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Pervious Concrete Research Design

Phase Two (50% Report)

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1.0 Introduction

The purpose of this project is to help Dr. Chun-Hsing (Jun) Ho with his research in developing pervious concrete mix design formulas. The pervious concrete mix design formula must withstand the cold climate conditions, especially in Flagstaff, Arizona. This is the second phase of this research project as the team continues with the project while having results and mix formulas created in phase one. This project includes producing specimens, laboratory testing, creating the final data sheet and the final mix design formula. Also, the team will compare mix design formulas depending on having the admixture, Silica Fume, and fiber.

2.0 Acknowledgements

This project acknowledges the work done by Dr. Chun-Hsing Ho, Junyi Shen, Darius Ikan-Tubui Ishaku, Mengxi Du for phase one of the same project, Phase one started in January of the year, 2013 and ended in the December of the same year. This project also acknowledges Dr. Wilbert Odem, and Mark Odem for helping the team with their guidance in order to construct professional proposal and report. Moreover, the research team would like to thank CEMEX Company, especially Mr. Vern Harris, for providing the team with coarse aggregate.

3.0 Background

The US Environmental Protection Agency (EPA) recommends the pervious concrete pavement system to manage surface storm-water runoff and treat the storm-water. When looking at the mix materials and the mixing techniques, the conventional concrete mix is similar to the pervious concrete mix. The pervious concrete has a higher void ratio, which reduces its strength when compared to the conventional concrete. Pervious concrete has been applied in pavements for more than 20 years around the United States. Unfortunately, 25% of the installations have failed. A parking lot located near the Applied Research and Development building (ARD) of the campus was made of pervious concrete in 2009. This parking lot failed after three years from the application and completion. A team from phase one was to develop pervious concrete mix formulas. The team members were Junyi Shen and Darius Ikan-tubui Ishaku. Then, based on the formulas, the team produced specimens. While a few pervious concrete mixtures appeared to be a promising product, there is still a need to improve its performance in durability, strength, and air void. The information gathered from phase one is necessary for applying and monitoring part of this phase. Also, the information is important to know the mistakes made by the first team as well as the different mixtures created in the first phase. This will help in avoiding the same mistakes and have more ideas in creating the stronger and more appropriate mixture for the parking lots. The city of Flagstaff winter climate is often below freezing and this affects mixtures due to freeze-thaw cycle. Also, the city of Flagstaff usually experiences high frequency of freeze-thaw cycles, which will need to be considered when creating the mixtures.

4.0 Project Description

This section will explain the research as it includes the project understanding, the current conditions and the constraints and limitations of the project.

4.1 Project Understanding

Pervious concrete is a mixture of concrete that specializes in high void ratio that allows water to pass through the pavement to the ground in a short amount of time without affecting the pavement. This helps in managing storm water by reducing flooding. The purpose of phase two of the pervious concrete project is to apply the mixtures created in phase one of the same in a parking lot near the Sky Dome building on NAU campus and another parking lot near the City Hall of Flagstaff. After the completion of the two pervious concrete paving projects, monitoring the performance of the mixtures is needed for this project. Another purpose for this project is to create a stronger mixture of the pervious concrete by adding an admixture, Silica-Fume, which helps in increasing the strength of concrete. The new mixture includes fiber, aggregate, cement, water and Silica-Fume. These mixtures will be expected to increase the strength and void ratio of specimens, which will advance the performance of pervious concrete.

4.2 Current Conditions

The failure of the parking lot near the ARD building started the project. Since then, specimens have been created in order to find the best concrete mix design formula and apply it to the parking lot. The specimens have different ratios of cement, coarse aggregate, water and sand. Also, the specimens have chemical admixtures added to them like Hydration Stabilizer (DELVO), Mid-range Water Reducer (P900), Viscosity Modifier (VMA), Air Entrainment (Micro Air). These chemical admixtures were added to the specimens for both phases; however, for the second phase and after looking up for more admixtures, Silica Fume admixture was added to the mix formulas. These admixtures are used to increase the quality of performance of concrete. Two different molds were used for testing the specimens created. The first mold is a cylindrical mold with a 4 inch diameter and a height of 8 inches. This mold is used for the Compression Strength Test and the Void Ratio Test. The second mold is rectangular mold that has a length of 16 inches, width of 4 inches and a height of 4 inches. These molds are used for the freeze-thaw cycle tests.

