of PCPC cylinders of aggregate L for #89.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.007	5.88	19,947	2,809	5 top
2	2.997	5.892	24,096	3,416	5/4
3	3.001	5.885	20,161	2,850	5/4
5	2.993	5.756	18,988	2,699	
Mean	**3.00**	**5.85**	**20,798**	**2,943**	
Standard Deviation	0.006	0.073	**2,257**	**321**	
Coefficient of Variation	0.19%	1.25%	**10.85%**	**10.92%**	

Table A.12 Compressive strength of PCPC cylinders of aggregate L for #89-F.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.008	5.755	14,003	1,971	4
2	3.008	5.767	14,165	1,994	2
4	3.004	5.782	14,230	2,008	5/4
5	3.020	5.778	13,806	1,928	2
Mean	3.009	5.771	**13,574**	**1,975**	
Standard Deviation	0.006	0.011	**1,078**	**35**	
Coefficient of Variation	0.22%	0.18%	**7.94%**	**1.76%**	

Table A.13 Compressive strength of PCPC cylinders of aggregate L for ⅜ in.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.011	5.7446	15,760	2,213	1/4
3	3.003	5.7265	13,581	1,917	4
4	3.008	5.7148	13,623	1,918	4
5	2.998	5.742	12,018	1,703	5
Mean	**3.00**	**5.73**	**13,746**	**1,938**	
Standard Deviation	**0.006**	**0.014**	**1537**	**210**	
Coefficient of Variation	**0.20%**	**0.24%**	**11.18%**	**10.81%**	

Table A.14 Compressive strength of PCPC cylinders of aggregate L for #78-C.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.011	5.778	12,719	1,787	
2	3.004	5.781	12,510	1,766	
3	3.013	5.775	14,041	1,969	
4	3.006	5.735	13,067	1,841	
5	3.009	5.764	12,106	1,702	
Mean	3.008	5.767	**12,888**	**1,813**	
Standard Deviation	0.004	0.019	**732**	**101**	
Coefficient of Variation	0.12%	0.32%	**5.68%**	**5.54%**	

Table A.15 Compressive strength of PCPC cylinders of aggregate L for A9.5-C.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.012	5.683	15,160	2,128	2
2	3.013	5.770	13,759	1,930	2
3	3.014	5.771	13,376	1,875	4
4	3.019	5.779	13,897	1,942	4
5	3.010	5.793	13,721	1,929	4
Mean	3.013	5.759	**13,983**	**1,961**	
Standard Deviation	0.003	0.044	**686**	**97**	
Coefficient of Variation	0.11%	0.76%	**4.90%**	**4.94%**	

Table A.16 Compressive strength of PCPC cylinders of aggregate L for A9.5.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.004	5.768	17,849	2,518	5
2	3.004	5.794	20,663	2,915	5
3	2.996	5.762	12,920	1,833	2
4	3.007	5.79	22,388	3,153	2
5	3.003	5.804	21,842	3,084	5
Mean	3.003	5.784	**19,133**	**2,701**	
Standard Deviation	0.004	0.018	**3,890**	**544**	
Coefficient of Variation	0.14%	0.31%	**20.33%**	**20.14%**	

Table A.17 Compressive strength of PCPC cylinders of aggregate L for #78.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
Tended tohave side blowouts 1	3.009	5.808	17,968	2,527	2
2	2.973	5.791	17,086	2,461	2/4
3	2.992	5.816	17,806	2,532	2/4
4	3.008	5.776	17,528	2,467	4
Mean	2.996	5.798	**17,597**	**2,497**	
Standard Deviation	0.015	0.017	**386**	**38**	
Coefficient of Variation	0.49%	0.30%	**2.19%**	**1.53%**	

Table A.18 Compressive strength of PCPC cylinders of aggregate L for ½ in.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
2	2.990	5.763	12,302	1,752	2
3	3.008	5.760	15,469	2,177	5
4	3.016	5.769	14,057	1,968	5
5	3.011	5.762	12,023	1,689	2
Mean	**3.005**	**5.763**	**13,463**	**1,896**	
Standard Deviation	**0.010**	**0.004**	**2,337**	**324**	
Coefficient of Variation	**0.34%**	**0.07%**	**17.36%**	**17.10%**	

Table A.19 Compressive strength of PCPC cylinders of aggregate L for #67-I.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.009	5.745	11,445	1,609	2
2	3.012	5.771	16,126	2,264	2
retested 3	3.010	5.767	13,548	1,904	
4	3.015	5.761	12,646	1,772	4
retested 5	3.013	5.750	13,418	1,882	5
Mean	**3.012**	**5.762**	**13,437**	**1,886**	
Standard Deviation	**0.002**	**0.009**	**1,720**	**241**	
Coefficient of Variation	**0.07%**	**0.16%**	**12.80%**	**12.79%**	

Table A.20 Compressive strength of PCPC cylinders of aggregate L for #67.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.017	5.786	12,136	1,698	4/2
Retested 2	3.019	5.763	14,518	2,028	5
3	2.990	5.767	14,900	2,122	5
4	3.012	5.759	16,869	2,367	2
Mean	3.009	5.769	**14,606**	**2,054**	
Standard Deviation	0.013	0.012	**1,942**	**277**	
Coefficient of Variation	0.44%	0.21%	**13.30%**	**13.49%**	

Table A.21 Compressive strength of PCPC cylinders of aggregate L for #A12.5-C.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.057	5.758	16,991	2,314	2
2	3.012	5.7695	17,469	2,452	2
3	3.007	5.7473	16,135	2,272	4
4	3.010	5.7573	12,409	1,744	4
5	3.013	5.7988	14,777	2,073	4
6	3.005	5.727	13,748	1,938	
Mean	**3.02**	**5.76**	**15,255**	**2,132**	
Standard Deviation	**0.020**	**0.024**	**1964**	**263**	
Coefficient of Variation	**0.66%**	**0.41%**	**12.88%**	**12.35%**	

Table A.22 Compressive strength of PCPC cylinders of aggregate L for #A12.5.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	2.983	5.776	19,315	2,764	5
2	2.997	5.804	16,385	2,323	5
no padding 3	3.005	5.812	19,298	2,721	4
no padding 5	3.001	5.778	18,551	2,623	5
Mean	**2.997**	**5.793**	**18,387**	**2,608**	
Standard Deviation	**0.008**	**0.017**	**436**	**72**	
Coefficient of Variation	**0.28%**	**0.29%**	**2.37%**	**2.77%**	

Table A.23 Compressive strength of PCPC cylinders of aggregate L for #A12.5-F.

Sample #	Dia. of Specimen (in.)	Height of Specimen (in.)	Max. Force (lb)	Compressive Strength (psi)	Type of Failure
1	3.011	5.726	15797	2219	4
2	3.010	5.801	13621	1914	4
3	3.008	5.745	16374	2304	5/4
4	3.012	5.767	13497	1894	5
retested 5	3.015	5.767	13733	1923	4
Mean	**3.011**	**5.761**	**14604**	**2051**	
Standard Deviation	**0.003**	**0.028**	**1370**	**195**	
Coefficient of Variation	**0.09%**	**0.49%**	**9.38%**	**9.50%**	

Appendix B

Split Tensile Strength Experimental Data

Aggregate B

Table B.1 Split-Tensile strength of PCPC cylinders of aggregate B for #4.

Sample #	**Dia. of Specimen (in.)**	**Length of Specimen (in.)**	**Max. Force (lb)**	**Split Tensile Strength (psi)**
6	3.034	5.771	5,908	215
7	3.030	5.812	5,620	203
8	3.035	5.752	7,194	262
9	3.028	5.821	7,648	276
10	3.075	5.824	6,642	236
Mean	3.040	5.796	**6,602**	**239**
Standard Deviation	0.020	0.032	**850**	**31**
Coefficient of Variation	0.64%	0.56%	**12.87%**	**12.93%**

Table B.2 Split-Tensile strength of PCPC cylinders of aggregate B for #89.

Sample #	**Dia. of Specimen (in.)**	**Length of Specimen (in.)**	**Max. Force (lb)**	**Split Tensile Strength (psi)**
6	3.010	5.846	10,203	369
7	3.019	5.835	10,768	389
8	3.013	5.793	10,285	375
9	3.008	5.834	9,981	362
10	3.007	5.813	11,610	423
Mean	3.011	5.824	10,569	384
Standard Deviation	0.005	0.021	649	24
Coefficient of Variation	0.17%	0.36%	6.14%	6.27%

Table B.3 Split-Tensile strength of PCPC cylinders of aggregate B for ⅜ in.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.013	5.764	9,080	333
7	2.998	5.786	9,379	344
8	3.009	5.770	6,882	253
9	3.028	5.846	8,261	297
10	3.013	5.779	7,601	278
Mean	**3.012**	**5.789**	**8,241**	**301**
Standard Deviation	**0.011**	**0.033**	**1032**	**38**
Coefficient of Variation	**0.36%**	**0.57%**	**12.52%**	**12.65%**

Table B.4 Split-Tensile strength of PCPC cylinders of aggregate B for A9.5.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	2.990	5.780	9,929	366
7	3.000	5.825	9,934	362
8	3.017	5.797	10,470	381
9	3.016	5.800	9,278	338
10	2.998	5.816	10,828	396
Mean	3.004	5.803	**10,088**	**369**
Standard Deviation	0.012	0.017	**591**	**22**
Coefficient of Variation	0.40%	0.30%	**5.86%**	**5.89%**

Table B.5 Split-Tensile strength of PCPC cylinders of aggregate B for #78.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.001	5.770	10,110	372
7	3.006	5.778	7,946	291
8	3.011	5.790	9,573	350
9	3.006	5.800	10,615	388
10	3.045	5.799	7,888	285
Mean	3.014	5.787	9,226	337
Standard Deviation	0.018	0.013	1,251	47
Coefficient of Variation	0.59%	0.22%	13.56%	13.90%

Table B.6 Split-Tensile strength of PCPC cylinders of aggregate B for ½ in.

Sample #	Dia. of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
7	3.004	6,040	213
8	3.011	5,321	188
9	3.015	5,,854	206
10	3.006	6479	229
Mean	**3.007**	**5,924**	**209**
Standard Deviation	**0.006**	**480**	**17**
Coefficient of Variation	**0.19%**	**8.10%**	**8.19%**

Table B.7 Split-Tensile strength of PCPC cylinders of aggregate B for #67.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.022	5.758	8,513	312
7	3.008	5.804	7,005	256
8	3.032	5.782	8,340	303
9	3.037	5.839	11,383	409
10	3.009	5.793	8,783	321
Mean	3.021	**5.795**	**8,805**	**320**
Standard Deviation	0.013	**0.03**	**1,596**	**56**
Coefficient of Variation	0.43%	**0.51%**	**18.13%**	**17.41%**

Table B.8 Split-Tensile strength of PCPC cylinders of aggregate B for A12.5.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.005	5.830	9,630	350
7	3.007	5.848	8,728	316
8	3.013	5.845	8,771	317
9	3.008	5.763	9,553	351
10	3.016	5.891	9,887	354
Mean	**3.010**	**5.835**	**9,314**	**338**
Standard Deviation	**0.005**	**0.047**	**530**	**19**
Coefficient of Variation	**0.16%**	**0.80%**	**5.69%**	**5.72%**

Aggregate L

Table B.9 Split-Tensile strength of PCPC cylinders of aggregate L for #4.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.004	5.777	8,561	314
7	3.016	5.772	7,352	269
8	2.992	5.768	6,511	240
9	3.006	5.789	7,995	293
10	2.993	5.784	6,972	257
Mean	3.002	5.778	**7,478**	**275**
Standard Deviation	0.010	0.009	**814**	**29**
Coefficient of Variation	0.32%	0.15%	**10.88%**	**10.67%**

Table B.10 Split-Tensile strength of PCPC cylinders of aggregate L for #89-C.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.005	5.746	7,362	272
7	3.011	5.759	7,514	276
8	3.018	5.680	5,884	219
9	3.018	5.705	5,283	195
10	3.011	5.799	6,887	251
Mean	**3.01**	**5.74**	**6,586**	**243**
Standard Deviation	0.006	0.047	968	**35**
Coefficient of Variation	0.19%	0.82%	14.69%	**14.32%**

Table B.11 Split-Tensile strength of PCPC cylinders of aggregate L for #89.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.005	5.725	9,912	367
7	3.018	5.753	9,641	354
8	3.009	5.800	10,347	378
9	3.000	5.800	10,154	372
10	2.989	5.816	10,789	395
Mean	3.004	5.779	**10,169**	**373**
Standard Deviation	0.011	0.038	**436**	**15**
Coefficient of Variation	0.36%	0.66%	**4.29%**	**4.09%**

Table B.12 Split-Tensile strength of PCPC cylinders of aggregate L for #89-C.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.013	5.735	7,980	294
7	3.005	5.773	7,866	289
8	3.008	5.763	7,084	260
9	3.012	5.793	8,132	297
10	3.015	5.759	7,734	284
Mean	3.010	5.764	**7,759**	**285**
Standard Deviation	0.004	0.02	**405**	**15**
Coefficient of Variation	0.13%	0.37%	**5.22%**	**5.13%**

Table B.13 Split-Tensile strength of PCPC cylinders of aggregate L for ⅜ in.

Sample #	Dia. of Specimen	Length of Specimen	Max. Force	Split Tensile Strength
	(in.)	(in.)	(lb)	(psi)
6	3.009	5.744	7,618	281
7	3.017	5.773	6,844	250
8	3.015	5.752	6,251	230
9	3.015	5.733	7,727	285
10	3.015	5.754	7,392	271
Mean	**3.014**	**5.751**	**7,166**	**263**
Standard Deviation	**0.003**	**0.015**	**615**	**23**
Coefficient of Variation	**0.10%**	**0.26%**	**8.58%**	**8.77%**

Table B.14 Split-Tensile strength of PCPC cylinders of aggregate L for #78-C.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.004	5.771	7,693	283
7	3.000	5.810	7,842	287
8	3.001	5.805	6,714	246
9	3.006	5.745	8,131	300
10	3.011	5.826	7,501	272
Mean	3.004	5.792	**7,576**	**277**
Standard Deviation	0.005	0.033	**534**	**20**
Coefficient of Variation	0.15%	0.56%	**7.05%**	**7.34%**

Table B.15 Split-Tensile strength of PCPC cylinders of aggregate L for A9.5-C.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.009	5.801	8,522	311
7	3.015	5.770	8,365	306
8	3.003	5.799	7,138	261
9	3.013	5.739	5,701	210
10	3.009	5.780	7,847	287
Mean	3.010	5.778	**7,515**	**275**
Standard Deviation	0.004	0.025	**1,149**	**41**
Coefficient of Variation	0.15%	0.44%	**15.29%**	**15.03%**

Table B.16 Split-Tensile strength of PCPC cylinders of aggregate L for A9.5.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	2.995	5.775	9,951	366
7	3.002	5.770	9,946	366
8	3.002	5.782	10,008	367
10	3.012	5.730	9,996	369
Mean	3.00	5.76	9,975	**367**
Standard Deviation	0.007	0.024	31	**1**
Coefficient of Variation	0.22%	0.42%	0.31%	**0.37%**

Table B.17 Split-Tensile strength of PCPC cylinders of aggregate L for #78.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	2.990	5.831	7,465	273
7	2.989	5.818	9,398	344
8	2.998	5.801	7,711	282
9	3.005	5.715	8,139	302
10	3.008	5.805	9,035	330
Mean	2.998	5.794	**8,349**	**306**
Standard Deviation	0.009	0.046	**837**	**30**
Coefficient of Variation	0.29%	0.79%	**10.03%**	**9.93%**

Table B.18 Split-Tensile strength of PCPC cylinders of aggregate L for ½ in.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	2.996	5.748	7179	266
7	3.013	5.760	6588	242
8	3.011	5.770	7030	258
9	2.988	5.846	5758	210
Mean	**3.002**	**5.781**	**6639**	**244**
Standard Deviation	**0.012**	**0.044**	**639**	**25**
Coefficient of Variation	**0.40%**	**0.77%**	**9.62%**	**10.09%**

Table B.19 Split-Tensile strength of PCPC cylinders of aggregate L for #67-I.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.010	5.751	9,181	338
7	3.014	5.800	7,248	264
8	3.013	5.760	6,018	221
9	3.012	5.762	7,412	272
10	3.013	5.765	8,922	327
Mean	**3.012**	**5.767**	**7,756**	**284**
Standard Deviation	**0.002**	**0.019**	**1,302**	**48**
Coefficient of Variation	**0.06%**	**0.33%**	**16.79%**	**16.95%**

Table B.20 Split-Tensile strength of PCPC cylinders of aggregate L for #67.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	2.997	5.731	7,872	292
7	3.004	5.739	8,531	315
8	3.019	5.754	9,376	344
9	3.013	5.785	8,124	297
10	3.016	5.780	7,278	266
Mean	3.010	5.758	**8,236**	**303**
Standard Deviation	0.009	0.02	**782**	**29**
Coefficient of Variation	0.30%	0.42%	**9.50%**	**9.56%**

Table B.21 Split-Tensile strength of PCPC cylinders of aggregate L for A12.5-C.

