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Improving the Long-Term Maintenance and Durability of Pervious Concrete Pavements

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IMPROVING THE LONG-TERM MAINTENANCE AND

DURABILITY OF PERVIOUS CONCRETE PAVEMENTS

by

Kate Elizabeth Christiansen

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ABSTRACT

Improving The Long-Term Maintenance and Durability

of Pervious Concrete Pavements

by

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Utah State University 2024

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Impervious concrete is constructed for most new infrastructure such as housing developments, commercial projects, and industrial facilities, which prevents stormwater runoff from infiltrating into groundwater storage. Pervious concrete is a sustainable, economical, and safe alternative to collect runoff and prevent the issues resulting from new land development.

Although pervious concrete has the benefit of a large porous structure for water infiltration, this high porosity leads to issues with debris, sand, and other materials clogging the pores or porous volumes. Pervious concrete also has the challenge of non-standardized material preparation techniques, testing, and construction practices. As such, more research is needed to improve the strength, durability, and long-term maintenance of the concrete before pervious concrete can be used in wider applications.

This thesis seeks to utilize advanced concrete mix designs and innovative maintenance strategies to improve the long-term maintenance and durability of pervious concrete structures. To address the first objective of this thesis, two pervious concrete mix designs are developed using normal cement as a control mix and a rapid-set cement mix as an advanced alternative construction material. The viability of the rapid-set cement mix is analyzed by implementing compressive strength and freeze-thaw durability tests for both mix designs.

The second objective of the thesis is to determine the most effective maintenance method to remove debris and maintain the porous structure of a pervious concrete system. The maintenance methods used in this thesis compare an innovative upward flush system with vacuuming method to the typical pressure washing and vacuuming method.

The results of the compressive strength and freeze-thaw durability testing show that using rapid-set cement as an advanced construction material would be a suitable replacement in pervious concrete pavements. The maintenance method testing results demonstrate the effectiveness of the innovative upward flush system as being the most efficient at removing sand from the pervious concrete model.

With the conclusions from this study, further research can be carried out to find other innovative, eco-friendly, and cost-effective ways to implement and improve pervious concrete developments.

(138 pages)

PUBLIC ABSTRACT

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Impervious concrete is constructed for most new infrastructure such as housing developments, commercial projects, and industrial facilities, which prevents stormwater runoff from infiltrating into groundwater storage. Pervious concrete is a sustainable, economical, and safe alternative to collect runoff and prevent the issues resulting from increased land development.

Although pervious concrete has the benefit of a large porous structure for water infiltration, this high porosity leads to issues with debris, sand, and other materials clogging the porous areas. Pervious concrete also has the challenge of non-standardized material preparation techniques, testing, and construction practices. As such, more research is needed to improve the strength, durability, and long-term maintenance of the concrete before pervious concrete can be used in wider applications.

This thesis seeks to utilize advanced concrete mix designs and innovative maintenance strategies to improve the long-term maintenance and durability of pervious concrete structures. To address the first objective of this thesis, two pervious concrete mix designs are developed using normal cement as a control mix and a rapid-set cement mix as an advanced alternative construction material. The viability of the rapid-set cement mix is analyzed by implementing compressive strength and freeze-thaw durability tests for both mix designs.

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With the conclusions from this study, further research can be carried out to find other innovative, eco-friendly, and cost-effective ways to implement and improve pervious concrete developments.

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1 INTRODUCTION

1.1 Background Information

Pervious concrete is an innovative**,** environmentally friendly solution to problems that arise from increased land development. Most new development utilizes impervious concrete, which prevents storm runoff from infiltrating into the groundwater storage. As a result, the increased runoff gains higher levels of pollutants, and there are increased chances of flash floods. Impervious pavement systems also cause other problems including hydroplaning surfaces, non-skid resistant wearing courses, and changes in the surrounding thermal ambience (Chandrappa and Biligiri 2016).

Low-impact developments such as detention and retention basins are often used to collect runoff and prevent flooding (see Figure 1-1). Although these basins are sustainable strategies in decreasing the effects of impervious concrete surfaces, the economics of the solution need to be considered because of the need for the runoff water to be treated before discharge into natural water bodies (Ghafoori and Dutta 1995; McCain and Dewoolkar 2009).

Therefore, pervious concrete becomes a sustainable, economical, and safe potential alternative to collect runoff and prevent the issues resulting from impervious surfaces.

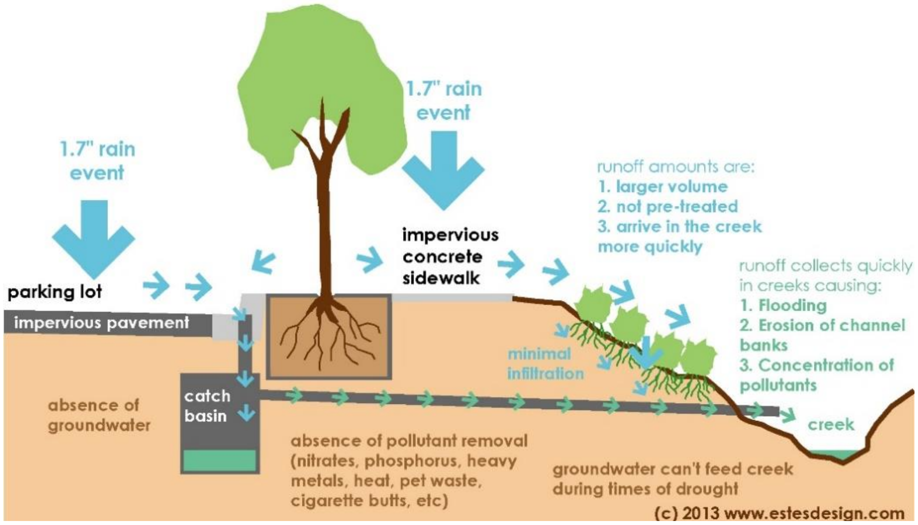

Figure 1-1: Impervious concrete pavement and runoff diagram (Estes Design 2009)

Pervious concrete is effective at collecting rainwater and snow runoff because of the larger pores inside the material. This porous structure helps to prevent flash floods, hydroplaning surfaces, and other conditions relating to severe weather events. Because water can infiltrate the pervious concrete pores more efficiently, and less pollutants are picked up in the runoff, using pervious concrete leads to positive environmental effects such as water balance maintenance, biodiversity protection, and thermal ambience (Li et al. 2017). Figure 1-2 shows some of the benefits of a pervious concrete system design.

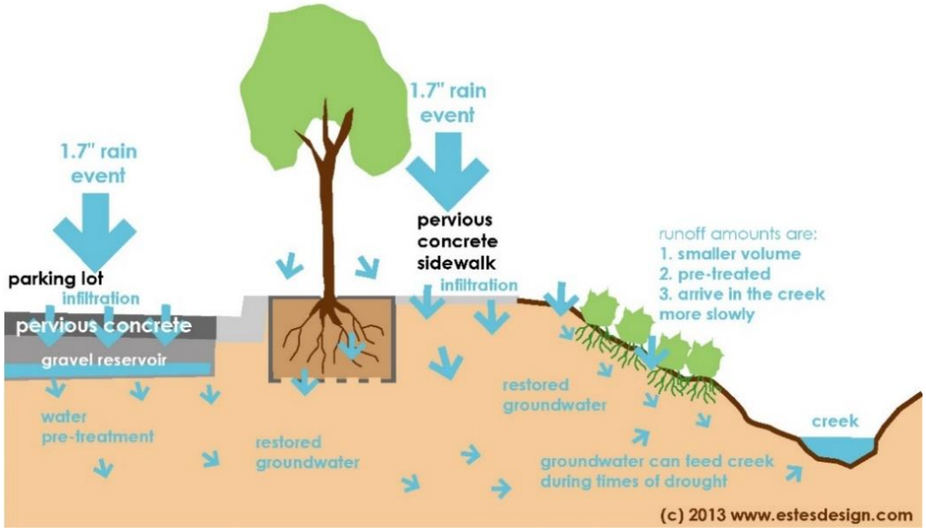

Figure 1-2: Pervious concrete pavement and runoff diagram (Estes Design 2009)

1.2 Problem Statement

Pervious concrete has the potential to solve many of the issues resulting from increased land development; however, the application of the material has two challenges that still need to be addressed.

1.2.1 Challenge 1: Durability and Construction Methods

The first challenge results from non-standardized material preparation techniques, testing, and construction practices. Pervious concrete is currently limited to use for light loading constructions such as sidewalks, driveways, parking lots, or residential streets. As such, more research is needed to improve the strength and durability of the concrete before pervious concrete can be used for heavier loading constructions such as pavements with heavy wheel loads or high traffic (Chandrappa and Biligiri 2016; Li et al. 2017).

Despite the unique characteristics of pervious concrete, the construction of pervious pavements is still being implemented with traditional construction materials and methods. In a report on pervious concrete written by the American Concrete Institute (ACI), Committee 522 described how “there is a substantial need to develop modifications or surrogates to the most common tests for conventional concrete” (ACI 522 2023). Some of these modifications include standardization for testing, field placement, and field quality control.

Further research on advanced construction materials would be beneficial towards the field uses of pervious concrete pavements, such as using rapid-set cement mixes to construct sidewalks and parking lot areas in a faster timeframe. Rapid-set cement mixes could shorten the curing time from weeks to days or hours for when the pervious concrete could begin to be used for its intended purposes such as transportation, stormwater management, and pollutant control.

Due to the chemical components of rapid-set cements, this cement requires much more water for hydration in the mixing and curing process. Portland cement requires just as much water for the mixing and placement of the concrete, however, the water used to make the concrete fluid enough for placement is more than what water is needed to hydrate the Portland cement.

Throughout the curing process, the water evaporates from the Portland cement concrete mix and forms pores, voids, and drying shrinkage cracks throughout the concrete. Because the rapid-set cement requires all the water for hydration, those pores, voids, and shrinkage cracks are not formed in concrete with rapid-setting cement. Therefore, the rapid-set cement concrete is more durable than the Portland cement concrete due to the more dense and low drying shrinkage nature of the rapid-setting concrete (Senatore 2010).

This higher durability and early compressive strength from the rapid-set cement would be beneficial towards increasing the strength and long-term durability of a pervious concrete pavement.

Despite the durability and early strength benefits of rapid-setting cement, there needs to be more research performed on the testing of rapid-setting cement before it can be implemented more widely in the field. According to the National Concrete Pavement Technology Center, “the testing that has been performed [on rapid-setting cement] shows mixed results with significant vulnerabilities for certain conditions” (National Concrete Pavement Technology Center 2021). The technology center suggests further research on the freeze-thaw durability, resistivity tests, and internal curing of rapid-set cement concretes.

1.2.2 Challenge 2: Maintenance Methods

The second challenge is that although pervious concrete has the benefit of a large porous structure for water infiltration, this high porosity leads to issues with debris, sand, and other materials clogging the porous areas. There is a need for more research about pervious concrete maintenance issues related to pore clogging diminishing the permeability of the surface (Li et al. 2017).

The current best management practice for pervious concrete maintenance is simultaneously pressure washing and vacuum sweeping. However, these techniques are labor intensive and not as efficient at removing debris from the lower layers of pervious concrete pavements (Hu et al. 2020). This in turn causes the service life of pervious concrete to decrease since the pore structure is filled with debris and cannot perform stormwater management functions efficiently. There is a need to find a cleaning method for pervious concrete that is more efficient in terms of labor, cost, and long-term maintenance. By improving the maintenance of pervious concrete pavement, the long-term durability and functionality of the concrete would increase.

1.3 Objective

The objective of this study is to improve the long-term durability and maintenance of pervious concrete. This thesis seeks to utilize advanced concrete mix designs and different maintenance strategies to improve the long-term maintenance and durability of pervious concrete structures.

To address the objectives of this thesis, the following research activities are carried out:

- Objective 1: Utilize advanced concrete materials to determine the long-term durability of pervious concrete mix designs. The research activities to complete this objective are as follows:
    - Develop two pervious concrete mix designs using normal cement as a control mix and a rapid-set cement mix. To develop the mix design for a rapid-set cement mix, take the standard normal mix and vary the water-to-cement proportions until a workable and permeable mix is created.
    - Ensure the durability and strength of the rapid-set cement mix by implementing compressive strength and freeze-thaw durability tests for both mix designs.

  - The results of the strength and durability testing will show if using rapid-set cement as an advanced construction material would be a suitable replacement in pervious concrete pavements.
- Objective 2: Determine the most effective maintenance method to remove sand and maintain the porous structure of a pervious concrete system.
  - This objective is accomplished by developing three scale models of pervious concrete and applying chosen maintenance methods to remove debris. The maintenance methods used in this thesis will compare an innovative upward flush system with vacuuming method to the typical pressure washing and vacuuming method.
  - The upward flush system consists of hose attachments drilled into the sides of the models to allow water to flush sand and debris from the bottom and sides of the concrete. The upward flush system was designed for this study; one purpose of the maintenance test is to see if this new design could be a potential alternative for other maintenance methods.
  - The results of the maintenance method testing will demonstrate which maintenance method is the most efficient for removing sand from the pervious concrete system.

With the conclusions from this study, further research can be carried out to find other innovative, eco-friendly, and cost-effective ways to implement and improve pervious concrete developments.

1.4 Thesis Outline

This thesis is composed of five chapters. Following the introduction in Chapter 1, Chapter 2 contains a literature review of relevant history and research regarding the current applications, difficulties, and maintenance methods when implementing pervious concrete pavements. The testing methodology and experimental setups are discussed in Chapter 3. Chapter 4 includes the experimental testing results for the compressive strength tests, the freeze-thaw durability tests, and the maintenance method testing. Finally, Chapter 5 provides a summary of results and a discussion of future work to be considered. A page of references and appendix pages with calculations and test results are included at the end of the thesis.

2 LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of the literature relevant to the study of improving the long-term maintenance and durability of pervious concrete pavement. The chapter is divided into five sections.

The first section introduces the characteristics and challenges associated with pervious concrete pavements. The second section discusses the effects of clogging mechanisms on the permeability of the concrete system. The third section describes the cleaning methods used to maintain the pervious concrete. Section four introduces the use of high strength pervious concrete in new research. The final section provides a summary of the literature relevant to the study.

2.2 Characteristics and Challenges of Pervious Concrete

Kia et al. (2017) investigated the effect of clogging mechanisms and the existing maintenance methods for pervious concrete from several recent studies. The review paper concluded that despite recent research, there are still several challenges that need to be overcome before pervious concrete can be implemented sustainably. These challenges relate to the design, construction, maintenance, testing, and validation of long-term performance of pervious concrete. The paper emphasized that low tortuosity pervious concrete systems need to be developed to increase the effectiveness of the permeable storm-water runoff systems (Kia et al. 2017).

Previous research has shown that the design of pervious concrete comes from proportioning the mix design variables differently than regular concrete. The use of sufficient cement paste and the reduction or elimination of fine aggregates helps to balance the strength, void content, workability, and permeability of the concrete. A 28-day compressive strength of pervious concrete can be as high as 46 MPa with silica fume, fine aggregate content, and superplasticizers added, but the compressive strength values for typical pervious concrete range from 1 to 28 MPa.

The required design strength of pervious concrete ranges from 13.8 to 20.7 MPa for pavements not exposed to vehicles and pavements exposed to traffic, respectively. Pervious concrete has a service life ranging from 6-20 years (Kia et al. 2017). The durability and service life of pervious concrete decreases due to clogging, freeze-thaw conditions, and/or surface raveling (Chopra et al. 2010).

The cross section of a typical pervious concrete system is shown in Figure 2-1. The pervious concrete consists of large voids connected throughout the pore structure due to the narrow grading and larger size of the aggregates. This enables storm-water runoff to flow through the pore structure of the concrete system.

However, sediments (sand, clay, silt, etc.), organic matter, and other debris deposited on the surface of pervious pavements cause clogging mechanisms, which close the void space in the pervious concrete leading to reduced infiltration rates and a potential for flooding and other issues if not addressed. Clogging can either occur on the surface or in the deeper layers of the pervious concrete; the clogging mechanisms depend on the site location, type of clogging debris, and the pore size of the concrete (Kia et al. 2017).

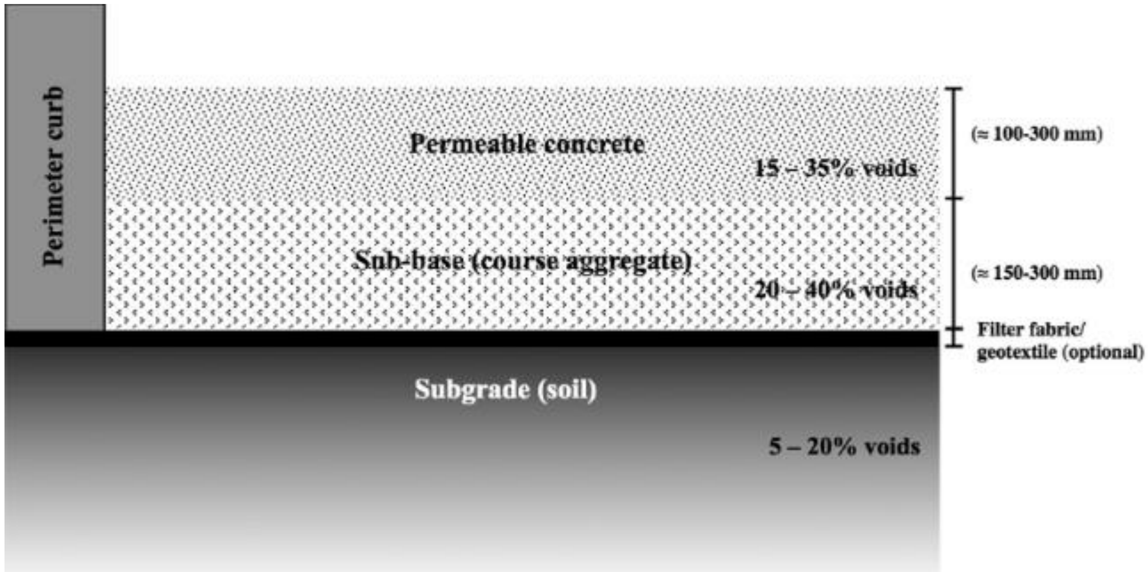

Figure 2-1: Typical pervious concrete pavement cross section (Kia et al. 2017)

To increase the infiltration capacity of the pervious concrete, it is necessary to research the most effective maintenance methods to unclog the void spaces in the concrete. The current recommended methods for maintenance are pressure/power washing with water and/or vacuum sweeping. The effectiveness of these maintenance methods depends on the site conditions of the pervious concrete system. Most of the studies have shown that the recovery rates of the permeability range from <15%-25%; the maintenance methods are not yet able to fully recover the initial infiltration rates.

However, Kia et al. (2017) explains how with future research about pervious concrete, the effectiveness of maintenance methods, decrease in clogging mechanisms, and overall performance of the pervious concrete will increase. This will enable the use of pervious concrete systems in widespread, sustainable applications (Kia et al. 2017).

In a pervious concrete report published by ACI, Committee 522 described the benefits and the disadvantages of constructing pervious concrete pavements. Several of the advantages of using pervious concrete pavements include stormwater runoff and pollution control, decreasing the need for water-retention areas, decreasing the interaction noise and glare on road surfaces from car to pavement, and reduction in surface icing. The disadvantages of pervious concrete pavement include limited application in heavy traffic areas, longer curing time, specialized construction practices, non-standardized test and design procedures, etc (ACI 522 2023).

The committee explains how there are limitations and needs for further research regarding pervious concrete in the areas of freeze-thaw durability, pore structure distribution, strength testing, field quality control, stormwater management, and construction, operation, and maintenance needs (ACI 522 2023).

2.3 Effects of Clogging Mechanisms on Permeability

2.3.1 Clogging Materials: Sand vs. Clay

In 2022, Rao et al. reported that pressure washing is an effective pervious concrete pavement maintenance strategy to decrease the clogging of wet clay. C*logging* is “the reduction in hydraulic conductivity that reduces infiltration into the pavement or exfiltration into the subgrade” (Coughlin et al. 2012). The pressure washing maintenance strategy was developed by studying the sand and clay clogging mechanisms of pervious concrete and the sand and clay clogged vertical sediment distributions of pervious concrete (Rao et al. 2022).

It was observed that clay clogging is likely more damaging than sand clogging given the lower permeability of clay. The typical infiltration rates are 1 mm/h for clay and 210 mm/h for sand (Ferguson 2005). Therefore, clay is more easily transported through the pervious concrete pore structure. Though wet clay can be scoured away through pressure washing, clay drying is a significant factor in the clogging of pervious concrete due to the soil cohesion and bond formation (Watts et al. 1996).

The study used cylindrical PVC molds (132 mm height and 110 mm diameter) for the pervious concrete specimens. The pervious concrete was clogged with clay and three sizes of sand with two exposure methods of drying and not drying. After each washing cycle, the permeability was measured using the falling head method; this permeability value was then compared to the initial clogged permeability values. The clogged samples were scanned with X-ray computed tomography (CT) to determine the vertical distribution of the sediment before and after 30 pressure washing cycles (Rao et al. 2022).

The results of the study show that the undried clay and fine sand were easily washed away, and few particles remained in the pervious concrete; the coarse sand mostly remained on the sample surface. This result indicates that the pore sizes of fine and coarse sand are smaller and larger, respectively, than the sample pore sizes. The main internal clogging of the pervious concrete was caused by the dried clay and medium sand particles. The medium sand samples had a clogged normalized permeability of 0.354 and permeability recovery ratio of 12.90%, which is much lower than the fine and coarse sand ratios. The dried clay samples had a clogged normalized permeability of 0.154 and a permeability recovery ratio of 4.91%, which was the lowest of all the samples.

Therefore, dried clay and medium sand are the most difficult clogging materials to recover. It is recommended that in field conditions, the clay and medium sand that cause the most clogging should be pressure washed before the heat can dry the retained clay and decrease the possibility of proper maintenance (Rao et al. 2022).

Teixeira et al. (2021) also investigated the effect of sediment deposition and maintenance on the hydraulic conductivity and performance of a pervious concrete material. The results of the study show that clay materials (fine sediments) clog the lower layers and sand (larger particles) clog the upper layers in pervious concrete causing a decrease in permeability.

The cohesive nature and the size of the clay particles increase its adhering capacity, which causes the clay to remain clogged in lower layer pores (Kia et al. 2017). However, periodic pavement maintenance/cleaning is effective at improving the hydraulic performance of pervious concrete.

The study shows that the maintenance of the concrete had a total recovery of permeability from the sand clogging and a 96.85% recovery for the clay clogging. The cleaning efficiency of the clay sedimentation clogging is lower, since there was a larger permeability loss and higher permeability reduction percentages. It is concluded that the service life of pavement can be continuously extended with periodic cleaning when the permeability of the material is recovered (Teixeira et al. 2021).

Coughlin et al. (2012) studied how a saturated pervious concrete pavement system is affected by the clogging of sand and clay and the cleaning by pressure washing. The models used in the study included a subgrade of sand (144 mm), a base course meeting the local Department of Transportation criteria (168 mm), and a surface course of pervious concrete (100+ mm). The model simulated a one-dimensional saturated flow through the layers, which also imposed constant head ponded conditions.

Throughout the study, eight runs (one without clogging materials, three with sand, three with clay, and one after pressure washing) recorded the infiltration and head loss of the four pervious concrete samples. The steady-state infiltration rates were calculated by dividing the discharge by the cross-sectional area of the sample.

Coughlin et. al (2012) observed that clogging always occurs after sand and clay are added, clay is more damaging than sand as a clogging material, and pressure washing is ineffective under the study conditions because of the infiltration rates compared between the maximum clogging and pressure washing runs.

After determining the hydraulic conductivity using Darcy's Law and the Reynolds number, it was determined that all layers had a decline in hydraulic conductivity due to the transport of the clogging materials through the base course and subgrade layers.

Therefore, the decrease in hydraulic conductivity is not due to the pressure washing but is rather due to the natural transport of the clogging materials away from the pervious concrete layer. The upper layers of the system represent a much smaller percentage of the overall head loss in this study. Therefore, the limiting factor is the hydraulic conductivity of the subgrade, not the base course or pervious concrete layer.

Though pressure washing was shown to not be effective in this study, in a study by Chopra et al. (2010), pressure washing was effective in increasing the infiltration rates after clogging. However, that study used pervious concrete with an open base rather than including the subgrade layers as well. The distinction between pervious concrete maintenance with and without subgrade layers is important to note. Maintaining a clogged area in a depth near the subgrade layers of pervious concrete is less effective using pressure washing, due to the difficulty of cleaning before the surface layers.

2.3.2 Analyzing Permeability Using X-ray Computed Tomography

Lee et al. (2022) used field conditions to analyze how clogging and cleaning processes affect pervious block systems. This study aimed to fill the gap in research about pore clogging mechanisms in pervious pavement; most of the previous research has been focused on the relationship between permeability and clogging (Kia et al. 2017). The researchers analyzed the clogging characteristics and cleaning efficiency using the lattice Boltzmann method (LBM) through three-dimensional (3D) X-ray computed tomography (CT) and flow simulations (Lee et al. 2022).

The methodology of the pervious block system research is as follows. The pervious block pavements consisted of three types (A, B, and C). For all types, the pore size is larger in the bottom section to allow for greater water drainage and less clogging, while the top of the blocks have smaller pore sizes to increase serviceability for pedestrians.

Each block's top section includes different sizes and types of material. Block A includes silica sand (1.0-2.5 mm), Block B includes small amounts of silica sand (1.2-1.5 mm) and limestone particles (>6.0 mm), and Block C includes silica sand (1.7-2.8 mm). The bottom materials were manufactured to have crushed granite (8.0-10.0 mm) for Block A, smaller sized silica sand and limestone (~8.0 mm) for Block B, and small amounts of silica sand and limestone (6.0-8.0 mm) for Block C (Lee et al. 2022).