4.3 Constraints and Limitations

There are several constraints and limitations for the concrete mix design formula. A water to cement ratio of 0.265-0.3 is required for the design. The resulted compression strength for the specimens must be no lower than 2500 psi. Moreover, the void ratio must exceed 17%. This is because having a lower percentage than 17 would decrease the chance of the seepage of water when applying pervious concrete on the pavement. The city of Flagstaff experiences around 250 cycles of freeze-thaw. Therefore, the specimens must be able to withstand the weather conditions and the high number of freeze-thaw cycles.

4.4 Task Lists

In order to complete the second phase of this research project, a set of tasks were developed. The tasks will include every aspect related to finishing the second phase. This include deliverables, meetings, preparation, designing and testing. The following is the list of tasks for the second phase of pervious concrete mix design formula:

Task 1- Team Management

Task 2- Project Development

Task 3- State of the Art Literature Review

Task 4- Material Preparation

Task 5- Mix Formula Development

Task 6- Specimen Production

Task 7- Lab Testing

Task 8- Data Analysis

Task 9- Final Deliverable

5.0 Literature Review

In the past eight years, many researches and projects have been made about pervious concrete. Also, some of the researches were done for the performance of pervious concrete at low temperatures and high frequency of freeze-thaw cycle. For example, Roseen et al. studied the performance of pervious concrete pavement for storm water management (1). Their research stated that pervious concrete has demonstrated its ability for drainage, but the pavement color and shading have been the major factors influencing the snow and ice accumulation in the studied parking lot. Wang et al. studied the freeze and thaw durability of low permeability concrete with and without air entrainment (2). They found out that air void system is the major factor that the effectiveness of air entrainment for resisting freezing and thawing deterioration is dependent mostly on. The air void system does not depend on the type of cementations material. They recommended the amount of air voids needed to be 6% or greater. Kevern et al. studied the influence of freeze-thaw cycle on the strength of pervious concrete and monitored the performance with some laboratory testing (3). They used many mix design formulas with and without fiber and the durability test was done under some number of freeze-thaw cycles. The results of the tests confirm that the short fibers improved the strength of concrete, permeability, and freeze-thaw durability of the mixes that do not have additional sand.

The National Ready Mixed Concrete Association (NRMCA) stated that most of pervious concrete mixtures have water-cement-ratio between 0.27-0.45 and containing no fine aggregate and made of single sided aggregate (4). There is no doubt that the aggregate influences the integrity of the pervious concrete structure. Particularly, the interlock effect of aggregate particles transfers loads between individual particles from the surface to the bottom of the pavements. It is still not clear how to maximize the strength and the freezing-thawing durability of pervious concrete. They can be changed by adjusting the rate of aggregates, fibers, admixtures, and voids. The mix design presented in the paper considered all factors by using locally available limestone and basalt, fibers, and admixtures (air entrainment, water reducer, viscosity modified, and hydration stabilizer). The mix design was made to produce a number of pervious concrete specimens and then characterize their porosity, compressive strength, and freezing-thawing resistance.