Sample #	Dia. of Specimen	Length of Specimen	Max. Force	Split Tensile Strength
	(in.)	(in.)	(lb)	(psi)
7	3.010	5.786	7,879	288
8	3.010	5.749	8,390	309
9	3.007	5.755	9,373	345
10	3.009	5.789	7,856	287
Mean	**3.009**	**5.770**	**8,374**	**307**
Standard Deviation	**0.001**	**0.021**	**710**	**27**
Coefficient of Variation	**0.05%**	**0.36%**	**8.48%**	**8.80%**

Table B.22 Split-Tensile strength of PCPC cylinders of aggregate L for A12.5.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
7	3.007	5.823	11,373	414
9	3.003	5.761	11,999	442
10	2.999	5.709	11,088	412
Mean	**3.00**	**5.76**	**11,487**	**423**
Standard Deviation	**0.00**	**0.06**	**466**	**17**
Coefficient of Variation	**0.13%**	**0.99%**	**4.06%**	**3.92%**

Table B.23 Split-Tensile strength of PCPC cylinders of aggregate L for A12.5-F.

Sample #	Dia. of Specimen (in.)	Length of Specimen (in.)	Max. Force (lb)	Split Tensile Strength (psi)
6	3.015	5.767	9,336	342
7	3.009	5.731	9,796	362
8	3.009	5.735	8,390	310
9	3.013	5.816	8,990	327
10	3.018	5.777	10,043	367
Mean	**3.013**	**5.765**	**9,311**	**341**
Standard Deviation	**0.004**	**0.035**	**656**	**24**
Coefficient of Variation	**0.13%**	**0.60%**	**7.05%**	**7.01%**

Appendix C

FLEXURAL STRENGTH EXPERIMENTAL DATA

Aggregate B

Table C.1 Flexural strength of PCPC prisms of aggregate B for #4.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	984	328
2	1106	369
3	933	311
4	909	303
5	1038	346
Mean	**994**	**331**
Standard Deviation	**80**	**27**
Coefficient of Variation	**8.05%**	**8.05%**

Table C.2 Flexural strength of PCPC prisms of aggregate B for #89.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	999	333
2	1,203	401
3	1,343	448
4	1,196	399
5	1,198	399
Mean	**1,188**	**396**
Standard Deviation	**123**	**41**
Coefficient of Variation	**10.33%**	**10.33%**

Table C.3 Flexural strength of PCPC prisms of aggregate B for ⅜ in.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	825	275
2	1,054	351
3	1,122	374
4	1,010	337
5	943	314
Mean	**991**	**330**
Standard Deviation	**113**	**38**
Coefficient of Variation	**11.43%**	**11.43%**

Table C.4 Flexural strength of PCPC prisms of aggregate B for A9.5.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	1,177	392
2	1,180	393
3	1,058	353
4	1,115	372
5	1,077	359
Mean	**1,121**	**374**
Standard Deviation	**56**	**19**
Coefficient of Variation	**4.99%**	**4.99%**

Table C.5 Flexural strength of PCPC prisms of aggregate B for #78.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	1,162	387
2	943	314
3	840	280
4	1,077	359
5	919	306
Mean	**988**	**329**
Standard Deviation	**129**	**43**
Coefficient of Variation	**13.06%**	**13.06%**

Table C.5 Flexural strength of PCPC prisms of aggregate B for ½ in.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	694.26	231
2	706.32	235
3	1,065.44	355
4	937.51	313
5	676.29	225
Mean	**815.96**	**272**
Standard Deviation	**175.61**	**58.54**
Coefficient of Variation	**21.52%**	**21.52%**

Table C.7 Flexural strength of PCPC prisms of aggregate B for #67.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	863	288
2	1,227	409
3	1,063	354
4	1,010	337
5	1,204	401
Mean	**1,073**	**358**
Standard Deviation	**150**	**50**
Coefficient of Variation	**13.93%**	**13.93%**

Table C.8 Flexural strength of PCPC prisms of aggregate B for A12.5.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	1,169	390
2	1,101	367
3	944	315
4	1,046	349
5	1,178	393
Mean	**1,087**	**362**
Standard Deviation	**97**	**32**
Coefficient of Variation	**8.90%**	**8.90%**

Aggregate L

Table C.9 Flexural strength of PCPC prisms of aggregate L for #4.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	927	309
2	1,031	344
3	1,047	349
4	1,080	360
5	1,121	374
Mean	**1,041**	**347**
Standard Deviation	**73**	**24**
Coefficient of Variation	**6.98%**	**6.98%**

Table C.10 Flexural strength of PCPC prisms of aggregate L for #89-C.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	957	319
2	748	249
3	1,028	343
4	761	254
5	815	272
Mean	**862**	**287**
Standard Deviation	**124**	**41**
Coefficient of Variation	**14.43%**	**14.43%**

Table C.11 Flexural strength of PCPC prisms of aggregate L for #89.

Sample #	Max. Force (lb)	Flexural Strength (psi)
1	1,037	346
2	1,098	366
3	1,019	340
4	922	307
5	984	328
Mean	**1,012**	**337**
Standard Deviation	**65**	**22**
Coefficient of Variation	**6.46%**	**6.46%**

Table C.12 Flexural strength of PCPC prisms of aggregate L for #89-F.

Sample #	**Max. Force (lb)**	**Flexural Strength (psi)**
1	731	244
2	777	259
3	775	258
4	861	287
5	768	256
Mean	**782**	**261**
Standard Deviation	**48**	**16**
Coefficient of Variation	**6.13%**	**6.13%**

Table C.13 Flexural strength of PCPC prisms of aggregate L for ⅜ in.

Sample #	**Max. Force**	**Flexural Strength**
	(lb)	**(psi)**
1	825	275
2	852	284
3	857	286
4	1,095	365
5	1,159	386
Mean	**958**	**319**
Standard Deviation	**157**	**52**
Coefficient of Variation	**16.37%**	**16.37%**

Table C.14 Flexural strength of PCPC prisms of aggregate L for #78-C.

Sample #	**Max. Force**	**Flexural Strength**
	(lb)	**(psi)**
1	821	274
2	924	308
3	868	289
4	1,003	334
5	944	315
Mean	**912**	**304**
Standard Deviation	**70**	**23**
Coefficient of Variation	**7.72%**	**7.72%**

Table C.15 Flexural strength of PCPC prisms of aggregate L for A9.5-C.

Sample #	Max. Force	Flexural Strength
	(lb)	(psi)
1	762	254
2	911	304
3	821	274
4	787	262
5	988	329
Mean	**854**	**285**
Standard Deviation	**94**	**31**
Coefficient of Variation	**10.99%**	**10.99%**

Table C.16 Flexural strength of PCPC prisms of aggregate L for A9.5.

Sample #	Max. Force	Flexural Strength
	(lb)	(psi)
1	1120	373
2	1236	412
3	1002	334
4	1137	379
5	1245	415
Mean	**1148**	**383**
Standard Deviation	**99**	**33**
Coefficient of Variation	**8.65%**	**8.65%**

Table C.17 Flexural strength of PCPC prisms of aggregate L for #78.

Sample #	Max. Force	Flexural Strength
	(lb)	(psi)
1	1,041	347
2	1,007	336
3	1,274	425
4	1,133	378
5	977	326
Mean	**1,086**	**362**
Standard Deviation	**120**	**40**
Coefficient of Variation	**11.07%**	**11.07%**

Table C.18 Flexural strength of PCPC prisms of aggregate L for ½ in.

Sample #	Max. Force	Flexural Strength
	(lb)	**(psi)**
1	914	305
2	917	306
3	864	288
4	976	325
5	915	305
Mean	**917**	**306**
Standard Deviation	**40**	**13**
Coefficient of Variation	**4.33%**	**4.33%**

Table C.19 Flexural strength of PCPC prisms of aggregate L for #67-I.

Sample #	Max. Force	Flexural Strength
	(lb)	**(psi)**
1	909	303
2	1,195	398
3	787	262
4	890	297
5	929	310
Mean	**942**	**314**
Standard Deviation	**152**	**51**
Coefficient of Variation	**16.09%**	**16.09%**

Table C.20 Flexural strength of PCPC prisms of aggregate L for #67.

Sample #	Max. Force	Flexural Strength
	(lb)	**(psi)**
1	1,166	389
2	1,030	343
3	1,108	369
4	976	325
5	954	318
Mean	**1,047**	**349**
Standard Deviation	**89**	**30**
Coefficient of Variation	**8.52%**	**8.52%**

Table C.21 Flexural strength of PCPC prisms of aggregate L for A12.5-C.

Sample #	Max. Force	Flexural Strength
	(lb)	(psi)
1	989	330
2	1,258	419
3	1,067	356
4	971	324
Mean	**1,071**	**357**
Standard Deviation	**131**	**44**
Coefficient of Variation	**12.24%**	**12.24%**

Table C.22 Flexural strength of PCPC prisms of aggregate L for A12.5.

Sample #	Max. Force	Flexural Strength
	(lb)	(psi)
1	1,065	355
2	976	325
3	1,207	402
4	1,166	389
5	1,362	454
Mean	**1,155**	**385**
Standard Deviation	**146**	**49**
Coefficient of Variation	**12.66%**	**12.66%**

Table C.23 Flexural strength of PCPC prisms of aggregate L for A12.5-F.

Sample #	Max. Force	Flexural Strength
	(lb)	(psi)
1	848	283
2	1,274	425
3	931	310
4	833	278
5	968	323
Mean	**971**	**324**
Standard Deviation	**178**	**59**
Coefficient of Variation	**18.38%**	**18.38%**

Appendix D

Specific Gravity, Air Voids, and Porosity Experimental Data

Aggregate B

Table D.1 Maximum specific gravity of PCPC of aggregate B for the #4 mix.

	Sample #1	**Sample #2**
Mass Bowl in air (g)	2,486.1	2,244.9
Mass Sample in air (g)	**1,537.4**	**1,537.7**
Mass Bowl & Sample in air (g)	4,023.5	3,782.6
Mass Bowl under water (g)	**1,567.2**	**1,416.0**
Mass Bowl & Sample under water (g)	**2,540.3**	**2,390.1**
Mass Sample under water (g)	973.1	974.1
Max. Specific Gravity of Samples, SG	**2.724**	**2.728**
Mean Max. Specific Gravity of Samples, SG	**2.726**	
Standard Deviation	**0.003**	
Difference in Max. Specific Gravities	**0.004**	

Table D.2 Air voids and porosity of PCPC of aggregate B for the #4 mix.

Specimen No.	**Mass of Specimen**	**Mass of Bag**	**Mass of Sealed Specimen**	**Mass of Sealed Submerged Specimen**	**Mass of Unsealed Submerged Specimen**	**Bulk Spec. Gravity**	**App. Spec. Gravity**	**% Air Voids**	**% Porosity**
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,301.0	22.6	1,323.6	629.7	824.3	1.96	2.76	28.3	29.3
2	1,296.9	22.5	1,319.4	622.7	822.1	1.94	2.77	28.8	29.9
3	1,287.6	22.5	1,310.1	618.1	816.3	1.94	2.77	28.9	29.9
4	1,251.9	22.4	1,274.3	592.5	793.6	1.92	2.77	29.8	30.8
5	1,300.7	22.7	1,323.4	627.8	823.2	1.95	2.76	28.5	29.3
Mean	**1,287.6**	**22.5**	**1,310.2**	**618.2**	**815.9**	**1.94**	**2.76**	**28.9**	**29.8**
Std. Dev.	**20.7**	**0.1**	**20.8**	**15.0**	**12.8**	**0.015**	**0.004**	**0.006**	**0.006**
Coeff. Var.	**1.6%**	**0.5%**	**1.6%**	**2.4%**	**1.6%**	**0.8%**	**0.1%**	**1.9%**	**2.1%**

Table D.3 Maximum specific gravity of PCPC of aggregate B for the #89 mix.

	Sample #1	**Sample #2**
Mass Bowl in air (g)	2,486.2	2,245.2
Mass Sample in air (g)	**1,556.1**	**1,592.7**
Mass Bowl & Sample in air (g)	4,042.3	3,837.9
Mass Bowl under water (g)	**1,567.0**	**1,416.2**
Mass Bowl & Sample under water (g)	**2,547.9**	**2,418.3**
Mass Sample under water (g)	980.9	1,002.1
Max. Specific Gravity of Samples, SG	**2.705**	**2.697**
Mean Max. Specific Gravity of Samples, SG	**2.701**	
Standard Deviation	**0.006**	
Difference in Max. Specific Gravities	**0.009**	

Table D.4 Air voids and porosity of PCPC of aggregate B for the #89 mix.

Specimen No.	**Mass of Specimen**	**Mass of Bag**	**Mass of Sealed Specimen**	**Mass of Sealed Submerged Specimen**	**Mass of Unsealed Submerged Specimen**	**Bulk Spec. Gravity**	**App. Spec. Gravity**	**% Air Voids**	**% Porosity**
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,417.1	22.4	1,439.5	735.3	895.4	2.10	2.75	22.4	23.7
2	1,385.9	22.6	1,408.5	707.5	874.8	2.06	2.74	23.7	24.9
3	1,416.8	22.3	1,439.1	726.5	890.9	2.07	2.72	23.4	24.0
4	1,390.1	22.1	1,412.2	709.7	877.8	2.06	2.74	23.7	24.9
Mean	**1,402.5**	**22.4**	**1,424.8**	**719.8**	**884.7**	**2.07**	**2.74**	**23.3**	**24.4**
Std. Dev.	**16.8**	**0.2**	**16.8**	**13.4**	**10.0**	**0.017**	**0.010**	**0.627**	**0.619**
Coeff. Var.	**1.2%**	**0.9%**	**1.2%**	**1.9%**	**1.1%**	**0.8%**	**0.4%**	**2.7%**	**2.5%**

Table D.5 Maximum specific gravity of PCPC of aggregate B for the #⅜ in. mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,486.4	2,245.4
Mass Sample in air (g)	**1,501.5**	**1,504.0**
Mass Bowl & Sample in air (g)	3,987.9	3,749.4
Mass Bowl under water (g)	**1,566.3**	**1,413.8**
Mass Bowl & Sample under water (g)	**2,526.8**	**2,374.9**
Mass Sample under water (g)	960.5	961.1
Max. Specific Gravity of Samples, SG	**2.775**	**2.770**
Mean Max. Specific Gravity of Samples, SG	**2.773**	
Standard Deviation	**0.004**	
Difference in Max. Specific Gravities	**0.005**	

Table D.4 Air voids and porosity of PCPC of aggregate B for the ⅜ in. mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,345.7	22.1	1,367.8	676.1	852.9	2.03	2.76	26.9	26.7
2	1,333.4	22.1	1,355.5	673.0	844.8	2.04	2.76	26.5	26.3
3	1,325.4	21.6	1,347.0	668.1	843.9	2.03	2.79	26.7	27.0
4	1,363.3	22.4	1,385.7	688.1	865.3	2.04	2.77	26.6	26.5
5	1,342.6	22.3	1,364.9	675.0	852.3	2.03	2.77	26.8	26.8
Mean	**1,342.1**	**22.1**	**1,364.2**	**676.1**	**851.8**	**2.03**	**2.77**	**26.7**	**26.6**
Std. Dev.	**14.3**	**0.3**	**14.6**	**7.4**	**8.6**	**0.005**	**0.009**	**0.163**	**0.283**
Coeff. Var.	**1.1%**	**1.4%**	**1.1%**	**1.1%**	**1.0%**	**0.2%**	**0.3%**	**0.6%**	**1.1%**

Table D.7 Maximum specific gravity of PCPC of aggregate B for the A9.5 mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,486.1	2,244.8
Mass Sample in air (g)	**1,549.7**	**1,548.0**
Mass Bowl & Sample in air (g)	4,035.8	3,792.8
Mass Bowl under water (g)	**1,567.0**	**1,416.4**
Mass Bowl & Sample under water (g)	**2,547.0**	**2,391.6**
Mass Sample under water (g)	980.0	975.2
Max. Specific Gravity of Samples, SG	**2.720**	**2.703**
Mean Max. Specific Gravity of Samples, SG	**2.711**	
Standard Deviation	**0.013**	
Difference in Max. Specific Gravities	**0.0177**	

Table D.8 Air voids and porosity of PCPC of aggregate B for the A9.5 mix.

