Spring 2017

Porous Concrete Design

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Department of Civil Engineering

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ENTITLED

Porous Concrete Design

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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Porous Concrete Design

By

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SENIOR DESIGN PROJECT REPORT

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1 - Background Information

1.1 – What is Porous Concrete?

Porous concrete is a special kind of concrete that has high porosity. The only difference between porous concrete and normal concrete is that a porous concrete mix does not consist of sand or other small particles. The lack of sand and small particles creates voids in the concrete. The voids that area created are the reason why water is able to pass through a porous concrete mix. Porous concrete is used for low traffic areas such as parking lots and pavements. The main purpose of porous concrete is to reduce or even eliminate storm water runoff which has a number of benefits.

1.2 – Project Description

For this project, the team developed a porous pavement mixture that will be applicable for practical and real life use. This means that the porous concrete mixture must have a certain permeability and compressive strength.

There were two main parts to the project. Initially the team found what value of water to cement ratio would give the highest possible compression strength. The team started with experimenting with water to cement ratio due to the fact that it is the only variable that affects compressive strength and barely, if at all, affects permeability. After figuring out what the best water to cement ratio was, the next part of the project was about experimenting with other variables that affect the permeability and compression strength of a porous concrete.

After acquiring the best water to cement ratio for the highest compression strength, the second part of the experiment will consist of varying two other variables, which were aggregate size and types of aggregate. By optimizing these variables, an optimal porous concrete mixture was found that could be used for practical use. The hope was to find a mixture that can be used for either pavements or parking lots.

2 – Possible Benefits and Problems

2.1 – Benefits

Having porous concrete on a project site is both financially and environmentally beneficial. One major financial benefit of porous concrete is its ability to control storm water runoff. In many states, and especially in California, an owner is responsible for controlling its storm water runoff. Most of the time owners will use methods such as retention ponds. Retention ponds are a water retention system that store storm water and release it underground slowly or move it into the sewage. A problem with this method is that the retention system itself requires quite a bit of space and can be expensive to make. If a project site has porous concrete, it will eliminate the need for a retention system. This means that the area that is usually used for a retention system could be used for something else, such as extra parking space or an additional building. Not only does porous concrete save space, but it is also saves money by not having to build a retention pond in the first place, as seen in Figures 1 and 2. Furthermore, porous concrete will enable a building to get additional LEED points which has a number of benefits on its own.

In addition to financial benefits, porous concrete also has environmental benefits. The greatest environmental benefits is that it is able to restore the natural hydrological cycle. It allows water to infiltrate back into soil rather than it going into a sewage system. This is especially beneficial to those areas that depend on ground water as a water resource. Porous concrete is able to maintain the reservoir in the soils, and it helps the soil retains its water content.

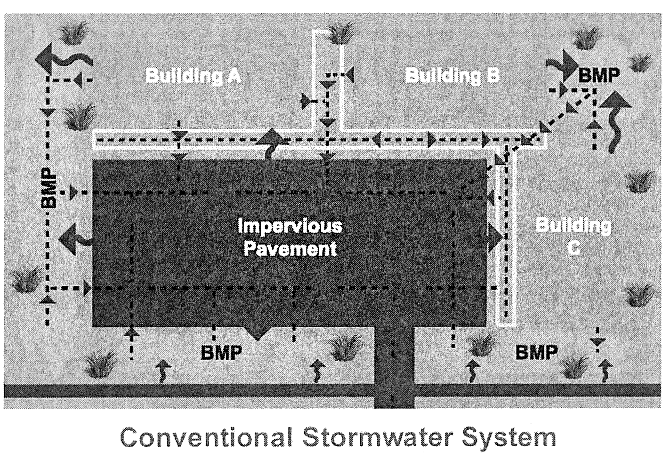

Figure 1: Conventional Stormwater System

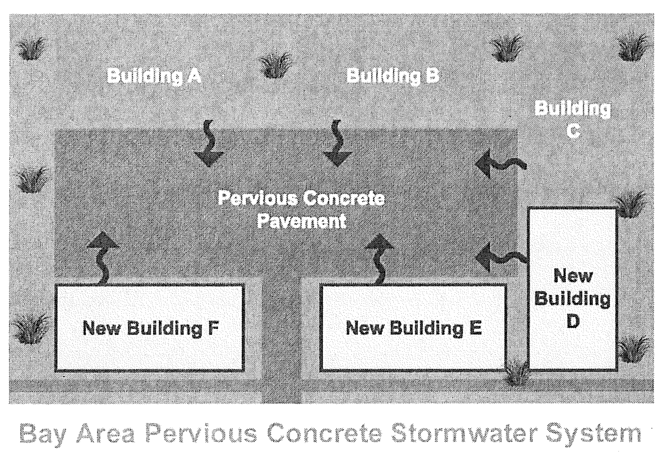

Figure 2: Pervious Concrete Stromwater System

2.2 – Possible problems

The main problem with porous concrete is its voids. Having voids means that it will not be as strong and durable as conventional concrete. That is why porous concrete cannot be used for areas with heavy traffic or areas that demand heavy loads. Additionally, porous concrete is very susceptible to cold weather areas due to its weakness to freeze and thaw. Porous concrete will always experience freeze and thaw conditions due to its voids. Currently porous concrete is typically not used in cold weather climates.