One 100-mm diameter cylinder was cored from each type of specimen to measure the permeability. The X-ray imaging and flow simulation used a 35-mm diameter core sample from one block. The pervious pavement blocks were installed in field conditions with 15-cm of sand thickness below. The sublayer below the sand had a permeability of

0.001 mm/sec. Three pervious blocks of each type were collected for samples after a general usage of six months in the field conditions (Lee et al. 2022).

Pressurized water washing and wastewater vacuuming were used to clean the surface of the pavement. The pressure of the clean water spray is between 160 and 180 bar. The water is sprayed at a 70-degree angle with the surface at 45-cm above the pavement. A vacuum pump collected the wastewater (Lee et al. 2022).

Using a constant head permeability apparatus, the researchers found the hydraulic conductivity of each specimen. Three cores from fresh blocks, used blocks before cleaning, and used blocks after cleaning were analyzed for a total of nine cores. These cores were also analyzed for clogging using the X-ray CT image, which shows the spatial distribution of the pores, air, and clogging in each specimen (Lee et al. 2022).

The results of the research show that the average permeability of the fresh pervious blocks is 0.92 mm/sec for Block A, 0.71 mm/sec for Block B, and 0.76 mm/sec for Block C. The permeability of the pervious blocks decreased to between 10 to 21.3% of the initial permeability after six months of general usage. The permeability of Blocks A and C recovered about 46.3 and 29.6%, respectively, of their permeability after the cleaning process (Lee et al. 2022). A potential gap in the research is that Block B had a decrease of 12.8% of the initial permeability value after the cleaning process. This could show a possible error in measurement.

This study shows that general usage of pervious pavements decreases the permeability of the samples, and the permeability can be partially restored through cleaning methods. Though this study did not aim to focus on the effectiveness of the various cleaning methods, it was shown that the infiltration capacity decreases through time as clogs form in pore spaces.

2.4 Maintenance Methods

2.4.1 Comparison of Cleaning Methods

Merten et al. (2022) found that pervious concrete pavement requires periodic cleaning to maintain the service life of the pavement. This study used five different cleaning and maintenance methods to analyze the infiltration capacity of the pervious concrete over time. The experiment sample was subjected to the natural clogging process and then infiltration rate tests were done. The five cleaning methods used to maintain the sample were high-pressure water jets with vacuuming, high-pressure water jets, wetting followed by sweeping, sweeping with subsequent vacuuming, and vacuuming (Merten et al. 2022).

The pervious concrete sample (3.5 m wide by 3.5 m long) was made using recycled concrete aggregates (RCA) and was placed in a light traffic lane with two opposing directions. The pavement is located on top of a lining layer (18 cm thick) and a granular layer (20 cm thick). Merten et al. (2022) used the ASTM C1701/C1701M procedures to analyze the infiltration rate of the section (ASTM C1701 2023). The pavement was built in March 2020 and was not used for maintenance testing until 14 months after its construction (Merten et al. 2022).

The maintenance methods used in this study were chosen based on sustainability aspects, financial feasibility, and easy accessibility to equipment. The only maintenance method that produced an infiltration rate in the pavement higher than the infiltration rate in the first month of evaluation was the high-pressure water jet combined with the vacuuming. The method of wetting followed by sweeping was found to not be effective in increasing the infiltration rate compared to the condition before cleaning.

It was found that to maintain a pervious pavement's service life in terms of infiltration rate and hydraulic performance, the pavement should be cleaned and maintained from the start of use. The maintenance method used should be chosen based on the type of debris clogging the pavement. This study proposes that high-pressure water jet with subsequent vacuuming is best used for clay and other fine sediments, while vacuuming maintenance is best used for coarse sediments (Merten et al. 2022).

In 2020, Hu et al. also found that the most effective maintenance procedure for pervious concrete pavement clogged by rainwater runoff sediment is the combination of pressure wash and vacuum suction. Despite numerous studies on the cleaning effect on pervious concrete pavements, the external factors and inconsistent test points between the studies make it difficult to find the most effective maintenance method.

In this study, Hu et al. sought to overcome those inconsistencies by focusing on the effect of the periodic clogging and maintenance process on the permeability recovery of the pervious concrete pavement (Hu et al. 2020).

The 300 mm diameter test sample of pervious concrete pavement (100 mm thick) was built on a 150 mm single graded gravel base and a soil subgrade. 600 g of variously graded sediment was used as the clogging material, which was dispersed with water into the test rings. The single-ring infiltrometer test method was used to evaluate the permeability of the 32 test points in the pavement before and after applying the cleaning methods (ASTM C1701 2023). The purpose of the single-ring infiltration test is to measure how long a fall head of water takes to infiltrate through the pervious concrete beneath the ring.

The maintenance procedure was to apply the cleaning method two times back and forth on each test point. There were eight cleaning methods for four clogging materials (32 test points overall), and the test was repeated nine times. The maintenance methods chosen to be applied were a pressure wash (2.5, 5, 10, 15, and 20 MPa), pressure wash plus a vacuum (10 + 0.05, 20 + 0.05 MPa), and a sweep plus a vacuum (0.05 MPa) (Hu et al. 2020).

The maximum initial permeability of the 32 test points was 16.67 mm/s, the minimum initial permeability was 3.85 mm/s, and the average initial permeability was 9.71 mm/s. After the clogging procedure, the permeability was reduced to less than 0.5 mm/s. It was found that the full-graded sand was most likely to cause the most clogging issues (compared to coarse and fine sand used separately) due to the coarse and fine sands combining to fill the large and small voids in the pore structure.

After the cleaning methods were applied, the permeability increased past 0.5 mm/s. The pressure wash plus vacuum (20 + 0.05 MPa) and then the pressure wash plus vacuum (10 + 0.05 MPa) were the most effective cleaning methods. This is due to the water forcing the debris to leave the pores with the vacuum sucking away the debris before it can fall back into the pore structure. Hu et al. (2020) also found that despite the pressure wash plus vacuum (20 + 0.05 MPa) being the most expensive maintenance option, that cleaning method would be the most cost effective since it maintains the service life of the pavement the most effectively (Hu et al. 2020).

Zhang et al. (2022) also found that the most effective cleaning method for pervious concrete pavement is the 20 MPa pressure washing and vacuum cleaning as well as the 20 MPa pressure cleaning. The study focused on how to improve the permeability performance and service life of pervious pavements through various cleaning methods. The cleaning effects were studied using computational fluid dynamics – discrete element method (CFD-DEM) as a numerical simulation (Zhang et al. 2022).

In a previous study, Zhang et al. (2018) used CFD-DEM to study the clogging mechanism of pervious concrete, which showed that the upper layer of pavement concentrates the clogging materials most of the time. Water flow will move fine particles until the particles either collect in the pore structures of the concrete or are carried away through the sublayers. (Zhang et al. 2018). A CFD-DEM coupling model was also used in research by Nan et al. (2021) to study the seepage velocity, total fluid force, and particle spatial distribution to find how the change of particle location affected the pervious pavement clogging (Nan et al. 2021). In this study, a total of 54 simulation tests were run to test the cleaning efficiency of the power washing and vacuum sweeping methods (Zhang et al. 2022).

The conclusions found in this study are as follows. The coarse sand and well graded sand were able to be cleaned more efficiently than the fine sand, which took the longest time. The fine sand was removed most effectively by the vacuum cleaning method, which has a large action depth. The pressure washing is less effective at cleaning deep layers of pavement despite the strong impact force of the water.

The highest cleaning efficiency came from the 20 MPa pressure washing and vacuum cleaning as well as the individual use of the 20 MPa pressure washing. The pressure of the cleaning methods can be selected from a range of reasonable pressure values for certain pavement conditions given the small changes in cleaning effect for that range of cleaning pressure. The angle of 45°-60° provides the best cleaning efficiency with a target distance of 15-20 mm for coarse particles and any target distance for fine particles (Zhang et al. 2022).

2.4.2 Field Studies of Maintenance Methods

In 2013, Hein et al. studied small-area pervious concrete pavements and the effect of cleaning techniques on the clogging of the porous structure. The study sought to increase the infiltration rates of the pervious concrete systems through power blowing, pressure washing, vacuuming, and a combination of those cleaning techniques. The results of the study showed that pressure washing and vacuuming combined provided the most effective solution to increasing the infiltration rate of the sample (Hein et al. 2013).

The initial infiltration rate of the pervious concrete samples was 2030 cm/hr (800 in/hr). The 48 concrete sample testing areas were located on two parking slabs (6 m x 18 m) on a university campus in Alabama. Using a single-ring infiltration test, the infiltration rates were measured before and after the cleaning techniques were performed. The amount of water used in this test was 11 L (3 gal) (Hein et al. 2013).

The equipment used was a Husky 2600 psi pressure washer with the short-range nozzle attached; the nozzle was used at a 45° angle at a distance of 13 cm from the pavement surface. The 25.4 cc power blower engine could blow 217 km/hr, which was held at a 45° angle directly above the pavement surface. The vacuum was a 68.6 cm width, 4847-watt engine used in six passes on each test area.

The results of the study showed that the falling head surface infiltration rates never exceeded 2500 cm/hr; this number can be used for future reference of similar pervious concrete studies as a comparison for older pervious concrete infiltration rates. It was found that the infiltration rate of the pervious concrete increased significantly with a combination of vacuuming and pressure washing.

Though by itself, pressure washing is an effective initial cleaning method, power blowing following power washing is not effective in increasing the infiltration rate. Pressure washing and vacuuming are equally effective as initial maintenance methods. Hein et al. (2013) concludes that these routine, inexpensive cleaning methods are effective at maintaining the sustainability benefits of pervious concrete pavements (Hein et al. 2013).

Chopra et al. (2010) performed an experimental study of eight pervious concrete pavements in the southeastern United States to demonstrate how maintenance methods can restore the hydraulic performance of these pavements after clogging. The eight pervious concrete pavements were in the range of 6 to 18 years since construction, and none had noticeable wear. The locations varied in terms of the concrete mix design, the original pore structure, the level of clogging, and size.

By using a 300 mm diameter concrete coring machine to core an annular space, the single-ring infiltrometer was installed (ASTM C1701 2023). This single-ring infiltrometer was used to perform the ASTM C1701 procedure for pervious concrete infiltration testing (Chopra et al. 2010).

The concrete cores were then recovered from each site and taken to the laboratory for rejuvenation testing of their infiltration capacity. The rejuvenation methods for maintenance of the concrete were vacuum sweeping (4.85 kW wet/dry vacuum sweeper), pressure washing (20.7 MPa pressure washer), and vacuum sweeping followed by pressure washing. After performing the cleaning methods, the clogging material recovered from the pervious concrete cores was found to be a silty fine sand with an average of 43% of the sand passing through a 0.075 mm (ASTM No. 200) sieve (Chopra et al. 2010).

The infiltration tests showed that the pervious concrete cores had infiltration rates ranging from 10.2 mm/h to 5.771 x 10^3 mm/h. The infiltration rates of the soil sublayers ranged from 0 to 0.876 x 10^3 mm/h, which shows that the pervious concrete and/or the soil sublayers get partially or completely clogged during the system's service life. It was also found that pressure washing is more effective at rejuvenation of the pervious concrete than vacuum sweeping. The vacuum sweeping was not always powerful enough to dislodge trapped debris. Chopra et al. (2010) suggest that infiltrometers be installed during new pervious concrete construction projects to monitor the performance of pavements (Chopra et al. 2010).

2.4.3 The Effects of Maintenance Methods on Freeze-Thaw Durability

Henderson and Tighe evaluated the effects of various maintenance methods on the freeze-thaw conditions of pervious concrete pavement in Canada. Previous research has shown that raveling happens when sand accumulates on pervious concrete surfaces. When precipitation is trapped by the sand or debris on the surface, the expansion of the freezing water and debris causes aggregate loss and raveling (Henderson and Tighe 2010). Therefore, one of this study's purposes was to find the most effective pervious concrete maintenance procedure to prevent the damage caused by freeze-thaw conditions (Henderson and Tighe 2011).

The study focused on five test sites constructed across Canada. The maintenance methods used for the study were vacuuming, sweeping, power washing, garden hose rinsing, and fire hose washing of the sample surfaces. A Gilson permeameter was used to test the permeability of each site. The sites were tested on either a full-scale or a trial-scale; the full-scale trial tested the maintenance methods across the entire site, whereas the trial-scale selected only a few locations to perform the maintenance and permeability tests (Henderson and Tighe 2011).

The study found that pressure washing was less effective than rinsing with a garden hose or a large hose. This was due to the lower pressure and larger diameter water stream of the hoses, which loosed and flushed the debris out of the pervious concrete more effectively than pressure washing could. Pressure washing has the potential of pushing debris deeper into the voids rather than flushing debris out to increase the permeability. The maintenance method of sweeping is only effective when the clogging debris is on the surface of the pervious concrete since the broom cannot reach into the deep voids to remove debris.

Henderson and Tighe (2011) emphasized the importance of choosing maintenance methods based on site specific conditions such as location, amount of debris, type of debris, etc. The study also determined that the maintenance methods should be performed prior to freeze-thaw conditions so the raveling damage due to the expansion of freezing water and sand can be minimized (Henderson and Tighe 2011).

2.4.4 The Periodicity of Cleaning Methods

Sandolval et al. (2020) found that a periodicity of cleaning pervious concrete is important to maintaining a hydraulic performance close to what the initial permeability was even after sediment clogs the concrete. The study was divided into three phases: clogging, cleaning methods, and the periodicity of cleaning.

Three types of sediments (sand, clay, and a mixture of sand and clay combined) were chosen to simulate clogging in the pervious concrete; the maximum concentration of the sediments was 1.27 g/cm^2. The ASTM C1701 test was performed on clogged pervious concrete samples; there was a total of 24 experimental field slabs used in the study (2.5 to 3.5 m x 1 m x 0.45 m). A 3D microtomography was then used to show how the sediments distributed through the pore structure of nine cylindrical pervious concrete specimens (50 mm x 100 mm (Sandolval et al. 2020).

After the experimental field slabs were exposed to the weather for four months, phase two began with the three cleaning methods: surface cleaning (broom sweeping), water cleaning (hydro-washer with 1037 psi pressure), and air cleaning (compressor with 120 psi pressure). The ASTM C1701 test was performed again on the clean samples to determine the recovered permeability and the most effective cleaning method. In phase three, a medium and high version of a periodicity of cleaning was performed on the samples to evaluate how often the pervious concrete should be cleaned based on the type of sediment clogging the sample pores (Sandolval et al. 2020).

After the three phases of clogging, cleaning, and analyzing the periodicity of cleaning, several results were obtained. The water cleaning was the most effective at cleaning the fine sediments such as clay; the air cleaning was the most effective at cleaning the sand sediments. The 3D microtomography showed that most of the sediments clogged the surface of the pervious concrete, which made the chosen cleaning methods more effective. It was recommended that the periodicity of cleaning be chosen based on the sediment clogging the pervious concrete to make sure the cleaning strategy is the most effective possible (Sandolval et al. 2020).

2.5 High Strength Pervious Concrete

Besides the issues with clogging and maintenance in pervious concrete, another challenge inhibiting the widespread use of pervious concrete is the low strength of the concrete. In 2017, Lit et al. designed a high strength pervious concrete (HSPC) pavement to research how pervious concrete could be implemented in heavier loading construction and transportation conditions. The HSPC was designed using a matrix of a reactive powder concrete (RPC) as well as designing an accessible pore structure in the concrete.

The materials used in the HSPC were ordinary Portland cement, silica fume, reactive powder fly ash, U-type expansion agent, superplasticizer, river sand, styrene-butadiene latex, silica sol, and polypropylene fibers (PP). The purpose of the reactive powder and other materials added to the HSPC was to increase the strength, durability, and toughness of the pervious concrete samples. The compressive strength of the HSPC was 70 MPa and the flexural strength was 10 MPa. Compared to the compressive strength of 5.5-40 MPa of typical pervious concrete, the HSPC compressive strength is much higher (Li et al. 2017).

Rather than using large aggregate sizes and eliminating the fine sands from the traditional method of constructing pervious concrete, this study cast the typical HSPC into forms and inserted pore-making components into the set concrete. These 4-mm pore-making components created a vertical matrix of straight pores to connect the top and bottom of the samples (Li et al. 2017).

Despite the lowered porosity of the samples, the permeability coefficient varied from 13.02 mm/s (1.246% porosity) to 21.84 mm/s (2.769% porosity), which is high compared to the typical permeability coefficient of 0.3-14 mm/s of traditional pervious concrete. Therefore, the non-traditional system of creating vertical pore structures is effective in its ability to stay maintained and to transmit water (Li et al. 2017).

2.6 Summary

This chapter presents a review of the literature relevant to the study of improving the long-term maintenance and durability of pervious concrete pavement. A summary of the significant topics is presented:

1. Despite recent research, there are still several challenges that need to be overcome before pervious concrete can be implemented sustainably. These challenges relate to the design, construction, maintenance, testing, and validation of the long-term performance of pervious concrete.
2. The general usage of pervious pavements decreases the permeability of the samples due to natural clogging of the pore structure. Despite the issues with clogging mechanisms, the permeability of the pervious concrete is able to be partially restored through cleaning methods.
3. The main internal clogging of pervious concrete is caused by dried clay and medium sand particles. Therefore, dried clay and medium sand are the most

difficult clogging materials to recover. It is recommended that in field conditions, the clay and medium sand that cause the most clogging should be pressure washed before the heat can dry the retained clay and decrease the possibility of proper maintenance.

4. To maintain a pervious pavement’s service life in terms of infiltration rate and hydraulic performance, the pavement should be cleaned and maintained from the start of use. The maintenance method used should be chosen based on the type of debris clogging the pavement.
5. In terms of maintenance method options, high-pressure water jet with subsequent vacuuming is best used for clay and other fine sediments, while vacuuming maintenance is best used for coarse sediments. Most of the reviewed studies agree that pressure washing and vacuuming combined provide the most effective solution to increasing the infiltration rate of pervious concrete pavement samples.
6. When precipitation is trapped by sand or debris on a pervious concrete pavement surface, the expansion of the freezing water and debris causes aggregate loss and raveling. Maintenance methods should be performed on pervious concrete pavements prior to freeze-thaw conditions so the raveling damage due to the expansion of freezing water and sand can be minimized.
7. It is recommended that the periodicity of cleaning for pervious concrete pavements be chosen based on the type of clogging sediment to verify the use of the most effective cleaning strategy possible.

3 METHODOLOGY

3.1 Introduction

The following chapter details the methodology of the lab setup and research used in the thesis. The thesis studies the effectiveness of various maintenance methods to remove debris from a pervious concrete pavement as well as compares the durability of two pervious concrete mix designs. ASTM and AASHTO standards are followed for the tests. The methodology categories are subdivided into these sections as follows:

- Section 3.2 Material Proportions and Mix Design
- Section 3.3 Cylinder Casting
- Section 3.4 Compressive Strength Testing
- Section 3.5 Freeze-Thaw Durability
- Section 3.6 Maintenance Model Casting and Setup
- Section 3.7 Maintenance Method Testing

The results of these tests are analyzed in Chapter 4; Section 4.2 presents the result of the compressive strength testing (Sections 3.2 to 3.4), Section 4.3 presents the durability tests (Section 3.5), and Section 4.4 presents the results of the maintenance method testing (Sections 3.6 to 3.7).

3.2 Material Proportions and Mix Design

This section describes the materials and the material proportions used in designing the batch of a pervious concrete mix used in the experimental tests of this thesis. The materials used in a typical pervious concrete mix design are cementitious materials (e.g. Portland cement, fly ash, etc.), aggregates, water, and optional admixtures. The typical ranges for material proportions for pervious concrete are included in Table 3.1.

Table 3-1: Material proportions in pervious concrete (NRMCA 2011)

	Proportions, lb/yd^3	**Proportions, kg/m^3**
Cementitious materials	450 to 550	267 to 326
Coarse Aggregate	2000 to 2500	1190 to 1480
Water: cement ratio (by mass)	0.27 to 0.36	——
Fine aggregate	0 to 500 lbs.	0 to 297

3.2.1 Cementitious Materials

The cementitious materials used for typical pervious concrete are Portland cements (ASTM C150 2022), blended cements (ASTM C1157 2023), and supplementary cementitious materials (SCMs) such as fly ash, pozzolans (ASTM C618 2023), and ground-granulated blast furnace slag (ASTM C989 2022). The performance properties for a given pervious concrete mix such as setting time, rate of strength development, porosity, and permeability are typically found through testing the materials through trial batching (NRMCA 2011). The cementitious material used in the pervious concrete mix for the cylinders and the models was a Type I/II Portland cement (ASTM C150 2022). Another mix was created to act as a strength and durability comparison to the control samples. This second mix was designed using a rapid-set cement (ASTM C1157 2023). The same mix proportions were used for this second mix.

3.2.2 Aggregates

The materials for pervious concrete and impervious concrete are the same except for the aggregate. Pervious concrete does not include fine aggregate and the coarse aggregate is kept to a narrow grading. This even size distribution of the coarse aggregate makes it so the pervious concrete has more porous space where water can infiltrate; the design void content is typically between 15% to 30% for pervious concrete. When the void content increases, the permeability increases and the strength decreases (NRMCA 2011).

According to the National Ready Mix Concrete Association (NRMCA), coarse aggregate gradations include follow the ASTM C33 Standard Specification for Concrete Aggregates (ASTM C33 2023), which uses No. 67 (¾ in. to No. 4), No. 8 (⅜ in. to No. 16), and No. 89 (⅜ in. to No. 50) sieves (NRMCA 2011). The coarse aggregate being used for this mix has a target bulk specific gravity of 1.6 and a target bulk density of 100 lb/ft^3.

3.2.3 Water

The water-to-cement ratio for pervious concrete typically ranges between 0.27 to 0.36. Pervious concrete does not have the same relationship between the water-to-cement ratio and strength as conventional concrete because the aggregate void content is greater than the amount of cement paste between aggregates. NRMCA specifies that the water quality must meet either the ASTM C94 or the AASHTO M157 Standard Specification for Ready-Mixed Concrete (ASTM C94 2024, AASHTO M157 2013). The water-to-cement ratio is 0.35 for the trial mix design of this project.

3.2.4 Mix Design Calculations

The proportions for a pervious concrete mix design were determined by creating a detailed analysis spreadsheet tool in Microsoft Excel. The aggregate, cement, and water proportions for a pervious concrete mix design are shown in Table 3.2. The spreadsheet takes inputs for the aggregate bulk density, percent volume of the void, water density, bulk specific gravity, and apparent density to calculate the percentage of aggregate void content and paste volume in cubic feet per cubic yard.

The aggregate material properties were determined from previous lab testing according to ASTM standards. The standards included ASTM C29 Standard Test Method for Bulk Density (‘Unit Weight’) and Voids in Aggregate (ASTM C29 2023), ASTM C128 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate (ASTM C128 2023), ASTM C136 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates (ASTM C136 2020), and ASTM D75 Standard Practice for Sampling Aggregates (ASTM D75 2019).

Table 3-2: Pervious concrete mix design proportions

Material	**Proportions (lb/yd^3)**
Cementitious materials	606.8
Coarse Aggregate	2212.5
Water	212.4
Fine aggregate	0

A water to cement ratio of 0.35 and the specific gravity of cement (typically 3.15) were used to calculate the absolute volume of cement. The volume of water is calculated by subtracting the volume of cement from the paste volume. The volume of the saturated-surface-dry aggregate is used with the specific gravity of the aggregate to find the pound per cubic yard proportion of coarse aggregate in the mix. The details of these calculations can be found in Appendix A.

Using the pervious concrete mix design spreadsheet tool, a pervious concrete control mix was designed using normal cement. The mix for the rapid-set cement pervious concrete was developed by varying the water-to-cement ratio for the standard normal mix until a workable concrete mix was created. The concrete mix needed to have a water and cement paste that was workable enough to cast the concrete into cylinders and forms, but not so workable that the porous structure would close, and the permeability of the structure would decrease.

Multiple trial batches were prepared and tested to determine the best mix proportions. The rapid-set cement pervious concrete was deemed both workable and permeable after creating a scale model of a pervious pavement system as a course laboratory example (see Figure 3-1).

Figure 3-1: Scale model of pervious concrete pavement system

The rapid-set cement pervious concrete pavement system model included layers from the bottom to the top of sand, gravel, and pervious concrete with filter fabric layered in between. The model had holes drilled into the Plexiglas material at the bottom to allow water to drain through the system.

Figure 3-2 shows the side profile of the model layers when the model is dry, and Figure 3-3 demonstrates the permeability of the model as the water can be seen seeping through the pore spaces to the bottom of the system. It can be concluded that the rapid-set cement pervious concrete mix behaves with the same functionality as a typical pervious concrete mix.

Figure 3-2: Side profile of pervious concrete pavement system

Figure 3-3: Water infiltrating the porous structure of the model

3.3 Cylinder Casting

The respective ASTM and AASHTO standards for concrete mixing, casting, and curing were followed in this thesis. The applied ASTM standards for the aggregate testing include ASTM C33 Standard Specification for Concrete Aggregates (ASTM C33 2023), ASTM C125 Standard Terminology Relating to Concrete and Concrete

Aggregates (ASTM C125 2021), and ASTM C192 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory (ASTM C192 2020).

The concrete is mixed using a portable drum cement mixer. The concrete laboratory at Utah State University is used to cast all the concrete specimens. The concrete is cast into 4 in. x 8 in. cylinders. Of the normal cement pervious concrete mix, 15 cylinder specimens were cast to be divided evenly between the 7-day and 28-day compressive strength testing and the freeze-thaw durability test. For the rapid-set cement pervious concrete mix, 10 cylinder specimens were cast for both the 7-day compressive strength test and the freeze-thaw durability test.

3.4 Compressive Strength Testing

The compressive strength of the pervious concrete cylinders was obtained by following the ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39 2023). The universal testing machine (UTM) in the laboratory at Utah State University was used for all compressive strength testing of the pervious concrete specimens (see Figure 3-4). The compressive axial load was applied to the cylinders by the UTM until failure occurred. The compressive strength of each concrete specimen is obtained by dividing the load at failure by the specimen's cross-sectional area.