Specimen No.	**Mass of Specimen**	**Mass of Bag**	**Mass of Sealed Specimen**	**Mass of Sealed Submerged Specimen**	**Mass of Unsealed Submerged Specimen**	**Bulk Spec. Gravity**	**App. Spec. Gravity**	**% Air Voids**	**% Porosity**
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,363.7	22.4	1,386.1	685.2	861.3	2.03	2.75	25.2	26.2
2	1,367.1	22.3	1,389.4	695.5	862.6	2.05	2.74	24.3	25.1
3	1,390.5	22.2	1,412.7	713.1	874.3	2.07	2.72	23.6	24.0
4	1,375.0	22.4	1,397.4	704.1	869.5	2.07	2.75	23.8	24.9
5	1,390.6	22.4	1,413.0	713.6	879.2	2.07	2.75	23.6	24.7
Mean	**1,377.4**	**22.3**	**1,399.7**	**702.3**	**869.4**	**2.06**	**2.74**	**24.1**	**25.0**
Std. Dev.	**12.7**	**0.1**	**12.7**	**12.1**	**7.6**	**0.019**	**0.011**	**0.691**	**0.793**
Coeff. Var.	**0.9%**	**0.4%**	**0.9%**	**1.7%**	**0.9%**	**0.9%**	**0.4%**	**2.9%**	**3.2%**

Table D.9 Maximum specific gravity of PCPC of aggregate B for the #78 mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,486.1	2,244.8
Mass Sample in air (g)	**1,541.1**	**1,538.3**
Mass Bowl & Sample in air (g)	4,027.2	3,783.1
Mass Bowl under water (g)	**1,567.0**	**1,416.4**
Mass Bowl & Sample under water (g)	**2,539.7**	**2,391.1**
Mass Sample under water (g)	972.7	974.7
Max. Specific Gravity of Samples, SG	**2.711**	**2.729**
Mean Max. Specific Gravity of Samples, SG	**2.720**	
Standard Deviation	**0.013**	
Difference in Max. Specific Gravities	**0.0181**	

Table D.10 Air voids and porosity of PCPC of aggregate B for the #78 mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,348.4	22.2	1,370.6	676.4	832.0	2.02	2.64	25.6	23.4
2	1,343.5	22.3	1,365.8	671.3	848.8	2.02	2.75	25.9	26.7
3	1,325.8	22.3	1,348.1	653.2	836.7	1.99	2.74	26.9	27.5
4	1,348.3	22.3	1,370.6	680.2	851.4	2.04	2.75	25.2	25.9
5	1,339.1	22.6	1,361.7	672.7	845.9	2.03	2.75	25.5	26.2
Mean	**1,341.0**	**22.3**	**1,363.4**	**670.8**	**843.0**	**2.02**	**2.73**	**25.8**	**25.9**
Std. Dev.	**9.3**	**0.2**	**9.3**	**10.4**	**8.3**	**0.018**	**0.047**	**0.670**	**1.562**
Coeff. Var.	**0.7%**	**0.7%**	**0.7%**	**1.6%**	**1.0%**	**0.9%**	**1.7%**	**2.6%**	**6.0%**

Table D.11 Maximum specific gravity of PCPC of aggregate B for the ½ in mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,486.3	2,245.2
Mass Sample in air (g)	**1,509.5**	**1,505.0**
Mass Bowl & Sample in air (g)	3,995.8	3,750.2
Mass Bowl under water (g)	**1,567.5**	**1,416.2**
Mass Bowl & Sample under water (g)	**2,527.6**	**2,376.3**
Mass Sample under water (g)	960.1	960.1
Max. Specific Gravity of Samples, SG	**2.748**	**2.762**
Mean Max. Specific Gravity of Samples, SG	**2.755**	
Standard Deviation	**0.010**	
Difference in Max. Specific Gravities	**0.014**	

Table D.12 Air voids and porosity of PCPC of aggregate B for the ½ in. mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,292.1	22.3	1,314.4	657.0	821.9	2.05	2.78	25.5	26.2
2	1,268.4	22.3	1,290.7	641.2	802.2	2.04	2.76	25.9	25.9
3	1,288.4	22.3	1,310.7	654.5	815.7	2.05	2.76	25.5	25.7
4	1,267.1	22.4	1,289.5	637.6	804.7	2.03	2.78	26.3	26.8
5	1,289.7	22.5	1,312.2	657.7	818.5	2.06	2.77	25.2	25.7
Mean	**1,281.1**	**22.4**	**1,303.5**	**649.6**	**812.6**	**2.05**	**2.77**	**25.7**	**26.1**
Std. Dev.	**12.3**	**0.1**	**12.3**	**9.5**	**8.7**	**0.011**	**0.011**	**0.401**	**0.469**
Coeff. Var.	**1.0%**	**0.4%**	**0.9%**	**1.5%**	**1.1%**	**0.5%**	**0.4%**	**1.6%**	**1.8%**

Table D.13 Maximum specific gravity of PCPC of aggregate B for the #67 mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,486.1	2,244.9
Mass Sample in air (g)	**1,532.9**	**1,531.6**
Mass Bowl & Sample in air (g)	4,019.0	3,776.5
Mass Bowl under water (g)	**1,567.2**	**1,416.0**
Mass Bowl & Sample under water (g)	**2,536.9**	**2,383.9**
Mass Sample under water (g)	969.7	967.9
Max. Specific Gravity of Samples, SG	**2.722**	**2.717**
Mean Max. Specific Gravity of Samples, SG	**2.719**	
Standard Deviation	**0.003**	
Difference in Max. Specific Gravities	**0.005**	

Table D.14 Air voids and porosity of PCPC of aggregate B for the #67 mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,360.7	22.2	1,382.9	698.2	862.8	2.07	2.77	23.8	25.1
2	1,325.2	22.4	1,347.6	674.8	838.8	2.06	2.76	24.4	25.5
3	1,350.1	22.6	1,372.7	694.3	855.5	2.08	2.76	23.6	24.8
4	1,342.4	22.2	1,364.6	688.6	824.9	2.07	2.62	23.8	21.1
5	1,345.8	22.5	1,368.3	688.5	853.8	2.07	2.77	24.0	25.4
Mean	**1,344.8**	**22.4**	**1,367.2**	**688.9**	**847.2**	**2.07**	**2.74**	**23.9**	**24.4**
Std. Dev.	**13.0**	**0.2**	**12.9**	**8.9**	**15.2**	**0.008**	**0.063**	**0.299**	**1.870**
Coeff. Var.	**1.0%**	**0.8%**	**0.9%**	**1.3%**	**1.8%**	**0.4%**	**2.3%**	**1.3%**	**7.7%**

Table D.15 Maximum specific gravity of PCPC of aggregate B for the A12.5 mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,486.1	2,244.9
Mass Sample in air (g)	**1,466.5**	**1,466.3**
Mass Bowl & Sample in air (g)	3,952.6	3,711.2
Mass Bowl under water (g)	**1,567.2**	**1,416.0**
Mass Bowl & Sample under water (g)	**2,500.6**	**2,350.1**
Mass Sample under water (g)	933.4	934.1
Max. Specific Gravity of Samples, SG	**2.751**	**2.755**
Mean Max. Specific Gravity of Samples, SG	**2.753**	
Standard Deviation	**0.003**	
Difference in Max. Specific Gravities	**0.004**	

Table D.16 Air voids and porosity of PCPC of aggregate B for the A12.5 mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,375.9	22.6	1,398.5	696.5	873.0	2.04	2.77	25.8	26.2
2	1,377.0	22.4	1,399.4	704.6	872.0	2.07	2.76	25.0	25.1
3	1,407.4	22.3	1,429.7	725.0	892.7	2.08	2.77	24.4	24.8
4	1,409.4	22.3	1,431.7	731.6	892.4	2.10	2.76	23.8	24.0
5	1,378.0	22.3	1,400.3	705.7	870.4	2.07	2.75	24.9	24.7
Mean	**1,389.5**	**22.4**	**1,411.9**	**712.7**	**880.1**	**2.07**	**2.76**	**24.8**	**25.0**
Std. Dev.	**17.2**	**0.1**	**17.2**	**14.9**	**11.4**	**0.020**	**0.009**	**0.730**	**0.826**
Coeff. Var.	**1.2%**	**0.6%**	**1.2%**	**2.1%**	**1.3%**	**1.0%**	**0.3%**	**2.9%**	**3.3%**

Aggregate L

Table D.17 Maximum specific gravity of PCPC of aggregate L for the #4 mix.

	Sample #1	**Sample #2**
Mass Bowl in air (g)	2,484.0	2,244.8
Mass Sample in air (g)	**1,536.9**	**1,536.2**
Mass Bowl & Sample in air (g)	4,020.9	3,781.0
Mass Bowl under water (g)	**1,564.6**	**1,415.9**
Mass Bowl & Sample under water (g)	**2,511.9**	**2,360.6**
Mass Sample under water (g)	947.3	944.7
Max. Specific Gravity of Samples, SG	**2.607**	**2.597**
Mean Max. Specific Gravity of Samples, SG	**2.60**	
Standard Deviation	**0.007**	
Difference in Max. Specific Gravities	**0.010**	

Table D.18 Air voids and porosity of PCPC of aggregate L for the #4 mix.

Specimen No.	**Mass of Specimen**	**Mass of Bag**	**Mass of Sealed Specimen**	**Mass of Sealed Submerged Specimen**	**Mass of Unsealed Submerged Specimen**	**Bulk Spec. Gravity**	**App. Spec. Gravity**	**% Air Voids**	**% Porosity**
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,289.1	26.4	1,315.5	614.8	791.5	1.93	2.63	25.8	26.5
2	1,269.9	26.8	1,296.7	601.4	777.9	1.92	2.62	26.2	26.7
3	1,252.6	26.6	1,279.2	582.5	746.3	1.89	2.51	27.4	24.7
4	1,246.4	26.7	1,273.1	580.0	765.1	1.89	2.63	27.4	28.1
5	1,305.5	27.0	1,332.5	625.5	801.8	1.94	2.63	25.5	26.2
Mean	**1,272.7**	**26.7**	**1,299.4**	**600.8**	**776.5**	**1.91**	**2.60**	**26.5**	**26.4**
Std. Dev.	**24.7**	**0.2**	**24.8**	**19.8**	**21.8**	**0.024**	**0.053**	**0.906**	**1.205**
Coeff. Var.	**1.9%**	**0.8%**	**1.9%**	**3.3%**	**2.8%**	**1.2%**	**2.0%**	**3.4%**	**4.6%**

Table D.19 Maximum specific gravity of PCPC of aggregate L for the #89-C mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.0	2,244.0
Mass Sample in air (g)	**1,675.2**	**1,660.1**
Mass Bowl & Sample in air (g)	4,160.2	3,904.1
Mass Bowl under water (g)	**1,566.6**	**1,415.7**
Mass Bowl & Sample under water (g)	**2,575.2**	**2,417.0**
Mass Sample under water (g)	1,008.6	1,001.3
Max. Specific Gravity of Samples, SG	**2.513**	**2.520**
Mean Max. Specific Gravity of Samples, SG	**2.52**	
Standard Deviation	**0.005**	
Difference in Max. Specific Gravities	**0.007**	

Table D.20 Air voids and porosity of PCPC of aggregate L for the #89-C mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	954.1	26.3	980.4	453.7	589.3	1.93	2.66	23.2	27.5
2	965.9	26.3	992.2	456.8	595.7	1.92	2.66	23.6	27.7
3	941.5	26.4	967.9	416.8	566.0	1.82	2.55	27.8	28.8
4	978.6	26.2	1,004.8	473.8	604.3	1.96	2.66	22.0	26.2
5	966.1	26.2	992.3	455.8	587.7	1.92	2.60	23.8	26.2
Mean	**961.2**	**26.3**	**987.5**	**451.4**	**588.6**	**1.91**	**2.63**	**24.1**	**27.3**
Std. Dev.	**14.0**	**0.1**	**14.0**	**20.9**	**14.2**	**0.055**	**0.050**	**2.199**	**1.099**
Coeff. Var.	**1.5%**	**0.3%**	**1.4%**	**4.6%**	**2.4%**	**2.9%**	**1.9%**	**9.1%**	**4.0%**

Table D.21 Maximum specific gravity of PCPC of aggregate L for the #89 mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.7	2,244.4
Mass Sample in air (g)	**1,517.6**	**1,517.0**
Mass Bowl & Sample in air (g)	4,003.3	3,761.4
Mass Bowl under water (g)	**1,566.8**	**1,416.1**
Mass Bowl & Sample under water (g)	**2,477.3**	**2,324.3**
Mass Sample under water (g)	910.5	908.2
Max. Specific Gravity of Samples, SG	**2.500**	**2.492**
Mean Max. Specific Gravity of Samples, SG	**2.50**	
Standard Deviation	**0.006**	
Difference in Max. Specific Gravities	**0.008**	

Table D.22 Air voids and porosity of PCPC of aggregate L for the #89 mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
2	1,365.6	26.4	1,392.0	680.0	840.0	2.011	2.632	19.4	23.6
3	1,383.3	26.6	1,409.9	701.6	842.5	2.050	2.591	17.9	20.9
4	1,369.6	26.2	1,395.8	687.9	838.4	2.029	2.612	18.7	22.3
5	1,342.5	26.4	1,368.9	667.6	824.6	2.009	2.627	19.5	23.5
Mean	**1,365.3**	**26.4**	**1,391.7**	**684.3**	**836.4**	**2.02**	**2.62**	**18.9**	**22.6**
Std. Dev.	**17.0**	**0.2**	**17.0**	**14.3**	**8.0**	**0.019**	**0.019**	**0.750**	**1.266**
Coeff. Var.	**1.2%**	**0.6%**	**1.2%**	**2.1%**	**1.0%**	**0.9%**	**0.7%**	**4.0%**	**5.6%**

Table D.23 Maximum specific gravity of PCPC of aggregate L for the #89-F mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.5	2,244.3
Mass Sample in air (g)	**1,693.4**	**1,686.9**
Mass Bowl & Sample in air (g)	4,178.9	3,931.2
Mass Bowl under water (g)	**1,566.3**	**1,415.0**
Mass Bowl & Sample under water (g)	**2,614.4**	**2,455.8**
Mass Sample under water (g)	1,048.1	1,040.8
Max. Specific Gravity of Samples, SG	**2.624**	**2.611**
Mean Max. Specific Gravity of Samples, SG	**2.62**	
Standard Deviation	**0.009**	
Difference in Max. Specific Gravities	**-0.013**	

Table D.24 Air voids and porosity of PCPC of aggregate L for the #89-F mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	967.8	26.4	994.2	451.9	600.4	1.90	2.68	27.4	29.2
2	954.9	26.4	981.3	441.0	592.6	1.88	2.68	28.1	29.9
3	951.5	26.5	978.0	433.2	561.8	1.86	2.48	29.0	25.1
4	952.3	26.1	978.4	442.6	590.6	1.89	2.68	27.7	29.4
5	960.0	26.1	986.1	445.9	592.8	1.89	2.66	27.8	29.0
Mean	**957.3**	**26.3**	**983.6**	**442.9**	**587.6**	**1.88**	**2.64**	**28.0**	**28.5**
Std. Dev.	**6.7**	**0.2**	**6.8**	**6.9**	**14.9**	**0.016**	**0.087**	**0.600**	**1.919**
Coeff. Var.	**0.7%**	**0.7%**	**0.7%**	**1.5%**	**2.5%**	**0.8%**	**3.3%**	**2.1%**	**6.7%**

Table D.25 Maximum specific gravity of PCPC of aggregate L for the ⅜ in. mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.0	2,244.0
Mass Sample in air (g)	**1,623.3**	**1,624.2**
Mass Bowl & Sample in air (g)	4,108.3	3,868.2
Mass Bowl under water (g)	**1,566.6**	**1,415.7**
Mass Bowl & Sample under water (g)	**2,564.5**	**2,411.4**
Mass Sample under water (g)	997.9	995.7
Max. Specific Gravity of Samples, SG	**2.596**	**2.584**
Mean Max. Specific Gravity of Samples, SG	**2.590**	
Standard Deviation	**0.008**	
Difference in Max. Specific Gravities	**0.011**	

Table D.26 Air voids and porosity of PCPC of aggregate L for the ⅜ in. mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	962.6	26.2	988.8	462.0	596.6	1.95	2.68	24.8	27.3
2	968.8	26.3	995.1	473.2	601.1	1.98	2.68	23.5	26.2
3	988.6	26.3	1,014.9	483.5	614.1	1.98	2.69	23.4	26.2
4	952.8	26.4	979.2	454.4	592.0	1.94	2.69	25.2	28.0
5	970.9	26.2	997.1	471.6	600.7	1.97	2.67	23.9	26.2
Mean	**968.7**	**26.3**	**995.0**	**468.9**	**600.9**	**1.96**	**2.68**	**24.2**	**26.8**
Std. Dev.	**13.1**	**0.1**	**13.1**	**11.1**	**8.2**	**0.020**	**0.008**	**0.785**	**0.824**
Coeff. Var.	**1.4%**	**0.3%**	**1.3%**	**2.4%**	**1.4%**	**1.0%**	**0.3%**	**3.2%**	**3.1%**

Table D.27 Maximum specific gravity of PCPC of aggregate L for the #78-C mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.5	2,244.3
Mass Sample in air (g)	**1,649.4**	**1,648.7**
Mass Bowl & Sample in air (g)	4,134.9	3,893.0
Mass Bowl under water (g)	**1,566.3**	**1,415.0**
Mass Bowl & Sample under water (g)	**2,591.4**	**2,438.2**
Mass Sample under water (g)	1,025.1	1,023.2
Max. Specific Gravity of Samples, SG	**2.642**	**2.636**
Mean Max. Specific Gravity of Samples, SG	**2.64**	
Standard Deviation	**0.004**	
Difference in Max. Specific Gravities	**0.006**	

Table D.28 Air voids and porosity of PCPC of aggregate L for the #78-C mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	950.5	26.6	977.1	437.0	569.4	1.87	2.54	28.95	26.14
2	950.9	26.3	977.2	459.6	585.7	1.96	2.65	25.68	26.03
3	959.2	26.2	985.4	463.1	587.2	1.96	2.62	25.76	25.37
4	930.2	26.4	956.6	443.4	574.0	1.94	2.66	26.61	27.21
5	955.9	26.3	982.2	463.8	591.7	1.97	2.67	25.41	26.36
Mean	**949.3**	**26.4**	**975.7**	**453.4**	**581.6**	**1.94**	**2.63**	**26.48**	**26.22**
Std. Dev.	**11.3**	**0.2**	**12.9**	**12.3**	**9.4**	**0.038**	**0.020**	**1.453**	**0.667**
Coeff. Var.	**1.2%**	**0.6%**	**1.3%**	**2.7%**	**1.6%**	**2.0%**	**0.8%**	**5.5%**	**2.5%**

Table D.29 Maximum specific gravity of PCPC of aggregate L for the A9.5-C mix.