In other words, unlike conventional concrete, porous concrete is not as versatile and has some restrictions with regards how it is used.

3 – LEED

LEED, also known as Leadership in Energy and Environmental Design, is the most recognizable green building rating system in the world. LEED provides a framework for evaluating building performance by establishing minimum requirements in several fields. There are four levels of LEED certifications: Gold, Silver, Bronze and Platinum. Platinum is the highest rating. In order to get a certification, the building must accumulate a certain amount of LEED points; the more the LEED points a building has, the better the certification it will receive.

There are several benefits to having a LEED certified building. LEED certified buildings have an average faster lease up rate, higher property value and qualify for tax rebates and zoning allowances. Since the building is sustainable and more energy efficient, it will reduce the overall cost of the building operations and thus save the owners money in the process.

The list below shows the additional; LEED points a project with porous concrete could have. As seen below, this project could give an additional 10 points, which could be crucial when it comes to getting a higher LEED certification.

Storm water design (Sustainable Sites -c6.1)

Intent: To limit the amount of disruption and pollution of natural waters, which is done by managing storm water runoff, increasing on site infiltration and eliminating contaminants.

Porous concrete is able to get this lead point because it reduces storm water runoff by allowing water to infiltrate into the soil. It also reduces pollutants because it filters contaminants as water passes through it.

Possible points: 1

Heat island effect (Sustainable Sites-c7.1)

Intent: To reduce heat island effect. To minimize microclimate and reduce urban energy demands.

Heat island effect can be reduced by providing shading, which can be done by plantations planted around the area. Porous concrete is good for growing plants and trees because its permeability allows water to infiltrate into its roots. This is relevant when it comes to having porous pavements in parking lots and sidewalks.

Possible points: 1

Water efficiency (Water Effeciency-c1)

Intent: To limit or eliminate the use of potable water or other unnatural surfaces for landscape irrigation.

The subgrade layer below the porous concrete can store rainwater and use the retained water for irrigation.

Possible points: 2

Materials and Resources (Material Resources-c4)

Intent: To increase demand for building products that have incorporated recycled content material, reducing the impacts resulting from extraction of new material.

The mixture could use recycled cementitious materials such as fly ash and silica fume. In addition, the team could use recycled aggregates instead of normal aggregates.

Possible points: 3

Innovative Design (Interior Design and Construction Innovation)

Intent: Use innovative design.

Since porous concrete is a relatively new innovation that has not yet been standardized by any institution, it is considered to be an innovative design.

Possible points: 3

Total Possible points: 10

4 - Aggregate Properties

4.1 - Design

Before the group determined the possible mix design, the ACI guidelines required finding the properties of the aggregates that were proposed. The aggregate properties are essential for calculating the proportion of water, aggregate and cement needed in a mix design. The properties the group needed to find were bulk specific weight, absorption and bulk unit weight. Using standard ASTM guidelines, the team found the properties of each type and size of aggregate.

4.2 – Absorption

Table 1: ASTM C127 – Absorption of Coarse Aggregate.

Sample	Absorption
3/4 normal	0.69
1/2 class 2	2.26
1/2 normal	0.75
3/4 class 2	3.62

4.3 –Specific gravity

Table 2: ASTM C127 – Specific Gravity of Coarse Aggregate.

Sample	Specific gravity
3/4 normal	2.86
1/2 class 2	2.52
1/2 normal	2.89
3/4 class 2	2.56

4.4 – Bulk Unit Weight

Table 3: ASTM C29 – Bulk Density in Aggregate.

Sample	Unit weight
3/4 normal	100.90
1/2 class 2	81.57
1/2 normal	102.10
3/4 class 2	92.25

5 – Mix design

5.1 – Part 1

Goal: "To find the optimum water to cement ratio for maximum compressive strength."

In part one of this two-part experiment, the team will be only using one type of aggregate with one specific aggregate mix. The experiment is trying to measure the effectiveness of one variable, which is the water to cement ratio. The aggregate the team used for this mix design was be gravel.

Mix Design
One -inch gravel (50%) + ¾ inch gravel (50%)

Note: The 50% means percentage by weight.

5.2 – Part 2

Goal: "Find a design mix that has adequate compressive strength and percolation rate for practical use. "

In part two of this two-part experiment, the team used two types of aggregates. The two aggregates were gravel and Class II recycled aggregates. After part one of the experiment, the best water to cement ratio was found for highest compression strength. With this value, the team was able to vary aggregate sizes and saw how it affected percolation rate and compression strength.