Figure 3-4: Universal testing machine for compressive strength

Five specimens of the normal cement pervious concrete were tested for the 7-day compressive strength and five specimens were tested for the 28-day compressive strength. Five of the rapid-set pervious concrete specimens were tested for the 7-day compressive strength, however, none of the rapid-set specimens were tested for the 28-day compressive strength. The results of the compressive strength testing are described in Section 4.2.

3.5 Freeze-Thaw Durability Test

The purpose of the freeze-thaw test is to determine the durability and resistance of a concrete specimen when exposed to rapid freezing and thawing. This research test ensures the durability of rapid-set cement pervious concrete as an advanced construction material comparative to a normal cement pervious concrete control mix. The standard followed is the ASTM C666 Standard Test Method for Resistance of Concrete to Rapid

Freezing and Thawing (ASTM C666 2011). Procedure A in the standard is used, which is the method of rapid freezing and thawing in water.

The freezing and thawing apparatus in the Utah State University laboratory is shown in Figure 3-5. The concrete specimens must be surrounded by not more than 1/8 in. but not less than 1/32 in. of water throughout the freeze-thaw cycles, according to the ASTM standard. The freeze-thaw cycle consists of fluctuating between lowering the chamber temperature from 40 to 0 °F (4 to -18 °C) and raising the temperature of the chamber from 0 to 40 °F (-18 to 4 °C). This cycle should last about four hours, and the thawing stage should not have less than 25% of the time.

Figure 3-5: Freeze-thaw chamber

There were 10 pervious concrete specimens included in the freeze-thaw durability test. Half of the specimens were normal cement pervious concrete specimens, and the other half were the rapid-set pervious concrete specimens. The ASTM C666 standard describes measuring the fundamental frequency (typically through the use of an emodumeter) after each freeze-thaw cycle to compare the change in the relative dynamic modulus of the concrete. This fundamental frequency test follows the ASTM C215 Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens (ASTM C215 2020).

However, for pervious concrete, using an emodumeter to record the fundamental frequency of a specimen is not as accurate given the large pore spaces. The ASTM C666 and ASTM C215 standards for durability testing were developed for normal concrete and do not have specifications for how to apply those tests for porous concrete specimens. Measuring the fundamental frequency of pervious concrete specimens produces inconsistent results and "ambiguous determination" of the fundamental frequency (Olek et al. 2003). Researchers have used a change in mass loss as the determination of freeze-thaw durability for the use of pervious concrete as an alternative method (Schaefer et al. 2006; Yang and Jiang 2003).

Therefore, for this study, the freeze-thaw durability was measured by the change in mass after each cycle. After the pervious concrete specimens failed to maintain a minimum of 60% of the original mass, the specimens were considered failed and were no longer subjected to additional freezing and thawing. The results of the freeze-thaw durability test for these specimens are shown in Section 4.3 of this thesis.

3.6 Maintenance Model Casting and Setup

For this thesis study, three 1 ft. x 2 ft. x 5.5 in. scale models of pervious concrete were created by casting the experimental mix design into wood forms (see Figure 3-6). to test their maintainability; specifically, how easily debris can be removed from the voids. These forms were built from 2 in. x 6 in. x 4 ft. premium southern yellow pine dimensional lumber. The forms had rope handles attached to be able to lift and weigh the samples to measure sand loss (see Figure 3-7). Each model had an average volume of 0.127 yd^3 of concrete poured inside.

Figure 3-6: Pervious concrete in wood forms

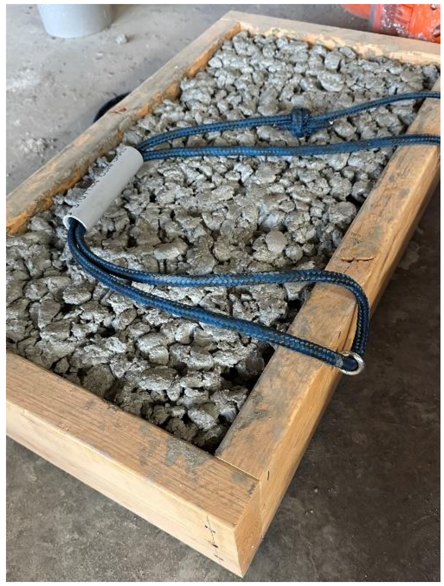

Figure 3-7: Handles attached to forms

Three different maintenance methods were performed on each model to compare the ability to remove sediment from the porous structure. Sand with medium sized particles was used as the sediment to replicate the normal debris that is collected in the voids (Rao et al. 2022). Using debris of other organic matter would be too inconsistent for the purposes of this study. Therefore, to reduce potential controlling factors and variables, the debris was limited to one type of medium grained sand.

The maintenance methods were chosen to compare the standard techniques of pressure washing and vacuum sweeping (Hu et al. 2020) to an innovative upward flush system maintenance technique. The upward flush system consists of hose attachments drilled into the side(s) of the concrete to allow for water to push through the bottom and side layers of the model and flush the sand out (see Figure 3-8). The upward flush system was designed for this study; one purpose of the maintenance test is to see if this innovative design could be a potential alternative for other maintenance methods.

Figure 3-8: Upward flush system example

The hose attachments were created by drilling a 3/4” in. diameter spade bit into the side(s) of the wood frames and into the first 1/2” of the concrete. A 3/4 in. galvanized malleable iron floor flange fitting was then screwed onto the side of the wood frame. Swivel fittings and threaded connections were added to be able to thread a hose into the system (see Figure 3-9). Each connection was thoroughly caulked to ensure that there would be no water leaks or escaped pressure at the hose attachment location(s).

Figure 3-9: Hose attachment location details

Water pressure test gauges were also used to confirm that each model was receiving the same amount of water pressure to the system. A Rain-wave LCD digital water flow meter was attached to measure the amount of water flowing through the hose attachment(s). A brass hose Y with a shut off valve was used to split the hose going into the two sides of a model as well as to attach the pressure gauge and the flow meter (see Figure 3-10).

Figure 3-10: Pressure gauge and flow meter attached to hose

3.7 Maintenance Method Testing

The three pervious concrete models were used to test each of the maintenance methods' ability to remove sand. Model 1 used pressure washing and vacuuming. Model 2 consisted of one upward flush attachment and vacuuming. Model 3 demonstrated the use of two upward flush attachments and vacuuming. Figure 3-11 shows the three different models with the hose attachment(s) on Models 2 and 3.

Figure 3-11: The three models with the various maintenance methods

After measuring the initial weights of the models, the three models were tested using the maintenance methods described. Three rounds of testing were performed, which included three tests each round for a total of nine maintenance method tests. The sand removal was calculated based on the initial weight of the concrete model without any sand added. The total sand removal per round was compared to the total sand distributed throughout the model at the beginning of the round.

Three pounds of sand were spread evenly on each model for the first test (see Figure 3-12). The sand was distributed into the concrete pores pouring 45 oz. of water on the sand to act as rainfall carrying the sand from the surface of the concrete to the inner porous structure. Each maintenance method was performed for three minutes. After testing each maintenance method, the models were weighed after at least 24 hours of drying time to obtain the amount of sand removed. The tests were repeated three times for each of the three rounds of testing.

Figure 3-12: A brush was used to spread sand on each model for three tests

To determine the amount of sand added for the second and third rounds of tests, the amount of sand remaining in the model was weighed and additional sand was added so each model started with 4.5 pounds of sand each round. This was to ensure that the models started each round with an even amount of sand distributed throughout the porous structure.

To ensure there was no clogged water or wet sand in the models when weighing, the models were weighed multiply times after the drying time had passed until there was no longer a change in weight. This consistency in the weight measurement indicated that the water had all evaporated and dried from the model and the only remaining weight was due to the wood form, concrete, and dry sand.

It was assumed minimal sand loss occurred in the specimens when completing the sand loss calculations, because the amount of sand was accounted for in the vacuum after the testing rounds. The water pressure and flow rate were measured for the tests to provide consistency in the hoses. A 16-gallon wet vacuum cart was used to vacuum the sand and water during the pressure washing and upward flush system maintenance. The experimental setup of the model with the hose attachment and the vacuum is shown in Figure 3-13.

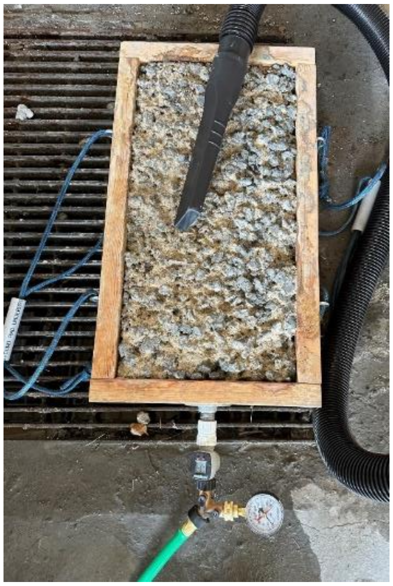

Figure 3-13: Experimental setup of model with hose attachment and vacuum

Observations from the maintenance methods performed were recorded after each test to share how the model was behaving (areas of most and least sand clogging, estimated infiltration rates, etc.). The results of the maintenance method testing are shown in Section 4.4 of this thesis.

4 EXPERIMENTAL RESULTS

4.1 Introduction

This chapter analyzes the data and results from the experiments presented in Chapter 3 of this thesis. Section 4.2 discusses the result of the compressive strength testing, Section 4.3 discusses the durability tests, and Section 4.4 discusses the results of the maintenance method testing.

4.2 Compressive Strength Testing

The ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39 2023) was used to find the compressive strength of the pervious concrete cylinders. The data obtained from the UTM shows the maximum stress in units of psi for each specimen (see Appendix B).

4.2.1 Compressive Strength Results

Six specimens of the normal cement pervious concrete were tested for the 7-day compressive strength and the 28-day compressive strength. Three of the rapid-set pervious concrete specimens were tested for the 7-day compressive strength. The purpose of designing the rapid-set cement mix was to compare the early compressive strength of the two pervious concrete mixes, therefore, the 28-day compressive strength was not tested for the rapid-set specimens. Figures 4-1 to 4-3 show examples of the compressive strength testing failures of the three testing days for the different pervious concrete mixes.

Figure 4-1: Example of 7-day compressive strength testing for normal cement mix

Figure 4-2: Example of 28-day compressive strength testing for normal cement mix

Figure 4-3: Example of 7-day compressive strength testing for rapid-set cement mix

The results of the compressive strength testing for the normal cement pervious concrete mix vs. the rapid-set cement pervious concrete mix is shown in Table 4.1 and Table 4.2, respectively. The average 7-day compressive strength for the normal cement pervious concrete mix was determined to be 838.2 psi and the average 28-day compressive strength is 1115.0 psi. The average 7-day compressive strength for the rapid-set cement pervious concrete is 921.5 psi.

Table 4-1: Compressive strength values for normal cement pervious concrete

Normal Cement Pervious Concrete	
7-day (psi) :	**28-day (psi) :**
805.0	1079.0
824.6	1079.8
885.1	1186.3
Average (Standard Deviation)	
838.2 (41.7)	**1115.0 (61.8)**

Table 4-2: Compressive strength values for rapid-set cement pervious concrete

Rapid-Set Cement Pervious Concrete	
7-day (psi) :	**28-day (psi) :**
1141.7	-
685.3	-
937.4	-
Average (Standard Deviation)	
921.5 (228.6)	**-**

4.2.2 Discussion of Compressive Strength Results

The average 7-day compressive strength for the rapid-set cement pervious concrete was higher than the 7-day strength for the normal cement mix due to the properties of the rapid-set cement mix providing a higher, earlier strength to the specimens.

However, the standard deviation of the rapid-set cement concrete strengths is higher than the standard deviation for the normal cement concrete. This indicates that the rapid-set cement concrete is less consistent than the normal cement concrete in how the concrete performed in the compressive strength testing.

The rapid-set cement mix had a higher variability in how the porous concrete settled within the specimens. Some of the rapid-set specimens settled and compacted more within the cylinder molds due to a thinner cement paste surrounding the aggregate. This could have created a stronger internal bond and less porous structure throughout the specimen, thus resulting in a higher earlier compressive strength and more variability in the standard deviation.

Figure 4-4 shows the rapid-set cement pervious concrete cylinders and the variability in the porous structure. Compare these cylinders to the more consistent porous structure of the normal cement pervious concrete cylinders shown in Figure 4-5.

The inconsistencies in the rapid-set cement pervious concrete cylinders could also be attributed to inconsistencies in the casting of the cylinders due to the lack of a specific ASTM standard related to pervious concrete casting. Currently, there is not a standardized test for the casting of pervious concrete; by following the ASTM C192 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory (ASTM C192 2020), the rodding of the concrete in the cylinders could cause the cement paste to sink to the bottom and the aggregate to be disconnected from the paste.

This can be compared to the pervious concrete pavement system model created with the same rapid-set cement mix design shown in Figure 3-1. Though the concrete mix does not appear to be consistently permeable in the cylinder view, the model demonstrates the permeability and workability of the rapid-set mix that was batched in a larger quantity for a larger scale project.

Figure 4-4: Rapid-set cement pervious concrete cylinders

Figure 4-5: Normal cement pervious concrete cylinders

This comparison demonstrates how the rapid-set cement mix became more dense and less porous from the thinner consistency of the water and cement mix, which resulted in much of the cement mix being concentrated in the bottom and sides of the cylinder specimens. Therefore, the rapid-set cement mix had a higher 7-day compressive strength due to its material properties and the lower amount of porous space within the specimen structure.

The compressive strength of pervious concrete is much lower than that of conventional concrete due to the porous space within the structure. Therefore, pervious concrete is currently not well suited for bearing heavy loads and resisting stress compared to normal concrete. However, the compressive strengths calculated for this mix design are within the range of typical pervious concrete strength values according to ACI 522 Specification for Construction of Pervious Concrete Pavement (ACI 522 2020). This specification states that typical pervious concrete compressive strength values are within a range of 2.8 MPa to 28.0 MPa (406 psi to 4060 psi).

4.3 Freeze-Thaw Durability Testing

A critical factor in the successful implementation of pervious concrete is the material’s ability to remain durable in regions with freeze-thaw cycles. The expansion of water as it freezes and the contraction of the concrete during thawing can cause damage to the concrete if the mix is not properly designed.

The freeze-thaw chamber simulated 30 freeze-thaw cycles on the ten pervious concrete cylinders. The specimens underwent the freezing cycle at 0 °F for 4 hours followed by the thawing cycle at 40 °F for 3 hours and 20 minutes. Figure 4-6 presents the experimental setup of the pervious concrete specimens within the freeze-thaw chamber.

Figure 4-6: Setup of pervious concrete specimens in freeze-thaw chamber

After the 30 cycles, the specimens were taken from the chamber, the loose material was removed from the cylinders, and the samples were weighed to find the change in mass due to the fracturing of the material. The specimens were subjected to three rounds of freeze-thaw cycles. An example of the structural deterioration caused by the freeze-thaw chamber is highlighted in Figure 4-7.

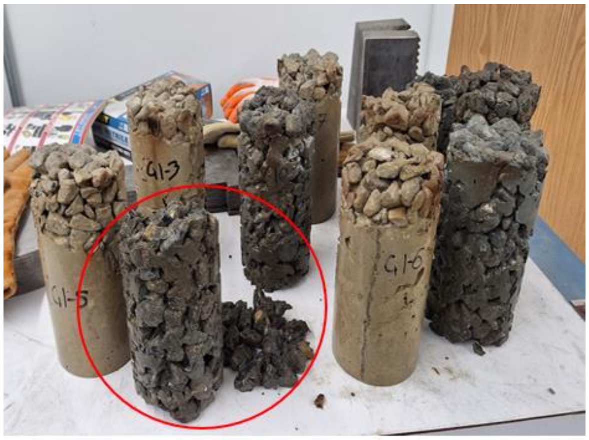

Figure 4-7: Structural deterioration of concrete after freeze-thaw testing

4.3.1 Freeze-Thaw Durability Results

The nominal data of the cylinder weights for each round of the freeze-thaw cycles is shown in Table 4.3. The normal cement pervious concrete cylinders are characterized by the symbol N followed by the specimen number, and the rapid-set cement cylinders are shown with the symbol RS followed by the specimen number.

Table 4-3: Freeze-thaw data for normal and rapid-set cement pervious concrete

Specimen ID	10/6/2023	10/19/2023	11/10/2023	11/29/2023
	Initial Weight (lb.)	**Round 1 Weight (lb.)**	**Round 2 Weight (lb.)**	**Round 3 Weight (lb.)**
N-1	7.05	6.6	5.8	3.2
N-2	6.95	6.25	4.85	4.85
N-3	7.0	6.7	6.65	6.65
N-4	7.2	7.15	7.15	3.6
N-5	7.15	7.0	7.0	7.0
RS-1	6.9	7.0	6.9	6.75
RS-2	7.65	7.7	7.7	7.7
RS-3	7.7	7.75	7.75	7.6
RS-4	7.9	7.95	8.0	7.85
RS-5	7.85	7.9	7.95	7.8

The data of the change in weight before and after each round of freeze-thaw cycles of the cylinders is shown in Table 4.4. This table includes both the change in weight in pounds and the percent change in weight of the cylinders. The values are shown as negative numbers when the weight has decreased between rounds, and the values are positive when the weight has increased between freeze-thaw rounds. The decreases in weight are caused by spalling or cracking in the concrete, and the increases in weight are caused by water retention in the concrete specimens.

Table 4-4: Change in weight (lb. and %) from freeze-thaw durability tests

Specimen ID	Initial to Round 1		Round 1 to Round 2		Round 2 to Round 3	
	Change in Weight (lb)	Change in Weight (%)	Change in Weight (lb)	Change in Weight (%)	Change in Weight (lb)	Change in Weight (%)
N-1	-0.45	-6.38%	-0.80	-12.12%	-2.60	-44.83%
N-2	-0.70	-10.07%	-1.40	-22.40%	0.00	0.00%
N-3	-0.30	-4.29%	-0.05	-0.75%	0.00	0.00%
N-4	-0.05	-0.69%	0.00	0.00%	-3.55	-49.65%
N-5	-0.15	-2.10%	0.00	0.00%	0.00	0.00%
RS-1	0.10	1.45%	-0.10	-1.43%	-0.15	-2.17%
RS-2	0.05	0.65%	0.00	0.00%	0.00	0.00%
RS-3	0.05	0.65%	0.00	0.00%	-0.15	-1.94%
RS-4	0.05	0.63%	0.05	0.63%	-0.15	-1.88%
RS-5	0.05	0.64%	0.05	0.63%	-0.15	-1.89%

Table 4.5 presents the average change in weight in pounds of the normal and rapid-set cylinders. Table 4.6 shows the average percent weight change for the cylinders for both types of cement. The data for both Table 4.5 and Table 4.6 includes the change in weight between each round and the average for all the rounds. The standard deviations are shown in parentheses following the average value.

Table 4-5: Average cylinder change in weight (lbs.) after each round

Specimen Cement Type	Initial to Round 1	Round 1 to Round 2	Round 2 to Round 3	All Rounds
	Average Change in Weight in lbs. (Standard Deviation)	Average Change in Weight in lbs. (Standard Deviation)	Average Change in Weight in lbs. (Standard Deviation)	Average Change in Weight in lbs. (Standard Deviation)
Normal	-0.33 (0.256)	-0.45 (0.630)	-1.23 (1.72)	-0.67 (0.489)
Rapid-Set	0.06 (0.022)	0.00 (0.061)	-0.12 (0.067)	-0.02 (0.092)

Table 4-6: Average cylinder change in weight (% change) after each round

Specimen Cement Type	Initial to Round 1	Round 1 to Round 2	Round 2 to Round 3	All Rounds
	Average % Change in Weight (Standard Deviation)	**Average % Change in Weight (Standard Deviation)**	**Average % Change in Weight (Standard Deviation)**	**Average % Change in Weight (Standard Deviation)**
Normal	-4.71% (0.0370)	-7.05% (0.100)	-18.9% (0.259)	-10.2% (0.0761)
Rapid-Set	0.80% (0.00361)	-0.03% (0.00841)	-1.57% (0.00888)	-0.27% (0.0121)

4.3.2 Discussion of Durability Results

Figure 4-8 presents the weight loss data of the specimens graphically. The percent change in weight (whether increased or decreased) is shown in Figure 4-9. The normal cement pervious concrete cylinders showed the greatest amount of change in mass, especially samples N-1, N-2, and N-4. Specimens N-3 and N-5 showed a smaller amount of mass change from the freeze-thaw test. Overall, the normal cement cylinders lost an average of 10.2% of the weight during each round of testing.

The rapid-set cement specimens did not show drastic changes in mass loss; the specimens showed only slight increases in weight due to the porous structure retaining water or slight decreases in weight due to spalling. The rapid-set cement cylinders only had an average change of weight of 0.27% between each round. This is a reasonable result to obtain higher durability values for rapid-set cement concrete than for Portland cement concrete based on the higher strength and durability properties provided by the more dense and low drying shrinkage nature of a rapid-set cement (Senatore 2010).

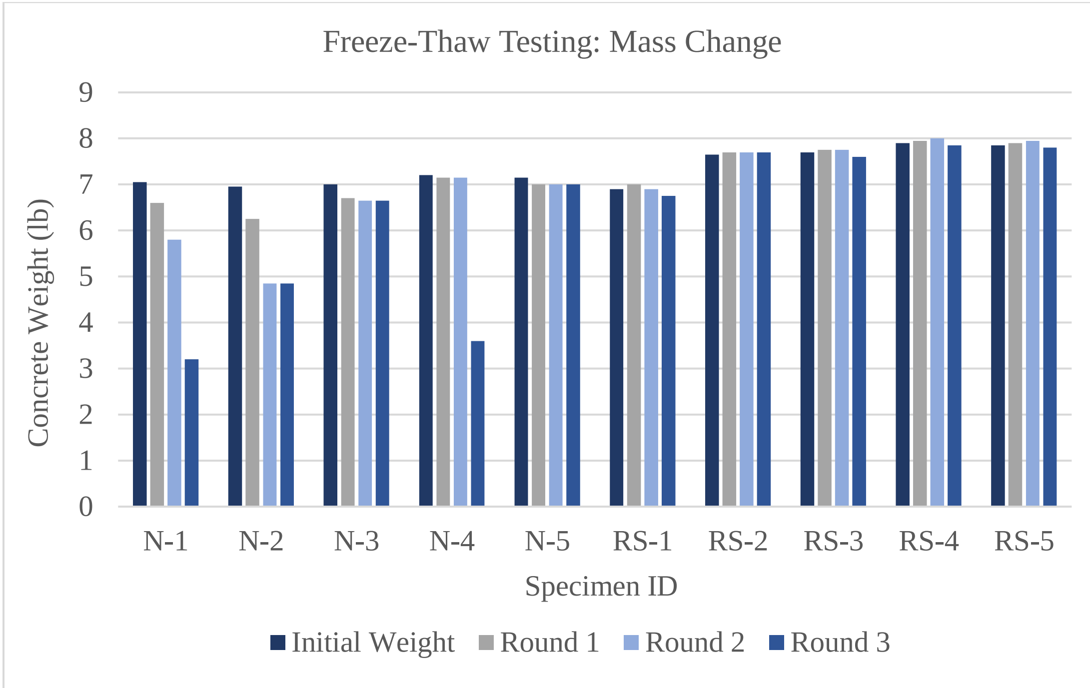

Figure 4-8: Mass change after each round of freeze-thaw cycles

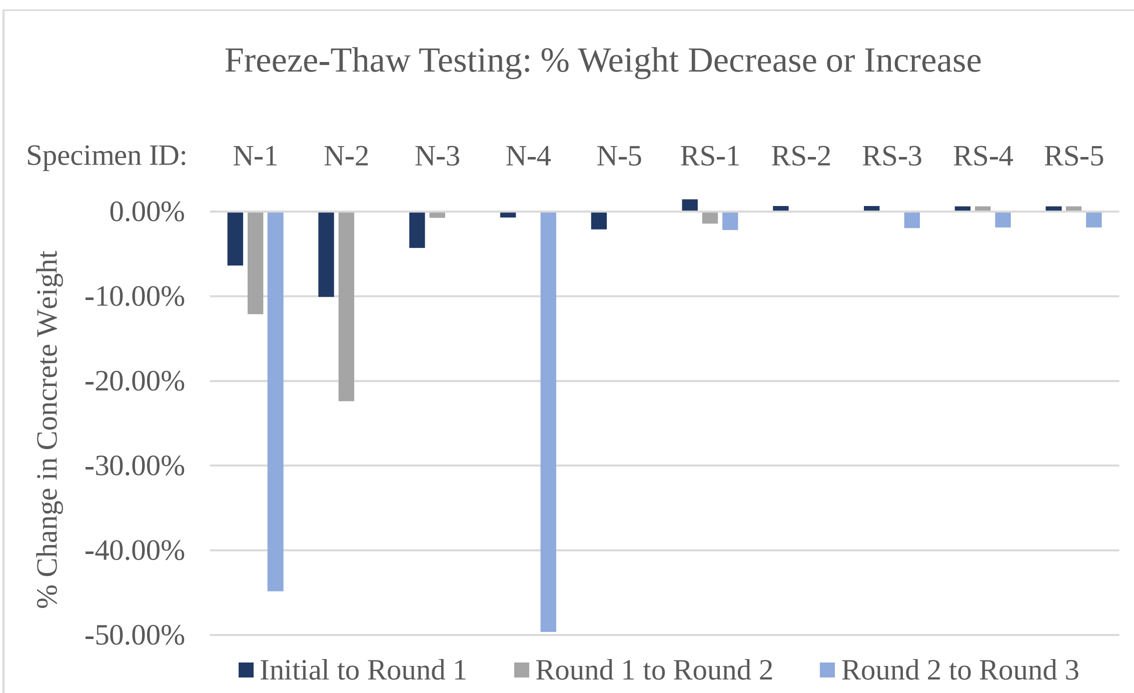

Figure 4-9: Percent weight change between freeze-thaw cycle rounds

After the freeze-thaw cycles, the visual inspections of the specimens showed minor surface distress, characterized by localized cracking and spalling of the concrete. The amount of surface distress varied among the ten specimens used in the freeze-thaw testing. The normal cement concrete had much more spalling than the rapid-set cement concrete. This could be a reason for why the normal cement concrete lost more mass throughout the three rounds than the rapid-set cement concrete.