6.0 Material Preparation

In order to produce pervious concrete, specimen material should be prepared before mixing. The pervious concrete specimens were produced using the following materials: Portland cement type II and V , water, coarse aggregate (1/2”, 3/8”,3/4” and #4), fine aggregate (nature sand) up to 2% fine sands by weight, fiber (Fibermesh@150), Air Entrainment, Mid-range Water Reducer, Hydration Stabilizer, Viscosity Modifier, and Silica Fume. The last five materials are admixtures. Admixtures were used in the mix design trying to improve the strength of pervious concrete mixtures. Admixtures are also used to improve the properties of concrete in any. Using some ready admixtures such as Micro Air, air-entraining admixture, is recommended because it provides more protection for the concrete by generating small, strong and closely spaced air bubbles. Also, it decreases the internal stresses caused by expansion and contraction of water in the concrete pores upon freezing and melting during a daily cycle. In addition, Viscosity-modifying (vma) admixture increase the viscidness of the concrete by enabling stability and flexibility in the concrete during the placement. Also, Stabilizer admixture (DELVO) delays the setting time of the concrete which controls the hydration of Portland cement. To improve the durability of the pervious concrete P900 admixture is used as a high range water reducing admixture along with fiber. For this phase, Silica Fume is added to the mixture formulas. This admixture is used to improve the compressive strength.

7.0 Specimen Production

A series of pervious concrete mixtures were created when specimen production was needed. The mixtures included three different kinds of coarse aggregate (3/4”, 1/2”, 3/8” and No.4). The mixtures had different ratios of each kind of aggregate and sometimes they were not included in the mix. The mixtures also had natural sands with a 2% ratio by weight as a finer. Water and cement are added into the mixture with a water to cement ratio of 27%. Four different admixtures in liquid forms are added to the mix with each having their influence on the performance of the specimens. Moreover, some of the mixtures had fiber mesh @150. For this phase, a new admixture is added to mixture, which is Silica Fume. Silica Fume is different than the other four admixtures in being in sold powder form. For each mix design formula, four specimens are made. Therefore, the volume of the specimens must contain at least four specimens. For this project, the volume was considered for five specimens in case of any mistakes taken through the mixing procedure.