The specification of mix designs seen below were calculated using the standards found in ACI handbook for porous concrete. The handbook will enable users to determine the amount of aggregate, water and cement needed in a specific mix design. These amounts will vary depending on the characteristic of the aggregate shown in Tables 1,2 and 3

Note: When calculating assume voids are 20%

Mix Design 1
½ inch gravel
Aggregate: 21lb
Water: 3.05 lb
Cement: 1 lb

Mix Design 2
¾ inch Gravel
Aggregate:21lb
Water: 3.05lb
Cement: 1.01lb

Mix Design 3

½ inch Gravel (50%) + ¾ inch Gravel (50%)
Aggregate: 21.15lb
Water: 3.04lb
Cement: 1.01lb

Mix Design 4
¾ inch Class II
Aggregate: 21lb
Water: 3.05lb
Cement: 1.01lb

Mix Design 5
½ inch Class II (50%) + ¾ inch Class II (50%)
Aggregate: 19lb
Water:3.05lb
Cement: 1lb

5.3 – Class II aggregate

For the second part of the two-part experiment, Class II aggregate was introduced. Class II aggregate is a type of recycled base rock. The reason why Class II aggregate was used is because it is more angular than the gravel aggregate. The belief is that its angularity creates more surface area that touches one another. This increased surface area will mean that there will be less voids and more fiction between particles. This will not only make the porous concrete mixture more compact but it will also help it bind more strongly due to its increased touching surface area.

5.4 – Test specimens

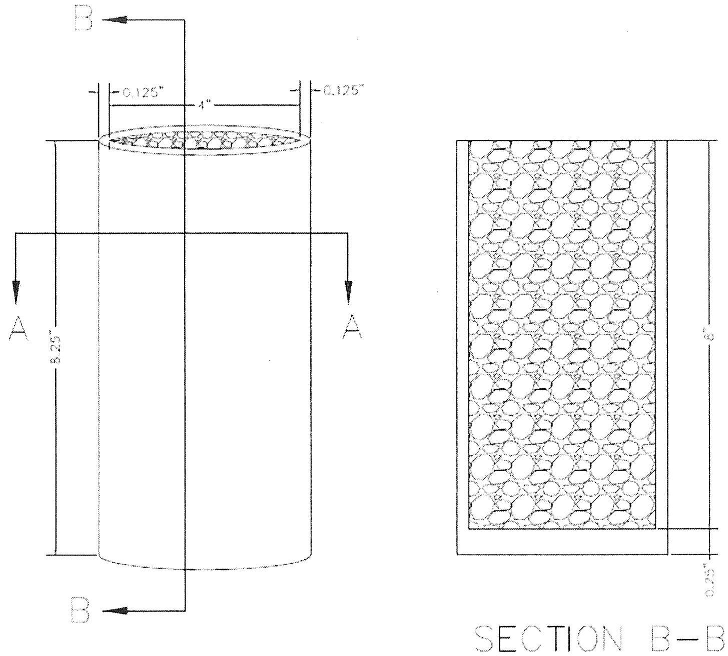

Figure 3: Sample in Mold

Once the mix was made it was placed into a plastic conatiner four inches in diameter and eight nches deep. When putting in the mixture the team made it as compact as possible using a metal rod ensuring all the spaces were occupied by the mixutre. Furthurmore, the team made sure the surface of the test specimen was as flat as possible. The flat surface is vital, not only for a practical use but it madethe compression test results more accurate because the weight was more evenly disitributed along the sample.

Once placed inside the mold, the mixture was left outside to air dry for 24 hours. Then it was placed in a bath of limewater where it cured for 28 days. After the curing process the mold was removed and left it to dry for a few days. Compression testing was able to be completed once the samples were completely dried.

6 - Ethics

The team believed that porous concrete will be very beneficial in regards with saving the environment. As the population of the world increases, more space will be required for people to live in. This means that as time passes, more and more of the Earth's surface will be occupied by concrete floors. One of the biggest problems concrete floors have is that it is not permeable. In other words, water does not infiltrate into the Earth's natural floors. This causes a number of problems, and it is especially relevant in countries that depend on underground water as a water supply.

Indonesia is an example of a country that heavily relies on groundwater as a source of water. The amount of water that they are taking from the ground is much more than the amount of water that goes into the ground. When this happens, not only will the soil start to compact, causing land to sink, but it will also deteriorate the soil's ability to store and retain water. It is estimated that Jakarta, Indonesia's capital city, is sinking at a fast rate of two millimeter (2mm) per year. A contributor to making the situation worse is the absence of natural infiltration systems and an abundance of concrete floors. For this specific situation, the presence of porous concrete will greatly help. It allows water to naturally infiltrate back into the soil; this enables soil to be able to recover the water that has been pumped out and thus prevents the soil from further compacting and the ground from sinking. Preventing the city of Jakarta from sinking will be greatly beneficial to its citizens. They will not have to worry about their homes being destroyed and their businesses being effected by heavy flooding caused by a sinking landscape.

Like Jakarta, other places in the world are having the same problem. Their lands are sinking and their grounds are drying up. Porous concrete is an inexpensive and effective solution to these problems.

7 – Compression Strength Test

Compression strength is another important feature for a porous concrete. Although it is will not be as strong as a conventional concrete mix, it still must be strong enough to handle the weight of people or cars, depending on what it is used for. For this experiment, the team followed the ASTM C39/39M guidelines. The team used the Tinius Olsen 400 kip Universal Test Machine to break the samples to failure.