The rapid-set cement concrete behaved well during the freeze-thaw durability cycles. The rapid-set cylinders did not reach the limit of failing to maintain a minimum of 60% of the mass. This is compared to the normal cement cylinders, which had two of the specimens reach that limit within the three rounds. Therefore, because the rapid-set cement concrete cylinders did not reach the failure limit in the same timeframe as the normal cement cylinders, using rapid-set cement as a replacement for normal cement in pervious concrete cylinders would be a viable alternative.

With more time available to use the freeze-thaw chamber in future studies, it would be advantageous to see how many rounds of freeze-thaw cycles the rapid-set cement cylinders could withstand before losing 40% of the mass. Because the three rounds of 30 cycles each took over 15 days to complete, there was not the time to perform more rounds of testing on the rapid-set cylinders for this thesis. However, the results of the durability testing still show beneficial outcomes. The utilization of rapid-set cement as an advanced concrete material within pervious concrete mix designs is a viable alternative to normal cement in terms of freeze-thaw durability.

4.4 Maintenance Method Testing

The three pervious concrete models were used to test each of the maintenance methods' ability to remove sand. Model 1 used pressure washing and vacuuming. Model 2 consisted of one upward flush attachment and vacuuming. Model 3 demonstrated the use of two upward flush attachments and vacuuming.

Three rounds of testing were performed, which included three tests each round for a total of nine maintenance method tests. The sand removal was calculated based on the initial weight of the concrete model without any sand added. The total sand removal per round was compared to the total sand distributed throughout the model at the beginning of the round.

4.4.1 Maintenance Method Results

After the nine rounds of testing, the amount of sand removed per the respective maintenance method for each model was averaged. The total amount of sand added to each model per round (3 pounds added per model for each test of round 1 and 4.5 pounds of sand is added for each test of rounds 2 and 3) is compared to the average amount removed by each maintenance method per round (see Figure 4-10). Model 1, Model 2, and Model 3 each removed on average 5.0 lbs., 6.5 lbs., and 7.6 lbs. of sand per maintenance round, respectively.

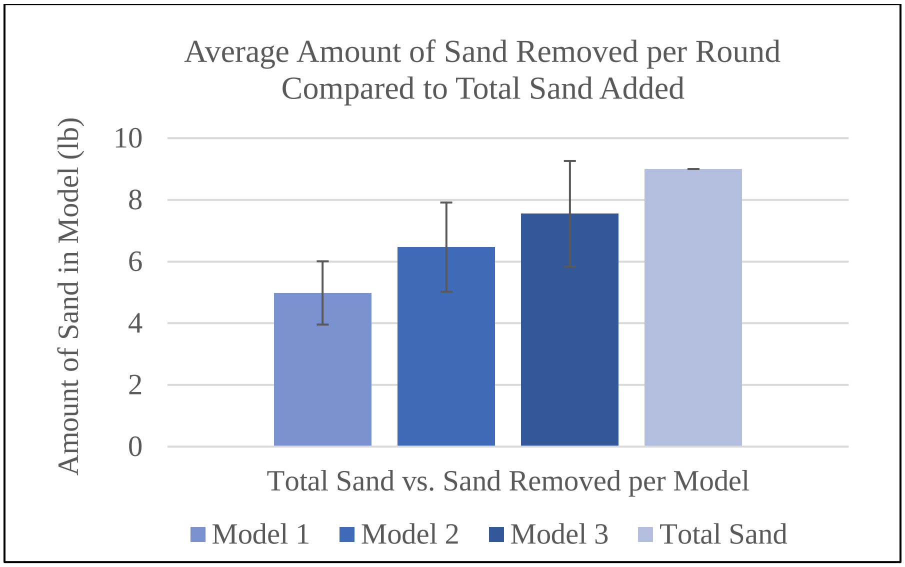

Figure 4-10: Sand removal per model based on maintenance method for Round 1

The average amount of sand removed per maintenance method is also shown in Table 4-7 and Figure 4-11 as the average percentage of sand removed after all three rounds of testing. The average percentage of sand removed per round is 49.5%, 64.1%, and 74.9% for Models 1, 2, and 3, respectively.

Therefore, it is concluded that Model 3 with the two upward flush system attachments and vacuuming maintenance method performed the best at removing debris from the porous structure. The results of the maintenance method testing are further discussed in Section 4.4.2 following the graphical data. The data collected during the maintenance method testing can be found in Appendix C.

Table 4-7: Percentage of sand removal per model for each round

% of Sand Removed per Round for each Model				
Model	**Round 1**	**Round 2**	**Round 3**	**Average (St. Dev.)**
1	42.8	55.7	50.0	49.5 (6.48)
2	53.3	68.6	70.5	64.1 (9.40)
3	62.2	78.6	83.8	74.9 (11.26)

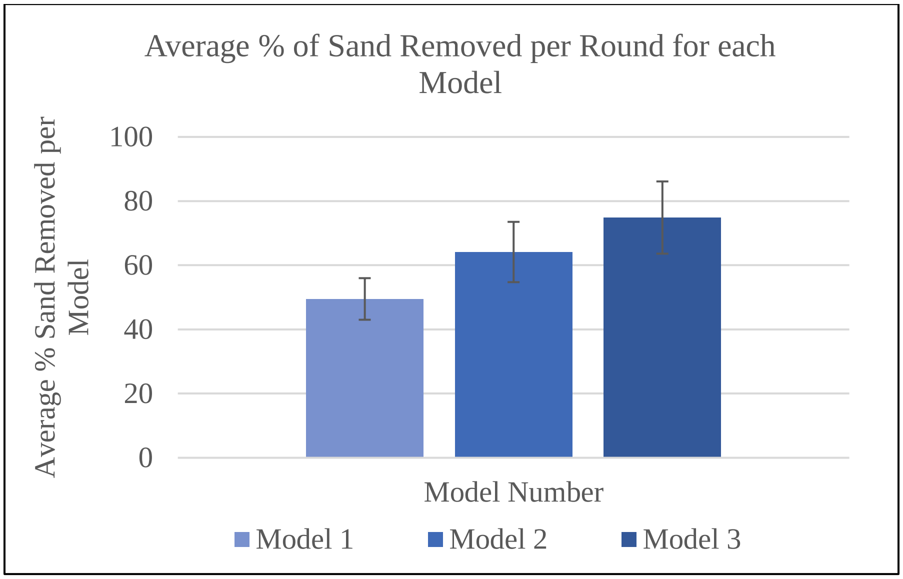

Figure 4-11: Average percentage of sand removal per model

4.4.2 Discussion of Maintenance Method Results

Model 3 (two upward flush system attachments with vacuuming) proved to be the most effective maintenance method in this experiment. Each round of testing had a similar trend of data; the order of least to best maintenance ability was Model 1, Model 2, and Model 3. After the three rounds of testing, Models 1, 2, and 3 achieved 50%, 65%, and 76% removal of sand, respectively. Figure 4-12 shows the three models after the maintenance method testing.

Figure 4-12: Models after maintenance method testing

The upward flushing systems most effectively cleaned the area between 3-5 inches away from the hose attachment; the middle of the concrete appeared to be more clogged with sand than the outer layers (see Figure 4-13). The infiltration rate of each model was observed to decrease after sand began clogging the concrete pores during each test. However, the implementation of the maintenance methods did improve the observed infiltration rate of the models by removing the sand from the porous structure.

Models 2 and 3 may have removed more sand based on the ability to flush sand from the bottom layers of the concrete more effectively. The pressure washing and vacuuming on Model 1 could only reach the sand on the top of the model. Though the area in the middle of Models 2 and 3 between the hose attachments was observed to be more clogged with sand, this could be addressed in future studies by adding additional upward flush system attachments in a grid-like pattern to be able to reach all areas of the concrete model. The study still demonstrates the benefits of using the upward flush system based on the ability to remove the most sand in the study despite there being slight sand residue remaining in the concrete.

Figure 4-13: Less sand observed in area within 3-5 inches of hose attachment

The next figures show the process of the maintenance method testing. The hose attachment is connected to start water flowing through the upward flush system. The water flows continuously for three minutes while the sand and excess water is being vacuumed.

On average, Model 3 with the hose attachments used about 16 gallons of water per three-minute test. This is compared to Model 1 with the pressure washing which used about 10 gallons of water per three-minute test (see Appendix C for the water measurements for each test). Though Model 3 used more gallons of water in the tests, when the data is normalized to the amount of sand removed per gallons of water used reach test, Model 3 is still the most efficient. Model 3 used approximately 1.7 gallons of water to remove one pound of sand, whereas Model 1 had to use about 2 gallons of water to remove one pound of sand.

Figure 4-14 shows the water flushing through the hose attachment on Model 2, and Figure 4-15 depicts the process of vacuuming while the upward flush system is running. Finally, Figure 4-16 presents the final result of the maintenance method for Model 2 after the tests were completed. The area surrounding the upward flush system attachment has less sand throughout all the pore spaces than the area further away from the upward flush system. This indicates how effective the upward flush system was at cleaning the porous area within reach of the water flow; with additional upward flush attachments in future studies, the residual sand in the middle of the model could be cleaned as effectively.

Figure 4-14: Water flowing through upward flush system attachment during test

Figure 4-15: Vacuuming Model 2 during maintenance method test

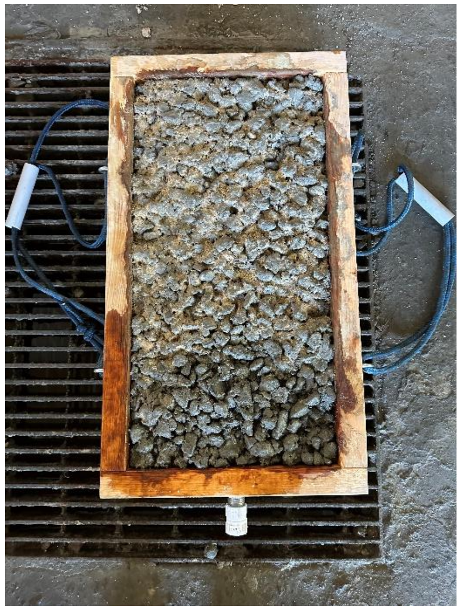

Figure 4-16: Final result of upward flush system and vacuuming for Model 2

The same type of process was completed for Model 3, only this time with upward flush system attachments on both sides of the model. Figure 4-17 shows the original model before sand was added; this original model can be compared to Figure 4-18 where the model is in the middle of a maintenance test with water flushing the sand up and Figure 4-19 depicting the model at the end of a maintenance test.

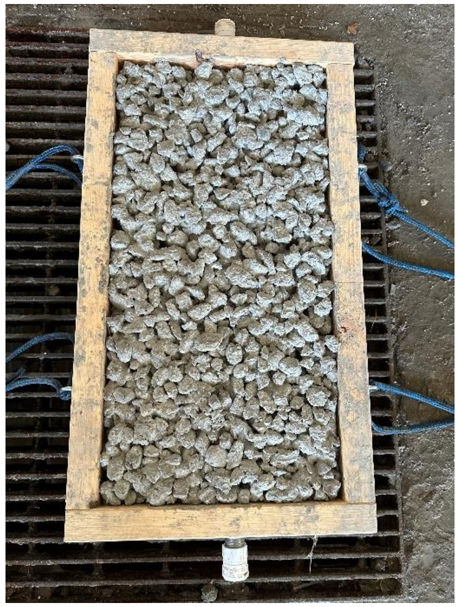

Figure 4-17: Original Model 3 before sand was added

Figure 4-18: Upward flush system working in a maintenance test for Model 3

Figure 4-19: Final result of upward flush system and vacuuming for Model 3

This thesis demonstrates that the innovative upward flush system hose attachments are a potential alternative to other maintenance methods. In this study, the models with the upward flush system attachments performed the best at removing sand from both the lower pore layers near the upward flush system attachments as well as throughout the surface of the model.

Though this new maintenance method worked well on a small-scale study, further research would need to be done to demonstrate how this would work on a large-scale project. This upward flush system was designed for this study and has not been utilized in other research or projects. Therefore, this innovative maintenance system needs additional research on how this could work on a practical level. Section 5.2 presents future research to consider before being able to implement an upward flush system practically and economically for field uses.

5 CONCLUSIONS

5.1 Summary of Results

Pervious concrete has the potential to be a sustainable, economical, and safe alternative to collect runoff and prevent the issues resulting from impervious surfaces such as flooding and pollutants in stormwater runoff. However, the high porosity of pervious concrete leads to issues with debris, sand, and other materials clogging the porous areas. Non-standardized material preparation techniques, testing, and construction practices can lead to issues with the strength and durability of pervious concrete pavements.

The first objective of the thesis was to utilize advanced concrete technology consisting of rapid setting cement to compare the compressive strength and long-term durability to a control mix of normal cement pervious concrete.

The second objective was to apply different maintenance methods to three models of pervious concrete to determine the most effective method to remove sand from the system and maintain the porous structure; an upward flush system with vacuuming was compared to a control model of power washing and vacuuming. The conclusions of the thesis study of the pervious concrete tests are as follows:

5.1.1 Compressive Strength Testing

- The average 7-day compressive strength for the normal cement pervious concrete mix was determined to be 838.2 psi and the average 28-day compressive strength is 1115.0 psi. The average 7-day compressive strength for the rapid-set cement pervious concrete is 921.5 psi.

- The average 7-day compressive strength for the rapid-set cement pervious concrete was higher than the 7-day strength for the normal cement mix due to the properties of the rapid-set cement mix providing a higher, earlier strength to the specimens.
- The compressive strengths calculated for both the normal cement and rapid-set cement mix designs are within the range of typical pervious concrete strength values according to ACI 522 Specification for Construction of Pervious Concrete Pavement (ACI 522 2020).
- Because of the higher, earlier strength obtained from the rapid-set cement and the compressive strength being within the range of typical strength values (ACI 522 2020), it is concluded that the rapid-set cement pervious concrete mix is a viable alternative in terms of compressive strength compared to the normal cement pervious concrete control mix.

5.1.2 Freeze-thaw Durability Testing

- The normal cement pervious concrete cylinders showed the greatest amount of change in mass during the three rounds of freeze-thaw testing. The rapid-set cement specimens did not show drastic changes in mass loss; the specimens showed only slight increases in weight due to the porous structure retaining water or slight decreases in weight due to spalling.
- Overall, the normal cement cylinders lost an average of 10.2% of the weight during each round of testing. The rapid-set cement cylinders only had an average change of weight of 0.27% between each round.
- After the freeze-thaw cycles, the visual inspections of the specimens showed minor surface distress, characterized by localized cracking and spalling of the concrete.

The amount of surface distress varied among the ten specimens used in the freeze-thaw testing. The normal cement concrete had much more spalling than the rapid-set cement concrete.

- The rapid-set cylinders did not reach the limit of failing to maintain a minimum of 60% of the mass. This is compared to the normal cement cylinders, which had two of the specimens reach that limit within the three rounds of freeze-thaw cycles.
- Therefore, because the rapid-set cement concrete cylinders did not reach the failure limit in the same timeframe as the normal cement cylinders, using rapid-set cement as a replacement for normal cement in pervious concrete cylinders would be a viable alternative.

5.1.3 Maintenance Method Testing

- Model 3 (two upward flush system attachments with vacuuming) proved to have the most effective maintenance method based on the ability to remove the highest amount of sand from the porous structure.
- After the three rounds of testing, Models 1, 2, and 3 achieved 49.5%, 64.1%, and 74.9% removal of sand, respectively.
- Models 2 and 3 may have removed more sand based on the ability to flush sand from the bottom layers of the concrete more effectively. The pressure washing and vacuuming on Model 1 could only reach the sand on the approximate ¼" of the top of the model.
- Though the area in the middle of Models 2 and 3 between the hose attachments was observed to be more clogged with sand, this could be addressed in future studies by adding additional upward flush system attachments in a grid-like

pattern to be able to reach all areas of the concrete model. Despite the slight sand residue remaining in the concrete for the upward flush system models, Model 3 was the most effective at removing sand from both the lower pore layers near the upward flush system attachments as well as throughout the surface of the model.

5.2 Future Work

It can be concluded that utilizing an advanced concrete material such as rapid setting cement is a suitable alternative for the replacement of normal cement in pervious concrete mix designs. It is recommended to perform future research on additional rapid-set cement mix designs to improve the freeze-thaw durability and compressive strength of the concrete. This thesis demonstrated the viability of the compressive strength, the long-term durability, and the permeability of the rapid-set cement pervious concrete mix.

This thesis also demonstrates that the innovative upward flush system hose attachments are a potential alternative to other maintenance methods. In this study, the models with the upward flush system attachments performed the best at removing sand from the clogged pores of the concrete system.

Though this new maintenance method worked well on a small-scale study, further research would need to be done to demonstrate how this would work on a large-scale project. This upward flush system was designed for this study, and, therefore, needs additional research on how this could work on a practical level.

Currently, the practicality of the upward flush system is limited by the basic design and implementation of the system to this one research study. However, research studies have already been performed regarding finding the pressurized fluid flow through a medium (Zhang et al. 2022; AlShareedah and Nassiri 2021); these models could be adapted to demonstrate how an upward flush system of maintenance could work for a large area of pervious concrete such as a driveway, parking lot, or sidewalk. With more research about the practicality of this upward flush system, a better design for the actual hose components could be invented and implemented in a grid pattern to cover a large area or volume of pervious concrete.

Computational fluid dynamics (CFD) and the discrete element method (DEM) are often used to study the extent of clogging in pervious concrete. This numerical simulation can demonstrate the flow of water through a finite volume model, which uses sphere packing and porosity values to estimate the hydraulic conductivity of a pervious concrete medium (Zhang et al. 2022; AlShareedah and Nassiri 2021).

The results of these CFD and DEM studies could be expanded to include multiple upward flush system attachments entering from the bottom and sides of the concrete. The discrete element models could simulate the water flow to measure the hydraulic conductivity and maintenance abilities of the upward flush system.

The use of physical models would also be necessary to verify the results of the finite element simulations and discover potential issues with the model testing. By using these finite element simulations and physical model testing on a pervious pavement, it would be possible to find the number of upward flush system attachments and the water pressure needed to clean a certain area of pervious concrete.

Overall, this thesis research has demonstrated the beneficial uses of implementing rapid-set cement and an upward flush system within pervious concrete. Given the research performed here and future research on these topics, pervious concrete will become an even more innovative, eco-friendly, and economical method for decreasing the effects from impervious surface development.

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APPENDICES

APPENDIX A: PERVIOUS CONCRETE MIX DESIGN CALCULATIONS

Pervious Concrete Mix Design Proportions

Material	Proportions (lb/yd^3)	Weight (lb)
Aggregate	2212.5	59.6
Cement	606.8	16.3
Water	212.4	5.7

Volume =	1256.6	in^3	(for 8"x 4" cylinders + 25% waste factor)
	0.0269	yd^3	# of cylinders = 10

1. Determine the dry-rodded unit weight of the aggregate and calculate the void content.

Unit weight of aggregate (Bulk Density)=	100	lb/ft^3
Vvoid (%) =	5	

2. Estimate the approximate percentage and volume of paste needed. The paste volume (PV) is then estimated as follows:

Vp (%) = Aggregate Void Content (%) + CI (%) - Vvoid (%)
Where CI = compaction index and
Vvoid = design void content of the pervious concrete mix.

Density of Water =	62.4	lb/ft^3
Bulk Specific Gravity =	1.6	
Apparent Density =	169.8	lb/ft^3
Aggregate Void Content (%) =	-0.160	%
Vvoid (%) =	5	%
CI (%) =	5	%
Vp (%) =	-0.160	

3. Calculate the paste volume, Vp in ft3 per cubic yard of pervious concrete:
Vp, ft3 = Vp (%) × 27

Vp (ft^3) =	-4.33	ft^3/yd^3

4. Select the w/c ratio for the paste. Recommended values are in the range of 0.25 to 0.36.

w/c ratio = 0.35

5. Calculate the absolute volume of cement

$$V_c, ft^3 = \frac{V_p}{[1 + (w/c \times RD_c}$$

Where: RDc is the specific gravity of cement (typically 3.15)

Vc (ft^3) = -2.06 ft^3/yd^3

6. Calculate the volume of water.
Vw
Vw, ft3 = Vp – Vc

Vw (ft^3) = -2.27 ft^3/yd^3

7. Calculate the volume of SSD aggregate. Vagg
Vagg = 27 – (Vp +
Vvoid)
Where: Vvoid is the design void content for the pervious concrete mix.

Vagg = 22.2 ft^3/yd^3

8. Convert the volumes to weights of ingredients per cubic yard and for trial batches:
Cement (lb/yd3) = Vc × RDc × 62.4
Water (lb/yd3) = Vw × 62.4
SSD Coarse Aggregate (lb/yd3) = Vagg × RDagg × 62.4

RDagg = 1.6 (Specific gravity of aggregate)

Cement	606.8	lb/yd^3	*50% increase in cement and water
Water	212.4	lb/yd^3	
SSD Coarse Aggregate	2212.5	lb/yd^3	

APPENDIX B: COMPRESSIVE STRENGTH DATA

Partner Data Point File
Start of Test Thu 14 Sep 2023 18:50:31
7-day normal cement pervious concrete test
Compressive strength = 824.6 psi

Time (min)	Stress (psi)	Position (in)	Load (lbf)	Zone
0	0	0	0	Speed 1
0.00167	7.162	0.008	90	Speed 1
0.00333	14.5626	0.0158	183	Speed 1
0.005	22.9183	0.0238	288	Speed 1
0.00667	31.9105	0.0315	401	Speed 1
0.00833	41.9372	0.0395	527	Speed 1
0.01	52.521	0.0473	660	Speed 1
0.01167	61.5928	0.0553	774	Speed 1
0.01333	73.2907	0.063	921	Speed 1
0.015	86.1822	0.0707	1083	Speed 1
0.01667	100.1082	0.0785	1258	Speed 1
0.01833	111.8857	0.0863	1406	Speed 1
0.02	124.9363	0.094	1570	Speed 1
0.02167	139.9765	0.1015	1759	Speed 1
0.02333	156.3694	0.109	1965	Speed 1
0.025	173.7968	0.1165	2184	Speed 1
0.02667	191.6221	0.1238	2408	Speed 1
0.02833	210.2432	0.131	2642	Speed 1
0.03	229.5009	0.1378	2884	Speed 1
0.03167	248.5995	0.144	3124	Speed 1
0.03333	266.6635	0.1495	3351	Speed 1
0.035	283.7726	0.1545	3566	Speed 1
0.03667	298.8127	0.159	3755	Speed 1
0.03833	310.1127	0.1628	3897	Speed 1
0.04	318.9458	0.1663	4008	Speed 1
0.04167	327.6197	0.169	4117	Speed 1
0.04333	335.2591	0.1715	4213	Speed 1
0.045	341.6253	0.1733	4293	Speed 1
0.04667	346.1612	0.1748	4350	Speed 1
0.04833	349.026	0.176	4386	Speed 1
0.05	350.4584	0.1768	4404	Speed 1
0.05167	350.6175	0.177	4406	Speed 1
0.05333	343.7739	0.1775	4320	Speed 1
0.055	335.5774	0.178	4217	Speed 1
0.05667	330.6436	0.1785	4155	Speed 1
0.05833	326.6648	0.1788	4105	Speed 1
0.06	321.1739	0.1788	4036	Speed 1
0.06167	317.5134	0.179	3990	Speed 1
0.06333	314.8873	0.179	3957	Speed 1
0.065	312.8979	0.1793	3932	Speed 1
0.06667	310.6697	0.1793	3904	Speed 1
0.06833	308.1233	0.1793	3872	Speed 1
0.07	305.8155	0.1793	3843	Speed 1
0.07167	303.9852	0.1793	3820	Speed 1
0.07333	302.4733	0.1793	3801	Speed 1
0.075	301.0409	0.1793	3783	Speed 1
0.07667	299.9268	0.1793	3769	Speed 1

0.07833	298.8127	0.1795	3755	Speed 1
0.08	297.8578	0.1795	3743	Speed 1
0.08167	296.8233	0.1795	3730	Speed 1
0.08333	295.9479	0.1795	3719	Speed 1
0.085	295.1522	0.1795	3709	Speed 1
0.08667	294.6747	0.1795	3703	Speed 1
0.08833	294.1972	0.1795	3697	Speed 1
0.09	293.7198	0.1795	3691	Speed 1
0.09167	293.3219	0.1797	3686	Speed 1
0.09333	293.0832	0.1797	3683	Speed 1
0.095	293.0832	0.18	3683	Speed 1
0.09667	293.5606	0.18	3689	Speed 1
0.09833	294.1177	0.1803	3696	Speed 1
0.1	294.993	0.1805	3707	Speed 1
0.10167	296.2662	0.181	3723	Speed 1
0.10333	297.8578	0.1813	3743	Speed 1
0.105	299.7676	0.1817	3767	Speed 1
0.10667	302.0754	0.1823	3796	Speed 1
0.10833	304.6219	0.1828	3828	Speed 1
0.11	307.4071	0.1833	3863	Speed 1
0.11167	310.2718	0.184	3899	Speed 1
0.11333	313.1366	0.1848	3935	Speed 1
0.115	316.3993	0.1855	3976	Speed 1
0.11667	319.9007	0.186	4020	Speed 1
0.11833	323.4817	0.187	4065	Speed 1
0.12	327.1422	0.1878	4111	Speed 1
0.12167	330.7232	0.1885	4156	Speed 1
0.12333	334.3838	0.1892	4202	Speed 1
0.125	338.1239	0.1903	4249	Speed 1
0.12667	341.864	0.191	4296	Speed 1
0.12833	345.6837	0.192	4344	Speed 1
0.13	349.6626	0.193	4394	Speed 1
0.13167	353.5619	0.194	4443	Speed 1
0.13333	357.6203	0.1947	4494	Speed 1
0.135	361.6788	0.1958	4545	Speed 1
0.13667	365.8168	0.1968	4597	Speed 1
0.13833	369.7957	0.1978	4647	Speed 1
0.14	373.8541	0.1985	4698	Speed 1
0.14167	377.9921	0.1995	4750	Speed 1
0.14333	381.971	0.2005	4800	Speed 1
0.145	385.8703	0.2015	4849	Speed 1
0.14667	389.7696	0.2025	4898	Speed 1
0.14833	393.7484	0.2035	4948	Speed 1
0.15	397.7273	0.2045	4998	Speed 1
0.15167	401.8653	0.2053	5050	Speed 1
0.15333	405.8442	0.2063	5100	Speed 1
0.155	409.7435	0.2073	5149	Speed 1
0.15667	413.6427	0.2083	5198	Speed 1
0.15833	417.542	0.2093	5247	Speed 1
0.16	421.5209	0.21	5297	Speed 1
0.16167	425.6589	0.211	5349	Speed 1
0.16333	429.6378	0.212	5399	Speed 1