Figure 1: mixer

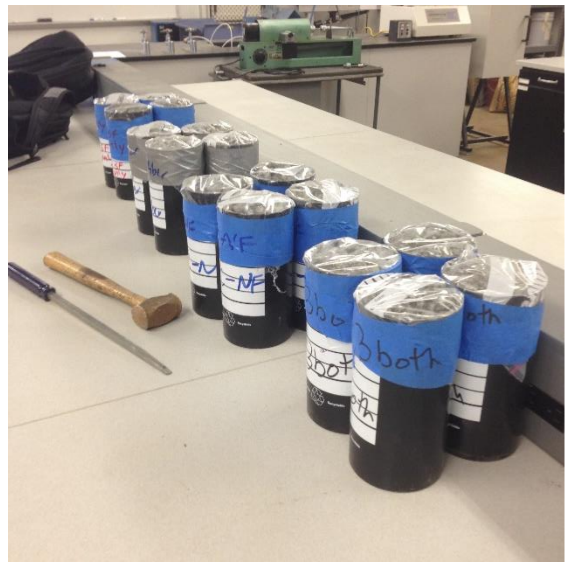

Figure 3: Covering Specimens

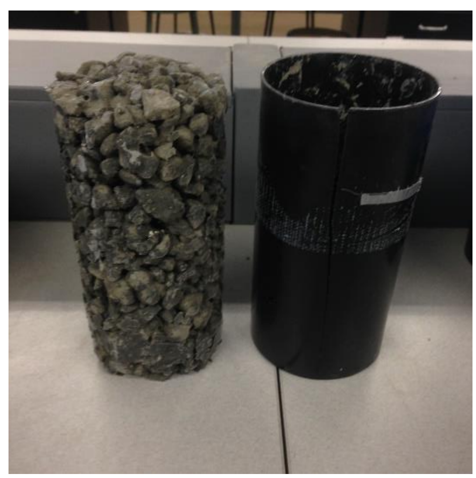

Figure 2: De-molding Specimens

For this mixture production, ASTM C 192/C 192M-02 Specimen Preparation Procedure was followed. First, the aggregate is dried and mixed with 10% of the cement until coated. The mix is put inside the mixer (Figure 1). Then, admixtures are added to the water and then added to the mix with the rest of the cement. Some specimens have the admixture, Silica Fume, in the mix design formula. These specimens have 5% Silica Fume replaced with 5% of the cement used on the mixture. The mixing lasts for three minutes. After, that three minutes for resting and another two minutes for mixing. The mixture is then removed and placed inside cylindrical molds. When placing the mix inside the mold, the mix is compacted for 25 hits in two layers. Also, the mold is pounded on the ground for ten times for each layer. The molds are then covered for 24 hours. But since the city of Flagstaff is at a high elevation (7000 ft.) and the cold weather, the molds need more than 24 hours for covering (Figure 3). Therefore, the molds are covered for three day. After the three days, the specimens are de-molded (Figure 2) are placed in buckets of water for curing (Figure 4).

Figure 4: Curing Specimens

8.0 Testing/Analysis

There are three tests that need to be made to the specimens in order to find the best mix design formula. The three tests are: Compressive Strength Test, Void Ratio Test and Freeze-Thaw Cycle Test. Each test has their steps in order to find the results.

8.1 Compressive Strength Test

For this test, ASTM C39 Compressive Strength Test is followed. The Compressive Strength Test decides how much pressure a specimen can withstand. For this test, a cylindrical specimen is needed. The specimens created had a four inch diameter and the height of eight. The compressive strength test machine (Figure 5) in the Mechanic of Materials Lab in the Engineering building in Northern Arizona University was used for the test. A specimen is placed into the machine where the top layer lowers until it touches the specimen. The pressure is then increased manually with a small ratio. A screen next to the testing machine shows the amount of pressure applied on the specimen being tested. The pressure is increased until the specimen breaks. The screen does not

Figure 5: Compressive Strength Test Machine

show the maximum pressure applied to the specimen; therefore, the person looking at the screen must notice the number when the specimen breaks.

8.2 Void Ratio Test

For this test, ASTM C127 was followed. The Void Ratio Test measures the void ratio of the specimen. The *Gilson Specific Gravity Bench* (Figure 6) was used for this test. The specimen tested is cylindrical and is placed on top of the scale and the dry weight of the specimen is measured. Then, the specimen is placed in the basket where it will lower into the bucket of water. After three minutes, the wet weight is measured. After that, the porosity or void ratio can be calculated using the following equation:

Figure 6: Gilson Specific Gravity Bench

$$P = \left[1 - \frac{W_2 - W_1}{\rho_w * Vol}\right] 100(\%) \text{ - Equation 1}$$

P is the porosity or the void ratio of the specimen. (%)

W_1 is the weight under water of the specimen. (g)

W_2 is the dry weight of the specimen. (g)

ρ_w is the density of water. (1 g/cm^3)

Vol is the volume of the specimen. (cm^3)

8.3 Freeze-Thaw Cycle Test

The Freeze-Thaw Cycle Test measure how much cycles a specimen can withstand before cracking. The specimen is made into a rectangular shape. The length of the specimen is 16 inches while the base and height of the specimen are four by four. The specimens being tested are placed inside the *Gilson HM-120 Automatic Freeze-Thaw Apparatus.* (Figure 7) This machine is located inside the Mechanics of Materials Lab in the Engineering building at NAU. The machine will run cycles on the specimens placed inside of it. Flagstaff,

Figure 7: Gilson HM-120 Automatic Freeze-Thaw Apparatus

Arizona usually experiences around 250 cycles per year. Therefore, the specimens are required to withstand at least 250 cycles and the testing will last till 300 cycles.