Before doing the compression test, it was ensured that the sample was dry. This was done by leaving it to dry over a few days, or the process could have been accelerated by using an air compressor to help water evaporate more quickly. After the sample was dry, the sample was then Sulphur capped on both sides. Sulphur capping ensures that the pressure is distributed evenly throughout the entire sample when it is compressed.

Figure 4:Sulphur capped sample

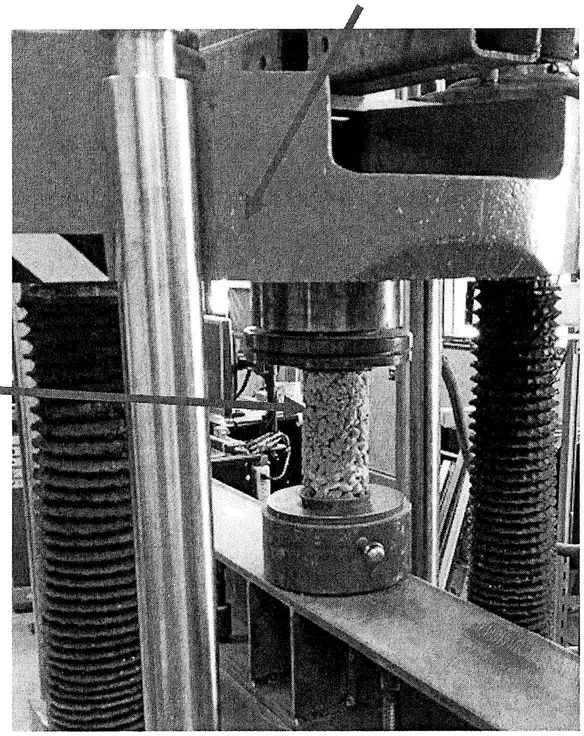

Figure 5:Tinus Olsen Machine

8 – Percolation Rate Test

One important feature of pervious concrete is its ability to let water percolate through it. The permeability of the test sample can be measured by a percolation rate, which refers to the rate of which water is able to pass through the concrete sample. The team decided that to use a simple falling head test in order to measure the sample's percolation rate. A falling head instead of constant head test was used since it was recommended by the ACI guidelines to porous concrete. Fortunately, the team did not have to make the falling head apparatus because a previous student in Santa Clara University already made one.

According to the Santa Clara student, that testing apparatus was made using PVC pipes, O-rings, a valve, rubber couplers and a used plastic container. Both Teflon tape and asphalt binder were used for all connections, to make sure that there would be no leaks.

<u>Dimensions of apparatus</u>

Diameter of plastic cylinder: eight (8) inches

Surface area of plastic cylinder: 50.27 inches

<u>Procedure</u>

1. Make sure the test is done on an even surface
2. Place the cylinder inside the PVC tube opening
3. Tighten it using a screwdriver to ensure water does not leak
4. Place the used plastic container on top of the test cylinder and tighten it using a screwdriver
5. Open valve to allow water to pass through
6. Pour water inside the plastic container until the pressure from each end of the apparatus is equalized. Then close valve
7. Pour water to the desired height of the plastic container
8. Open valve and measure how long it takes for all the water to pass through the sample
9. Take the time measurement and convert it into volume per hour Repeat 3 times for each sample