0.165	433.5371	0.2128	5448	Speed 1
0.16667	436.4814	0.2138	5485	Speed 1
0.16833	439.6645	0.2148	5525	Speed 1
0.17	443.2455	0.2155	5570	Speed 1
0.17167	447.2244	0.2165	5620	Speed 1
0.17333	451.2032	0.2175	5670	Speed 1
0.175	455.1821	0.2183	5720	Speed 1
0.17667	459.0018	0.2193	5768	Speed 1
0.17833	462.8215	0.22	5816	Speed 1
0.18	466.5616	0.221	5863	Speed 1
0.18167	470.3814	0.2218	5911	Speed 1
0.18333	474.3602	0.2228	5961	Speed 1
0.185	478.1799	0.2235	6009	Speed 1
0.18667	480.9651	0.2242	6044	Speed 1
0.18833	484.0687	0.2253	6083	Speed 1
0.19	487.4905	0.226	6126	Speed 1
0.19167	491.2306	0.2268	6173	Speed 1
0.19333	494.9707	0.2278	6220	Speed 1
0.195	498.7905	0.2285	6268	Speed 1
0.19667	502.5306	0.2293	6315	Speed 1
0.19833	506.2707	0.23	6362	Speed 1
0.2	509.8517	0.2308	6407	Speed 1
0.20167	513.5918	0.2317	6454	Speed 1
0.20333	517.2524	0.2323	6500	Speed 1
0.205	520.6742	0.233	6543	Speed 1
0.20667	524.096	0.2338	6586	Speed 1
0.20833	527.4383	0.2345	6628	Speed 1
0.21	530.8601	0.2352	6671	Speed 1
0.21167	534.5207	0.236	6717	Speed 1
0.21333	537.9425	0.2368	6760	Speed 1
0.215	541.1256	0.2372	6800	Speed 1
0.21667	544.1495	0.238	6838	Speed 1
0.21833	546.7756	0.2388	6871	Speed 1
0.22	549.7995	0.2395	6909	Speed 1
0.22167	553.1417	0.2403	6951	Speed 1
0.22333	556.6431	0.241	6995	Speed 1
0.225	560.3037	0.2418	7041	Speed 1
0.22667	564.0438	0.2423	7088	Speed 1
0.22833	567.784	0.243	7135	Speed 1
0.23	571.6832	0.2438	7184	Speed 1
0.23167	575.503	0.2445	7232	Speed 1
0.23333	579.1635	0.245	7278	Speed 1
0.235	582.7445	0.2458	7323	Speed 1
0.23667	586.405	0.2463	7369	Speed 1
0.23833	589.9064	0.247	7413	Speed 1
0.24	593.4874	0.2475	7458	Speed 1
0.24167	596.9888	0.2482	7502	Speed 1
0.24333	600.3311	0.2488	7544	Speed 1
0.245	603.6733	0.2495	7586	Speed 1
0.24667	607.0156	0.25	7628	Speed 1
0.24833	610.3578	0.2508	7670	Speed 1
0.25	613.8592	0.2513	7714	Speed 1

0.25167	617.4402	0.2518	7759	Speed 1
0.25333	620.862	0.2525	7802	Speed 1
0.255	624.2043	0.253	7844	Speed 1
0.25667	627.5465	0.2535	7886	Speed 1
0.25833	630.8887	0.2543	7928	Speed 1
0.26	634.4697	0.2548	7973	Speed 1
0.26167	637.8915	0.2553	8016	Speed 1
0.26333	641.3134	0.256	8059	Speed 1
0.265	644.7352	0.2565	8102	Speed 1
0.26667	648.0774	0.257	8144	Speed 1
0.26833	651.738	0.2578	8190	Speed 1
0.27	655.2394	0.2583	8234	Speed 1
0.27167	658.6612	0.2588	8277	Speed 1
0.27333	662.0035	0.2592	8319	Speed 1
0.275	665.4253	0.26	8362	Speed 1
0.27667	669.0858	0.2605	8408	Speed 1
0.27833	672.6668	0.261	8453	Speed 1
0.28	676.1682	0.2615	8497	Speed 1
0.28167	679.59	0.262	8540	Speed 1
0.28333	682.9323	0.2628	8582	Speed 1
0.285	686.5133	0.2633	8627	Speed 1
0.28667	689.9351	0.2638	8670	Speed 1
0.28833	693.2773	0.2643	8712	Speed 1
0.29	696.6992	0.2648	8755	Speed 1
0.29167	700.121	0.2655	8798	Speed 1
0.29333	703.702	0.266	8843	Speed 1
0.295	707.2829	0.2665	8888	Speed 1
0.29667	710.7048	0.267	8931	Speed 1
0.29833	714.2062	0.2675	8975	Speed 1
0.3	717.628	0.268	9018	Speed 1
0.30167	721.1294	0.2687	9062	Speed 1
0.30333	724.7104	0.2693	9107	Speed 1
0.305	728.3709	0.2698	9153	Speed 1
0.30667	731.8723	0.2703	9197	Speed 1
0.30833	735.2146	0.2708	9239	Speed 1
0.31	738.5568	0.2713	9281	Speed 1
0.31167	741.7399	0.2718	9321	Speed 1
0.31333	745.1617	0.2722	9364	Speed 1
0.315	748.6631	0.2728	9408	Speed 1
0.31667	752.0849	0.2733	9451	Speed 1
0.31833	755.4272	0.2738	9493	Speed 1
0.32	758.849	0.2742	9536	Speed 1
0.32167	762.1117	0.2748	9577	Speed 1
0.32333	765.7722	0.2753	9623	Speed 1
0.325	769.2736	0.2758	9667	Speed 1
0.32667	772.775	0.2763	9711	Speed 1
0.32833	776.2764	0.2768	9755	Speed 1
0.33	779.6187	0.2773	9797	Speed 1
0.33167	782.7222	0.2777	9836	Speed 1
0.33333	747.2307	0.28	9390	Speed 1
0.335	701.8717	0.2848	8820	Speed 1
0.33667	697.2562	0.2888	8762	Speed 1

0.33833	711.5801	0.292	8942	Speed 1
0.34	728.1322	0.295	9150	Speed 1
0.34167	745.0026	0.298	9362	Speed 1
0.34333	762.0321	0.3008	9576	Speed 1
0.345	779.6187	0.303	9797	Speed 1
0.34667	796.6482	0.305	10011	Speed 1
0.34833	811.4496	0.307	10197	Speed 1
0.35	824.5799	0.3088	10362	Speed 1
0.35167	821.3172	0.3108	10321	Speed 1
0.35333	812.325	0.3135	10208	Speed 1
0.355	760.4406	0.3178	9556	Speed 1
0.35667	664.152	0.3258	8346	Speed 1
0.35833	585.9276	0.334	7363	Speed 1
0.36	545.6615	0.342	6857	Speed 1
0.36167	467.0391	0.3508	5869	Speed 1
0.36333	311.0676	0.3588	3909	Speed 1
0.365	222.2594	0.367	2793	Speed 1
0.36667	179.0489	0.375	2250	Speed 1
0.36833	163.6905	0.3832	2057	Speed 1
0.37	160.1891	0.3913	2013	Speed 1
0.37167	163.1334	0.3993	2050	Speed 1
0.37333	169.42	0.4075	2129	Speed 1
0.375	167.6693	0.4155	2107	Speed 1
0.37667	173.956	0.4235	2186	Speed 1
0.37833	177.6961	0.4318	2233	Speed 1
0.38	173.8764	0.44	2185	Speed 1
0.38167	160.2687	0.448	2014	Speed 1
0.38333	148.1729	0.4563	1862	Speed 1
0.385	122.1511	0.4643	1535	Speed 1
0.38667	112.4427	0.4723	1413	Speed 1
0.38833	110.5329	0.4805	1389	Speed 1
0.39	107.5885	0.4885	1352	Speed 1
0.39167	105.6786	0.4968	1328	Speed 1
0.39333	106.3948	0.5048	1337	Speed 1
0.395	105.7582	0.5128	1329	Speed 1
0.39667	116.4216	0.521	1463	Speed 1
0.39833	114.9096	0.529	1444	Speed 1
0.4	119.4455	0.5373	1501	Speed 1
0.40167	124.618	0.5453	1566	Speed 1
0.40333	136.5546	0.5533	1716	Speed 1
0.405	144.5919	0.5615	1817	Speed 1
0.40667	147.4567	0.5695	1853	Speed 1
0.40833	159.075	0.5775	1999	Speed 1
0.41	169.9771	0.5855	2136	Speed 1

Partner Data Point File
Start of Test Thu 14 Sep 2023 18:55:31
7-day normal cement pervious concrete test
Compressive strength = 885.1 psi

Time (min)	Stress (psi)	Position (in)	Load (lbf)	Zone
0	0	0	0	Speed 1
0.00167	4.5359	0.008	57	Speed 1
0.00333	8.0373	0.016	101	Speed 1
0.005	11.6183	0.024	146	Speed 1
0.00667	17.2683	0.032	217	Speed 1
0.00833	23.5549	0.04	296	Speed 1
0.01	30.876	0.048	388	Speed 1
0.01167	38.9133	0.056	489	Speed 1
0.01333	47.5076	0.064	597	Speed 1
0.015	57.1365	0.072	718	Speed 1
0.01667	67.959	0.08	854	Speed 1
0.01833	79.7364	0.088	1002	Speed 1
0.02	91.3547	0.096	1148	Speed 1
0.02167	104.0871	0.104	1308	Speed 1
0.02333	118.0927	0.1117	1484	Speed 1
0.025	128.7561	0.1197	1618	Speed 1
0.02667	137.6687	0.1275	1730	Speed 1
0.02833	150.5602	0.1352	1892	Speed 1
0.03	165.6003	0.143	2081	Speed 1
0.03167	177.5369	0.1507	2231	Speed 1
0.03333	192.02	0.1582	2413	Speed 1
0.035	208.3333	0.1657	2618	Speed 1
0.03667	225.8403	0.1733	2838	Speed 1
0.03833	243.1086	0.1808	3055	Speed 1
0.04	256.6368	0.188	3225	Speed 1
0.04167	272.4726	0.1947	3424	Speed 1
0.04333	289.343	0.201	3636	Speed 1
0.045	306.1338	0.2065	3847	Speed 1
0.04667	322.0493	0.2115	4047	Speed 1
0.04833	336.6119	0.2157	4230	Speed 1
0.05	349.5035	0.2197	4392	Speed 1
0.05167	361.2013	0.223	4539	Speed 1
0.05333	371.0689	0.2255	4663	Speed 1
0.055	379.1062	0.2277	4764	Speed 1
0.05667	385.1541	0.2295	4840	Speed 1
0.05833	389.5308	0.231	4895	Speed 1
0.06	392.4752	0.232	4932	Speed 1
0.06167	393.5893	0.2325	4946	Speed 1
0.06333	393.1118	0.233	4940	Speed 1
0.065	391.5203	0.2333	4920	Speed 1
0.06667	389.1329	0.2333	4890	Speed 1
0.06833	386.666	0.2333	4859	Speed 1
0.07	384.1196	0.2333	4827	Speed 1
0.07167	381.4139	0.2333	4793	Speed 1
0.07333	378.8675	0.2333	4761	Speed 1
0.075	376.4802	0.2333	4731	Speed 1
0.07667	374.1724	0.2333	4702	Speed 1

0.07833	372.183	0.2333	4677	Speed 1
0.08	370.114	0.2333	4651	Speed 1
0.08167	368.1245	0.2333	4626	Speed 1
0.08333	366.2147	0.2333	4602	Speed 1
0.085	364.3048	0.2333	4578	Speed 1
0.08667	362.5541	0.2333	4556	Speed 1
0.08833	360.8034	0.2333	4534	Speed 1
0.09	359.1323	0.2333	4513	Speed 1
0.09167	357.3816	0.233	4491	Speed 1
0.09333	355.7105	0.233	4470	Speed 1
0.095	353.9598	0.233	4448	Speed 1
0.09667	352.607	0.2328	4431	Speed 1
0.09833	351.1746	0.2328	4413	Speed 1
0.1	349.7422	0.2328	4395	Speed 1
0.10167	348.3894	0.2325	4378	Speed 1
0.10333	347.1161	0.2325	4362	Speed 1
0.105	345.8429	0.2325	4346	Speed 1
0.10667	344.9675	0.2325	4335	Speed 1
0.10833	344.0922	0.2325	4324	Speed 1
0.11	343.2964	0.2322	4314	Speed 1
0.11167	342.5006	0.2322	4304	Speed 1
0.11333	341.7845	0.2322	4295	Speed 1
0.115	341.1478	0.2322	4287	Speed 1
0.11667	340.8295	0.2322	4283	Speed 1
0.11833	340.4316	0.2322	4278	Speed 1
0.12	340.1133	0.2322	4274	Speed 1
0.12167	339.8746	0.2322	4271	Speed 1
0.12333	339.9542	0.2322	4272	Speed 1
0.125	340.5908	0.2322	4280	Speed 1
0.12667	341.9436	0.2325	4297	Speed 1
0.12833	343.8535	0.233	4321	Speed 1
0.13	346.4795	0.2335	4354	Speed 1
0.13167	349.6626	0.234	4394	Speed 1
0.13333	353.4027	0.2347	4441	Speed 1
0.135	357.6999	0.2355	4495	Speed 1
0.13667	362.2358	0.2363	4552	Speed 1
0.13833	366.7717	0.237	4609	Speed 1
0.14	371.4668	0.2377	4668	Speed 1
0.14167	376.0823	0.2387	4726	Speed 1
0.14333	380.7773	0.2397	4785	Speed 1
0.145	385.7111	0.2405	4847	Speed 1
0.14667	390.5653	0.2415	4908	Speed 1
0.14833	395.2604	0.2425	4967	Speed 1
0.15	399.8759	0.2435	5025	Speed 1
0.15167	404.6505	0.2445	5085	Speed 1
0.15333	409.7435	0.2455	5149	Speed 1
0.155	414.5977	0.2465	5210	Speed 1
0.15667	418.8153	0.2478	5263	Speed 1
0.15833	423.4308	0.2487	5321	Speed 1
0.16	428.0462	0.2497	5379	Speed 1
0.16167	432.8209	0.251	5439	Speed 1
0.16333	437.2772	0.252	5495	Speed 1

0.165	441.7335	0.253	5551	Speed 1
0.16667	446.349	0.2542	5609	Speed 1
0.16833	450.8849	0.2553	5666	Speed 1
0.17	455.4208	0.2562	5723	Speed 1
0.17167	459.8772	0.2572	5779	Speed 1
0.17333	464.4926	0.2582	5837	Speed 1
0.175	466.7208	0.2595	5865	Speed 1
0.17667	419.2132	0.2623	5268	Speed 1
0.17833	359.9281	0.2687	4523	Speed 1
0.18	343.0577	0.275	4311	Speed 1
0.18167	349.2647	0.281	4389	Speed 1
0.18333	366.4534	0.2865	4605	Speed 1
0.185	387.9393	0.2918	4875	Speed 1
0.18667	408.2315	0.2967	5130	Speed 1
0.18833	426.8526	0.3015	5364	Speed 1
0.19	447.6223	0.306	5625	Speed 1
0.19167	467.8349	0.3103	5879	Speed 1
0.19333	478.6574	0.3145	6015	Speed 1
0.195	477.4637	0.3192	6000	Speed 1
0.19667	483.0341	0.3237	6070	Speed 1
0.19833	440.8582	0.3305	5540	Speed 1
0.2	433.4575	0.3377	5447	Speed 1
0.20167	441.654	0.3445	5550	Speed 1
0.20333	451.5215	0.351	5674	Speed 1
0.205	468.5511	0.3575	5888	Speed 1
0.20667	486.3764	0.3635	6112	Speed 1
0.20833	486.8539	0.37	6118	Speed 1
0.21	498.5517	0.3762	6265	Speed 1
0.21167	518.3665	0.382	6514	Speed 1
0.21333	528.4728	0.388	6641	Speed 1
0.215	542.0009	0.3935	6811	Speed 1
0.21667	558.8713	0.3987	7023	Speed 1
0.21833	575.3438	0.4037	7230	Speed 1
0.22	593.01	0.408	7452	Speed 1
0.22167	610.517	0.412	7672	Speed 1
0.22333	618.793	0.416	7776	Speed 1
0.225	595.7952	0.421	7487	Speed 1
0.22667	598.1825	0.426	7517	Speed 1
0.22833	612.2677	0.4302	7694	Speed 1
0.23	624.6817	0.434	7850	Speed 1
0.23167	630.1725	0.4377	7919	Speed 1
0.23333	633.9127	0.4415	7966	Speed 1
0.235	646.0084	0.4447	8118	Speed 1
0.23667	659.7753	0.4475	8291	Speed 1
0.23833	672.5077	0.45	8451	Speed 1
0.24	684.2851	0.452	8599	Speed 1
0.24167	694.5506	0.4537	8728	Speed 1
0.24333	703.0653	0.4553	8835	Speed 1
0.245	709.3519	0.4565	8914	Speed 1
0.24667	711.7393	0.4575	8944	Speed 1
0.24833	713.8879	0.4583	8971	Speed 1
0.25	715.7977	0.459	8995	Speed 1

0.25167	716.9118	0.4597	9009	Speed 1
0.25333	717.4688	0.4602	9016	Speed 1
0.255	717.7076	0.4605	9019	Speed 1
0.25667	717.3893	0.461	9015	Speed 1
0.25833	716.7526	0.4612	9007	Speed 1
0.26	716.0364	0.4615	8998	Speed 1
0.26167	715.1611	0.4618	8987	Speed 1
0.26333	714.604	0.4618	8980	Speed 1
0.265	713.8083	0.462	8970	Speed 1
0.26667	713.0921	0.4623	8961	Speed 1
0.26833	712.3759	0.4623	8952	Speed 1
0.27	711.8984	0.4625	8946	Speed 1
0.27167	711.5801	0.4628	8942	Speed 1
0.27333	711.6597	0.463	8943	Speed 1
0.275	711.8188	0.463	8945	Speed 1
0.27667	712.1372	0.4632	8949	Speed 1
0.27833	712.6146	0.4635	8955	Speed 1
0.28	713.2512	0.4637	8963	Speed 1
0.28167	714.3653	0.464	8977	Speed 1
0.28333	715.6386	0.4642	8993	Speed 1
0.285	716.9914	0.4645	9010	Speed 1
0.28667	718.5033	0.4647	9029	Speed 1
0.28833	720.0153	0.465	9048	Speed 1
0.29	721.6864	0.4652	9069	Speed 1
0.29167	723.835	0.4658	9096	Speed 1
0.29333	726.1428	0.466	9125	Speed 1
0.295	728.6097	0.4663	9156	Speed 1
0.29667	730.7582	0.4667	9183	Speed 1
0.29833	732.9864	0.467	9211	Speed 1
0.3	735.5329	0.4675	9243	Speed 1
0.30167	738.3977	0.468	9279	Speed 1
0.30333	741.342	0.4685	9316	Speed 1
0.305	744.2068	0.469	9352	Speed 1
0.30667	747.0716	0.4695	9388	Speed 1
0.30833	749.7772	0.47	9422	Speed 1
0.31	752.8011	0.4705	9460	Speed 1
0.31167	756.1434	0.471	9502	Speed 1
0.31333	759.4061	0.4715	9543	Speed 1
0.315	762.43	0.4722	9581	Speed 1
0.31667	765.4539	0.4727	9619	Speed 1
0.31833	768.2391	0.4735	9654	Speed 1
0.32	770.7856	0.4742	9686	Speed 1
0.32167	773.8891	0.475	9725	Speed 1
0.32333	777.6293	0.4757	9772	Speed 1
0.325	782.006	0.4765	9827	Speed 1
0.32667	786.5419	0.477	9884	Speed 1
0.32833	790.9982	0.4777	9940	Speed 1
0.33	795.2954	0.4785	9994	Speed 1
0.33167	799.1947	0.4792	10043	Speed 1
0.33333	802.7757	0.48	10088	Speed 1
0.335	806.675	0.4805	10137	Speed 1
0.33667	810.5743	0.4813	10186	Speed 1

0.33833	814.3144	0.482	10233	Speed 1
0.34	818.1341	0.4827	10281	Speed 1
0.34167	821.5559	0.4832	10324	Speed 1
0.34333	824.9777	0.484	10367	Speed 1
0.345	828.5587	0.4848	10412	Speed 1
0.34667	832.2989	0.4855	10459	Speed 1
0.34833	836.3573	0.4862	10510	Speed 1
0.35	840.5749	0.4867	10563	Speed 1
0.35167	844.6334	0.4875	10614	Speed 1
0.35333	848.5326	0.488	10663	Speed 1
0.355	851.3178	0.4888	10698	Speed 1
0.35667	854.0235	0.4895	10732	Speed 1
0.35833	857.2861	0.4902	10773	Speed 1
0.36	860.4692	0.491	10813	Speed 1
0.36167	863.6523	0.4918	10853	Speed 1
0.36333	867.0742	0.4925	10896	Speed 1
0.365	870.6551	0.493	10941	Speed 1
0.36667	873.3608	0.4937	10975	Speed 1
0.36833	874.7136	0.4947	10992	Speed 1
0.37	875.3502	0.4958	11000	Speed 1
0.37167	877.5784	0.4967	11028	Speed 1
0.37333	878.0558	0.4977	11034	Speed 1
0.375	879.6474	0.499	11054	Speed 1
0.37667	882.5917	0.5002	11091	Speed 1
0.37833	885.0586	0.5015	11122	Speed 1
0.38	700.8372	0.507	8807	Speed 1
0.38167	316.7972	0.514	3981	Speed 1
0.38333	106.3153	0.522	1336	Speed 1
0.385	-7.2415	0.53	-91	Speed 1

Partner Data Point File
Start of Test Thu 14 Sep 2023 18:59:47
7-day normal cement pervious concrete test
Compressive strength = 805.0 psi

Time (min)	Stress (psi)	Position (in)	Load (lbf)	Zone
0	0	0	0	Speed 1
0.00167	8.1169	0.008	102	Speed 1
0.00333	16.8704	0.016	212	Speed 1
0.005	23.7936	0.024	299	Speed 1
0.00667	31.8309	0.032	400	Speed 1
0.00833	40.9823	0.04	515	Speed 1
0.01	51.8048	0.048	651	Speed 1
0.01167	64.0597	0.056	805	Speed 1
0.01333	77.4287	0.0637	973	Speed 1
0.015	90.7977	0.0717	1141	Speed 1
0.01667	104.1667	0.0795	1309	Speed 1
0.01833	119.1272	0.087	1497	Speed 1
0.02	134.406	0.0947	1689	Speed 1
0.02167	150.5602	0.1022	1892	Speed 1
0.02333	167.9081	0.1097	2110	Speed 1
0.025	186.2109	0.1172	2340	Speed 1
0.02667	202.5242	0.1245	2545	Speed 1
0.02833	220.1108	0.1315	2766	Speed 1
0.03	238.1748	0.1377	2993	Speed 1
0.03167	255.5227	0.1432	3211	Speed 1
0.03333	271.6769	0.1482	3414	Speed 1
0.035	286.2395	0.1525	3597	Speed 1
0.03667	299.0515	0.1562	3758	Speed 1
0.03833	310.2718	0.1595	3899	Speed 1
0.04	319.9803	0.1622	4021	Speed 1
0.04167	295.1522	0.1662	3709	Speed 1
0.04333	279.8733	0.1703	3517	Speed 1
0.045	278.043	0.1738	3494	Speed 1
0.04667	281.1466	0.177	3533	Speed 1
0.04833	287.0353	0.1795	3607	Speed 1
0.05	293.8789	0.182	3693	Speed 1
0.05167	300.4043	0.1837	3775	Speed 1
0.05333	306.0543	0.1855	3846	Speed 1
0.055	310.5106	0.1867	3902	Speed 1
0.05667	313.4549	0.1877	3939	Speed 1
0.05833	314.569	0.1885	3953	Speed 1
0.06	279.3163	0.1912	3510	Speed 1
0.06167	246.9283	0.1947	3103	Speed 1
0.06333	234.5939	0.1982	2948	Speed 1
0.065	233.3206	0.2015	2932	Speed 1
0.06667	238.8114	0.2045	3001	Speed 1
0.06833	246.9283	0.207	3103	Speed 1
0.07	255.7614	0.2095	3214	Speed 1
0.07167	263.9579	0.2117	3317	Speed 1
0.07333	270.1649	0.2137	3395	Speed 1
0.075	276.3719	0.2157	3473	Speed 1
0.07667	282.0219	0.2175	3544	Speed 1