	Sample #1	**Sample #2**
Mass Bowl in air (g)	2,485.0	2,244.0
Mass Sample in air (g)	**1,689.5**	**1,691.6**
Mass Bowl & Sample in air (g)	4,174.5	3,935.6
Mass Bowl under water (g)	**1,566.6**	**1,415.7**
Mass Bowl & Sample under water (g)	**2,587.5**	**2,436.4**
Mass Sample under water (g)	1,020.9	1,020.7
Max. Specific Gravity of Samples, SG	**2.527**	**2.521**
Mean Max. Specific Gravity of Samples, SG	**2.52**	
Standard Deviation	**0.004**	
Difference in Max. Specific Gravities	**-0.006**	

Table D.30 Air voids and porosity of PCPC of aggregate L for the A9.5-C mix.

Specimen No.	**Mass of Specimen**	**Mass of Bag**	**Mass of Sealed Specimen**	**Mass of Sealed Submerged Specimen**	**Mass of Unsealed Submerged Specimen**	**Bulk Spec. Gravity**	**App. Spec. Gravity**	**% Air Voids**	**% Porosity**
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	967.8	26.3	994.1	457.4	575.5	1.92	2.51	23.9	23.5
2	976.9	26.6	1,003.5	467.8	587.9	1.94	2.56	23.0	23.9
3	964.0	26.2	990.2	460.0	587.9	1.94	2.61	23.2	25.7
4	976.6	26.1	1,002.7	470.5	606.8	1.95	2.69	22.6	27.3
5	970.2	26.3	996.5	465.7	597.6	1.95	2.65	22.8	26.5
Mean	**971.1**	**26.3**	**997.4**	**464.3**	**591.1**	**1.94**	**2.60**	**23.1**	**25.4**
Std. Dev.	**5.6**	**0.2**	**5.7**	**5.4**	**11.8**	**0.013**	**0.072**	**0.514**	**1.653**
Coeff. Var.	**0.6%**	**0.7%**	**0.6%**	**1.2%**	**2.0%**	**0.7%**	**2.8%**	**2.2%**	**6.5%**

Table D.31 Maximum specific gravity of PCPC of aggregate L for the A9.5 mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.7	2,244.4
Mass Sample in air (g)	**1,515.4**	**1,515.1**
Mass Bowl & Sample in air (g)	4,001.1	3,759.5
Mass Bowl under water (g)	**1,566.8**	**1,416.1**
Mass Bowl & Sample under water (g)	**2,503.4**	**2,353.7**
Mass Sample under water (g)	936.6	937.6
Max. Specific Gravity of Samples, SG	**2.618**	**2.624**
Mean Max. Specific Gravity of Samples, SG	**2.62**	
Standard Deviation	**0.004**	
Difference in Max. Specific Gravities	**0.005**	

Table D.32 Air voids and porosity of PCPC of aggregate L for the A9.5 mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,354.6	26.1	1,380.7	683.0	822.0	2.04	2.58	22.3	20.9
2	1,354.7	26.5	1,381.2	679.9	823.4	2.03	2.58	22.6	21.5
3	1,376.0	26.3	1,402.3	670.3	784.5	1.97	2.35	24.9	16.4
4	1,368.6	26.4	1,395.0	696.9	829.6	2.06	2.57	21.5	20.0
5	1,362.2	26.3	1,388.5	684.5	813.2	2.03	2.51	22.5	19.2
Mean	**1,363.2**	**26.3**	**1,389.5**	**682.9**	**814.5**	**2.02**	**2.52**	**22.8**	**19.6**
Std. Dev.	**9.2**	**0.1**	**9.2**	**9.6**	**17.8**	**0.033**	**0.097**	**1.276**	**2.013**
Coeff. Var.	**0.7%**	**0.6%**	**0.7%**	**1.4%**	**2.2%**	**1.7%**	**3.9%**	**5.6%**	**10.3%**

Table D.33 Maximum specific gravity of PCPC of aggregate L for the #78 mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.7	2,244.4
Mass Sample in air (g)	**1,557.0**	**1,554.0**
Mass Bowl & Sample in air (g)	4,042.7	3,798.4
Mass Bowl under water (g)	**1,566.8**	**1,416.1**
Mass Bowl & Sample under water (g)	**2,522.5**	**2,371.3**
Mass Sample under water (g)	955.7	955.2
Max. Specific Gravity of Samples, SG	**2.589**	**2.595**
Mean Max. Specific Gravity of Samples, SG	**2.59**	
Standard Deviation	**0.004**	
Difference in Max. Specific Gravities	**0.006**	

Table D.34 Air voids and porosity of PCPC of aggregate L for the #78 mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,346.6	26.4	1,373.0	673.0	825.6	2.02	2.62	22.1	22.9
2	1,351.5	26.6	1,378.1	678.8	828.0	2.03	2.62	21.7	22.4
3	1,338.7	26.3	1,365.0	655.7	820.7	1.98	2.62	23.6	24.4
4	1,351.7	26.5	1,378.2	678.8	828.6	2.03	2.62	21.7	22.5
5	1,363.1	26.6	1,389.7	687.3	837.5	2.04	2.63	21.4	22.5
Mean	**1,350.3**	**26.5**	**1,376.8**	**674.7**	**828.1**	**2.02**	**2.62**	**22.1**	**22.9**
Std. Dev.	**8.9**	**0.1**	**9.0**	**11.8**	**6.1**	**0.023**	**0.005**	**0.888**	**0.846**
Coeff. Var.	**0.7%**	**0.5%**	**0.7%**	**1.7%**	**0.7%**	**1.1%**	**0.2%**	**4.0%**	**3.7%**

Table D.35 Maximum specific gravity of PCPC of aggregate L for the ½ in. mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.9	2,246.2
Mass Sample in air (g)	1,539.4	1,542.0
Mass Bowl & Sample in air (g)	**4,025.3**	**3,788.2**
Mass Bowl under water (g)	1,566.8	1,417.3
Mass Bowl & Sample under water (g)	2,521.4	2,373.3
Mass Sample under water (g)	**954.6**	**956.0**
Max. Specific Gravity of Samples, SG	**2.632**	**2.631**
Mean Max. Specific Gravity of Samples, SG	**2.63**	
Standard Deviation	**0.001**	
Difference in Max. Specific Gravities	**-0.001**	

Table D.36 Air voids and porosity of PCPC of aggregate L for the ½ in. mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,258.3	26.4	1,284.7	616.1	762.4	1.98	2.57	24.8	23.0
2	1,225.1	26.3	1,251.4	596.0	743.5	1.97	2.58	25.2	23.7
3	1,273.4	26.3	1,299.7	615.4	755.8	1.95	2.49	25.7	21.6
4	1,259.8	26.3	1,286.1	601.6	756.7	1.93	2.54	26.5	23.8
5	1,241.2	26.6	1,267.8	604.7	765.8	1.97	2.65	25.1	25.6
Mean	**1,251.6**	**26.4**	**1,277.9**	**606.8**	**756.8**	**1.96**	**2.57**	**25.5**	**23.6**
Std. Dev.	**18.7**	**0.1**	**18.7**	**8.8**	**8.5**	**0.018**	**0.058**	**0.684**	**1.456**
Coeff. Var.	**1.5%**	**0.5%**	**1.5%**	**1.4%**	**1.1%**	**0.9%**	**2.2%**	**2.7%**	**6.2%**

Table D.37 Maximum specific gravity of PCPC of aggregate L for the #67-I mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.5	2,244.3
Mass Sample in air (g)	1,750.4	1,750.8
Mass Bowl & Sample in air (g)	**4,235.9**	**3,995.1**
Mass Bowl under water (g)	1,566.3	1,415.0
Mass Bowl & Sample under water (g)	2,645.7	2,494.5
Mass Sample under water (g)	**1,079.4**	**1,079.5**
Max. Specific Gravity of Samples, SG	**2.609**	**2.608**
Mean Max. Specific Gravity of Samples, SG	**2.61**	
Standard Deviation	**0.000**	
Difference in Max. Specific Gravities	**-0.001**	

Table D.38 Air voids and porosity of PCPC of aggregate L for the #67-Imix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	983.6	26.4	1,010.0	478.3	585.1	1.97	2.51	24.4	21.4
2	990.0	26.5	1,016.5	482.7	589.2	1.98	2.51	24.2	21.3
3	982.8	26.3	1,009.1	479.9	609.3	1.98	2.68	24.1	26.1
4	987.3	26.5	1,013.8	483.8	613.1	1.99	2.69	23.8	26.0
5	984.9	26.5	1,011.4	480.6	611.4	1.98	2.68	24.1	26.3
Mean	**985.7**	**26.4**	**1,012.2**	**481.1**	**601.6**	**1.98**	**2.61**	**24.1**	**24.2**
Std. Dev.	**2.9**	**0.1**	**3.0**	**2.2**	**13.4**	**0.005**	**0.095**	**0.204**	**2.623**
Coeff. Var.	**0.3%**	**0.3%**	**0.3%**	**0.5%**	**2.2%**	**0.3%**	**3.6%**	**0.8%**	**10.8%**

Table D.39 Maximum specific gravity of PCPC of aggregate L for the #67 mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,484.4	2,244.7
Mass Sample in air (g)	**1,531.3**	**1,531.8**
Mass Bowl & Sample in air (g)	4,015.7	3,776.5
Mass Bowl under water (g)	**1,566.1**	**1,416.2**
Mass Bowl & Sample under water (g)	**2,492.8**	**2,345.3**
Mass Sample under water (g)	926.7	929.1
Max. Specific Gravity of Samples, SG	**2.533**	**2.542**
Mean Max. Specific Gravity of Samples, SG	**2.54**	
Standard Deviation	**0.006**	
Difference in Max. Specific Gravities	**0.009**	

Table D.40 Air voids and porosity of PCPC of aggregate L for the #67mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,358.0	26.5	1,384.5	692.4	826.1	2.06	2.59	18.8	20.3
2	1,340.1	26.8	1,366.9	677.0	817.6	2.04	2.60	19.5	21.4
3	1,322.7	26.6	1,349.3	666.8	804.1	2.04	2.58	19.7	21.2
4	1,318.2	26.7	1,344.9	657.9	786.8	2.02	2.51	20.5	19.7
5	1,281.8	26.0	1,307.8	634.2	772.4	2.00	2.55	21.2	21.6
Mean	**1,324.2**	**26.5**	**1,350.7**	**665.7**	**801.4**	**2.03**	**2.57**	**19.9**	**20.8**
Std. Dev.	**28.4**	**0.3**	**28.6**	**21.8**	**22.0**	**0.024**	**0.035**	**0.935**	**0.791**
Coeff. Var.	**2.1%**	**1.2%**	**2.1%**	**3.3%**	**2.7%**	**1.2%**	**1.4%**	**4.7%**	**3.8%**

Table D.41 Maximum specific gravity of PCPC of aggregate L for the A12.5-C mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,485.0	2,244.0
Mass Sample in air (g)	1,677.7	1,679.2
Mass Bowl & Sample in air (g)	4,162.7	3,923.2
Mass Bowl under water (g)	**1,566.6**	**1,415.7**
Mass Bowl & Sample under water (g)	**2,586.4**	**2,439.5**
Mass Sample under water (g)	1,019.8	1,023.8
Max. Specific Gravity of Samples, SG	**2.550**	**2.562**
Mean Max. Specific Gravity of Samples, SG	**2.56**	
Standard Deviation	**0.008**	
Difference in Max. Specific Gravities	**-0.012**	

Table D.42 Air voids and porosity of PCPC of aggregate L for the A12.5-C mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	993.0	26.3	1,019.3	480.8	588.2	1.96	2.49	23.2	21.3
2	977.3	26.4	1,003.7	475.8	584.3	1.97	2.53	22.8	21.9
3	978.3	26.5	1,004.8	481.3	603.1	1.99	2.65	22.0	24.9
4	970.8	26.4	997.2	473.8	589.6	1.98	2.59	22.6	23.6
5	979.5	26.2	1,005.7	479.3	589.7	1.98	2.56	22.4	22.4
Mean	**979.8**	**26.4**	**1,006.1**	**478.2**	**591.0**	**1.98**	**2.57**	**22.6**	**22.8**
Std. Dev.	**8.1**	**0.1**	**8.1**	**3.3**	**7.1**	**0.011**	**0.062**	**0.449**	**1.433**
Coeff. Var.	**0.8%**	**0.4%**	**0.8%**	**0.7%**	**1.2%**	**0.6%**	**2.4%**	**2.0%**	**6.3%**

Table D.43 Maximum specific gravity of PCPC of aggregate L for the A12.5 mix.

	Sample #1	Sample #2
Mass Bowl in air (g)	2,486.1	2,244.9
Mass Sample in air (g)	**1,667.0**	**1,651.1**
Mass Bowl & Sample in air (g)	4,153.1	3,896.0
Mass Bowl under water (g)	**1,566.1**	**1,416.2**
Mass Bowl & Sample under water (g)	**2,584.7**	**2,428.6**
Mass Sample under water (g)	1,018.6	1,012.4
Max. Specific Gravity of Samples, SG	**2.571**	**2.585**
Mean Max. Specific Gravity of Samples, SG	**2.58**	
Standard Deviation	**0.010**	
Difference in Max. Specific Gravities	**0.014**	

Table D.44 Air voids and porosity of PCPC of aggregate L for the A12.5 mix.

Specimen No.	Mass of Specimen	Mass of Bag	Mass of Sealed Specimen	Mass of Sealed Submerged Specimen	Mass of Unsealed Submerged Specimen	Bulk Spec. Gravity	App. Spec. Gravity	% Air Voids	% Porosity
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	1,381.4	26.7	1,408.1	712.3	826.3	2.09	2.52	19.1	17.2
2	1,386.2	26.6	1,412.8	717.3	825.9	2.09	2.50	18.8	16.4
3	1,379.9	26.0	1,405.9	708.6	835.0	2.08	2.56	19.5	19.0
5	1,394.9	26.5	1,421.4	718.1	841.0	2.08	2.55	19.2	18.4
Mean	**1,385.6**	**26.5**	**1,412.1**	**714.1**	**832.1**	**2.08**	**2.53**	**19.2**	**17.8**
Std. Dev.	**6.8**	**0.3**	**6.9**	**4.5**	**7.3**	**0.007**	**0.027**	**0.285**	**1.165**
Coeff. Var.	**0.5%**	**1.2%**	**0.5%**	**0.6%**	**0.9%**	**0.4%**	**1.1%**	**1.5%**	**6.6%**

Table D.45 Maximum specific gravity of PCPC of aggregate L for the A12.5-F mix.

	Sample #1	**Sample #2**
Mass Bowl in air (g)	2,485.0	2,244.0
Mass Sample in air (g)	**1,638.0**	**1,639.0**
Mass Bowl & Sample in air (g)	4,123.0	3,883.0
Mass Bowl under water (g)	**1,566.6**	**1,415.7**
Mass Bowl & Sample under water (g)	**2,561.4**	**2,412.4**
Mass Sample under water (g)	994.8	996.7
Max. Specific Gravity of Samples, SG	**2.547**	**2.552**
Mean Max. Specific Gravity of Samples, SG	**2.55**	
Standard Deviation	**0.004**	
Difference in Max. Specific Gravities	**0.005**	

Table D.46 Air voids and porosity of PCPC of aggregate L for the A12.5-F mix.