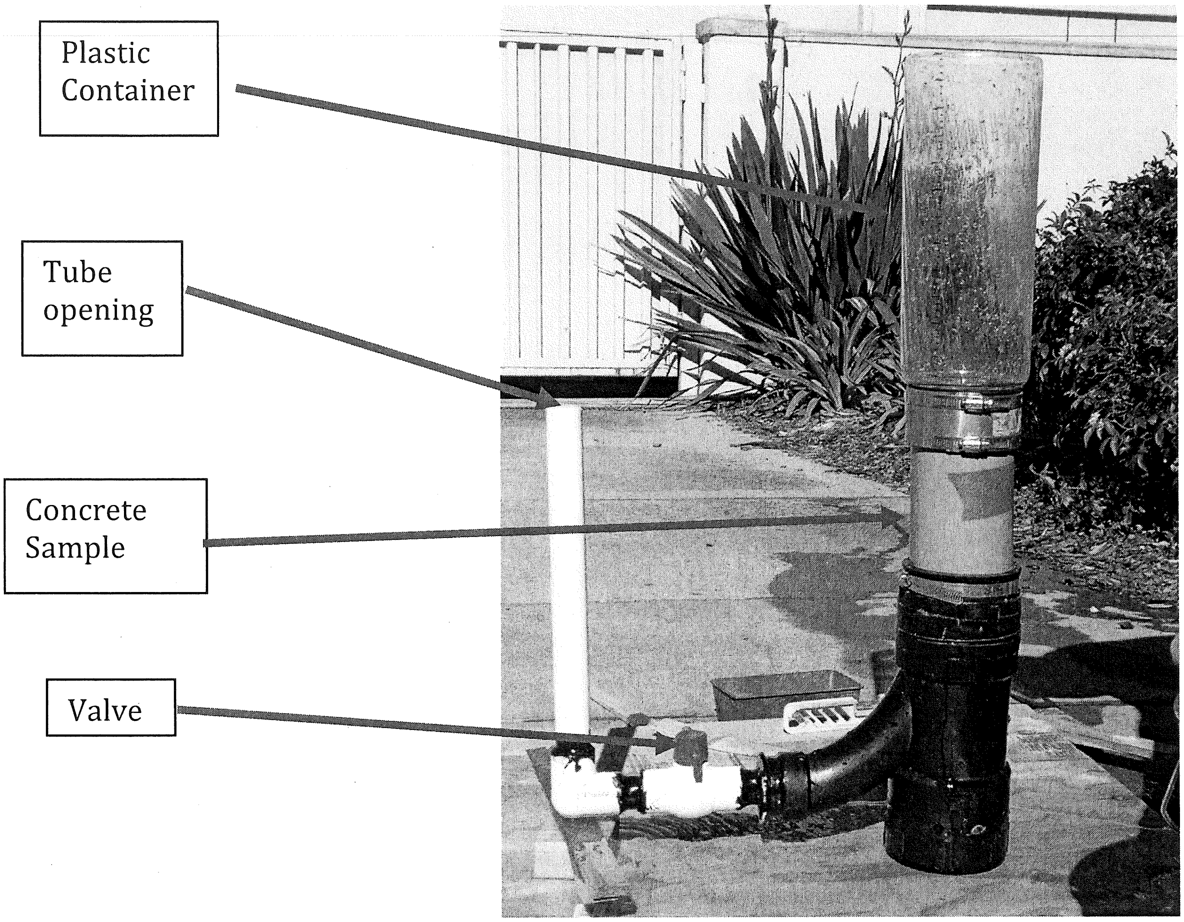

Figure 6: Falling head test

<u>Note</u>

Experiment one: height of water is 12 inches

Experiment two: height of water is six inches

9 – Test Results

9.1 – Compression (Part 1)

*Table 5:*Project test results compared to previous study.

W:CM ratio	0.27	0.30	**0.34**
Loading (lb)	N/A	5,136	**6,195**
Compression Test (psi)	N/A	409	**493**

Previous SCU Study Results.

W:CM ratio	0.27	0.30	**0.34**
Loading (lb)	3,851	10,010	**12,580**
Compression Test (psi)	306	797	**1,001**

9.2 – Takeaway (Part 1)

Previous studies on porous concrete done by a former SCU student found that the samples that had the highest compressive strength were the ones with a water to cement ratio of 0.34. As shown in Table 5, it is evident that these findings agree with previous studies.

Samples that have the highest compression strength are those with a higher water to cement ratio and in this case, it was 0.34, while the weakest samples are those with a water to cement ratio of 0.27. The reason there was N/A for the results with 0.27 water to cement ratio was because the sample itself was so weak that it barely held itself together. Some of the samples actually broke apart during the Sulphur capping process.

In conclusion, porous concrete with a water to cement ratio of 0.34 will yield porous concrete with the highest compressive strength.

9.3 – Compression (Part 2)

Table 7: Compression test results.

Mix Design	Loading (lb)	Compression strength (psi)
½ Gravel	17615	1401.35
¾ Gravel	13883	1104.46
Mix Gravel	8721	693.79
¾ Class II	3130	249.00
Mix Class II	5517	438.90