0.07833	287.1149	0.219	3608	Speed 1
0.08	291.7303	0.2205	3666	Speed 1
0.08167	294.8339	0.222	3705	Speed 1
0.08333	297.3803	0.2232	3737	Speed 1
0.085	297.3008	0.2247	3736	Speed 1
0.08667	299.131	0.226	3759	Speed 1
0.08833	301.7571	0.2272	3792	Speed 1
0.09	304.3831	0.2285	3825	Speed 1
0.09167	306.5317	0.2295	3852	Speed 1
0.09333	309.0782	0.2305	3884	Speed 1
0.095	312.0225	0.2315	3921	Speed 1
0.09667	314.7282	0.2325	3955	Speed 1
0.09833	317.1155	0.2335	3985	Speed 1
0.1	319.2641	0.2342	4012	Speed 1
0.10167	315.0465	0.2355	3959	Speed 1
0.10333	312.9775	0.2365	3933	Speed 1
0.105	313.3754	0.2377	3938	Speed 1
0.10667	315.2852	0.239	3962	Speed 1
0.10833	318.3887	0.2402	4001	Speed 1
0.11	321.8106	0.2412	4044	Speed 1
0.11167	325.4711	0.2422	4090	Speed 1
0.11333	329.3704	0.2435	4139	Speed 1
0.115	333.1901	0.2445	4187	Speed 1
0.11667	336.8507	0.2455	4233	Speed 1
0.11833	340.3521	0.2465	4277	Speed 1
0.12	343.7739	0.2472	4320	Speed 1
0.12167	347.1161	0.2482	4362	Speed 1
0.12333	350.4584	0.2492	4404	Speed 1
0.125	353.721	0.25	4445	Speed 1
0.12667	356.9041	0.251	4485	Speed 1
0.12833	359.9281	0.2518	4523	Speed 1
0.13	362.7929	0.2525	4559	Speed 1
0.13167	365.021	0.2535	4587	Speed 1
0.13333	367.1696	0.2542	4614	Speed 1
0.135	369.8752	0.2553	4648	Speed 1
0.13667	372.8992	0.2562	4686	Speed 1
0.13833	375.5252	0.257	4719	Speed 1
0.14	377.3555	0.258	4742	Speed 1
0.14167	379.7428	0.259	4772	Speed 1
0.14333	382.528	0.26	4807	Speed 1
0.145	385.6315	0.261	4846	Speed 1
0.14667	388.8146	0.2617	4886	Speed 1
0.14833	391.2019	0.263	4916	Speed 1
0.15	389.2125	0.2642	4891	Speed 1
0.15167	391.3611	0.2655	4918	Speed 1
0.15333	394.2259	0.2667	4954	Speed 1
0.155	397.6477	0.268	4997	Speed 1
0.15667	333.588	0.2715	4192	Speed 1
0.15833	264.7536	0.279	3327	Speed 1
0.16	232.6044	0.2865	2923	Speed 1
0.16167	230.5354	0.2942	2897	Speed 1
0.16333	247.6445	0.3017	3112	Speed 1

0.165	231.4108	0.3097	2908	Speed 1
0.16667	231.4108	0.3175	2908	Speed 1
0.16833	249.1565	0.3252	3131	Speed 1
0.17	266.1065	0.333	3344	Speed 1
0.17167	291.7303	0.3407	3666	Speed 1
0.17333	318.0704	0.3485	3997	Speed 1
0.175	338.6014	0.3562	4255	Speed 1
0.17667	358.0978	0.364	4500	Speed 1
0.17833	366.0555	0.3717	4600	Speed 1
0.18	380.2999	0.3795	4779	Speed 1
0.18167	396.6928	0.387	4985	Speed 1
0.18333	409.5047	0.3947	5146	Speed 1
0.185	416.985	0.4025	5240	Speed 1
0.18667	422.7941	0.4102	5313	Speed 1
0.18833	418.9744	0.4183	5265	Speed 1
0.19	424.4653	0.426	5334	Speed 1
0.19167	444.5983	0.4335	5587	Speed 1
0.19333	472.9278	0.4407	5943	Speed 1
0.195	500.1433	0.448	6285	Speed 1
0.19667	529.4277	0.4542	6653	Speed 1
0.19833	556.0065	0.46	6987	Speed 1
0.2	579.4818	0.4652	7282	Speed 1
0.20167	602.9571	0.4695	7577	Speed 1
0.20333	624.1247	0.4732	7843	Speed 1
0.205	632.0028	0.4767	7942	Speed 1
0.20667	622.5331	0.4808	7823	Speed 1
0.20833	626.3528	0.4845	7871	Speed 1
0.21	633.7535	0.4875	7964	Speed 1
0.21167	644.576	0.49	8100	Speed 1
0.21333	654.6028	0.492	8226	Speed 1
0.215	663.3563	0.4937	8336	Speed 1
0.21667	667.2556	0.495	8385	Speed 1
0.21833	669.0063	0.4962	8407	Speed 1
0.22	667.0168	0.4972	8382	Speed 1
0.22167	664.7091	0.4982	8353	Speed 1
0.22333	662.0035	0.4993	8319	Speed 1
0.225	660.4119	0.4998	8299	Speed 1
0.22667	659.2183	0.5002	8284	Speed 1
0.22833	657.8654	0.5007	8267	Speed 1
0.23	656.2739	0.501	8247	Speed 1
0.23167	654.5232	0.5012	8225	Speed 1
0.23333	652.6929	0.5012	8202	Speed 1
0.235	650.6239	0.5015	8176	Speed 1
0.23667	648.6345	0.5017	8151	Speed 1
0.23833	646.645	0.5017	8126	Speed 1
0.24	644.6556	0.502	8101	Speed 1
0.24167	642.9845	0.502	8080	Speed 1
0.24333	641.5521	0.5022	8062	Speed 1
0.245	640.3584	0.5022	8047	Speed 1
0.24667	639.3239	0.5025	8034	Speed 1
0.24833	638.5282	0.5025	8024	Speed 1
0.25	637.9711	0.5027	8017	Speed 1

0.25167	637.812	0.503	8015	Speed 1
0.25333	637.8915	0.503	8016	Speed 1
0.255	637.8915	0.5033	8016	Speed 1
0.25667	637.5732	0.5035	8012	Speed 1
0.25833	637.5732	0.5037	8012	Speed 1
0.26	637.8915	0.504	8016	Speed 1
0.26167	638.6873	0.5045	8026	Speed 1
0.26333	640.1197	0.5047	8044	Speed 1
0.265	641.8704	0.5052	8066	Speed 1
0.26667	642.9049	0.5055	8079	Speed 1
0.26833	644.8943	0.506	8104	Speed 1
0.27	647.2817	0.5065	8134	Speed 1
0.27167	649.5098	0.507	8162	Speed 1
0.27333	651.9767	0.5077	8193	Speed 1
0.275	654.9211	0.5082	8230	Speed 1
0.27667	658.0246	0.509	8269	Speed 1
0.27833	661.2873	0.5095	8310	Speed 1
0.28	664.6295	0.51	8352	Speed 1
0.28167	667.8126	0.5108	8392	Speed 1
0.28333	670.9957	0.5115	8432	Speed 1
0.285	674.4175	0.512	8475	Speed 1
0.28667	677.9189	0.5127	8519	Speed 1
0.28833	681.4999	0.5135	8564	Speed 1
0.29	685.3196	0.5143	8612	Speed 1
0.29167	689.2189	0.515	8661	Speed 1
0.29333	693.2773	0.5155	8712	Speed 1
0.295	697.097	0.5162	8760	Speed 1
0.29667	700.678	0.517	8805	Speed 1
0.29833	703.702	0.5178	8843	Speed 1
0.3	706.5667	0.5185	8879	Speed 1
0.30167	709.5111	0.5192	8916	Speed 1
0.30333	711.3414	0.5202	8939	Speed 1
0.305	714.7632	0.521	8982	Speed 1
0.30667	718.9808	0.522	9035	Speed 1
0.30833	723.4371	0.5227	9091	Speed 1
0.31	727.973	0.5237	9148	Speed 1
0.31167	732.1111	0.5245	9200	Speed 1
0.31333	733.7026	0.5255	9220	Speed 1
0.315	736.2491	0.5265	9252	Speed 1
0.31667	739.273	0.5275	9290	Speed 1
0.31833	743.1723	0.5285	9339	Speed 1
0.32	747.4695	0.5295	9393	Speed 1
0.32167	749.7772	0.5305	9422	Speed 1
0.32333	751.3688	0.5317	9442	Speed 1
0.325	755.1089	0.5328	9489	Speed 1
0.32667	758.6899	0.534	9534	Speed 1
0.32833	762.1117	0.535	9577	Speed 1
0.33	765.8518	0.5363	9624	Speed 1
0.33167	768.7166	0.5375	9660	Speed 1
0.33333	772.1384	0.5387	9703	Speed 1
0.335	776.7539	0.54	9761	Speed 1
0.33667	782.2447	0.541	9830	Speed 1

0.33833	788.3722	0.5422	9907	Speed 1
0.34	794.1018	0.5432	9979	Speed 1
0.34167	799.3539	0.5443	10045	Speed 1
0.34333	803.5715	0.5452	10098	Speed 1
0.345	805.0038	0.5465	10116	Speed 1
0.34667	802.7757	0.5478	10088	Speed 1
0.34833	800.0701	0.5492	10054	Speed 1
0.35	793.9426	0.5513	9977	Speed 1
0.35167	542.3988	0.5588	6816	Speed 1
0.35333	223.6918	0.5667	2811	Speed 1
0.355	54.6696	0.575	687	Speed 1

Partner Data Point File
Start of Test Thu 05 Oct 2023 10:02:29
28-day normal cement pervious concrete test
Compressive strength = 1186.3 psi

Time (min)	Stress (psi)	Position (in)	Load (lbf)	Zone
0	0	0	0	Speed 1
0.00167	4.0584	0.008	51	Speed 1
0.00333	8.8331	0.016	111	Speed 1
0.005	14.8014	0.024	186	Speed 1
0.00667	19.4169	0.0323	244	Speed 1
0.00833	24.1915	0.0403	304	Speed 1
0.01	32.0696	0.0482	403	Speed 1
0.01167	39.7091	0.0563	499	Speed 1
0.01333	47.9055	0.0643	602	Speed 1
0.015	57.1365	0.0722	718	Speed 1
0.01667	67.7203	0.0803	851	Speed 1
0.01833	79.7364	0.0883	1002	Speed 1
0.02	93.4237	0.0963	1174	Speed 1
0.02167	108.3047	0.1043	1361	Speed 1
0.02333	124.5385	0.112	1565	Speed 1
0.025	141.8067	0.12	1782	Speed 1
0.02667	159.9504	0.1278	2010	Speed 1
0.02833	179.1285	0.1352	2251	Speed 1
0.03	199.4207	0.1428	2506	Speed 1
0.03167	220.5882	0.1503	2772	Speed 1
0.03333	242.472	0.1575	3047	Speed 1
0.035	264.7536	0.1645	3327	Speed 1
0.03667	286.1599	0.1708	3596	Speed 1
0.03833	295.5501	0.1765	3714	Speed 1
0.04	309.5557	0.182	3890	Speed 1
0.04167	323.6408	0.1868	4067	Speed 1
0.04333	336.8507	0.191	4233	Speed 1
0.045	349.8218	0.1945	4396	Speed 1
0.04667	361.5196	0.1975	4543	Speed 1
0.04833	371.4668	0.2	4668	Speed 1
0.05	379.5041	0.2018	4769	Speed 1
0.05167	385.552	0.2033	4845	Speed 1
0.05333	389.6104	0.2045	4896	Speed 1
0.055	391.2815	0.2053	4917	Speed 1
0.05667	391.5998	0.2058	4921	Speed 1
0.05833	390.5653	0.206	4908	Speed 1
0.06	388.6555	0.206	4884	Speed 1
0.06167	386.1886	0.206	4853	Speed 1
0.06333	383.6421	0.206	4821	Speed 1
0.065	381.0956	0.206	4789	Speed 1
0.06667	378.7879	0.206	4760	Speed 1
0.06833	376.4006	0.206	4730	Speed 1
0.07	374.1724	0.206	4702	Speed 1
0.07167	372.0238	0.206	4675	Speed 1
0.07333	369.9548	0.206	4649	Speed 1
0.075	367.8858	0.206	4623	Speed 1
0.07667	365.8168	0.206	4597	Speed 1

0.07833	363.8274	0.206	4572	Speed 1
0.08	361.8379	0.206	4547	Speed 1
0.08167	359.8485	0.2058	4522	Speed 1
0.08333	357.7795	0.2058	4496	Speed 1
0.085	355.8696	0.2055	4472	Speed 1
0.08667	354.0394	0.2055	4449	Speed 1
0.08833	352.1295	0.2053	4425	Speed 1
0.09	350.3788	0.2053	4403	Speed 1
0.09167	348.6281	0.205	4381	Speed 1
0.09333	347.1161	0.205	4362	Speed 1
0.095	345.6837	0.205	4344	Speed 1
0.09667	344.3309	0.2048	4327	Speed 1
0.09833	343.0577	0.2048	4311	Speed 1
0.1	341.9436	0.2048	4297	Speed 1
0.10167	340.9887	0.2048	4285	Speed 1
0.10333	340.0338	0.2045	4273	Speed 1
0.105	339.238	0.2045	4263	Speed 1
0.10667	338.5218	0.2045	4254	Speed 1
0.10833	337.9647	0.2045	4247	Speed 1
0.11	337.5669	0.2045	4242	Speed 1
0.11167	337.169	0.2045	4237	Speed 1
0.11333	336.9302	0.2045	4234	Speed 1
0.115	336.9302	0.2045	4234	Speed 1
0.11667	337.169	0.2045	4237	Speed 1
0.11833	337.726	0.2045	4244	Speed 1
0.12	338.9992	0.2048	4260	Speed 1
0.12167	341.0683	0.2053	4286	Speed 1
0.12333	343.933	0.2055	4322	Speed 1
0.125	347.1957	0.2063	4363	Speed 1
0.12667	351.0154	0.2068	4411	Speed 1
0.12833	355.233	0.2075	4464	Speed 1
0.13	359.7689	0.208	4521	Speed 1
0.13167	364.3844	0.2088	4579	Speed 1
0.13333	369.159	0.2095	4639	Speed 1
0.135	373.9337	0.2105	4699	Speed 1
0.13667	378.8675	0.2113	4761	Speed 1
0.13833	383.7217	0.212	4822	Speed 1
0.14	388.4167	0.213	4881	Speed 1
0.14167	393.1914	0.2138	4941	Speed 1
0.14333	398.1252	0.2148	5003	Speed 1
0.145	403.059	0.2157	5065	Speed 1
0.14667	407.9132	0.2165	5126	Speed 1
0.14833	412.7674	0.2175	5187	Speed 1
0.15	417.4625	0.2185	5246	Speed 1
0.15167	422.1575	0.2193	5305	Speed 1
0.15333	426.6934	0.2203	5362	Speed 1
0.155	431.1498	0.2213	5418	Speed 1
0.15667	435.3674	0.2223	5471	Speed 1
0.15833	439.3462	0.223	5521	Speed 1
0.16	443.6434	0.224	5575	Speed 1
0.16167	448.0997	0.225	5631	Speed 1
0.16333	452.4765	0.226	5686	Speed 1

0.165	457.0124	0.227	5743	Speed 1
0.16667	461.4687	0.2278	5799	Speed 1
0.16833	465.8455	0.2288	5854	Speed 1
0.17	470.3018	0.2298	5910	Speed 1
0.17167	474.5194	0.2305	5963	Speed 1
0.17333	478.8961	0.2315	6018	Speed 1
0.175	483.1137	0.2323	6071	Speed 1
0.17667	487.2517	0.2333	6123	Speed 1
0.17833	491.3102	0.234	6174	Speed 1
0.18	495.289	0.235	6224	Speed 1
0.18167	499.1883	0.2358	6273	Speed 1
0.18333	503.0876	0.2365	6322	Speed 1
0.185	506.6686	0.2373	6367	Speed 1
0.18667	510.4087	0.2383	6414	Speed 1
0.18833	514.1489	0.239	6461	Speed 1
0.19	517.8094	0.2398	6507	Speed 1
0.19167	521.47	0.2405	6553	Speed 1
0.19333	524.9714	0.2413	6597	Speed 1
0.195	528.3136	0.242	6639	Speed 1
0.19667	531.7354	0.2428	6682	Speed 1
0.19833	535.3164	0.2435	6727	Speed 1
0.2	538.8974	0.2443	6772	Speed 1
0.20167	542.3988	0.245	6816	Speed 1
0.20333	545.9798	0.2458	6861	Speed 1
0.205	549.5608	0.2463	6906	Speed 1
0.20667	553.0622	0.247	6950	Speed 1
0.20833	556.5636	0.2478	6994	Speed 1
0.21	559.7467	0.2485	7034	Speed 1
0.21167	562.9297	0.2493	7074	Speed 1
0.21333	566.272	0.2498	7116	Speed 1
0.215	569.853	0.2505	7161	Speed 1
0.21667	573.3544	0.2513	7205	Speed 1
0.21833	576.9353	0.252	7250	Speed 1
0.22	580.5163	0.2525	7295	Speed 1
0.22167	584.0177	0.2533	7339	Speed 1
0.22333	587.4395	0.254	7382	Speed 1
0.225	590.7022	0.2545	7423	Speed 1
0.22667	594.0445	0.2553	7465	Speed 1
0.22833	597.3867	0.2558	7507	Speed 1
0.23	598.3416	0.2565	7519	Speed 1
0.23167	599.5353	0.2575	7534	Speed 1
0.23333	602.7184	0.2583	7574	Speed 1
0.235	606.7768	0.259	7625	Speed 1
0.23667	611.3127	0.2598	7682	Speed 1
0.23833	615.7691	0.2605	7738	Speed 1
0.24	620.1458	0.2613	7793	Speed 1
0.24167	624.3634	0.262	7846	Speed 1
0.24333	627.1486	0.2628	7881	Speed 1
0.245	627.5465	0.2635	7886	Speed 1
0.24667	630.3317	0.2645	7921	Speed 1
0.24833	634.3901	0.2653	7972	Speed 1
0.25	639.0056	0.266	8030	Speed 1

0.25167	643.6211	0.2668	8088	Speed 1
0.25333	648.157	0.2675	8145	Speed 1
0.255	652.5338	0.2683	8200	Speed 1
0.25667	656.8309	0.269	8254	Speed 1
0.25833	660.969	0.2695	8306	Speed 1
0.26	665.0274	0.2703	8357	Speed 1
0.26167	668.8471	0.271	8405	Speed 1
0.26333	672.5077	0.2715	8451	Speed 1
0.265	676.1682	0.2723	8497	Speed 1
0.26667	679.4309	0.2728	8538	Speed 1
0.26833	678.476	0.2738	8526	Speed 1
0.27	674.9746	0.2748	8482	Speed 1
0.27167	676.1682	0.276	8497	Speed 1
0.27333	680.545	0.277	8552	Speed 1
0.275	686.5928	0.278	8628	Speed 1
0.27667	692.7999	0.2788	8706	Speed 1
0.27833	698.7682	0.2798	8781	Speed 1
0.28	701.0759	0.2805	8810	Speed 1
0.28167	672.5077	0.2833	8451	Speed 1
0.28333	669.6429	0.2858	8415	Speed 1
0.285	677.6802	0.2878	8516	Speed 1
0.28667	689.6168	0.2895	8666	Speed 1
0.28833	701.9513	0.291	8821	Speed 1
0.29	709.5907	0.2928	8917	Speed 1
0.29167	718.2646	0.2943	9026	Speed 1
0.29333	727.5751	0.2955	9143	Speed 1
0.295	736.5674	0.2968	9256	Speed 1
0.29667	744.6047	0.298	9357	Speed 1
0.29833	751.7666	0.299	9447	Speed 1
0.3	758.0532	0.3	9526	Speed 1
0.30167	763.6237	0.3008	9596	Speed 1
0.30333	768.4779	0.3015	9657	Speed 1
0.305	741.7399	0.3038	9321	Speed 1
0.30667	735.135	0.3063	9238	Speed 1
0.30833	740.6258	0.3083	9307	Speed 1
0.31	750.4138	0.31	9430	Speed 1
0.31167	760.9976	0.3115	9563	Speed 1
0.31333	771.2631	0.3128	9692	Speed 1
0.315	780.7328	0.314	9811	Speed 1
0.31667	789.0884	0.3153	9916	Speed 1
0.31833	796.4095	0.3163	10008	Speed 1
0.32	802.5369	0.3173	10085	Speed 1
0.32167	806.4362	0.3183	10134	Speed 1
0.32333	798.7968	0.3198	10038	Speed 1
0.325	798.3989	0.321	10033	Speed 1
0.32667	803.7306	0.3225	10100	Speed 1
0.32833	810.813	0.3235	10189	Speed 1
0.33	817.8954	0.3245	10278	Speed 1
0.33167	824.1024	0.3255	10356	Speed 1
0.33333	828.3996	0.3265	10410	Speed 1
0.335	831.9805	0.3273	10455	Speed 1
0.33667	836.4369	0.328	10511	Speed 1

0.33833	840.9728	0.3288	10568	Speed 1
0.34	845.1108	0.3295	10620	Speed 1
0.34167	848.851	0.3303	10667	Speed 1
0.34333	852.1136	0.331	10708	Speed 1
0.345	855.3763	0.3315	10749	Speed 1
0.34667	858.4798	0.3323	10788	Speed 1
0.34833	861.5833	0.3328	10827	Speed 1
0.35	864.6073	0.3333	10865	Speed 1
0.35167	867.5516	0.3338	10902	Speed 1
0.35333	870.4164	0.3343	10938	Speed 1
0.355	873.2812	0.3348	10974	Speed 1
0.35667	875.8277	0.3355	11006	Speed 1
0.35833	877.4192	0.336	11026	Speed 1
0.36	877.7375	0.3368	11030	Speed 1
0.36167	879.3291	0.3373	11050	Speed 1
0.36333	882.0347	0.338	11084	Speed 1
0.365	884.8199	0.3388	11119	Speed 1
0.36667	887.2072	0.3393	11149	Speed 1
0.36833	890.1516	0.34	11186	Speed 1
0.37	893.7325	0.3408	11231	Speed 1
0.37167	897.5523	0.3415	11279	Speed 1
0.37333	901.6107	0.342	11330	Speed 1
0.375	905.5896	0.3428	11380	Speed 1
0.37667	909.4888	0.3433	11429	Speed 1
0.37833	911.3191	0.344	11452	Speed 1
0.38	912.6719	0.3448	11469	Speed 1
0.38167	914.8205	0.3455	11496	Speed 1
0.38333	918.0036	0.3465	11536	Speed 1
0.385	921.4254	0.3473	11579	Speed 1
0.38667	925.4043	0.348	11629	Speed 1
0.38833	929.7811	0.3488	11684	Speed 1
0.39	934.5557	0.3495	11744	Speed 1
0.39167	939.3303	0.3503	11804	Speed 1
0.39333	943.2296	0.351	11853	Speed 1
0.395	946.9697	0.3518	11900	Speed 1
0.39667	950.9486	0.3525	11950	Speed 1
0.39833	955.0071	0.353	12001	Speed 1
0.4	958.9063	0.3538	12050	Speed 1
0.40167	962.5669	0.3545	12096	Speed 1
0.40333	966.1479	0.355	12141	Speed 1
0.405	968.6148	0.3558	12172	Speed 1
0.40667	972.0366	0.3565	12215	Speed 1
0.40833	975.538	0.3573	12259	Speed 1
0.41	978.6415	0.3578	12298	Speed 1
0.41167	981.745	0.3585	12337	Speed 1
0.41333	984.9281	0.3593	12377	Speed 1
0.415	988.1908	0.36	12418	Speed 1
0.41667	991.6922	0.3608	12462	Speed 1
0.41833	995.2732	0.3615	12507	Speed 1
0.42	999.0929	0.362	12555	Speed 1
0.42167	1002.913	0.3628	12603	Speed 1
0.42333	1006.971	0.3635	12654	Speed 1

0.425	1010.95	0.364	12704	Speed 1
0.42667	1015.008	0.3648	12755	Speed 1
0.42833	1002.276	0.366	12595	Speed 1
0.43	961.2937	0.3693	12080	Speed 1
0.43167	936.7043	0.3733	11771	Speed 1
0.43333	939.5691	0.3768	11807	Speed 1
0.435	951.824	0.38	11961	Speed 1
0.43667	968.376	0.383	12169	Speed 1
0.43833	984.2915	0.3858	12369	Speed 1
0.44	1002.833	0.3883	12602	Speed 1
0.44167	1020.499	0.3905	12824	Speed 1
0.44333	1036.017	0.3925	13019	Speed 1
0.445	1047.396	0.3943	13162	Speed 1
0.44667	1045.884	0.3965	13143	Speed 1
0.44833	991.0556	0.4015	12454	Speed 1
0.45	962.169	0.4073	12091	Speed 1
0.45167	964.238	0.4125	12117	Speed 1
0.45333	983.6549	0.4173	12361	Speed 1
0.455	974.9014	0.4225	12251	Speed 1
0.45667	917.7649	0.4295	11533	Speed 1
0.45833	917.1283	0.437	11525	Speed 1
0.46	936.943	0.444	11774	Speed 1
0.46167	976.8908	0.4505	12276	Speed 1
0.46333	1016.6	0.456	12775	Speed 1
0.465	1057.423	0.4608	13288	Speed 1
0.46667	1095.222	0.4648	13763	Speed 1
0.46833	1128.247	0.468	14178	Speed 1
0.47	1154.587	0.471	14509	Speed 1
0.47167	1174.879	0.4732	14764	Speed 1
0.47333	1186.338	0.4755	14908	Speed 1
0.475	684.2851	0.4825	8599	Speed 1
0.47667	303.5874	0.491	3815	Speed 1
0.47833	104.8829	0.499	1318	Speed 1

Partner Data Point File
Start of Test Thu 05 Oct 2023 10:22:01
28-day normal cement pervious concrete test
Compressive strength = 1079.8 psi