Specimen No.	**Mass of Specimen**	**Mass of Bag**	**Mass of Sealed Specimen**	**Mass of Sealed Submerged Specimen**	**Mass of Unsealed Submerged Specimen**	**Bulk Spec. Gravity**	**App. Spec. Gravity**	**% Air Voids**	**% Porosity**
	(g)	(g)	(g)	(g)	(g)			(%)	(%)
	A		B	E	C				
1	973.3	26.6	999.9	442.9	576.9	1.86	2.50	27.1	25.6
2	979.7	26.2	1,005.9	480.0	604.6	1.99	2.66	22.1	25.3
3	1,008.7	26.2	1,034.9	506.2	625.0	2.03	2.67	20.2	24.0
4	980.2	26.5	1,006.7	482.5	608.2	2.00	2.68	21.7	25.6
5	997.2	26.3	1,023.5	499.0	615.5	2.03	2.66	20.4	23.7
Mean	**987.8**	**26.3**	**1,016.1**	**482.0**	**605.5**	**1.98**	**2.62**	**22.3**	**24.8**
Std. Dev.	**16.2**	**0.2**	**16.1**	**28.3**	**20.8**	**0.082**	**0.084**	**3.210**	**0.938**
Coeff. Var.	**1.6%**	**0.7%**	**1.6%**	**5.9%**	**3.4%**	**4.1%**	**3.2%**	**14.4%**	**3.8%**

Appendix E

Permeability Experimental Data

Aggregate B

Table E.1 Permeability of PCPC of aggregate B for the #4 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.02**	**4.48**	**15-12**	8.35	8.57	8.46	8.12	8.38	0.116	**15-3**	40.46	612
			12-9	9.70	9.23	9.40	9.28	9.40	0.133	**12-3**	32.09	663
			9-6	10.46	10.36	10.19	10.44	10.36	0.168	**9-3**	22.68	740
			6-3	12.59	12.21	12.28	12.20	12.32	0.237	**6-3**	12.32	853
			Total	41.10	40.37	40.33	40.04	40.46	0.170			
2	**3.02**	**4.51**	**15-12**	5.51	5.58	5.65	5.76	5.63	0.174	**15-3**	27.47	913
			12-9	6.40	6.29	6.11	6.20	6.25	0.202	**12-3**	21.85	986
			9-6	7.14	7.33	7.26	7.32	7.26	0.243	**9-3**	15.60	1090
			6-3	8.38	8.24	8.43	8.29	8.34	0.355	**6-3**	8.34	1279
			Total	27.43	27.44	27.45	27.57	27.47	0.254			
3	**3.01**	**4.50**	**15-12**	6.47	6.24	6.42	5.96	6.27	0.157	**15-3**	30.17	834
			12-9	7.33	7.10	6.46	6.99	6.97	0.181	**12-3**	23.90	904
			9-6	8.29	7.61	7.67	7.74	7.83	0.226	**9-3**	16.93	1008
			6-3	9.94	8.95	8.81	8.71	9.10	0.326	**6-3**	9.10	1172
			Total	32.03	29.90	29.36	29.40	30.17	0.232			
4	**3.01**	**4.48**	**15-12**	6.61	6.47	6.06	6.09	6.31	0.155	**15-3**	30.66	812
			12-9	7.50	7.19	7.06	6.91	7.17	0.175	**12-3**	24.36	878
			9-6	8.23	8.14	7.81	7.63	7.95	0.220	**9-3**	17.19	982
			6-3	9.33	9.42	9.26	8.94	9.24	0.318	**6-3**	9.24	1144
			Total	31.67	31.22	30.19	29.57	30.66	0.226			
5	**3.01**	**4.49**	**15-12**	4.06	3.81	3.87	3.89	3.91	0.251	**15-3**	19.63	1276
			12-9	4.64	4.69	4.36	4.42	4.53	0.278	**12-3**	15.72	1369
			9-6	5.50	5.05	5.08	4.87	5.13	0.344	**9-3**	11.19	1517
			6-3	6.11	5.89	6.20	6.07	6.07	0.487	**6-3**	6.07	1753
			Total	20.31	19.44	19.51	19.25	19.63	0.354			

Average Permeability of #4

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	29.68	889	3.02
12-3	23.58	960	2.84
9-3	16.72	1067	2.67
6-3	9.01	1240	2.48

Table E.2 Permeability of PCPC of aggregate B for the #89 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	(in.)	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	(in.)	(sec)	(in/hr)
1	3.02	4.48	15-12	46.58	46.84	48.11	50.08	47.90	0.0203	15-3	240.87	103
			12-9	53.78	53.85	54.72	54.95	54.33	0.0230	12-3	192.97	110
			9-6	61.43	62.65	60.84	61.99	61.73	0.0283	9-3	138.64	121
			6-3	77.4	78.64	72.91	78.71	76.92	0.0380	6-3	76.92	137
			Total	239.19	241.98	236.58	245.73	240.87	0.0286			
2	3.01	4.49	15-12	23.81	22.77	22.84	22.02	22.86	0.0430	15-3	110.05	228
			12-9	25.07	25.15	24.86	25.57	25.16	0.0502	12-3	87.19	247
			9-6	29.05	28.2	28.44	28.43	28.53	0.0619	9-3	62.03	275
			6-3	34.27	33.22	33.29	33.2	33.50	0.0885	6-3	33.50	318
			Total	112.2	109.34	109.43	109.22	110.05	0.0634			
3	3.02	4.48	15-12	85.3	66.36	47.26	Very Slow Flow	66.31	0.0147	15-3	298.02	83
			12-9	92.78	56.45	50.53		66.59	0.0188	12-3	231.72	92
			9-6	106.03	64.78	58.2		76.34	0.0229	9-3	165.13	102
			6-3	122.65	74.76	68.97		88.79	0.0330	6-3	88.79	119
			Total	406.76	262.35	224.96	0	298.02	0.0232			
4	3.01	4.48	15-12	45.93	48.16	50.7	Very Slow Flow	48.26	0.0203	15-3	230.70	108
			12-9	50.96	54.81	53.04		52.94	0.0237	12-3	182.44	117
			9-6	58.88	61.31	59.72		59.97	0.0293	9-3	129.50	130
			6-3	68.36	71.05	69.19		69.53	0.0422	6-3	69.53	152
			Total	224.13	235.33	232.65	0	230.70	0.0300			
5	3.02	4.51	15-12	38.33	37.59	37.14	35.71	37.19	0.0263	15-3	178.70	140
			12-9	42.68	41.8	40.11	39.24	40.96	0.0306	12-3	141.51	152
			9-6	47.65	46	45.27	45.41	46.08	0.0381	9-3	100.55	168
			6-3	56.38	54.52	53.42	53.54	54.47	0.0541	6-3	54.47	195
			Total	185.04	179.91	175.94	173.9	178.70	0.0388			

Average Permeability of #89

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	211.67	132	0.45
12-3	167.16	144	0.43
9-3	119.17	159	0.40
6-3	64.64	184	0.37

Table E.3 Permeability of PCPC of aggregate B for the ⅜ in. mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.02**	**4.49**	**15-12**	12.26	11.54	10.94	10.72	11.37	0.086	**15-3**	54.01	461
			12-9	14.39	11.2	12.28	11.8	12.42	0.101	**12-3**	42.65	502
			9-6	15.57	13.41	13.59	13.3	13.97	0.126	**9-3**	30.23	559
			6-3	17.85	15.74	15.83	15.63	16.26	0.181	**6-3**	16.26	651
			Total	60.07	51.89	52.64	51.45	54.01	0.128			
2	**3.02**	**4.49**	**15-12**	8.08	7.96	8.3	7.67	8.00	0.122	**15-3**	38.35	648
			12-9	8.92	8.79	8.88	8.4	8.75	0.143	**12-3**	30.35	704
			9-6	10.25	9.76	10.04	9.86	9.98	0.175	**9-3**	21.60	780
			6-3	12.59	11.47	11.66	10.77	11.62	0.252	**6-3**	11.62	908
			Total	39.84	37.98	38.88	36.7	38.35	0.180			
3	**3.02**	**4.51**	**15-12**	9.03	8.03	7.67	7.25	8.00	0.123	**15-3**	49.01	512
			12-9	10.41	9.05	9.45	8.38	9.32	0.135	**12-3**	41.01	525
			9-6	12.02	10.82	40.55	10.06	18.36	0.096	**9-3**	31.69	537
			6-3	14.76	13.22	13.16	12.16	13.33	0.222	**6-3**	13.33	799
			Total	46.22	41.12	70.83	37.85	49.01	0.142			
4	**3.02**	**4.47**	**15-12**	5.54	5.44	5.34	5.23	5.39	0.180	**15-3**	26.99	914
			12-9	6.48	6.25	6.11	6.32	6.29	0.198	**12-3**	21.60	981
			9-6	7.12	7.11	7.15	7.05	7.11	0.244	**9-3**	15.31	1092
			6-3	8.44	8.38	8.03	7.95	8.20	0.354	**6-3**	8.20	1276
			Total	27.58	27.18	26.63	26.55	26.99	0.254			
5	**3.01**	**4.47**	**15-12**	10.78	9.13	8.7	8.33	9.24	0.106	**15-3**	43.97	567
			12-9	11.31	9.8	9.74	9.37	10.06	0.125	**12-3**	34.73	616
			9-6	12.5	10.92	11.3	10.92	11.41	0.154	**9-3**	24.68	684
			6-3	15.02	12.7	12.88	12.46	13.27	0.221	**6-3**	13.27	796
			Total	49.61	42.55	42.62	41.08	43.97	0.157			

Average Permeability of ⅜ in.

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	42.46	621	2.12
12-3	34.07	666	1.98
9-3	24.70	730	1.84
6-3	12.54	886	1.78

Table E.4 Permeability of PCPC of aggregate B for the A9.5 in. mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.02**	**4.48**	**15-12**	13.88	13.63	14.38	13.68	13.89	0.0698	**15-3**	67.01	369
			12-9	15.48	15.51	15.76	15.28	15.51	0.0803	**12-3**	53.12	400
			9-6	17.17	17.44	17.56	16.90	17.27	0.1008	**9-3**	37.61	445
			6-3	20.72	20.36	20.47	19.83	20.35	0.1431	**6-3**	20.35	515
			Total	67.25	66.94	68.17	65.69	67.01	0.1025			
2	**3.01**	**4.49**	**15-12**	25.79	25.43	24.17	24.43	24.96	0.0393	**15-3**	119.36	210
			12-9	28.90	27.77	26.35	25.73	27.19	0.0463	**12-3**	94.41	228
			9-6	32.68	32.03	29.20	30.41	31.08	0.0566	**9-3**	67.22	252
			6-3	38.02	36.49	35.10	34.94	36.14	0.0816	**6-3**	36.14	294
			Total	125.39	121.72	114.82	115.51	119.36	0.0582			
3	**3.01**	**4.49**	**15-12**	19.75	18.71	19.33	17.99	18.95	0.0519	**15-3**	93.48	269
			12-9	22.19	21.50	21.89	20.42	21.50	0.0587	**12-3**	74.54	289
			9-6	25.43	24.40	23.87	23.20	24.23	0.0729	**9-3**	53.04	321
			6-3	30.15	28.90	28.66	27.53	28.81	0.1028	**6-3**	28.81	370
			Total	97.52	93.51	93.75	89.14	93.48	0.0746			
4	**3.01**	**4.50**	**15-12**	17.13	15.23	15.08	15.25	15.67	0.0626	**15-3**	76.93	326
			12-9	19.23	17.04	16.91	17.03	17.55	0.0718	**12-3**	61.26	351
			9-6	22.04	19.52	19.55	19.37	20.12	0.0876	**9-3**	43.70	389
			6-3	26.25	23.00	22.21	22.87	23.58	0.1253	**6-3**	23.58	451
			Total	84.65	74.79	73.75	74.52	76.93	0.0905			
5	**3.02**	**4.54**	**15-12**	25.19	22.83	23.17	22.67	23.47	0.0420	**15-3**	116.31	217
			12-9	27.96	26.14	26.14	25.26	26.38	0.0480	**12-3**	92.85	234
			9-6	31.37	30.66	29.49	30.29	30.45	0.0583	**9-3**	66.47	258
			6-3	37.24	35.12	35.61	36.10	36.02	0.0829	**6-3**	36.02	299
			Total	121.76	114.75	114.41	114.32	116.31	0.0603			

Average Permeability of A9.5

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	94.62	278	0.94
12-3	75.23	300	0.89
9-3	53.61	333	0.83
6-3	28.98	386	0.77

Table E.5 Permeability of PCPC of aggregate B for the #78 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.48**	**15-12**	12.94	11.54	10.92	10.34	**11.44**	0.085	**15-3**	54.50	456
			12-9	15.20	11.76	12.06	11.69	**12.68**	0.099	**12-3**	43.07	496
			9-6	14.88	13.73	13.65	13.16	**13.86**	0.126	**9-3**	30.39	554
			6-3	18.83	16.16	15.71	15.43	**16.53**	0.177	**6-3**	16.53	638
			Total	61.85	53.19	52.34	50.62	**54.50**	0.127			
2	**3.01**	**4.50**	**15-12**	14.15	13.62	13.69	12.95	**13.60**	0.072	**15-3**	67.02	374
			12-9	15.38	15.22	15.87	15.03	**15.38**	0.082	**12-3**	53.42	404
			9-6	17.92	17.63	17.79	17.10	**17.61**	0.100	**9-3**	38.04	447
			6-3	20.43	20.33	20.99	19.97	**20.43**	0.145	**6-3**	20.43	522
			Total	67.88	66.80	68.34	65.05	**67.02**	0.104			
3	**3.01**	**4.50**	**15-12**	12.27	11.25	11.68	11.36	**11.64**	0.084	**15-3**	56.48	444
			12-9	13.65	12.51	12.52	12.66	**12.84**	0.098	**12-3**	44.84	481
			9-6	15.30	14.59	14.57	14.40	**14.72**	0.120	**9-3**	32.01	532
			6-3	17.97	17.13	17.12	16.94	**17.29**	0.171	**6-3**	17.29	620
			Total	59.19	55.48	55.89	55.36	**56.48**	0.123			
4	**3.03**	**4.51**	**15-12**	9.15	8.63	8.63	8.17	**8.65**	0.113	**15-3**	42.63	584
			12-9	10.91	10.18	9.41	9.01	**9.88**	0.127	**12-3**	33.99	630
			9-6	12.19	11.08	11.01	11.06	**11.34**	0.155	**9-3**	24.11	701
			6-3	13.67	13.10	12.26	12.06	**12.77**	0.230	**6-3**	12.77	829
			Total	45.92	42.99	41.31	40.30	**42.63**	0.162			
5	**3.01**	**4.52**	**15-12**	13.98	13.66	12.73	12.68	**13.26**	0.074	**15-3**	62.75	403
			12-9	14.77	14.50	14.58	14.27	**14.53**	0.087	**12-3**	49.49	439
			9-6	17.10	16.67	15.36	15.53	**16.17**	0.110	**9-3**	34.96	490
			6-3	19.69	19.08	18.24	18.17	**18.80**	0.159	**6-3**	18.80	572
			Total	65.54	63.91	60.91	60.65	**62.75**	0.112			

Average Permeability of #78

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	56.68	452	1.53
12-3	44.96	490	1.45
9-3	31.90	545	1.36
6-3	17.16	636	1.27

Table E.6 Permeability of PCPC of aggregate B for the ½ in. mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.50**	**15-12**	5.44	4.38	5.75	5.56	**5.28**	0.186	**15-3**	26.69	942
			12-9	6.16	6.39	5.96	5.98	**6.12**	0.206	**12-3**	21.41	1009
			9-6	6.94	6.90	6.91	7.07	**6.96**	0.254	**9-3**	15.28	1115
			6-3	8.37	8.25	8.31	8.38	**8.33**	0.356	**6-3**	8.33	1282
			Total	26.91	25.92	26.93	26.99	**26.69**	0.262			
2	**3.01**	**4.47**	**15-12**	6.96	7.02	7.03	7.28	**7.07**	0.138	**15-3**	34.45	723
			12-9	7.86	7.89	7.80	7.58	**7.78**	0.161	**12-3**	27.37	781
			9-6	8.67	8.27	8.85	8.83	**8.66**	0.202	**9-3**	19.59	861
			6-3	11.62	11.15	10.47	10.50	**10.94**	0.268	**6-3**	10.94	965
			Total	35.11	34.33	34.15	34.19	**34.45**	0.201			
3	**3.00**	**4.50**	**15-12**	3.97	3.78	4.02	3.71	**3.87**	0.255	**15-3**	19.53	1291
			12-9	4.34	4.67	4.64	4.31	**4.49**	0.282	**12-3**	15.66	1383
			9-6	5.23	5.27	5.23	4.83	**5.14**	0.345	**9-3**	11.17	1531
			6-3	6.00	6.26	6.00	5.87	**6.03**	0.493	**6-3**	6.03	1761
			Total	19.54	19.98	19.89	18.72	**19.53**	0.359			
4	**3.00**	**4.50**	**15-12**	4.08	3.46	3.23	2.98	**3.44**	0.287	**15-3**	18.34	1375
			12-9	4.89	4.06	3.91	3.56	**4.11**	0.309	**12-3**	14.91	1454
			9-6	5.87	4.79	4.63	4.32	**4.90**	0.362	**9-3**	10.80	1584
			6-3	7.41	5.50	5.40	5.28	**5.90**	0.505	**6-3**	5.90	1817
			Total	22.25	17.81	17.17	16.14	**18.34**	0.382			
5	**3.01**	**4.48**	**15-12**	4.21	4.26	4.10	4.25	**4.21**	0.232	**15-3**	21.73	1147
			12-9	5.44	5.15	5.15	4.87	**5.15**	0.243	**12-3**	17.52	1221
			9-6	5.86	5.85	5.57	5.50	**5.70**	0.308	**9-3**	12.37	1365
			6-3	6.90	6.63	6.83	6.34	**6.68**	0.440	**6-3**	6.68	1584
			Total	22.41	21.89	21.65	20.96	**21.73**	0.319			

Average Permeability of ½ in.