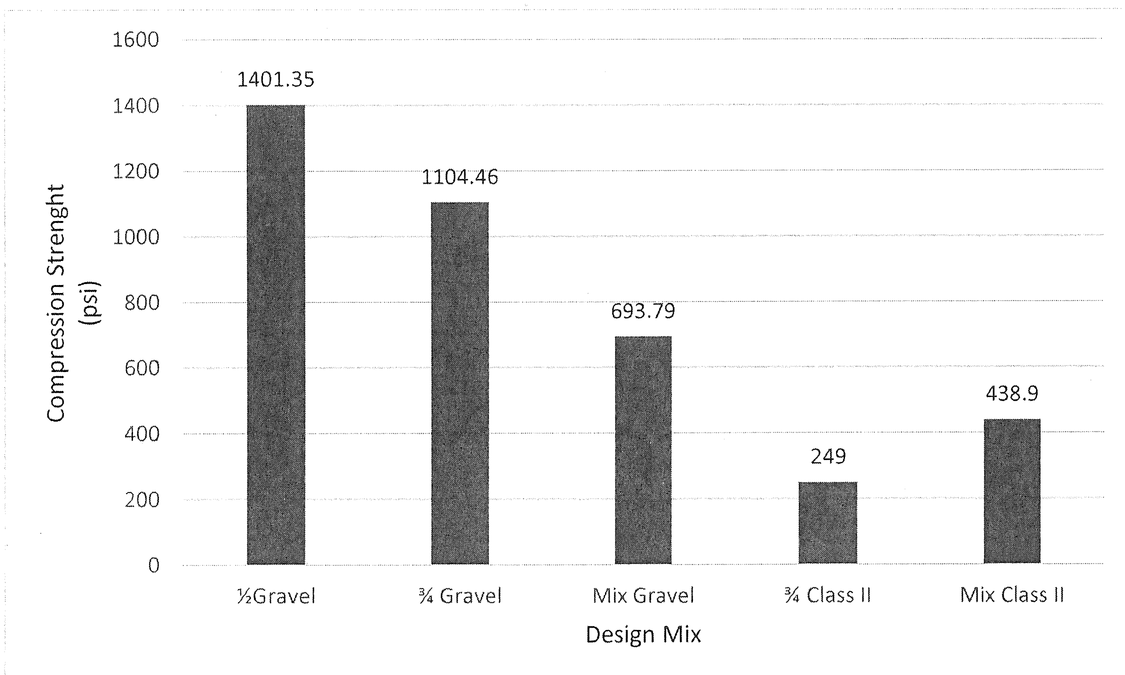

Figure 7: Compression Strength Graph.

Getting compression strength

Equation [#1]

Compression strength = Loading / Surface Area of sample

Radius of sample = 4 inch
Surface area = πr^2

9.4 – Percolation (Part 2)

Table 8: Percolation test results.

Mix Design	Time (s)	Percolation (in/s)
½ norm	21.68	0.216
¾ norm	16.52	0.284
Mix norm	14.24	0.329
¾ Class II	14.09	0.333
Mix Class II	14.35	0.327

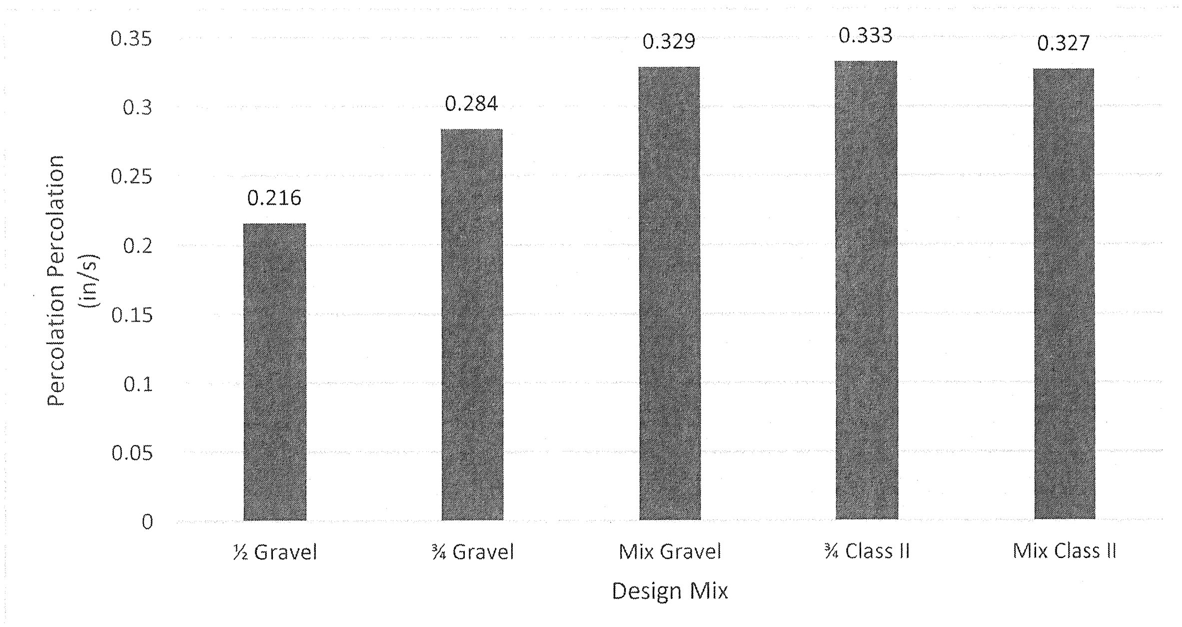

Figure 8: Percolation rates of different mixes

Getting percolation rate

Equation [#2]

Flow rate = Total volume of water / Time

Percolation rate = Flow rate / Surface area of sample

Height of water = 12 inches
Diameter of plastic container = 5 inches
Diameter of sample = 4 inches
Volume water = 235.5 inch^3

9.4 – Takeaway (Part 2)

The results showed that gravel had a much higher compression strength compared to Class II aggregate. This meant that the hypothesis was incorrect. The reason why the gravel mix had a higher compression strength than the Class II mix was that the Class II aggregate is a recycled material. This can be seen from its aggregate properties. Class II aggregate has higher water absorption and a lower unit weight compared to the gravel. Another reason why this might be the case is due to cementitious material. The cementitious material seems to be able to bind better to the gravel mix than the Class II aggregate mix. Cementitious material is the glue that binds one aggregate to another. The reason for this has to do with the fact that Class II aggregates have a rougher surface area. The rough surface means more cementitious material will be used for covering up its rough edges rather than being used to bind to other aggregates.

It was also found that smaller aggregate size leads to a higher compressive strength as seen from the Figure 8. Half-inch gravel has a higher compressive strength compared to ¾-inch gravel. Similarly, Mix class II has a higher compressive strength than ¾ class II aggregate. The smaller aggregate size means more compaction and surface area contact between each aggregate, which leads to greater overall strength.