Time (min)	Stress (psi)	Position (in)	Load (lbf)	Zone
0	0	0	0	Speed 1
0.00167	4.2972	0.008	54	Speed 1
0.00333	8.4352	0.016	106	Speed 1
0.005	15.1197	0.024	190	Speed 1
0.00667	22.4408	0.032	282	Speed 1
0.00833	29.2844	0.04	368	Speed 1
0.01	37.5605	0.048	472	Speed 1
0.01167	47.1098	0.056	592	Speed 1
0.01333	57.4548	0.064	722	Speed 1
0.015	69.0731	0.072	868	Speed 1
0.01667	82.84	0.08	1041	Speed 1
0.01833	98.4371	0.088	1237	Speed 1
0.02	114.5117	0.096	1439	Speed 1
0.02167	131.3821	0.1037	1651	Speed 1
0.02333	149.7645	0.1115	1882	Speed 1
0.025	169.3405	0.119	2128	Speed 1
0.02667	189.951	0.1265	2387	Speed 1
0.02833	211.9143	0.134	2663	Speed 1
0.03	234.6734	0.141	2949	Speed 1
0.03167	257.6713	0.1475	3238	Speed 1
0.03333	279.7937	0.1533	3516	Speed 1
0.035	300.2451	0.158	3773	Speed 1
0.03667	318.5479	0.1623	4003	Speed 1
0.03833	334.5429	0.166	4204	Speed 1
0.04	348.1506	0.1688	4375	Speed 1
0.04167	359.0527	0.1712	4512	Speed 1
0.04333	367.4083	0.173	4617	Speed 1
0.045	372.5013	0.1742	4681	Speed 1
0.04667	375.2069	0.1752	4715	Speed 1
0.04833	376.5597	0.176	4732	Speed 1
0.05	376.321	0.1763	4729	Speed 1
0.05167	374.7294	0.1763	4709	Speed 1
0.05333	372.3421	0.1765	4679	Speed 1
0.055	369.7161	0.1765	4646	Speed 1
0.05667	367.1696	0.1765	4614	Speed 1
0.05833	364.7027	0.1765	4583	Speed 1
0.06	362.2358	0.1765	4552	Speed 1
0.06167	359.7689	0.1765	4521	Speed 1
0.06333	357.2224	0.1765	4489	Speed 1
0.065	354.7556	0.1765	4458	Speed 1
0.06667	352.2887	0.1765	4427	Speed 1
0.06833	349.7422	0.1763	4395	Speed 1
0.07	347.0366	0.176	4361	Speed 1
0.07167	344.3309	0.176	4327	Speed 1
0.07333	341.5457	0.1758	4292	Speed 1
0.075	338.7605	0.1755	4257	Speed 1
0.07667	335.8957	0.1752	4221	Speed 1

0.07833	333.1105	0.175	4186	Speed 1
0.08	330.4049	0.1747	4152	Speed 1
0.08167	327.8584	0.1747	4120	Speed 1
0.08333	325.2324	0.1745	4087	Speed 1
0.085	322.9246	0.1742	4058	Speed 1
0.08667	320.7761	0.174	4031	Speed 1
0.08833	318.7866	0.174	4006	Speed 1
0.09	316.8768	0.1738	3982	Speed 1
0.09167	315.2056	0.1738	3961	Speed 1
0.09333	313.8528	0.1735	3944	Speed 1
0.095	312.5796	0.1735	3928	Speed 1
0.09667	311.4655	0.1735	3914	Speed 1
0.09833	310.5106	0.1733	3902	Speed 1
0.1	309.6352	0.1733	3891	Speed 1
0.10167	308.919	0.1733	3882	Speed 1
0.10333	308.2824	0.1733	3874	Speed 1
0.105	307.8845	0.1733	3869	Speed 1
0.10667	307.5662	0.1733	3865	Speed 1
0.10833	307.3275	0.1733	3862	Speed 1
0.11	307.1683	0.1733	3860	Speed 1
0.11167	307.2479	0.1733	3861	Speed 1
0.11333	307.7254	0.1733	3867	Speed 1
0.115	308.8395	0.1733	3881	Speed 1
0.11667	310.7493	0.1735	3905	Speed 1
0.11833	313.4549	0.174	3939	Speed 1
0.12	317.0359	0.1745	3984	Speed 1
0.12167	321.3331	0.175	4038	Speed 1
0.12333	326.1077	0.1758	4098	Speed 1
0.125	331.1211	0.1765	4161	Speed 1
0.12667	336.214	0.177	4225	Speed 1
0.12833	341.3866	0.178	4290	Speed 1
0.13	346.4795	0.1787	4354	Speed 1
0.13167	351.7316	0.1795	4420	Speed 1
0.13333	356.9837	0.1803	4486	Speed 1
0.135	362.0767	0.181	4550	Speed 1
0.13667	367.09	0.182	4613	Speed 1
0.13833	372.2626	0.1827	4678	Speed 1
0.14	377.4351	0.1838	4743	Speed 1
0.14167	382.3689	0.1845	4805	Speed 1
0.14333	387.2231	0.1855	4866	Speed 1
0.145	391.9977	0.1862	4926	Speed 1
0.14667	396.7724	0.1873	4986	Speed 1
0.14833	401.4674	0.188	5045	Speed 1
0.15	406.0033	0.189	5102	Speed 1
0.15167	410.6188	0.19	5160	Speed 1
0.15333	415.2343	0.1908	5218	Speed 1
0.155	419.6906	0.1918	5274	Speed 1
0.15667	424.0674	0.1925	5329	Speed 1
0.15833	428.5237	0.1935	5385	Speed 1
0.16	433.0596	0.1943	5442	Speed 1
0.16167	437.4364	0.195	5497	Speed 1
0.16333	441.7335	0.196	5551	Speed 1

0.165	445.9511	0.1967	5604	Speed 1
0.16667	450.2483	0.1975	5658	Speed 1
0.16833	454.3863	0.1985	5710	Speed 1
0.17	458.6039	0.1993	5763	Speed 1
0.17167	462.7419	0.2	5815	Speed 1
0.17333	466.88	0.2007	5867	Speed 1
0.175	470.7792	0.2015	5916	Speed 1
0.17667	474.599	0.2023	5964	Speed 1
0.17833	478.4982	0.203	6013	Speed 1
0.18	482.2384	0.2037	6060	Speed 1
0.18167	485.9785	0.2045	6107	Speed 1
0.18333	489.6391	0.2053	6153	Speed 1
0.185	493.2996	0.206	6199	Speed 1
0.18667	496.9602	0.2065	6245	Speed 1
0.18833	500.382	0.2073	6288	Speed 1
0.19	503.8038	0.208	6331	Speed 1
0.19167	507.2256	0.2085	6374	Speed 1
0.19333	510.6475	0.2093	6417	Speed 1
0.195	513.9897	0.21	6459	Speed 1
0.19667	517.332	0.2105	6501	Speed 1
0.19833	520.7538	0.2112	6544	Speed 1
0.2	524.2552	0.2117	6588	Speed 1
0.20167	527.677	0.2125	6631	Speed 1
0.20333	530.9397	0.2133	6672	Speed 1
0.205	534.3615	0.2138	6715	Speed 1
0.20667	537.8629	0.2145	6759	Speed 1
0.20833	541.3643	0.215	6803	Speed 1
0.21	544.7861	0.2157	6846	Speed 1
0.21167	548.2079	0.2163	6889	Speed 1
0.21333	551.7093	0.217	6933	Speed 1
0.215	554.972	0.2175	6974	Speed 1
0.21667	558.3143	0.2183	7016	Speed 1
0.21833	561.179	0.219	7052	Speed 1
0.22	564.4417	0.2195	7093	Speed 1
0.22167	568.0227	0.2203	7138	Speed 1
0.22333	571.4445	0.2208	7181	Speed 1
0.225	575.1051	0.2215	7227	Speed 1
0.22667	578.7656	0.222	7273	Speed 1
0.22833	582.267	0.2227	7317	Speed 1
0.23	585.9276	0.2235	7363	Speed 1
0.23167	589.2698	0.224	7405	Speed 1
0.23333	592.6121	0.2248	7447	Speed 1
0.235	596.1135	0.2253	7491	Speed 1
0.23667	599.774	0.226	7537	Speed 1
0.23833	603.355	0.2265	7582	Speed 1
0.24	606.936	0.2273	7627	Speed 1
0.24167	610.517	0.2278	7672	Speed 1
0.24333	614.1775	0.2285	7718	Speed 1
0.245	617.7585	0.229	7763	Speed 1
0.24667	620.9416	0.2297	7803	Speed 1
0.24833	624.3634	0.2302	7846	Speed 1
0.25	628.024	0.231	7892	Speed 1

0.25167	631.6049	0.2315	7937	Speed 1
0.25333	635.1063	0.232	7981	Speed 1
0.255	638.6873	0.2328	8026	Speed 1
0.25667	642.2683	0.2333	8071	Speed 1
0.25833	644.9739	0.234	8105	Speed 1
0.26	645.0535	0.2348	8106	Speed 1
0.26167	642.6662	0.2358	8076	Speed 1
0.26333	620.7029	0.238	7800	Speed 1
0.265	604.9465	0.2407	7602	Speed 1
0.26667	604.7874	0.2435	7600	Speed 1
0.26833	613.7001	0.246	7712	Speed 1
0.27	627.4669	0.2482	7885	Speed 1
0.27167	639.4831	0.2503	8036	Speed 1
0.27333	650.5443	0.2522	8175	Speed 1
0.275	662.7992	0.254	8329	Speed 1
0.27667	674.4971	0.2555	8476	Speed 1
0.27833	682.6936	0.257	8579	Speed 1
0.28	690.1738	0.2585	8673	Speed 1
0.28167	698.3703	0.2597	8776	Speed 1
0.28333	706.1689	0.261	8874	Speed 1
0.285	712.535	0.262	8954	Speed 1
0.28667	718.2646	0.263	9026	Speed 1
0.28833	723.4371	0.264	9091	Speed 1
0.29	727.8935	0.265	9147	Speed 1
0.29167	731.7927	0.2658	9196	Speed 1
0.29333	735.5329	0.2665	9243	Speed 1
0.295	739.0343	0.2672	9287	Speed 1
0.29667	742.4561	0.268	9330	Speed 1
0.29833	745.6392	0.2688	9370	Speed 1
0.3	748.4244	0.2695	9405	Speed 1
0.30167	750.0159	0.2703	9425	Speed 1
0.30333	751.2892	0.271	9441	Speed 1
0.305	754.0744	0.2718	9476	Speed 1
0.30667	757.0983	0.2723	9514	Speed 1
0.30833	760.2814	0.273	9554	Speed 1
0.31	763.6237	0.2738	9596	Speed 1
0.31167	767.1251	0.2742	9640	Speed 1
0.31333	770.3877	0.2747	9681	Speed 1
0.315	773.5708	0.2755	9721	Speed 1
0.31667	776.356	0.276	9756	Speed 1
0.31833	779.1412	0.2765	9791	Speed 1
0.32	782.006	0.2773	9827	Speed 1
0.32167	784.5525	0.2777	9859	Speed 1
0.32333	763.5441	0.2793	9595	Speed 1
0.325	742.1378	0.282	9326	Speed 1
0.32667	738.8751	0.2848	9285	Speed 1
0.32833	740.9441	0.2873	9311	Speed 1
0.33	749.061	0.2895	9413	Speed 1
0.33167	759.3265	0.2918	9542	Speed 1
0.33333	763.0666	0.2943	9589	Speed 1
0.335	742.4561	0.2983	9330	Speed 1
0.33667	745.2413	0.3018	9365	Speed 1

0.33833	761.2363	0.3047	9566	Speed 1
0.34	780.0962	0.3075	9803	Speed 1
0.34167	795.7729	0.31	10000	Speed 1
0.34333	811.9271	0.312	10203	Speed 1
0.345	827.5242	0.3138	10399	Speed 1
0.34667	841.2115	0.3155	10571	Speed 1
0.34833	852.6707	0.317	10715	Speed 1
0.35	853.7052	0.3185	10728	Speed 1
0.35167	860.3897	0.32	10812	Speed 1
0.35333	868.3474	0.3213	10912	Speed 1
0.355	875.7481	0.3222	11005	Speed 1
0.35667	882.0347	0.3232	11084	Speed 1
0.35833	887.4459	0.3243	11152	Speed 1
0.36	891.9023	0.325	11208	Speed 1
0.36167	895.5628	0.3255	11254	Speed 1
0.36333	898.4276	0.3262	11290	Speed 1
0.365	899.86	0.3267	11308	Speed 1
0.36667	901.8494	0.3273	11333	Speed 1
0.36833	904.0776	0.3278	11361	Speed 1
0.37	906.3853	0.3283	11390	Speed 1
0.37167	908.5339	0.3288	11417	Speed 1
0.37333	910.5234	0.3293	11442	Speed 1
0.375	912.4332	0.3295	11466	Speed 1
0.37667	914.3431	0.33	11490	Speed 1
0.37833	916.3325	0.3305	11515	Speed 1
0.38	918.0036	0.3308	11536	Speed 1
0.38167	919.5952	0.3313	11556	Speed 1
0.38333	921.6642	0.3318	11582	Speed 1
0.385	923.8923	0.3323	11610	Speed 1
0.38667	926.2797	0.3325	11640	Speed 1
0.38833	928.9057	0.333	11673	Speed 1
0.39	931.6113	0.3332	11707	Speed 1
0.39167	934.3965	0.3337	11742	Speed 1
0.39333	937.1817	0.334	11777	Speed 1
0.395	940.0465	0.3345	11813	Speed 1
0.39667	942.9113	0.3348	11849	Speed 1
0.39833	945.6965	0.3353	11884	Speed 1
0.4	948.3226	0.3355	11917	Speed 1
0.40167	950.9486	0.336	11950	Speed 1
0.40333	953.4951	0.3365	11982	Speed 1
0.405	956.2007	0.3368	12016	Speed 1
0.40667	959.0655	0.3372	12052	Speed 1
0.40833	962.2486	0.3377	12092	Speed 1
0.41	965.5908	0.338	12134	Speed 1
0.41167	968.7739	0.3385	12174	Speed 1
0.41333	972.0366	0.339	12215	Speed 1
0.415	975.2197	0.3393	12255	Speed 1
0.41667	978.4028	0.3398	12295	Speed 1
0.41833	981.745	0.3403	12337	Speed 1
0.42	985.0873	0.3407	12379	Speed 1
0.42167	988.4295	0.341	12421	Speed 1
0.42333	991.6126	0.3415	12461	Speed 1

0.425	978.2436	0.3425	12293	Speed 1
0.42667	949.4366	0.3452	11931	Speed 1
0.42833	952.381	0.3473	11968	Speed 1
0.43	965.5113	0.349	12133	Speed 1
0.43167	980.5514	0.3503	12322	Speed 1
0.43333	995.2732	0.3515	12507	Speed 1
0.435	1008.403	0.3525	12672	Speed 1
0.43667	1018.589	0.3533	12800	Speed 1
0.43833	1026.945	0.354	12905	Speed 1
0.44	1033.709	0.3548	12990	Speed 1
0.44167	1039.518	0.3553	13063	Speed 1
0.44333	1044.452	0.356	13125	Speed 1
0.445	1048.67	0.3565	13178	Speed 1
0.44667	1052.728	0.357	13229	Speed 1
0.44833	1056.468	0.3575	13276	Speed 1
0.45	1059.89	0.358	13319	Speed 1
0.45167	1060.447	0.3585	13326	Speed 1
0.45333	1059.731	0.3592	13317	Speed 1
0.455	1062.993	0.3597	13358	Speed 1
0.45667	1067.45	0.3602	13414	Speed 1
0.45833	1071.508	0.3608	13465	Speed 1
0.46	1074.85	0.3613	13507	Speed 1
0.46167	1077.477	0.3618	13540	Speed 1
0.46333	1079.784	0.3623	13569	Speed 1
0.465	1079.625	0.363	13567	Speed 1
0.46667	1015.804	0.366	12765	Speed 1
0.46833	978.8802	0.3707	12301	Speed 1
0.47	962.8056	0.3763	12099	Speed 1
0.47167	689.2189	0.3835	8661	Speed 1
0.47333	549.4812	0.3915	6905	Speed 1
0.475	491.3102	0.3993	6174	Speed 1
0.47667	480.4081	0.4072	6037	Speed 1
0.47833	490.1961	0.4152	6160	Speed 1
0.48	510.8862	0.4233	6420	Speed 1
0.48167	531.9742	0.4313	6685	Speed 1
0.48333	559.4283	0.4393	7030	Speed 1
0.485	584.4952	0.4475	7345	Speed 1
0.48667	610.4374	0.4555	7671	Speed 1
0.48833	635.6634	0.4635	7988	Speed 1
0.49	670.5978	0.4715	8427	Speed 1
0.49167	708.4766	0.4795	8903	Speed 1
0.49333	675.1337	0.4878	8484	Speed 1
0.495	654.7619	0.496	8228	Speed 1
0.49667	633.5148	0.5045	7961	Speed 1
0.49833	542.6375	0.5125	6819	Speed 1
0.5	483.9891	0.5208	6082	Speed 1
0.50167	462.9011	0.5288	5817	Speed 1
0.50333	464.4926	0.5368	5837	Speed 1
0.505	473.087	0.5447	5945	Speed 1
0.50667	486.8539	0.553	6118	Speed 1
0.50833	507.4644	0.561	6377	Speed 1
0.51	528.0749	0.5693	6636	Speed 1

0.51167	540.1706	0.5773	6788	Speed 1
0.51333	555.1312	0.5855	6976	Speed 1
0.515	569.2163	0.5938	7153	Speed 1
0.51667	575.1051	0.6023	7227	Speed 1
0.51833	573.4339	0.6105	7206	Speed 1
0.52	578.3677	0.6185	7268	Speed 1
0.52167	583.6994	0.6265	7335	Speed 1
0.52333	586.1663	0.6345	7366	Speed 1
0.525	584.4952	0.6428	7345	Speed 1
0.52667	583.1424	0.6508	7328	Speed 1
0.52833	581.7896	0.6588	7311	Speed 1
0.53	576.4579	0.667	7244	Speed 1
0.53167	565.7945	0.675	7110	Speed 1
0.53333	566.829	0.683	7123	Speed 1
0.535	572.3994	0.691	7193	Speed 1
0.53667	566.9882	0.6993	7125	Speed 1
0.53833	566.7495	0.7072	7122	Speed 1
0.54	572.2403	0.7152	7191	Speed 1
0.54167	580.6755	0.7233	7297	Speed 1

Partner Data Point File
Start of Test Wed 11 Oct 2023 15:48:41
7-day rapid-set cement pervious concrete test
Compressive strength = 937.4 psi

Time (min)	Stress (psi)	Position (in)	Load (lbf)	Zone
0	0	0	0	Speed 1
0.00167	5.8091	0.0077	73	Speed 1
0.00333	12.8119	0.0155	161	Speed 1
0.005	24.9077	0.023	313	Speed 1
0.00667	40.4253	0.0305	508	Speed 1
0.00833	58.0118	0.038	729	Speed 1
0.01	76.9512	0.0453	967	Speed 1
0.01167	96.5273	0.052	1213	Speed 1
0.01333	115.6258	0.0585	1453	Speed 1
0.015	120.5596	0.0648	1515	Speed 1
0.01667	112.2836	0.0718	1411	Speed 1
0.01833	114.4321	0.0785	1438	Speed 1
0.02	122.9469	0.085	1545	Speed 1
0.02167	129.9497	0.0913	1633	Speed 1
0.02333	136.0772	0.0973	1710	Speed 1
0.025	145.3877	0.103	1827	Speed 1
0.02667	156.2102	0.1085	1963	Speed 1
0.02833	169.1017	0.1135	2125	Speed 1
0.03	181.4362	0.118	2280	Speed 1
0.03167	186.7679	0.1222	2347	Speed 1
0.03333	195.7601	0.1262	2460	Speed 1
0.035	204.7524	0.1297	2573	Speed 1
0.03667	211.1186	0.133	2653	Speed 1
0.03833	215.5749	0.1363	2709	Speed 1
0.04	221.7023	0.139	2786	Speed 1
0.04167	229.3417	0.1413	2882	Speed 1
0.04333	236.4241	0.1433	2971	Speed 1
0.045	242.7903	0.145	3051	Speed 1
0.04667	248.122	0.1463	3118	Speed 1
0.04833	250.4297	0.1475	3147	Speed 1
0.05	251.703	0.1485	3163	Speed 1
0.05167	252.7375	0.1493	3176	Speed 1
0.05333	252.4987	0.15	3173	Speed 1
0.055	251.703	0.1505	3163	Speed 1
0.05667	250.9072	0.151	3153	Speed 1
0.05833	250.1114	0.1513	3143	Speed 1
0.06	249.2361	0.1515	3132	Speed 1
0.06167	248.3607	0.1518	3121	Speed 1
0.06333	247.4854	0.1518	3110	Speed 1
0.065	246.61	0.152	3099	Speed 1
0.06667	245.8142	0.152	3089	Speed 1
0.06833	244.9389	0.1523	3078	Speed 1
0.07	243.984	0.1523	3066	Speed 1
0.07167	243.1882	0.1523	3056	Speed 1
0.07333	242.5516	0.1525	3048	Speed 1
0.075	241.9945	0.1525	3041	Speed 1
0.07667	241.5967	0.1528	3036	Speed 1

0.07833	241.3579	0.1528	3033	Speed 1
0.08	241.3579	0.153	3033	Speed 1
0.08167	241.3579	0.153	3033	Speed 1
0.08333	241.5967	0.1533	3036	Speed 1
0.085	241.915	0.1535	3040	Speed 1
0.08667	242.472	0.1535	3047	Speed 1
0.08833	243.2678	0.1538	3057	Speed 1
0.09	244.3023	0.154	3070	Speed 1
0.09167	245.4959	0.1545	3085	Speed 1
0.09333	246.8488	0.1548	3102	Speed 1
0.095	248.4403	0.155	3122	Speed 1
0.09667	250.1114	0.1555	3143	Speed 1
0.09833	252.0213	0.156	3167	Speed 1
0.1	254.0903	0.1565	3193	Speed 1
0.10167	256.1593	0.157	3219	Speed 1
0.10333	258.3875	0.1578	3247	Speed 1
0.105	260.6952	0.1583	3276	Speed 1
0.10667	263.1621	0.159	3307	Speed 1
0.10833	266.1065	0.1598	3344	Speed 1
0.11	269.4487	0.1605	3386	Speed 1
0.11167	272.9501	0.1613	3430	Speed 1
0.11333	276.3719	0.1623	3473	Speed 1
0.115	279.6346	0.163	3514	Speed 1
0.11667	283.3747	0.1638	3561	Speed 1
0.11833	287.1149	0.1648	3608	Speed 1
0.12	290.855	0.1655	3655	Speed 1
0.12167	294.8339	0.1665	3705	Speed 1
0.12333	297.3008	0.1673	3736	Speed 1
0.125	300.3247	0.1683	3774	Speed 1
0.12667	303.9057	0.1693	3819	Speed 1
0.12833	306.85	0.1705	3856	Speed 1
0.13	310.7493	0.1715	3905	Speed 1
0.13167	315.2056	0.1725	3961	Speed 1
0.13333	319.5824	0.1735	4016	Speed 1
0.135	324.1183	0.1745	4073	Speed 1
0.13667	328.8134	0.1755	4132	Speed 1
0.13833	333.4288	0.1765	4190	Speed 1
0.14	335.8162	0.1775	4220	Speed 1
0.14167	338.6014	0.1785	4255	Speed 1
0.14333	341.307	0.1795	4289	Speed 1
0.145	344.8084	0.1808	4333	Speed 1
0.14667	348.2302	0.1817	4376	Speed 1
0.14833	352.2887	0.183	4427	Speed 1
0.15	357.0633	0.184	4487	Speed 1
0.15167	361.9175	0.185	4548	Speed 1
0.15333	366.6921	0.1863	4608	Speed 1
0.155	371.5464	0.1873	4669	Speed 1
0.15667	375.8435	0.1883	4723	Speed 1
0.15833	379.5837	0.1893	4770	Speed 1
0.16	383.1646	0.1903	4815	Speed 1
0.16167	386.109	0.1913	4852	Speed 1
0.16333	388.7351	0.1925	4885	Speed 1

0.165	391.5203	0.1935	4920	Speed 1
0.16667	394.6238	0.1945	4959	Speed 1
0.16833	397.8864	0.1958	5000	Speed 1
0.17	400.6716	0.1968	5035	Speed 1
0.17167	403.616	0.198	5072	Speed 1
0.17333	405.2871	0.1993	5093	Speed 1
0.175	402.6611	0.2008	5060	Speed 1
0.17667	384.9153	0.203	4837	Speed 1
0.17833	369.3182	0.2065	4641	Speed 1
0.18	370.3527	0.2095	4654	Speed 1
0.18167	373.6154	0.2125	4695	Speed 1
0.18333	378.8675	0.2158	4761	Speed 1
0.185	391.1224	0.2185	4915	Speed 1
0.18667	405.6054	0.2213	5097	Speed 1
0.18833	419.2132	0.2235	5268	Speed 1
0.19	428.285	0.226	5382	Speed 1
0.19167	439.0279	0.2283	5517	Speed 1
0.19333	446.9061	0.2303	5616	Speed 1
0.195	454.1476	0.2323	5707	Speed 1
0.19667	462.4236	0.2343	5811	Speed 1
0.19833	470.9384	0.236	5918	Speed 1
0.2	478.1004	0.2378	6008	Speed 1
0.20167	485.2623	0.2393	6098	Speed 1
0.20333	491.4693	0.2407	6176	Speed 1
0.205	498.313	0.242	6262	Speed 1
0.20667	504.9179	0.2433	6345	Speed 1
0.20833	510.2496	0.2443	6412	Speed 1
0.21	513.9101	0.2453	6458	Speed 1
0.21167	517.0136	0.2463	6497	Speed 1
0.21333	519.8784	0.2473	6533	Speed 1
0.215	518.8439	0.2482	6520	Speed 1
0.21667	517.4115	0.2495	6502	Speed 1
0.21833	520.2763	0.2505	6538	Speed 1
0.22	524.7326	0.2515	6594	Speed 1
0.22167	529.5073	0.2525	6654	Speed 1
0.22333	534.2023	0.2533	6713	Speed 1
0.225	538.4995	0.254	6767	Speed 1
0.22667	542.4784	0.2548	6817	Speed 1
0.22833	545.741	0.2555	6858	Speed 1
0.23	548.6058	0.256	6894	Speed 1
0.23167	551.2319	0.2565	6927	Speed 1
0.23333	553.3805	0.2573	6954	Speed 1
0.235	555.8474	0.2578	6985	Speed 1
0.23667	558.4734	0.2585	7018	Speed 1
0.23833	561.0199	0.259	7050	Speed 1
0.24	561.2586	0.2598	7053	Speed 1
0.24167	563.1685	0.2603	7077	Speed 1
0.24333	565.8741	0.261	7111	Speed 1
0.245	567.8635	0.2618	7136	Speed 1
0.24667	570.2509	0.2623	7166	Speed 1
0.24833	573.1952	0.263	7203	Speed 1
0.25	576.4579	0.2638	7244	Speed 1