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	24.15	1096	3.70
12-3	19.37	1170	3.45
9-3	13.84	1291	3.22
6-3	7.57	1482	2.95

Table E.7 Permeability of PCPC of aggregate B for the #67 mix

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.49**	**15-12**	25.76	22.39	22.71	21.56	23.11	0.042	**15-3**	109.52	228
			12-9	25.77	23.82	25.12	24.69	24.85	0.051	**12-3**	86.42	248
			9-6	29.30	26.86	27.55	29.43	28.29	0.062	**9-3**	61.57	275
			6-3	36.09	32.76	32.69	31.58	33.28	0.089	**6-3**	33.28	319
			Total	116.92	105.83	108.07	107.26	109.52	0.063			
2	**3.01**	**4.48**	**15-12**	21.35	23.23	21.78	20.16	21.63	0.045	**15-3**	102.20	244
			12-9	22.26	24.10	23.07	22.06	22.87	0.055	**12-3**	80.57	265
			9-6	26.57	28.06	26.30	25.39	26.58	0.066	**9-3**	57.69	293
			6-3	30.25	32.69	31.21	30.30	31.11	0.094	**6-3**	31.11	340
			Total	100.43	108.08	102.36	97.91	102.20	0.068			
3	**3.02**	**4.48**	**15-12**	17.59	14.05	14.38	12.63	14.66	0.066	**15-3**	76.74	324
			12-9	19.13	16.35	16.92	14.55	16.74	0.075	**12-3**	62.08	344
			9-6	22.70	19.55	19.84	17.79	19.97	0.088	**9-3**	45.34	371
			6-3	28.07	25.15	25.52	22.73	25.37	0.115	**6-3**	25.37	420
			Total	87.49	75.10	76.66	67.70	76.74	0.090			
4	**3.01**	**4.45**	**15-12**	7.84	7.46	6.77	6.52	7.15	0.136	**15-3**	37.41	661
			12-9	9.08	7.96	7.96	7.75	8.19	0.152	**12-3**	30.26	701
			9-6	10.85	10.01	9.55	9.02	9.86	0.177	**9-3**	22.08	758
			6-3	13.50	12.07	11.81	11.49	12.22	0.238	**6-3**	12.22	857
			Total	41.27	37.50	36.09	34.78	37.41	0.184			
5	**3.01**	**4.52**	**15-12**	12.02	11.50	10.93	10.77	11.31	0.087	**15-3**	55.99	451
			12-9	13.91	12.73	12.38	12.53	12.89	0.098	**12-3**	44.69	486
			9-6	15.46	14.60	14.09	14.02	14.54	0.122	**9-3**	31.80	539
			6-3	18.78	17.44	16.51	16.29	17.26	0.173	**6-3**	17.26	622
			Total	60.17	56.27	53.91	53.61	55.99	0.125			

Average Permeability of #67

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	76.37	381	1.30
12-3	60.80	409	1.22
9-3	43.69	447	1.12
6-3	23.85	511	1.02

Table E.8 Permeability of PCPC of aggregate B for the A12.5 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.49**	**15-12**	20	15.41	14.51	14.49	**16.10**	0.0610	**15-3**	78.24	321
			12-9	21.65	17.19	16.44	15.87	**17.79**	0.0709	**12-3**	62.14	347
			9-6	24.03	20.34	18.96	18.74	**20.52**	0.0860	**9-3**	44.35	383
			6-3	28.23	23.56	22.1	21.45	**23.84**	0.1242	**6-3**	23.84	447
			Total	93.91	76.5	72.01	70.55	**78.24**	0.0891			
2	**3.01**	**4.47**	**15-12**	40.38	31.18	31.62	30.93	**33.53**	0.0290	**15-3**	158.75	156
			12-9	43.74	34.29	34.19	33.13	**36.34**	0.0344	**12-3**	125.22	170
			9-6	49.59	39.75	39.25	36.87	**41.37**	0.0422	**9-3**	88.89	189
			6-3	56.02	45.19	45.53	43.34	**47.52**	0.0615	**6-3**	47.52	221
			Total	189.73	150.41	150.59	144.27	**158.75**	0.0434			
3	**3.01**	**4.48**	**15-12**	51.24	52.65	35.47	Very Slow Flow	**46.45**	0.0211	**15-3**	213.25	117
			12-9	56.67	45.14	39.03		**46.95**	0.0268	**12-3**	166.80	129
			9-6	63.73	49.89	44.6		**52.74**	0.0334	**9-3**	119.85	141
			6-3	82.11	63.17	56.06		**67.11**	0.0439	**6-3**	67.11	159
			Total	253.75	210.85	175.16	0	**213.25**	0.0326			
4	**3.01**	**4.47**	**15-12**	39.01	35.11	32.49	Very Slow Flow	**35.54**	0.0274	**15-3**	167.70	148
			12-9	39.46	41.06	34.7		**38.41**	0.0326	**12-3**	132.16	161
			9-6	44.57	42.27	39.68		**42.17**	0.0415	**9-3**	93.75	180
			6-3	53.78	54.54	46.42		**51.58**	0.0568	**6-3**	51.58	204
			Total	176.82	172.98	153.29	0	**167.70**	0.0412			
5	**3.01**	**4.51**	**15-12**	61.48	58.98	58.2	Very Slow Flow	**59.55**	0.0166	**15-3**	294.19	86
			12-9	69.03	67.76	63.99		**66.93**	0.0189	**12-3**	234.63	92
			9-6	79.13	76.9	75.17		**77.07**	0.0230	**9-3**	167.71	102
			6-3	96.22	95.45	80.25		**90.64**	0.0329	**6-3**	90.64	118
			Total	305.86	299.09	277.61	0	**294.19**	0.0238			

Average Permeability of A12.5

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	182.43	166	0.56
12-3	144.19	180	0.53
9-3	102.91	199	0.50
6-3	56.14	230	0.46

Aggregate L

Table E.9 Permeability of PCPC of aggregate L for the #4 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.46**	**15-12**	7.87	7.71	7.55	7.42	7.64	0.127	**15-3**	36.10	686
			12-9	8.74	8.6	7.93	7.99	8.32	0.150	**12-3**	28.46	747
			9-6	9.82	9.47	8.86	8.89	9.26	0.188	**9-3**	20.15	832
			6-3	11.14	11.28	10.5	10.62	10.89	0.268	**6-3**	10.89	963
			Total	37.57	37.06	34.84	34.92	36.10	0.190			
2	**3.00**	**4.46**	**15-12**	6.79	6.62	6.5	6.3	6.55	0.149	**15-3**	31.46	791
			12-9	7.17	7.04	7.07	7.44	7.18	0.175	**12-3**	24.90	858
			9-6	8.13	8.06	7.95	8.24	8.10	0.216	**9-3**	17.72	951
			6-3	9.83	9.4	9.65	9.63	9.63	0.304	**6-3**	9.63	1095
			Total	31.92	31.12	31.17	31.61	31.46	0.220			
3	**3.01**	**4.53**	**15-12**	8.13	7.87	7.91	8	7.98	0.124	**15-3**	38.59	658
			12-9	9.26	9.1	8.67	8.62	8.91	0.143	**12-3**	30.61	713
			9-6	9.74	10.1	10.34	10,22	10.06	0.177	**9-3**	21.70	794
			6-3	11.71	11.65	11.51	11.67	11.64	0.258	**6-3**	11.64	929
			Total	38.84	38.72	38.43	28.29	38.59	0.183			
4	**3.01**	**4.49**	**15-12**	7.39	7.3	6.91	7.42	7.26	0.135	**15-3**	34.41	726
			12-9	7.93	8.05	7.76	7.73	7.87	0.160	**12-3**	27.16	790
			9-6	9.16	8.71	9.04	8.84	8.94	0.197	**9-3**	19.29	878
			6-3	10.66	10.36	10.22	10.17	10.35	0.284	**6-3**	10.35	1024
			Total	35.14	34.42	33.93	34.16	34.41	0.202			
5	**3.00**	**4.49**	**15-12**	6.91	6.29	6.18	6.39	6.44	0.153	**15-3**	31.18	809
			12-9	7.22	7.41	7.42	6.99	7.26	0.175	**12-3**	24.74	876
			9-6	8.04	7.82	7.93	8.21	8.00	0.222	**9-3**	17.48	978
			6-3	9.96	9.37	9.41	9.18	9.48	0.314	**6-3**	9.48	1130
			Total	32.13	30.89	30.94	30.77	31.18	0.225			

Average Permeability of #4

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	34.35	734	2.49
12-3	27.17	797	2.36
9-3	19.27	887	2.22
6-3	10.40	1028	2.05

Table E.10 Permeability of PCPC of aggregate L for the #89-C mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.44**	**15-12**	6.84	6.87	6.61	6.68	6.75	0.143	**15-3**	32.47	758
			12-9	7.43	7.26	7.39	7.36	7.36	0.169	**12-3**	25.72	821
			9-6	8.53	8.4	8.39	8.34	8.42	0.206	**9-3**	18.36	907
			6-3	9.98	9.92	9.96	9.93	9.95	0.291	**6-3**	9.95	1047
			Total	32.78	32.45	32.35	32.31	32.47	0.211			
2	**3.01**	**4.52**	**15-12**	5.2	5	5.12	4.82	5.04	0.197	**15-3**	25.05	1011
			12-9	5.82	5.62	5.48	5.39	5.58	0.228	**12-3**	20.01	1087
			9-6	6.86	6.68	6.51	6.32	6.59	0.270	**9-3**	14.43	1190
			6-3	8.06	7.89	7.76	7.65	7.84	0.381	**6-3**	7.84	1373
			Total	25.94	25.19	24.87	24.18	25.05	0.281			
3	**3.00**	**4.47**	**15-12**	4.96	4.7	4.8	4.45	4.73	0.207	**15-3**	23.23	1073
			12-9	5.64	5.32	5.36	5.12	5.36	0.234	**12-3**	18.51	1156
			9-6	6.18	6.2	6.04	5.9	6.08	0.289	**9-3**	13.15	1284
			6-3	7.24	7.15	7.15	6.72	7.07	0.415	**6-3**	7.07	1496
			Total	24.02	23.37	23.35	22.19	23.23	0.298			
4	**3.02**	**4.49**	**15-12**	7.18	6.96	6.84	6.75	6.93	0.141	**15-3**	34.63	719
			12-9	8	7.65	7.76	7.51	7.73	0.162	**12-3**	27.70	773
			9-6	9.24	9	9	8.76	9.00	0.195	**9-3**	19.97	846
			6-3	11.4	10.64	10.9	10.92	10.97	0.268	**6-3**	10.97	964
			Total	35.82	34.25	34.5	33.94	34.63	0.200			
5	**3.01**	**4.50**	**15-12**	5.15	5.15	5.06	4.96	5.08	0.193	**15-3**	24.80	1009
			12-9	5.72	5.56	5.59	**5.65**	5.63	0.224	**12-3**	19.72	1090
			9-6	6.54	6.65	**6.43**	**6.4**	6.51	0.271	**9-3**	14.09	1204
			6-3	7.65	7.58	7.65	7.46	7.59	0.389	**6-3**	7.59	1402
			Total	25.06	24.94	24.73	24.47	24.80	0.280			

Average Permeability of #89-C

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	28.04	914	3.10
12-3	22.33	986	2.92
9-3	16.00	1086	2.72
6-3	8.68	1256	2.51

Table E.11 Permeability of PCPC of aggregate L for the #89 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.45**	**15-12**	21.36	20.68	19.57	19.14	20.19	0.0479	**15-3**	101.72	242
			12-9	23.87	22.96	21.47	21.43	22.43	0.0553	**12-3**	81.53	259
			9-6	27.91	27.03	25.48	25.2	26.41	0.0656	**9-3**	59.10	282
			6-3	33.83	33.63	30.94	32.36	32.69	0.0885	**6-3**	32.69	319
			Total	106.97	104.3	97.46	98.13	101.72	0.0672			
2	**3.01**	**4.44**	**15-12**	17.49	16.16	15.95	15.46	16.27	0.0594	**15-3**	80.09	306
			12-9	19.08	18.07	18	17.79	18.24	0.0679	**12-3**	63.82	330
			9-6	22.35	20.76	19.74	20.21	20.77	0.0832	**9-3**	45.59	364
			6-3	26.21	24.67	24.47	23.94	24.82	0.1162	**6-3**	24.82	418
			Total	85.13	79.66	78.16	77.4	80.09	0.0851			
3	**3.01**	**4.48**	**15-12**	28.86	27.46	24.67	22.85	25.96	0.0377	**15-3**	135.82	184
			12-9	32.59	26.96	29.99	26.73	29.07	0.0432	**12-3**	109.86	195
			9-6	39.49	35.29	35.05	34.59	36.11	0.0487	**9-3**	80.79	209
			6-3	48	43.57	45.54	41.62	44.68	0.0659	**6-3**	44.68	238
			Total	148.94	133.28	135.25	125.79	135.82	0.0511			
4	**3.00**	**4.51**	**15-12**	16.81	16.66	16.72	16.27	16.62	0.0597	**15-3**	82.64	307
			12-9	18.92	18.22	17.72	18.22	18.27	0.0697	**12-3**	66.02	330
			9-6	21.76	21.59	21.63	21.47	21.61	0.0824	**9-3**	47.75	360
			6-3	26.41	26.56	25.34	26.24	26.14	0.1144	**6-3**	26.14	412
			Total	83.9	83.03	81.41	82.2	82.64	0.0852			
5	**3.01**	**4.48**	**15-12**	22.17	20.59	19.38	18.7	20.21	0.0486	**15-3**	98.02	256
			12-9	24.22	22.32	22.57	21.18	22.57	0.0558	**12-3**	77.81	276
			9-6	27.13	25.72	24.49	23.99	25.33	0.0696	**9-3**	55.24	307
			6-3	32.14	29.95	29.5	28.02	29.90	0.0987	**6-3**	29.90	355
			Total	105.66	98.58	95.94	91.89	98.02	0.0710			

Average Permeability of #89

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	99.65	259	0.88
12-3	79.81	278	0.83
9-3	57.69	305	0.77
6-3	31.65	348	0.70

Table E.12 Permeability of PCPC of aggregate L for the #89-F mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydrauli c Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.50**	**15-12**	7.21	6.84	6.8	6.75	6.90	0.143	**15-3**	33.58	748
			12-9	7.68	7.72	7.68	7.54	7.66	0.165	**12-3**	26.68	809
			9-6	8.86	8.84	8.7	8.7	8.78	0.201	**9-3**	19.02	895
			6-3	10.54	10.09	10.29	10.06	10.25	0.289	**6-3**	10.25	1041
			Total	34.29	33.49	33.47	33.05	33.58	0.208			
2	**3.01**	**4.51**	**15-12**	6.9	6.7	6.84	6.61	6.76	0.146	**15-3**	33.17	760
			12-9	7.67	7.61	7.59	7.46	7.58	0.167	**12-3**	26.40	820
			9-6	8.78	8.65	8.67	8.56	8.67	0.204	**9-3**	18.82	908
			6-3	10.29	10.26	10.07	10	10.16	0.293	**6-3**	10.16	1054
			Total	33.64	33.22	33.17	32.63	33.17	0.211			
3	**3.00**	**4.50**	**15-12**	5.96	5.82	5.7	5.67	5.79	0.170	**15-3**	28.57	881
			12-9	6.62	6.62	6.37	6.39	6.50	0.195	**12-3**	22.78	949
			9-6	7.8	7.4	7.21	7.31	7.43	0.238	**9-3**	16.28	1048
			6-3	9.1	8.82	8.82	8.67	8.85	0.336	**6-3**	8.85	1207
			Total	29.48	28.66	28.1	28.04	28.57	0.245			
4	**3.01**	**4.45**	**15-12**	7.36	7.61	7.37	7.26	7.40	0.131	**15-3**	35.93	688
			12-9	8.61	8.07	8.02	7.96	8.17	0.153	**12-3**	28.53	743
			9-6	9.48	9.42	9.31	9.28	9.37	0.186	**9-3**	20.36	821
			6-3	11.28	11.1	10.93	10.64	10.99	0.264	**6-3**	10.99	952
			Total	36.73	36.2	35.63	35.14	35.93	0.191			
5	**3.01**	**4.50**	**15-12**	7.15	7.18	7.02	7	7.09	0.139	**15-3**	34.86	723
			12-9	8.06	7.9	7.95	7.73	7.91	0.160	**12-3**	27.77	780
			9-6	9.37	9.1	9.02	8.92	9.10	0.195	**9-3**	19.86	860
			6-3	10.92	10.86	10.58	10.68	10.76	0.276	**6-3**	10.76	995
			Total	35.5	35.04	34.57	34.33	34.86	0.201			