9.0 Mix Design Formulas

After understanding the current conditions, reading about recent research and phase's one results, the team started designing the pervious concrete formulas. The mix design formulas from phase one were developed in phase two. The mix design formula has coarse aggregate (3/4", 1/2", 3/8" and/or No.4), cement, water, sand, admixtures, and fiber. Each have their percentage in the mix formula. Most of these materials do not change from one formula to the other. The percentage change mostly with the coarse aggregate and whether or not a certain size is available in the formula. The water to cement ratio is kept between 26.5% and 30%. A new admixture is added to the mix design formula, Silica Fume. Silica Fume is new to this research as it was not used in the first phase. This admixture replaces 5% of the cement added to the mix. Four other admixtures (vma, P900, Micro Air, DELVO) are in the mix design formula. Each admixture have their impact on the performance of the specimen. The fiber used in the formulas is Fiber mesh @150. A small amount of sand is added to the mix formula because sand is known to fill the voids between the aggregate. Pervious concrete is designed so that it allows water to pass through it without any obstacles. The following tables (1, 2) includes the mix design formulas produced for testing. Table 1 is for the developing the mix design formula and finding the best one that have the highest compressive strength and the highest void ratio. Table 2 is for the comparison of the effect of the admixture, Silica Fume, and fiber. A mix design formula from table 1 was chosen to compare between the four mix formulas. The first formula has only fiber, the second doesn't have any of them, the third has both and the last one has only Silica Fume.

Table 1: Mix Design Formulas

Mix ID#	Material Proportion (lb./cu yard)								admixture(oz.)				Fiber (kg/m^3)
	Cement	Water	w/c ratio	Sand	Aggregate gradation				Delvo	p900	Micro Air	vma	
					#4	3/8"	1/2"	3/4"					
#24 CV	616	197.4	0.320	200		650	1850		105	36	12	20	0.6
#25 CV	616	239.2	0.388	200	250	400	1850		105	36	12	20	0.6
#26 CV	616	169.4	0.275	200	500	500	1500		105	36	12	20	0.6
#27 CV	616	169.4	0.275	200	250	750	1500		105	36	12	20	0.6
#26 PR	616	169.4	0.275	200	500	500	1500		105	36	12	20	0.6
#27 PR	616	169.4	0.275	200	250	750	1500		105	36	12	20	0.6
#30 PR	616	169.4	0.275	200	500	500	1250	250	105	36	12	20	0.6
#31 PR	616	166.3	0.270	200		1000	1500		105	36	12	20	0.6
#32 PR	616	166.3	0.270	200	750	200	1550		105	36	12	20	0.6
#33 PR	617	169.7	0.275	200	750	350	1400		105	36	12	20	0.6
#16 PR	616	163.2	0.265	200	1000	1500			105	36	12	20	0.6
#34 PR	616	196.9	0.275	200	850	450	1200		105	36	12	20	0.6

Table 2: Comparison Table

Mix ID#	Material Proportion (lb./cu yard)								admixture(oz.)				Fiber (kg/m^3)	Silica Fume (g)
	Cement	Water	w/c ratio	Sand	Aggregate gradation				Delvo	P900	Micro air	vma		
					#4	3/8"	1/2"	3/4"						
#31 Fiber	616	166.3	0.270	200	1000		1500		105	36	12	20	Fiber 150, 0.6	
#31 no-Fiber	616	166.3	0.270	200	1000		1500		105	36	12	20		
#31 SF/Fiber	585.2	166.3	0.270	200	1000		1500		105	36	12	20	Fiber 150, 0.6	30.8
#31 SF	585.2	166.3	0.270	200	1000		1500		105	36	12	20		30.8

10.0 Testing Results

After producing the specimens using the ASTM C 192/C 192M-02 Specimen Preparation Procedure and testing the specimens using the three tests specified in the Testing/Analysis section, the team was able to create tables showing the results.