0.25167	580.198	0.2643	7291	Speed 1
0.25333	584.0177	0.265	7339	Speed 1
0.255	587.5987	0.2655	7384	Speed 1
0.25667	590.4635	0.2663	7420	Speed 1
0.25833	591.1001	0.267	7428	Speed 1
0.26	591.8163	0.2678	7437	Speed 1
0.26167	593.567	0.2685	7459	Speed 1
0.26333	596.7501	0.2695	7499	Speed 1
0.265	601.2064	0.2703	7555	Speed 1
0.26667	603.1958	0.271	7580	Speed 1
0.26833	604.5487	0.272	7597	Speed 1
0.27	608.6867	0.273	7649	Speed 1
0.27167	613.3022	0.2738	7707	Speed 1
0.27333	617.9176	0.2748	7765	Speed 1
0.275	623.3289	0.2755	7833	Speed 1
0.27667	629.2972	0.2763	7908	Speed 1
0.27833	634.9472	0.277	7979	Speed 1
0.28	640.0401	0.2775	8043	Speed 1
0.28167	644.576	0.278	8100	Speed 1
0.28333	648.3957	0.2788	8148	Speed 1
0.285	652.0563	0.2793	8194	Speed 1
0.28667	655.7169	0.2798	8240	Speed 1
0.28833	659.2978	0.2803	8285	Speed 1
0.29	662.7992	0.2808	8329	Speed 1
0.29167	666.1415	0.2813	8371	Speed 1
0.29333	669.1654	0.2815	8409	Speed 1
0.295	672.1098	0.282	8446	Speed 1
0.29667	674.895	0.2825	8481	Speed 1
0.29833	677.521	0.283	8514	Speed 1
0.3	680.0675	0.2835	8546	Speed 1
0.30167	681.3407	0.2843	8562	Speed 1
0.30333	683.8076	0.2848	8593	Speed 1
0.305	686.3541	0.2852	8625	Speed 1
0.30667	690.6513	0.286	8679	Speed 1
0.30833	695.4259	0.2865	8739	Speed 1
0.31	699.9618	0.2868	8796	Speed 1
0.31167	704.4182	0.2873	8852	Speed 1
0.31333	708.7153	0.2878	8906	Speed 1
0.315	712.4555	0.2883	8953	Speed 1
0.31667	716.0364	0.2885	8998	Speed 1
0.31833	719.5378	0.289	9042	Speed 1
0.32	722.9597	0.2895	9085	Speed 1
0.32167	726.3019	0.2898	9127	Speed 1
0.32333	729.6442	0.2903	9169	Speed 1
0.325	732.9864	0.2908	9211	Speed 1
0.32667	736.2491	0.291	9252	Speed 1
0.32833	739.5913	0.2915	9294	Speed 1
0.33	742.9336	0.2918	9336	Speed 1
0.33167	746.2758	0.2923	9378	Speed 1
0.33333	749.5385	0.2925	9419	Speed 1
0.335	752.8807	0.293	9461	Speed 1
0.33667	756.1434	0.2933	9502	Speed 1

0.33833	759.3265	0.2938	9542	Speed 1
0.34	762.6687	0.294	9584	Speed 1
0.34167	766.011	0.2945	9626	Speed 1
0.34333	769.1145	0.295	9665	Speed 1
0.345	772.2976	0.2953	9705	Speed 1
0.34667	775.5602	0.2958	9746	Speed 1
0.34833	778.7433	0.296	9786	Speed 1
0.35	781.3694	0.2965	9819	Speed 1
0.35167	784.3933	0.297	9857	Speed 1
0.35333	787.7356	0.2975	9899	Speed 1
0.355	791.3961	0.2978	9945	Speed 1
0.35667	795.2158	0.2983	9993	Speed 1
0.35833	798.8764	0.2988	10039	Speed 1
0.36	802.5369	0.299	10085	Speed 1
0.36167	806.1179	0.2995	10130	Speed 1
0.36333	809.6989	0.3	10175	Speed 1
0.365	812.9616	0.3003	10216	Speed 1
0.36667	816.3038	0.3008	10258	Speed 1
0.36833	819.7256	0.3013	10301	Speed 1
0.37	823.0679	0.3015	10343	Speed 1
0.37167	826.4101	0.302	10385	Speed 1
0.37333	829.4341	0.3025	10423	Speed 1
0.375	832.0601	0.303	10456	Speed 1
0.37667	834.4474	0.3035	10486	Speed 1
0.37833	837.4714	0.304	10524	Speed 1
0.38	841.0524	0.3045	10569	Speed 1
0.38167	845.0312	0.305	10619	Speed 1
0.38333	849.3284	0.3055	10673	Speed 1
0.385	853.6256	0.306	10727	Speed 1
0.38667	857.6045	0.3065	10777	Speed 1
0.38833	861.6629	0.307	10828	Speed 1
0.39	865.7213	0.3073	10879	Speed 1
0.39167	869.6206	0.3078	10928	Speed 1
0.39333	873.3608	0.3083	10975	Speed 1
0.395	876.9417	0.3088	11020	Speed 1
0.39667	880.4431	0.309	11064	Speed 1
0.39833	883.9445	0.3095	11108	Speed 1
0.4	887.5255	0.31	11153	Speed 1
0.40167	890.7086	0.3105	11193	Speed 1
0.40333	893.8121	0.311	11232	Speed 1
0.405	897.0748	0.3115	11273	Speed 1
0.40667	900.1783	0.3118	11312	Speed 1
0.40833	902.1677	0.3125	11337	Speed 1
0.41	904.7142	0.313	11369	Speed 1
0.41167	908.0565	0.3135	11411	Speed 1
0.41333	911.4783	0.314	11454	Speed 1
0.415	914.6614	0.3145	11494	Speed 1
0.41667	916.8895	0.3153	11522	Speed 1
0.41833	917.367	0.316	11528	Speed 1
0.42	917.6853	0.317	11532	Speed 1
0.42167	919.993	0.3178	11561	Speed 1
0.42333	923.4944	0.3188	11605	Speed 1

0.425	927.7916	0.3198	11659	Speed 1
0.42667	931.9296	0.3205	11711	Speed 1
0.42833	934.7148	0.3218	11746	Speed 1
0.43	936.943	0.3228	11774	Speed 1
0.43167	937.1817	0.324	11777	Speed 1
0.43333	937.4205	0.3253	11780	Speed 1
0.435	908.5339	0.328	11417	Speed 1
0.43667	829.5136	0.3343	10424	Speed 1
0.43833	738.4772	0.3425	9280	Speed 1
0.44	710.3865	0.3503	8927	Speed 1
0.44167	709.7498	0.358	8919	Speed 1
0.44333	719.3787	0.3658	9040	Speed 1
0.445	733.623	0.3738	9219	Speed 1
0.44667	747.549	0.3815	9394	Speed 1
0.44833	756.1434	0.3898	9502	Speed 1
0.45	740.6258	0.398	9307	Speed 1
0.45167	702.19	0.4063	8824	Speed 1
0.45333	682.5344	0.4143	8577	Speed 1
0.455	618.5543	0.4225	7773	Speed 1
0.45667	605.7423	0.4305	7612	Speed 1
0.45833	593.4078	0.4388	7457	Speed 1
0.46	599.0578	0.4465	7528	Speed 1
0.46167	616.5648	0.4548	7748	Speed 1
0.46333	638.6077	0.4628	8025	Speed 1
0.465	662.3218	0.4708	8323	Speed 1
0.46667	656.5922	0.479	8251	Speed 1
0.46833	669.4837	0.487	8413	Speed 1
0.47	682.5344	0.4953	8577	Speed 1
0.47167	654.6824	0.5033	8227	Speed 1
0.47333	635.6634	0.5115	7988	Speed 1
0.475	605.0261	0.5195	7603	Speed 1
0.47667	542.9558	0.5278	6823	Speed 1
0.47833	459.9567	0.5363	5780	Speed 1
0.48	389.3717	0.5443	4893	Speed 1
0.48167	339.0788	0.5525	4261	Speed 1
0.48333	264.4353	0.5608	3323	Speed 1
0.485	230.6946	0.5688	2899	Speed 1
0.48667	222.3389	0.5768	2794	Speed 1
0.48833	222.6573	0.585	2798	Speed 1
0.49	215.5749	0.5933	2709	Speed 1
0.49167	202.2855	0.6013	2542	Speed 1
0.49333	181.1179	0.6095	2276	Speed 1
0.495	147.4567	0.6178	1853	Speed 1
0.49667	129.8701	0.6258	1632	Speed 1
0.49833	119.0476	0.634	1496	Speed 1
0.5	110.7716	0.642	1392	Speed 1

Partner Data Point File
Start of Test Wed 11 Oct 2023 15:52:33
7-day rapid-set cement pervious concrete test
Compressive strength = 685.3 psi

Time (min)	Stress (psi)	Position (in)	Load (lbf)	Zone
0	0	0	0	Speed 1
0.00167	5.65	0.008	71	Speed 1
0.00333	12.1753	0.016	153	Speed 1
0.005	15.7563	0.0242	198	Speed 1
0.00667	21.4063	0.0323	269	Speed 1
0.00833	28.7274	0.0403	361	Speed 1
0.01	37.4013	0.0482	470	Speed 1
0.01167	47.5076	0.0562	597	Speed 1
0.01333	59.5238	0.0642	748	Speed 1
0.015	73.2907	0.0722	921	Speed 1
0.01667	89.1266	0.0803	1120	Speed 1
0.01833	106.4744	0.088	1338	Speed 1
0.02	125.3342	0.0958	1575	Speed 1
0.02167	129.3927	0.1037	1626	Speed 1
0.02333	138.2258	0.1115	1737	Speed 1
0.025	154.4595	0.119	1941	Speed 1
0.02667	174.8313	0.1265	2197	Speed 1
0.02833	197.5108	0.134	2482	Speed 1
0.03	221.8615	0.141	2788	Speed 1
0.03167	246.7692	0.1475	3101	Speed 1
0.03333	270.5628	0.153	3400	Speed 1
0.035	292.6853	0.1578	3678	Speed 1
0.03667	312.4204	0.1618	3926	Speed 1
0.03833	329.2908	0.1653	4138	Speed 1
0.04	343.376	0.1677	4315	Speed 1
0.04167	353.5619	0.17	4443	Speed 1
0.04333	360.0872	0.1715	4525	Speed 1
0.045	346.0816	0.1735	4349	Speed 1
0.04667	325.9486	0.1763	4096	Speed 1
0.04833	321.0148	0.1782	4034	Speed 1
0.05	322.4472	0.18	4052	Speed 1
0.05167	325.5507	0.1813	4091	Speed 1
0.05333	328.5746	0.1822	4129	Speed 1
0.055	330.8028	0.1827	4157	Speed 1
0.05667	332.076	0.1832	4173	Speed 1
0.05833	326.9831	0.1835	4109	Speed 1
0.06	321.731	0.184	4043	Speed 1
0.06167	318.9458	0.1843	4008	Speed 1
0.06333	317.1155	0.1845	3985	Speed 1
0.065	315.4444	0.1845	3964	Speed 1
0.06667	314.012	0.1845	3946	Speed 1
0.06833	312.7387	0.1848	3930	Speed 1
0.07	311.3859	0.1848	3913	Speed 1
0.07167	310.1127	0.1848	3897	Speed 1
0.07333	308.919	0.1848	3882	Speed 1
0.075	307.805	0.1848	3868	Speed 1
0.07667	306.9296	0.1848	3857	Speed 1

0.07833	305.8951	0.1848	3844	Speed 1
0.08	304.9402	0.1848	3832	Speed 1
0.08167	304.1444	0.1848	3822	Speed 1
0.08333	303.3486	0.1848	3812	Speed 1
0.085	302.6324	0.1848	3803	Speed 1
0.08667	301.9162	0.1848	3794	Speed 1
0.08833	301.3592	0.1848	3787	Speed 1
0.09	300.8022	0.1848	3780	Speed 1
0.09167	300.3247	0.1848	3774	Speed 1
0.09333	300.0064	0.185	3770	Speed 1
0.095	299.7676	0.185	3767	Speed 1
0.09667	299.6881	0.185	3766	Speed 1
0.09833	299.8472	0.1852	3768	Speed 1
0.1	300.4043	0.1852	3775	Speed 1
0.10167	301.1205	0.1855	3784	Speed 1
0.10333	302.2345	0.1857	3798	Speed 1
0.105	303.8261	0.186	3818	Speed 1
0.10667	305.6564	0.1862	3841	Speed 1
0.10833	307.805	0.1867	3868	Speed 1
0.11	310.3514	0.187	3900	Speed 1
0.11167	312.9775	0.1875	3933	Speed 1
0.11333	316.0014	0.188	3971	Speed 1
0.115	319.1845	0.1885	4011	Speed 1
0.11667	322.5268	0.189	4053	Speed 1
0.11833	326.0282	0.1897	4097	Speed 1
0.12	329.6887	0.1902	4143	Speed 1
0.12167	333.4288	0.1907	4190	Speed 1
0.12333	337.2485	0.1915	4238	Speed 1
0.125	341.1478	0.192	4287	Speed 1
0.12667	345.0471	0.1927	4336	Speed 1
0.12833	349.026	0.1935	4386	Speed 1
0.13	353.0049	0.194	4436	Speed 1
0.13167	357.0633	0.1948	4487	Speed 1
0.13333	361.0422	0.1955	4537	Speed 1
0.135	365.021	0.1962	4587	Speed 1
0.13667	369.0795	0.1967	4638	Speed 1
0.13833	373.0583	0.1975	4688	Speed 1
0.14	377.0372	0.1983	4738	Speed 1
0.14167	380.9365	0.199	4787	Speed 1
0.14333	384.7562	0.1995	4835	Speed 1
0.145	388.5759	0.2002	4883	Speed 1
0.14667	392.5548	0.201	4933	Speed 1
0.14833	396.5336	0.2017	4983	Speed 1
0.15	400.2738	0.2023	5030	Speed 1
0.15167	404.0935	0.203	5078	Speed 1
0.15333	408.0723	0.2037	5128	Speed 1
0.155	411.8125	0.2045	5175	Speed 1
0.15667	415.473	0.205	5221	Speed 1
0.15833	419.054	0.2058	5266	Speed 1
0.16	422.7146	0.2065	5312	Speed 1
0.16167	426.2955	0.207	5357	Speed 1
0.16333	430.1153	0.2077	5405	Speed 1

0.165	433.935	0.2085	5453	Speed 1
0.16667	437.6751	0.2092	5500	Speed 1
0.16833	441.4152	0.2098	5547	Speed 1
0.17	445.2349	0.2105	5595	Speed 1
0.17167	448.5772	0.211	5637	Speed 1
0.17333	452.2377	0.2117	5683	Speed 1
0.175	455.8187	0.2125	5728	Speed 1
0.17667	459.0018	0.213	5768	Speed 1
0.17833	462.7419	0.2138	5815	Speed 1
0.18	466.5616	0.2145	5863	Speed 1
0.18167	470.2222	0.215	5909	Speed 1
0.18333	473.8828	0.2157	5955	Speed 1
0.185	477.4637	0.2162	6000	Speed 1
0.18667	480.9651	0.217	6044	Speed 1
0.18833	484.5461	0.2175	6089	Speed 1
0.19	488.2862	0.2183	6136	Speed 1
0.19167	491.8672	0.2187	6181	Speed 1
0.19333	495.4482	0.2195	6226	Speed 1
0.195	499.1088	0.22	6272	Speed 1
0.19667	502.7693	0.2208	6318	Speed 1
0.19833	506.2707	0.2213	6362	Speed 1
0.2	509.8517	0.222	6407	Speed 1
0.20167	513.3531	0.2225	6451	Speed 1
0.20333	516.8545	0.223	6495	Speed 1
0.205	520.3559	0.2237	6539	Speed 1
0.20667	523.7777	0.2243	6582	Speed 1
0.20833	527.0404	0.2248	6623	Speed 1
0.21	530.3826	0.2255	6665	Speed 1
0.21167	533.5657	0.226	6705	Speed 1
0.21333	536.7488	0.2267	6745	Speed 1
0.215	540.0911	0.2272	6787	Speed 1
0.21667	543.115	0.228	6825	Speed 1
0.21833	546.1389	0.2285	6863	Speed 1
0.22	549.0833	0.2293	6900	Speed 1
0.22167	547.0143	0.2302	6874	Speed 1
0.22333	547.8101	0.231	6884	Speed 1
0.225	551.5502	0.232	6931	Speed 1
0.22667	556.1657	0.233	6989	Speed 1
0.22833	561.0199	0.234	7050	Speed 1
0.23	566.0333	0.2347	7113	Speed 1
0.23167	571.1262	0.2358	7177	Speed 1
0.23333	575.8213	0.2365	7236	Speed 1
0.235	580.198	0.2372	7291	Speed 1
0.23667	584.7339	0.238	7348	Speed 1
0.23833	588.7924	0.2387	7399	Speed 1
0.24	592.9304	0.2395	7451	Speed 1
0.24167	597.3071	0.2403	7506	Speed 1
0.24333	600.729	0.241	7549	Speed 1
0.245	600.729	0.242	7549	Speed 1
0.24667	603.6733	0.2428	7586	Speed 1
0.24833	608.0501	0.2438	7641	Speed 1
0.25	612.7451	0.2445	7700	Speed 1

0.25167	617.4402	0.2452	7759	Speed 1
0.25333	622.0557	0.246	7817	Speed 1
0.255	626.4324	0.2465	7872	Speed 1
0.25667	630.7296	0.2473	7926	Speed 1
0.25833	634.788	0.2478	7977	Speed 1
0.26	638.6873	0.2485	8026	Speed 1
0.26167	642.4275	0.249	8073	Speed 1
0.26333	646.088	0.2497	8119	Speed 1
0.265	649.5894	0.2503	8163	Speed 1
0.26667	652.8521	0.2508	8204	Speed 1
0.26833	656.1147	0.2513	8245	Speed 1
0.27	659.2978	0.252	8285	Speed 1
0.27167	661.3668	0.2525	8311	Speed 1
0.27333	661.9239	0.2532	8318	Speed 1
0.275	664.6295	0.254	8352	Speed 1
0.27667	668.2901	0.2545	8398	Speed 1
0.27833	672.3485	0.2553	8449	Speed 1
0.28	676.4865	0.256	8501	Speed 1
0.28167	680.3062	0.2565	8549	Speed 1
0.28333	683.7281	0.2572	8592	Speed 1
0.285	685.3196	0.258	8612	Speed 1
0.28667	682.9323	0.259	8582	Speed 1
0.28833	679.5105	0.26	8539	Speed 1
0.29	673.5422	0.2618	8464	Speed 1
0.29167	644.4169	0.265	8098	Speed 1
0.29333	534.0432	0.2712	6711	Speed 1
0.295	388.8146	0.2792	4886	Speed 1
0.29667	319.0253	0.2875	4009	Speed 1
0.29833	287.9106	0.2955	3618	Speed 1
0.3	279.7142	0.3035	3515	Speed 1
0.30167	283.9318	0.3115	3568	Speed 1
0.30333	293.8789	0.3197	3693	Speed 1
0.305	305.6564	0.3278	3841	Speed 1
0.30667	318.3887	0.3358	4001	Speed 1
0.30833	324.0387	0.344	4072	Speed 1
0.31	329.0521	0.352	4135	Speed 1
0.31167	319.8211	0.3602	4019	Speed 1
0.31333	321.2535	0.3682	4037	Speed 1
0.315	330.8824	0.3765	4158	Speed 1
0.31667	339.9542	0.3845	4272	Speed 1
0.31833	304.3831	0.393	3825	Speed 1
0.32	230.7741	0.4012	2900	Speed 1
0.32167	193.9299	0.4093	2437	Speed 1
0.32333	168.306	0.4175	2115	Speed 1
0.325	144.3532	0.4258	1814	Speed 1
0.32667	114.0343	0.434	1433	Speed 1
0.32833	76.1555	0.442	957	Speed 1
0.33	51.3274	0.4503	645	Speed 1

APPENDIX C: MAINTENANCE METHOD TESTING RESULTS

ROUND 1			Step 1			Step 2	Step 3	
Method	**Model**	**Test**	Frame Weight (lbs)	Weight of concrete with frame (lbs)	Weight of concrete (lbs)	Weight of sand spread over model (lbs)	Total model weight with sand (lbs)	Weight of remaining sand (lbs)
Power Washing + Vacuum	1	1	10.45	118.8	108.35	3	121.8	3
		2				3	123.86	5.06
		3				3	125.9	7.1
One Sided Upward Flush	2	1	11.5	120.2	108.7	3	123.2	3
		2				3	124.75	4.55
		3				3	126.05	5.85
Two Sided Upward Flush	3	1	13	126.6	113.55	3	129.55	3
		2				3	131.4	4.85
		3				3	131.65	5.1

ROUND 1-CONTINUED			Step 4		Step 5 - 24 hour sample drying time	Step 6		
Method	**Model**	**Test**	Pressure of maintenance method (psi)	Gallons of Water Used		Total model weight with sand after maintenance (lbs)	Weight of remaining sand after maintenance (lbs)	Sand removed by maintenance (lbs)
Power Washing + Vacuum	1	1	180-200	11.9 gal water		120.86	2.06	0.94
		2		10.5 gal water		122.9	4.1	0.96
		3		10.8 gal water		123.95	5.15	1.95
One Sided Upward Flush	2	1	180-200	18.5 gal water		121.75	1.55	1.45
		2		19.6 gal water		123.05	2.85	1.7
		3		20.1 gal water		124.4	4.2	1.65
Two Sided Upward Flush	3	1	180-200	21.1 gal water		128.4	1.85	1.15
		2		21.6 gal water		128.65	2.1	2.75
		3		21.2 gal water		129.95	3.4	1.7

ROUND 2			Step 1				Step 2	
Method	Model	Test	Frame Weight (lbs)	Weight of concrete with frame after flushing (lbs)	Weight of sand remaining in model (lbs)	Weight of concrete (lbs)	How much sand to add to model to get to 4.5 lbs each initially	Weight of sand spread over/in model (lbs)
Power Washing + Vacuum	1	1	10.45	123.05	4.25	108.35	0.25	4.5
		2						3
		3						3
One Sided Upward Flush	2	1	11.5	123.4	3.20	108.7	1.3	4.5
		2						3
		3						3
Two Sided Upward Flush	3	1	13	129.1	2.55	113.55	1.95	4.5
		2						3
		3						3

ROUND 2-CONTINUED			Step 3		Step 4	Step 5 - 24 hour sample drying time	Step 6	
Method	Model	Test	Total model weight with sand (lbs)	Weight of remaining sand (lbs)	Comments on Maintenance Method		Total model weight with sand after maintenance (lbs)	Sand removed by maintenance (lbs)
Power Washing + Vacuum	1	1	123.3	4.5	9.9 gal water		122.65	0.65
		2	125.65	2.6	9.7 gal water		121.9	3.75
		3	124.9	1.85	9.5 gal water		123.45	1.45
One Sided Upward Flush	2	1	124.7	4.5	15.7 gal water		122.95	1.75
		2	125.95	2.55	16.8 gal water		122.75	3.2
		3	125.75	2.35	16.2 gal water		123.5	2.25
Two Sided Upward Flush	3	1	131.05	4.5	15.3 gal water		128.7	2.35
		2	131.7	2.6	14.3 gal water		128.75	2.95
		3	131.75	2.65	15.4 gal water		128.8	2.95

ROUND 3			Step 1				Step 2	
Method	**Model**	**Test**	Frame Weight (lbs)	Weight of concrete with frame after flushing (lbs)	Weight of sand remaining in model (lbs)	Weight of concrete (lbs)	How much sand to add to model to get to 4.5 lbs each initially	Weight of sand spread over/in model (lbs)
Power Washing + Vacuum	1	1	10.45	122.45	3.65	108.35	0.85	4.5
		2						3
		3						3
One Sided Upward Flush	2	1	11.5	122.5	2.30	108.7	2.2	4.5
		2						3
		3						3
Two Sided Upward Flush	3	1	13	127.8	1.25	113.55	3.25	4.5
		2						3
		3						3

ROUND 3-CONTINUED			Step 3		Step 4	Step 5 - 24 hour sample drying time	Step 6	
Method	**Model**	**Test**	Total model weight with sand (lbs)	Weight of remaining sand (lbs)	Comments on Maintenance Method		Total model weight with sand after maintenance (lbs)	Sand removed by maintenance (lbs)
Power Washing + Vacuum	1	1	123.3	4.5	9.0 gal water		122.15	1.15
		2	125.15	2.7	9.3 gal water		122.75	2.4
		3	125.75	3.3	9.1 gal water		124.05	1.7
One Sided Upward Flush	2	1	124.7	4.5	16.3 gal water		122.7	2
		2	125.7	3.2	15.8 gal water		122.45	3.25
		3	125.45	2.95	16.9 gal water		123.3	2.15
Two Sided Upward Flush	3	1	131.05	4.5	15.4 gal water		128.55	2.5
		2	131.55	3.75	15.3 gal water		128.8	2.75
		3	131.8	4	14.9 gal water		128.25	3.55