The results for the percolation rate was the complete opposite of compression strength. Smaller aggregates tend to lead to a slower percolation rate while larger aggregates leads to a higher percolation rate. The smaller aggregates have more but smaller voids. This slows down the movement of water flowing through it.

Moreover, in general Class II aggregate mix has a higher percolation rate than the gravel mix. The reason for this is the cementitious material once again. The rough surface of the Class II aggregates used some of its cementitious material to cover them up. This means that there is less cementitious material actually binding the aggregate itself. Since there is less material binding the aggregates together, they will have larger voids in-between its aggregate. The larger voids leads to a higher percolation rate

10 – Clogging

10.1 – Problems with Clogging

Clogging is one of the main concerns with porous concrete. Porous concrete has such as its susceptibility in cold climates due to freeze and thaw but clogging is something that is avoidable. There are two primary ways to prevent clogging: vacuuming or using a pressure washer. Due to the size of the sample vacuuming, vacuuming would be most practical.

During research, no methods of experimental procedure on how to evaluate the effectiveness on vacuuming debris in porous concrete were found. So the team came up with an experimental procedure.

This procedure consists of two parts. The first part was to make sure that the porous concrete sample had been somewhat clogged, while the second part determined how effective vacuuming was regarding the clogging problem.

10.2 – Experiment Procedure

Clogging Procedure

1. Test for porosity
2. Place about 30grams of debris on the top of the sample
3. Test for porosity
4. Note the difference in porosity
5. Redo steps 2-4 again until clogged
6. Take off debris that is left on top of sample
7. Test for porosity
8. Record final results
9. Compare result to initial porosity test
10. Wait for sample to dry

Vacuum procedure

1. Vacuum top of sample (shop vacuum)
    a. Back and forth motion
2. Test for porosity
3. Record Results
4. Compare results to Clogged results

10.3 – Results

Table 9: Results of clogging test.

Aggregate / Debris	0 grams	30 grams	60 Grams	90 Grams
1/2 Gravel	11.5 s	17.4 s	22 s	23.7 s
Mix CII	9.2 s	12.6 s	14.2 s	19.8 s
3/4 Gravel	10.7 s	13 s	14.3 s	16.8 s
3/4 CII	8.94 s	12.33 s	21.06 s	53.68 s
Mix Gravel	8.83 s	9.53 s	12.8 s	16.6 s

Note

The values are in seconds and it represents amount of time it takes for a volume of water to pass through the sample, which was the same as when the percolation rate was found.

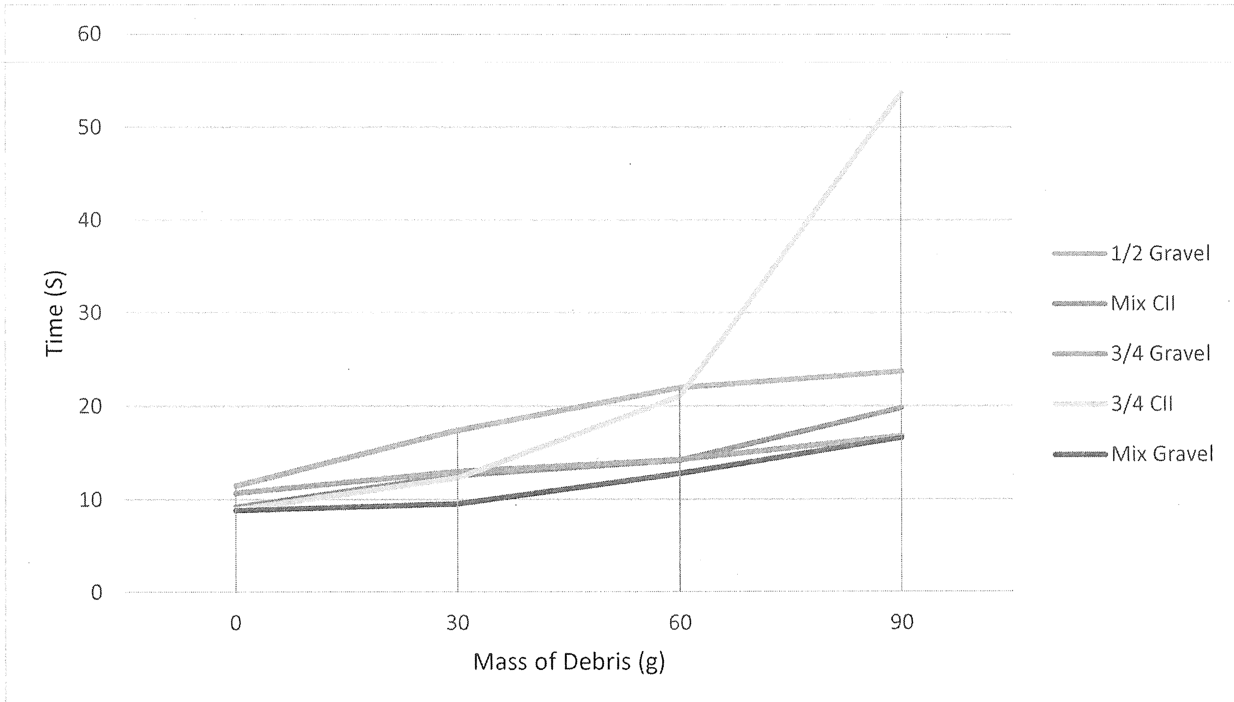

Figure 9: How samples react to clogging

Figure 9 shows the relationship between the amount of debris that was placed in the sample and the amount of time it took for a certain amount of water to pass through it. Essentially, it is a graph that shows the relationship between clogging and percolation rate.