Average Permeability of #89-F

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	33.22	760	2.57
12-3	26.43	820	2.42
9-3	18.87	907	2.26
6-3	10.20	1050	2.09

Table E.13 Permeability of PCPC of aggregate L for the ⅜ in. mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.55**	**15-12**	2.74	2.5	2.36	2.42	2.51	0.399	**15-3**	13.87	1850
			12-9	3	2.87	2.75	2.79	2.85	0.451	**12-3**	11.36	1941
			9-6	4.07	3.77	3.74	3.64	3.81	0.474	**9-3**	8.51	2048
			6-3	5.01	4.83	4.52	4.46	4.71	0.646	**6-3**	4.71	2325
			Total	14.82	13.97	13.37	13.31	13.87	0.514			
2	**3.01**	**4.55**	**15-12**	6.09	5.79	5.33	5.54	5.69	0.176	**15-3**	29.06	884
			12-9	7.2	6.39	6.07	6.49	6.54	0.197	**12-3**	23.37	945
			9-6	8.09	7.51	7.23	7.32	7.54	0.239	**9-3**	16.83	1037
			6-3	9.79	9.45	8.97	8.97	9.30	0.327	**6-3**	9.30	1178
			Total	31.17	29.14	27.6	28.32	29.06	0.246			
3	**3.01**	**4.59**	**15-12**	4.59	4.34	4.32	4.35	4.40	0.230	**15-3**	23.64	1100
			12-9	5.49	5.24	5.28	5.23	5.31	0.245	**12-3**	19.24	1163
			9-6	6.71	6.2	6.04	6.12	6.27	0.291	**9-3**	13.93	1270
			6-3	8.31	7.34	7.46	7.53	7.66	0.403	**6-3**	7.66	1439
			Total	25.1	23.12	23.1	23.23	23.64	0.306			
4	**3.01**	**4.56**	**15-12**	4.89	4.91	4.46	4.58	4.71	0.213	**15-3**	23.38	1101
			12-9	5.72	5.49	5.31	4.98	5.38	0.240	**12-3**	18.67	1186
			9-6	6.41	6.39	5.75	5.88	6.11	0.296	**9-3**	13.30	1316
			6-3	7.6	7.31	6.99	6.85	7.19	0.425	**6-3**	7.19	1529
			Total	24.62	24.1	22.51	22.29	23.38	0.306			
5	**3.00**	**4.54**	**15-12**	5.04	4.54	4.69	4.53	4.70	0.213	**15-3**	23.55	1087
			12-9	5.58	5.56	5.07	5.12	5.33	0.241	**12-3**	18.85	1167
			9-6	6.66	6.07	6.15	5.92	6.20	0.290	**9-3**	13.51	1286
			6-3	7.76	7.42	7.01	7.06	7.31	0.414	**6-3**	7.31	1491
			Total	25.04	23.59	22.92	22.63	23.55	0.302			

Average Permeability of ⅜ in.

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	22.70	1205	3.97
12-3	18.30	1280	3.68
9-3	13.22	1391	3.38
6-3	7.23	1593	3.08

Table E.14 Permeability of PCPC of aggregate L for the #78-C mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.45**	**15-12**	5.65	5.5	5.24	5.18	5.39	0.1801	**15-3**	27.61	895
			12-9	6.39	6.28	6.2	6.05	6.23	0.2000	**12-3**	22.21	955
			9-6	7.42	7.32	7.18	7.14	7.27	0.2395	**9-3**	15.98	1046
			6-3	9.01	8.84	8.56	8.46	8.72	0.3334	**6-3**	8.72	1200
			Total	28.47	27.94	27.18	26.83	27.61	0.2486			
2	**3.01**	**4.42**	**15-12**	4.54	4.17	4.06	4.09	4.22	0.2283	**15-3**	22.02	1109
			12-9	5.39	4.98	4.87	4.82	5.02	0.2460	**12-3**	17.80	1177
			9-6	6.12	5.75	5.62	5.51	5.75	0.2993	**9-3**	12.79	1291
			6-3	7.45	7.02	6.87	6.81	7.04	0.4072	**6-3**	7.04	1466
			Total	23.5	21.92	21.42	21.23	22.02	0.3081			
3	**3.00**	**4.46**	**15-12**	4.76	4.8	4.61	4.7	4.72	0.2072	**15-3**	23.45	1061
			12-9	5.75	5.36	5.31	5.02	5.36	0.2340	**12-3**	18.73	1141
			9-6	6.46	6.12	6.01	5.95	6.14	0.2856	**9-3**	13.37	1260
			6-3	7.67	7.17	7.07	7.04	7.24	0.4048	**6-3**	7.24	1449
			Total	24.64	23.45	23	22.71	23.45	0.2948			
4	**3.01**	**4.45**	**15-12**	3.89	4	3.56	3.68	3.78	0.2561	**15-3**	19.13	1288
			12-9	4.65	4.23	4.32	4.29	4.37	0.2842	**12-3**	15.35	1379
			9-6	5.15	5.2	5	4.87	5.06	0.3433	**9-3**	10.97	1520
			6-3	6.14	5.92	5.75	5.86	5.92	0.4898	**6-3**	5.92	1763
			Total	19.83	19.35	18.63	18.7	19.13	0.3579			
5	**3.01**	**4.46**	**15-12**	3.78	3.58	3.75	3.65	3.69	0.2634	**15-3**	18.96	1305
			12-9	4.56	4.42	4.4	4.21	4.40	0.2836	**12-3**	15.27	1392
			9-6	5.02	5.04	4.82	4.86	4.94	0.3530	**9-3**	10.87	1542
			6-3	6.21	5.89	5.81	5.82	5.93	0.4908	**6-3**	5.93	1767
			Total	19.57	18.93	18.78	18.54	18.96	0.3626			

Average Permeability of #78-C

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	22.23	1132	3.89
12-3	17.87	1209	3.63
9-3	12.80	1332	3.38
6-3	6.97	1529	3.11

Table E.15 Permeability of PCPC of aggregate L for the A9.5-C mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.47**	**15-12**	7.34	6.86	6.84	6.67	**6.93**	0.141	**15-3**	33.56	739
			12-9	8.02	7.53	7.48	7.23	**7.57**	0.165	**12-3**	26.63	800
			9-6	9.44	8.82	8.48	8.41	**8.79**	0.199	**9-3**	19.07	881
			6-3	10.84	10.21	10.12	9.95	**10.28**	0.284	**6-3**	10.28	1023
			Total	35.64	33.42	32.92	32.26	**33.56**	0.205			
2	**3.02**	**4.49**	**15-12**	4.96	4.87	4.87	4.75	**4.86**	0.200	**15-3**	23.75	1044
			12-9	5.57	5.36	5.42	5.07	**5.36**	0.233	**12-3**	18.89	1128
			9-6	6.27	6.27	6.1	6.27	**6.23**	0.280	**9-3**	13.53	1242
			6-3	7.6	7.2	7.41	7.01	**7.31**	0.400	**6-3**	7.31	1441
			Total	24.4	23.7	23.8	23.1	**23.75**	0.290			
3	**3.02**	**4.45**	**15-12**	8.45	8.31	7.86	7.72	**8.09**	0.119	**15-3**	38.83	632
			12-9	9.17	8.86	8.64	8.56	**8.81**	0.141	**12-3**	30.75	685
			9-6	10.66	10.14	9.9	9.62	**10.08**	0.171	**9-3**	21.94	757
			6-3	12.39	11.87	11.67	11.5	**11.86**	0.243	**6-3**	11.86	880
			Total	40.67	39.18	38.07	37.4	**38.83**	0.176			
4	**3.01**	**4.49**	**15-12**	5.78	5.75	5.64	5.51	**5.67**	0.173	**15-3**	27.86	899
			12-9	6.39	6.46	6.29	6.21	**6.34**	0.199	**12-3**	22.19	970
			9-6	7.48	7.22	7.28	7.13	**7.28**	0.242	**9-3**	15.86	1071
			6-3	8.56	8.63	8.65	8.47	**8.58**	0.344	**6-3**	8.58	1240
			Total	28.21	28.06	27.86	27.32	**27.86**	0.250			
5	**3.02**	**4.47**	**15-12**	6.73	6.24	6.12	5.98	**6.27**	0.155	**15-3**	30.61	808
			12-9	7.34	7.02	6.96	6.65	**6.99**	0.178	**12-3**	24.35	873
			9-6	8.23	7.84	7.76	7.76	**7.90**	0.220	**9-3**	17.35	966
			6-3	9.92	9.5	9.51	8.89	**9.46**	0.308	**6-3**	9.46	1109
			Total	32.22	30.6	30.35	29.28	**30.61**	0.224			

Average Permeability of A9.5-C

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	30.92	824	2.82
12-3	24.56	891	2.66
9-3	17.55	983	2.48
6-3	9.50	1139	2.29

Table E.16 Permeability of PCPC of aggregate L for the A9.5 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.51**	**15-12**	38.61	36.11	35.65	35.15	36.38	0.0272	**15-3**	177.17	143
			12-9	41.09	40.89	40.83	40.4	40.80	0.0311	**12-3**	140.79	154
			9-6	48.33	45.75	45.26	44.53	45.97	0.0386	**9-3**	99.99	171
			6-3	56.33	53.4	53.34	53.01	54.02	0.0552	**6-3**	54.02	199
			Total	184.36	176.15	175.08	173.09	177.17	0.0396			
2	**3.01**	**4.50**	**15-12**	57.86	42.93	44.45	44.15	47.35	0.0208	**15-3**	235.24	107
			12-9	62.19	49.42	47.08	47.61	51.58	0.0246	**12-3**	187.90	115
			9-6	74.44	56.65	55.53	55.35	60.49	0.0293	**9-3**	136.32	125
			6-3	97.08	71.12	69.36	65.75	75.83	0.0392	**6-3**	75.83	141
			Total	291.57	220.12	216.42	212.86	235.24	0.0298			
3	**3.01**	**4.49**	**15-12**	53.5	51.95	51.34	50.54	51.83	0.0188	**15-3**	260.81	95
			12-9	63.67	60.37	57.71	57.78	59.88	0.0209	**12-3**	208.98	102
			9-6	70.38	67.33	68.27	64.96	67.74	0.0259	**9-3**	149.09	113
			6-3	84.61	81.47	81.35	78	81.36	0.0361	**6-3**	81.36	130
			Total	272.16	261.12	258.67	251.28	260.81	0.0265			
4	**3.01**	**4.49**	**15-12**	46.67	41.61	42.13	38.99	42.35	0.0231	**15-3**	211.89	118
			12-9	52.62	47.87	45.56	43.29	47.34	0.0265	**12-3**	169.54	126
			9-6	61.88	53.76	53.07	53.29	55.50	0.0316	**9-3**	122.21	138
			6-3	76.46	64.32	63.92	62.12	66.71	0.0440	**6-3**	66.71	159
			Total	237.63	207.56	204.68	197.69	211.89	0.0327			
5	**3.01**	**4.48**	**15-12**	131.49	83.76			107.63	0.0091	**15-3**	515.73	48
			12-9	132.5	97.73			115.12	0.0109	**12-3**	408.10	52
			9-6	147.56	115.7	**Very slow flow**		131.63	0.0133	**9-3**	292.99	58
			6-3	175.59	147.12			161.36	0.0182	**6-3**	161.36	66
			Total	587.14	444.31	0	0	515.73	0.0134			

Average Permeability of 9.5 mm

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	280.17	102	0.35
12-3	223.06	110	0.33
9-3	160.12	121	0.30
6-3	87.85	139	0.28

Table E.17 Permeability of PCPC of aggregate L for the #78 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.45**	**15-12**	12.7	12.69	13.19	12.39	**12.74**	0.076	**15-3**	61.58	402
			12-9	14.81	14.23	14	13.63	**14.17**	0.088	**12-3**	48.83	435
			9-6	16.97	16.23	15.93	15.24	**16.09**	0.108	**9-3**	34.67	483
			6-3	19.55	18.94	17.9	17.9	**18.57**	0.157	**6-3**	18.57	564
			Total	64.03	62.09	61.02	59.16	**61.58**	0.112			
2	**3.01**	**4.49**	**15-12**	24.35	18.53	17.37	18.12	**19.59**	0.050	**15-3**	92.75	270
			12-9	25.3	19.55	18.86	19.49	**20.80**	0.061	**12-3**	73.16	294
			9-6	28.73	22.95	22.21	22.82	**24.18**	0.073	**9-3**	52.36	324
			6-3	33.89	26.49	25.87	26.48	**28.18**	0.105	**6-3**	28.18	377
			Total	112.27	87.52	84.31	86.91	**92.75**	0.075			
3	**3.06**	**4.48**	**15-12**	13.78	12.54	12.91	12.77	**13.00**	0.073	**15-3**	62.19	388
			12-9	14.6	14.05	14.11	13.82	**14.15**	0.086	**12-3**	49.19	422
			9-6	16.8	16.17	16.16	15.81	**16.24**	0.105	**9-3**	35.04	467
			6-3	19.39	18.58	18.54	18.71	**18.81**	0.151	**6-3**	18.81	566
			Total	64.57	61.34	61.72	61.11	**62.19**	0.108			
4	**3.01**	**4.53**	**15-12**	19.48	19.05	19.56	16.25	**18.59**	0.054	**15-3**	90.23	282
			12-9	21.65	20.28	21.33	18.6	**20.47**	0.062	**12-3**	71.64	306
			9-6	25.04	23.67	24.87	21.45	**23.76**	0.075	**9-3**	51.18	338
			6-3	28.81	27.75	28.45	24.67	**27.42**	0.110	**6-3**	27.42	396
			Total	94.98	90.75	94.21	80.97	**90.23**	0.078			
5	**3.00**	**4.49**	**15-12**	16.43	15.67	15.56	15.36	**15.76**	0.063	**15-3**	76.99	327
			12-9	18.36	17.8	16.95	17.37	**17.62**	0.072	**12-3**	61.23	353
			9-6	20.67	20.33	19.94	20.25	**20.30**	0.087	**9-3**	43.61	391
			6-3	23.97	23.25	23.02	23.02	**23.32**	0.127	**6-3**	23.32	458
			Total	79.43	77.05	75.47	76	**76.99**	0.091			

Average Permeability of #78

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	76.75	334	1.14
12-3	60.81	362	1.08
9-3	43.37	401	1.01
6-3	23.26	472	0.94

Table E.18 Permeability of PCPC of aggregate L for the ½ in. mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.48**	**15-12**	8.37	9.03	8.75	8.66	8.70	0.112	**15-3**	41.49	601
			12-9	9.25	9.32	9.37	9.21	9.29	0.135	**12-3**	32.79	653
			9-6	11.29	11.34	10.87	10.34	10.96	0.160	**9-3**	23.50	719
			6-3	12.42	12.49	12.66	12.58	12.54	0.234	**6-3**	12.54	844
			Total	41.33	42.18	41.65	40.79	41.49	0.167			
2	**3.01**	**4.44**	**15-12**	7.34	7.43	7.23	6.79	7.20	0.135	**15-3**	34.36	717
			12-9	8.23	8.03	8	7.24	7.88	0.158	**12-3**	27.17	778
			9-6	9.21	8.88	8.57	8.51	8.79	0.197	**9-3**	19.29	864
			6-3	10.66	10.76	10.17	10.4	10.50	0.276	**6-3**	10.50	992
			Total	35.44	35.1	33.97	32.94	34.36	0.199			
3	**3.01**	**4.46**	**15-12**	6.64	5.95	5.41	5.63	5.91	0.165	**15-3**	28.78	861
			12-9	7.04	6.86	6.45	6.06	6.60	0.189	**12-3**	22.88	930
			9-6	8.21	8.11	7.14	6.87	7.58	0.230	**9-3**	16.27	1031
			6-3	9.46	9	8.36	7.94	8.69	0.335	**6-3**	8.69	1218
			Total	31.35	29.92	27.36	26.5	28.78	0.239			
4	**3.01**	**4.48**	**15-12**	9.31	8.83	8.61	8.1	8.71	0.112	**15-3**	41.75	597
			12-9	10.64	10.11	9.52	8.79	9.77	0.128	**12-3**	33.04	648
			9-6	11.95	10.61	10.57	9.63	10.69	0.164	**9-3**	23.28	725
			6-3	13.64	11.67	12.33	12.7	12.59	0.233	**6-3**	12.59	840
			Total	45.54	41.22	41.03	39.22	41.75	0.166			
5	**3.00**	**4.49**	**15-12**	6.6	5.91	5.65	5.48	5.91	0.167	**15-3**	28.05	896
			12-9	7.09	5.93	6.13	5.75	6.23	0.203	**12-3**	22.14	975
			9-6	8.36	6.93	7.33	6.89	7.38	0.240	**9-3**	15.91	1070
			6-3	9.6	8.08	8.54	7.91	8.53	0.347	**6-3**	8.53	1250
			Total	31.65	26.85	27.65	26.03	28.05	0.249			

Average Permeability of ½ in.