10.1 Compressive Strength Results

The compressive strength results varied due to using different kinds of aggregate in the mix design formulas. First, the team brought aggregate for the city of Camp Verde, Arizona and the results were not consistent. This is because the coarse aggregate from Camp Verde is a combination of Basalt, Limestone, Quartzite, and Granite. Each kind of rock has different characteristics in terms of compression strength. Therefore, the team brought aggregate from the city of Prescott, Arizona. The results came out to be very consistent. This is because the coarse aggregate was mainly Basalt. The specimens created were tested on the 7^{th} and 28^{th} days of curing. Table 3 shows the results of compressive strength on the specimens created. Since the first phase group started with specimen production, the team from phase two continued with the numbering. The first mix starts with the number 24 as it is the 24^{th} mix formula from the start of the project. CV means that the aggregate is from the city of Camp Verde, AZ and PR means that the aggregate is from the city of Prescott, AZ.

Table 3: Compressive Strength Results

Mix Number	Test Result			
	7-day Comp.(psi)		28-day Comp.(psi)	
#24 CV	151	207	88	104
#25 CV	1107	955	N/A	1115
#26 CV	1300	1354	1415	1354
#27 CV	1115	1258	1369	1831
#26 PR	2548	2189	2651	N/A
#27 PR	1871	N/A	2014	2309
#30 PR	1433	1690	1823	1779
#31 PR	2699	2879	2946	2923
#32 PR	2538	1982	2787	2548
#33 PR	2502	1911	2946	2962
#16 PR	2866	2906	3177	2986
#34 PR	1831	1672	2070	N/A

10.2 Void Ratio Results

After completing the ASTM C127 procedure, the void ratio results were obtained for the specimens produced. Table 4 has the results for the specimens. The team's goal is to have a porosity ratio higher than 17%. Most of the specimens were tested on the 28th day of curing and that's why not results were found for the other two specimens on the formulas (24 CV- 33 PR). The last two formulas have the four specimens testing results (16 PR and 34 PR). Some of the specimens tested had a lower void ratio than 17%. This might be because the smaller size aggregate, either No. 4 or 3/8", had a high percentage in the formula and that caused the voids to close more than they need to be.

Table 4: Porosity Test Results

Mix Number	Porosity (%)			
	Sample 1	Sample 2	Sample 3	Sample 4
24 CV	27.3	32.5	N/A	N/A
25 CV	24.5	26.7	N/A	N/A
26 CV	23.6	22.6	N/A	N/A
26 PR	18.7	23.8	N/A	N/A
27 CV	22.2	20.4	N/A	N/A
27 PR	19.2	14.9	N/A	N/A
30 PR	20.1	20.5	N/A	N/A
31 PR	17.5	17.1	N/A	N/A
32 PR	20.6	18.8	N/A	N/A
33 PR	17.2	14.4	N/A	N/A
16 PR	21.2	23	18.2	19.2
34 PR	17.3	15.3	17.8	14.4

Freeze-Thaw Cycle Test Results

To be determined…..

Summary of Project Costs

To be determined…..

Timeline

To be determined…..

Conclusions

After producing specimens and developing the mix design formula from phase one, results were found regarding the compressive strength, the void ratio and the freeze-thaw cycles. After completing phase two from pervious concrete research, many conclusions were found:

- Fiber has a great impact on the performance of pervious concrete. Fiber connects the components of the specimens together which makes the specimen stronger and can hold more under a lot of pressure. This leads to having a higher compressive strength for the specimen.
- Testing results show that the admixture, Silica Fume, had increased the compressive strength of the specimens. This helps the specimens in have to hold for a higher pressure if applied on the pavement.
- The void ratio is impacted by the components of the mix design formula; especially, the size of the aggregate used in the formula. As the size of the aggregate gets smaller, the void ratio of the specimen lowers and vice versa. Therefore, it is better to use a big size aggregate like 1/2" or 3/8" when designing the pervious concrete formula.
- Freeze-thaw : to be determined
- When comparing four different mix design formulas with each other in having fiber and the admixture, Silica Fume, it turns out that the mix design with ……. (to be determined)
- The best design formula was ….. (to be determined)

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5.

Appendices