Table 10: Results of clogging test.

Mix	Initial (s)	Clogged (s)	After Vacuum (s)	Time increase
½ Gravel	11.5	23.9	16.6	5.1
¾ Gravel	10.7	20.2	14.63	3.93
Mix Gravel	8.93	16.2	10.36	1.37
¾ Class II	8.94	53.58	10.2	1.34
Mix Class II	9.2	28.7	12.3	3.1

Table 11: Percentage of permeability lost.

Mix	Initial (in/s)	Clogged (in/s)	After vacuum (in/s)	Loss with clogging (%)	Loss after vacuum (%)
½ Gravel	0.815	0.392	0.565	51.88	30.72
¾ Gravel	0.877	0.464	0.640	47.03	26.86
Mix Gravel	1.050	0.579	0.905	44.88	13.80
¾ Class II	1.049	0.175	0.919	83.31	12.35
Mix Class II	1.019	0.327	0.762	67.94	25.20

Equation

% Loss with clogging = (Initial – clogged) / Initial

% Loss after vacuum = (Vacuum – Initial) / Initial

10.4 – Takeaways

From the results, the team found that vacuuming was most ineffective with samples that had smaller aggregate size. The small voids make it more difficult for the vacuum to take out the debris. Vacuuming the design mix with the Class II aggregates was more effective than vacuuming the design mix with the gravel aggregate.

Additionally, when the team broke open the mold to every sample after the test, the team was able to see where the debris stayed inside the sample. It was found that the vacuum was able to remove debris that was closer to the surface, but it was not able to do so with debris that has infiltrated about five inches below the surface of the sample.

11 - Conclusion

Each and every mixture can fulfill the requirements for even the worst rainstorm but only some of them have the compressive strength necessary for particle use. In other words, only some mixtures are able to withstand the compression forces of human traffic and vehicles. From the findings of this project, it was found that the samples that had the highest compression strength were the half inch gravel mixture. Due to this fact, the half inch gravel would be the best design mixture for practical use.

Furthermore, smaller aggregate mixes are more practical because of their small surface voids. Small surface voids will prevent punctures and, for example, will enable people wearing high heels to walk on its surfaces without worrying that their heels would get stuck inside the surface voids. Overall, smaller aggregates mixes are simple a safer and aesthetically pleasing option. Aggregates that are used should be no bigger than half inch.

11.1 – Improvements

Some further improvements could be made in order to improve compressive strength of design mixture. The first possible improvements would be done by adding chemical admixtures to the mixture. Some admixtures such as water retarders will help increase compression strength by lowering the water to cement ratio. Another possibility is by using another type of aggregates that is angular similar to Class II aggregate. But this time the new aggregate should not be a recycled so that's it will yield a higher compression strength.

12 – Appendix

A-1

Raw Data for Specific gravity and absorption test

Sample	Container (g)	Container +aggregate	Aggregate	Weight in h20	Weight Wire	Weight aggregate	Container + aggregate dry	Container dry	Aggregate dry	Specific gravity	Abs
3/4 gravel	217.5	1524.3	1306.8	0.96	0.11	850	1515.4	217.5	1297.9	2.860	0.6851
1/2 class 2	233.3	1245.5	1012.2	0.72	0.11	610	1223.1	233.3	989.8	2.516	2.26
1/2 gravel	216.6	1226.6	1010	0.77	0.11	660	1220.1	217.6	1002.5	2.885	0.748
3/4 class 2	314.9	1233.5	918.6	0.68	0.12	560	1114.7	228.2	886.5	2.56	3.62

A-2

Raw Data for Specific gravity and absorption test

Sample	Bucket +aggregate	Bucket	Aggregate	Water + bucket	Water specific gravity	temperature	Density g/cm3	Volume cm3	volume ft3	aggregate weight lb	unit weight
3/4 class 2	7.35	0.16	7.19	5.22	5.16	23	0.997538	5172.7	0.182	16.85	92.249
3/4 gravel	8.52	0.16	8.36	5.22	5.16	23	0.997538	5172.7	0.1821	18.43	100.89
1/2 gravel	8.62	0.16	8.46	5.22	5.16	23	0.997538	5172.7	0.182	18.65	102.10
1/2 class 2	6.92	0.16	6.76	5.22	5.16	23	0.997538	5172.7	0.182	14.9	81.57

13 - References:

ACI 522.1-13 Specification for Pervious Concrete Pavement