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	34.89	734	2.50
12-3	27.60	797	2.37
9-3	19.65	882	2.22
6-3	10.57	1029	2.06

Table E.19 Permeability of PCPC of aggregate L for the #67-I mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.49**	**15-12**	13.81	12.89	11.51	11.37	12.40	0.0794	**15-3**	58.87	427
			12-9	15.53	13.52	12.4	12.39	13.46	0.0939	**12-3**	46.47	465
			9-6	17.17	15.37	14.07	14.1	15.18	0.116	**9-3**	33.01	516
			6-3	20.17	18.21	16.58	16.37	17.83	0.166	**6-3**	17.83	599
			Total	66.68	59.99	54.56	54.23	58.87	0.119			
2	**3.01**	**4.50**	**15-12**	9.95	9.32	8.76	8.67	9.18	0.107	**15-3**	44.25	568
			12-9	10.95	10.26	9.67	9.68	10.14	0.125	**12-3**	35.07	615
			9-6	12.43	11.7	10.82	10.75	11.43	0.155	**9-3**	24.93	683
			6-3	14.62	13.68	12.95	12.78	13.51	0.219	**6-3**	13.51	790
			Total	47.95	44.96	42.2	41.88	44.25	0.158			
3	**3.02**	**4.51**	**15-12**	9.96	9.9	9.01	8.53	9.35	0.105	**15-3**	46.55	537
			12-9	11.06	11.09	10.01	9.36	10.38	0.121	**12-3**	37.20	578
			9-6	13.14	12.75	11.64	11.18	12.18	0.144	**9-3**	26.82	633
			6-3	15.54	15.56	14.01	13.45	14.64	0.202	**6-3**	14.64	729
			Total	49.7	49.3	44.67	42.52	46.55	0.149			
4	**3.01**	**4.50**	**15-12**	10.31	8.98	9.18	7.26	8.93	0.110	**15-3**	42.39	592
			12-9	11.43	10.06	9.01	8.18	9.67	0.131	**12-3**	33.46	645
			9-6	12.89	10.84	10.15	9.53	10.85	0.163	**9-3**	23.79	716
			6-3	15.18	13.31	12.06	11.2	12.94	0.229	**6-3**	12.94	825
			Total	49.81	43.19	40.4	36.17	42.39	0.165			
5	**3.01**	**4.50**	**15-12**	7	6.78	6.34	6.36	6.62	0.148	**15-3**	32.21	779
			12-9	7.73	7.48	7.43	7.2	7.46	0.169	**12-3**	25.59	842
			9-6	8.51	8.45	8.14	8.18	8.32	0.212	**9-3**	18.13	938
			6-3	10.21	9.9	9.68	9.45	9.81	0.302	**6-3**	9.81	1086
			Total	33.45	32.61	31.59	31.19	32.21	0.216			

Average Permeability of #67-I

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	44.85	581	1.96
12-3	35.56	629	1.86
9-3	25.34	697	1.74
6-3	13.75	806	1.60

Table E.20 Permeability of PCPC of aggregate L for the #67 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	(in.)	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	(in.)	(sec)	(in/hr)
1	**3.02**	**4.46**	**15-12**	49.9	30.37	27.72	24.28	33.07	0.029	**15-3**	158.42	155
			12-9	52.86	32.57	30.14	27.39	35.74	0.035	**12-3**	125.36	168
			9-6	60.02	37.54	34.67	31.42	40.91	0.042	**9-3**	89.62	186
			6-3	72.36	43.97	40.85	37.63	48.70	0.059	**6-3**	48.70	214
			Total	235.14	144.45	133.38	120.72	158.42	0.043			
2	**3.00**	**4.51**	**15-12**	20.16	16.07	17.5	17.73	17.87	0.056	**15-3**	86.73	292
			12-9	22.42	18.9	19.01	18.8	19.78	0.064	**12-3**	68.87	316
			9-6	25.32	21.55	21.9	21.5	22.57	0.079	**9-3**	49.09	350
			6-3	29.2	26.03	25.37	25.47	26.52	0.113	**6-3**	26.52	406
			Total	97.1	82.55	83.78	83.5	86.73	0.081			
3	**3.01**	**4.50**	**15-12**							**15-3**	0.00	0
			12-9	***Specimen did not drain***						**12-3**	0.00	0
			9-6							**9-3**	0.00	0
			6-3							**6-3**	0.00	0
			Total	0	0	0	0					
4	**3.02**	**4.49**	**15-12**	43.23	36.02	42.99	37.41	39.91	0.024	**15-3**	189.53	131
			12-9	45.23	41.02	45.03	42.51	43.45	0.029	**12-3**	149.61	143
			9-6	51.91	45.98	50.47	47.43	48.95	0.036	**9-3**	106.17	159
			6-3	61.49	52.74	58.54	56.1	57.22	0.051	**6-3**	57.22	185
			Total	201.86	175.76	197.03	183.45	189.53	0.036			
5	**3.01**	**4.47**	**15-12**	19.84	18.63	17.86	17.32	18.41	0.053	**15-3**	86.63	287
			12-9	21.11	20.24	19.43	18.08	19.72	0.063	**12-3**	68.22	312
			9-6	24.12	22.77	22.43	19.97	22.32	0.078	**9-3**	48.50	347
			6-3	28.38	26.15	26.42	23.77	26.18	0.112	**6-3**	26.18	402
			Total	93.45	87.79	86.14	79.14	86.63	0.080			

Average Permeability of #67

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	130.33	216	0.59
12-3	103.01	235	0.56
9-3	73.34	260	0.52
6-3	39.65	302	0.48

Table E.21 Permeability of PCPC of aggregate L for the A12.5-C mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	(in.)	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	(in.)	(sec)	(in/hr)
1	**3.06**	**4.45**	**15-12**	10.51	9.81	9.59	9.14	9.76	0.096	**15-3**	48.51	492
			12-9	11.65	11.1	10.7	10.46	10.98	0.110	**12-3**	38.75	529
			9-6	13.53	12.9	12.48	11.75	12.67	0.133	**9-3**	27.77	582
			6-3	16.07	15.21	14.56	14.59	15.11	0.186	**6-3**	15.11	669
			Total	51.76	49.02	47.33	45.94	48.51	0.137			
2	**3.02**	**4.44**	**15-12**	11.73	11.2	10.75	10.68	11.09	0.087	**15-3**	52.10	470
			12-9	12.68	11.82	11.62	11.24	11.84	0.104	**12-3**	41.01	512
			9-6	14.4	13.24	13.29	12.95	13.47	0.128	**9-3**	29.17	568
			6-3	16.73	15.51	15.54	15.01	15.70	0.183	**6-3**	15.70	659
			Total	55.54	51.77	51.2	49.88	52.10	0.130			
3	**3.01**	**4.41**	**15-12**	11.48	11.12	10.7	10.51	10.95	0.087	**15-3**	53.41	454
			12-9	12.95	12.42	11.84	12.1	12.33	0.100	**12-3**	42.45	490
			9-6	14.37	14.04	13.81	13.48	13.93	0.123	**9-3**	30.13	544
			6-3	16.9	16.59	15.75	15.56	16.20	0.176	**6-3**	16.20	637
			Total	55.7	54.17	52.1	51.65	53.41	0.126			
4	**3.01**	**4.43**	**15-12**	9.92	9.89	9.26	8.84	9.48	0.102	**15-3**	47.27	518
			12-9	10.98	11.36	10.43	10.14	10.73	0.115	**12-3**	37.80	556
			9-6	12.5	12.65	11.75	11.59	12.12	0.142	**9-3**	27.07	612
			6-3	15.73	15.12	14.32	14.61	14.95	0.192	**6-3**	14.95	693
			Total	49.13	49.02	45.76	45.18	47.27	0.144			
5	**3.01**	**4.44**	**15-12**	10.17	9.7	9.65	9.43	9.74	0.099	**15-3**	47.42	518
			12-9	11.36	10.82	10.72	10.53	10.86	0.114	**12-3**	37.68	560
			9-6	12.62	12.1	12.7	12.48	12.48	0.139	**9-3**	26.82	620
			6-3	14.68	14.17	14.32	14.21	14.35	0.201	**6-3**	14.35	725
			Total	48.83	46.79	47.39	46.65	47.42	0.144			

Average Permeability of A12.5-C

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	49.74	490	1.71
12-3	39.54	529	1.61
9-3	28.19	585	1.51
6-3	15.26	677	1.39

Table E.22 Permeability of PCPC of aggregate L for the A12.5 mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**2.99**	**4.45**	**15-12**	107.49	80.73	45.1	46.37	**69.92**	0.0141	**15-3**	326.01	77
			12-9	119.67	68.52	48.24	50.53	**71.74**	0.0176	**12-3**	256.09	84
			9-6	136.52	81.34	57.68	60.05	**83.90**	0.0210	**9-3**	184.35	92
			6-3	165.38	98.66	67.92	69.83	**100.45**	0.0293	**6-3**	100.45	105
			Total	529.06	329.25	218.94	226.78	**326.01**	0.0213			
2	**3.01**	**4.48**	**15-12**							**15-3**	0.00	0
			12-9	***Specimen did not drain***						**12-3**	0.00	0
			9-6							**9-3**	0.00	0
			6-3							**6-3**	0.00	0
3	**3.01**	**4.49**	**15-12**							**15-3**	0.00	0
			12-9	***Specimen did not drain***						**12-3**	0.00	0
			9-6							**9-3**	0.00	0
			6-3							**6-3**	0.00	0
4	**3.01**	**4.48**	**15-12**							**15-3**	0.00	0
			12-9	***Specimen did not drain***						**12-3**	0.00	0
			9-6							**9-3**	0.00	0
			6-3							**6-3**	0.00	0
5	**3.02**	**4.46**	**15-12**	157.4	113.72	98.38		**123.17**	0.0079	**15-3**	585.94	42
			12-9	163.88	136.06	86.22		**128.72**	0.0097	**12-3**	462.77	46
			9-6	199.16	154.39	97.56		**150.37**	0.0115	**9-3**	334.05	50
			6-3	250.02	183.2	117.82		**183.68**	0.0158	**6-3**	183.68	57
			Total	770.46	587.37	399.98	0	**585.94**	0.0117			

<u>Average Permeability of 12.5 mm</u>

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	455.97	24	0.08
12-3	359.43	26	0.08
9-3	259.20	28	0.07
6-3	142.06	32	0.07

Table E.23 Permeability of PCPC of aggregate L for the A12.5-F mix.

No.	Dia.	Height	Δ Head	Time 1	Time 2	Time 3	Time 4	Avg. Time	Hydraulic Cond. (*k*)	Δ Head	Avg. Time	Hydraulic Cond. (*k*)
	(in.)	(in.)	**(in.)**	(sec)	(sec)	(sec)	(sec)	(sec)	(in/sec)	**(in.)**	(sec)	(in/hr)
1	**3.01**	**4.41**	**15-12**	8.31	7.26	6.98	6.81	**7.34**	0.1307	**15-3**	36.59	665
			12-9	9.12	8.37	8.02	7.98	**8.37**	0.1468	**12-3**	29.25	713
			9-6	10.54	9.46	9.29	8.98	**9.57**	0.1792	**9-3**	20.88	788
			6-3	12.61	11.42	10.7	10.51	**11.31**	0.2523	**6-3**	11.31	908
			Total	40.58	36.51	34.99	34.28	**36.59**	0.1846			
2	**3.01**	**4.44**	**15-12**	10.58	9.32	9.32	8.81	**9.51**	0.1009	**15-3**	45.56	540
			12-9	11.09	10.45	10.12	9.78	**10.36**	0.1186	**12-3**	36.06	585
			9-6	12.72	11.67	11.39	11.06	**11.71**	0.1464	**9-3**	25.70	647
			6-3	14.93	14.17	13.8	13.04	**13.99**	0.2040	**6-3**	13.99	744
			Total	49.32	45.61	44.63	42.69	**45.56**	0.1483			
3	**3.01**	**4.44**	**15-12**	17.61	16.5	15.34	16.02	**16.37**	0.0586	**15-3**	80.86	303
			12-9	18.84	18.62	18.15	17.95	**18.39**	0.0668	**12-3**	64.49	326
			9-6	21.73	21.43	20.87	20.56	**21.15**	0.0811	**9-3**	46.10	359
			6-3	26.21	24.95	24.37	24.29	**24.96**	0.1143	**6-3**	24.96	413
			Total	84.39	81.5	78.73	78.82	**80.86**	0.0835			
4	**3.01**	**4.42**	**15-12**	11.61	10.75	10.26	10.18	**10.70**	0.0896	**15-3**	54.23	448
			12-9	12.89	12.26	11.62	11.7	**12.12**	0.1014	**12-3**	43.53	479
			9-6	15.34	14.1	13.78	13.48	**14.18**	0.1209	**9-3**	31.41	523
			6-3	18.56	17.15	16.68	16.56	**17.24**	0.1655	**6-3**	17.24	595
			Total	58.4	54.26	52.34	51.92	**54.23**	0.1246			
5	**3.01**	**4.42**	**15-12**	13.32	12.28	12.09	12.37	**12.52**	0.0766	**15-3**	61.09	398
			12-9	14.76	13.75	13.75	13.46	**13.93**	0.0882	**12-3**	48.58	429
			9-6	16.61	15.78	15.62	15.34	**15.84**	0.1081	**9-3**	34.65	474
			6-3	19.67	18.54	18.78	18.24	**18.81**	0.1516	**6-3**	18.81	546
			Total	64.36	60.35	60.24	59.41	**61.09**	0.1105			

Average Permeability of A12.5-F

Δ Head	Avg. Time	Hydraulic Cond. (*k*)	Flow Rate
(in.)	(sec)	(in/hr)	(in^3/sec)
15-3	55.67	471	1.64
12-3	44.38	507	1.54
9-3	31.75	558	1.44
6-3	17.26	641	1.32

<u>Appendix F</u>

Example Gradation Selection for Pervious Concrete

Consider a pavement that will be constructed in an area that experiences a rain fall intensity of approximately 400 in./hr. In the event that the aggregate is from source B in this study, then the bold arrows on Figure F.1 will guide from the permeability to the estimated compressive strength and uniformity coefficient that will match the site specifications. For the permeability of 400 in/hr, the compressive strength of the pervious concrete mixture is estimated to be just over 1860 psi (12.8 MPa) and the corresponding uniformity coefficient of the aggregate gradation is 2.6. Therefore, the recommended aggregate gradation based on the results from this study would be either A9.5 or #78, but the #78 meets the permeability requirements..

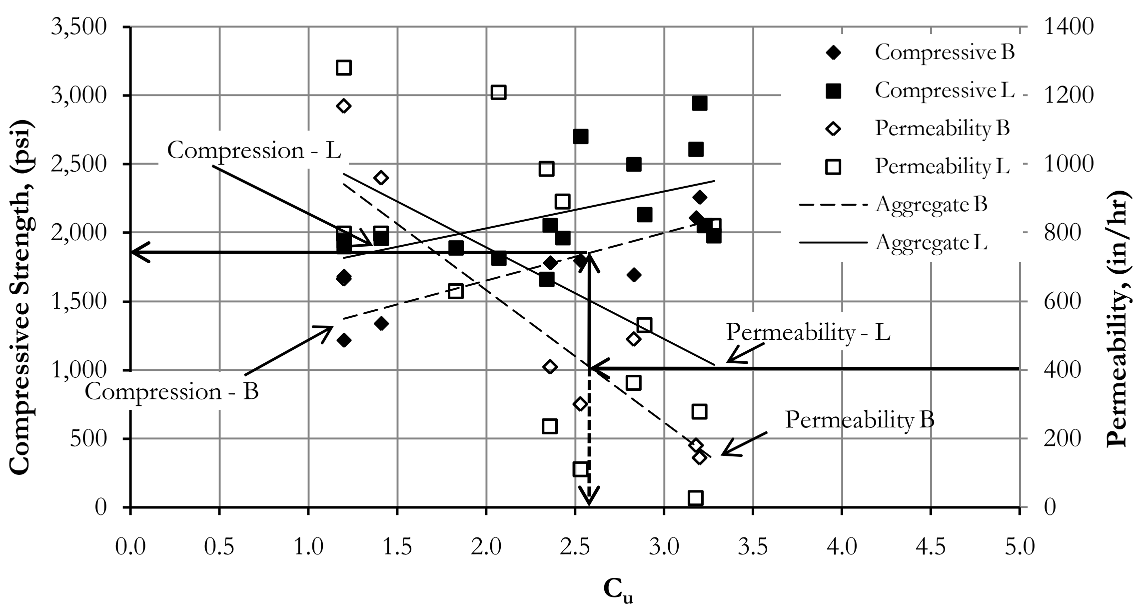

Figure F.1 Example using the correlation among compressive strength, permeability and uniformity coefficient.

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