Pervious Pavements: A Miniature Examination

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***Abstract*— Our cities are being covered with buildings and the air-proof concrete road more. Because of the lack of water permeability and air permeability of the common concrete pavement, the rainwater is not filtered underground. Pervious concrete pavements are the ones which allow the water to penetrate through them thereby reducing the various problems faced by many cities. Water stagnation, low groundwater level are a few problems which have been tormenting our cities. This material attempts to fill this gap by experimenting on a miniature scale, the pervious concrete. The result of the experimentation is found out and the test of infiltration according to the American Society for Testing and Materials (ASTM C1701) is carried out. The result of the investigation clearly indicates the need for adopting this on a larger scale thanks to the infiltration of water at a considerable rate. Based on the method carried out, various applications of the same have also been discussed henceforth.**

Keywords— **Pervious concrete, water stagnation, ASTM, infiltration rate, applications**

I. INTRODUCTION

Pervious concrete is a mixture of gravel or stone, cement, water and little or no sand which creates an open cell structure that allows water and air to pass through it. According to EPA (Environmental Protection Agency's), storm water runoff can send as much as 90% of pollutant such as oil and other hydrocarbon. The ability of pervious concrete to allow water to flow through itself recharges ground water and minimizes the extent of pollution and storm water runoff. Pervious concrete is used to allow storm water to infiltrate through the pavement and reduce or eliminate the need for additional control structures, such as retention ponds. The pervious concrete pavement possesses many advantages that improve city environment such as the rainwater quickly filtering into ground, so the groundwater resources can renew in time. Also, a s the pavement is air permeable and water permeable, the soil underneath can be kept wet. The pervious concrete pavement can absorb the noise of vehicles, which creates quiet and comfortable environment. In rainy days, the pervious concrete pavement has no plash on the surface and does not glisten at night. This improves the comfort and safety of drivers. The pervious concrete pavement materials have holes that can cumulate heat. Such pavement can adjust the temperature and humidity of the Earth's surface and eliminates the phenomenon of hot island in cities. An experienced installer is vital to success of pervious concrete pavements as with any concrete pavement, proper subgrade preparation is important.

II. CONSTITUENTS

The subgrade should be properly compacted to provide a uniform and stable surface. When pervious pavement is placed directly on sandy soil it is recommended to compact the subgrade to 92 to 96% of the maximum density. With silty or clayey soils, the level of compaction will depend on specifics of pavement design and a layer open graded stone may have to be placed over soil.

The mixture is composed of cementious materials, coarse aggregates, water with little or no fine aggregate and admixtures if needed. Addition of small amounts of fine aggregates will gradually reduce the void content and increase the strength, which may be desirable in certain situations. This material is sensitive to changes in water content, so field adjustment of fresh mixture is usually necessary.

The correct quantity of water in the concrete is critical. Too much water will cause segregation, and too little water will lead to balling in the mixer and very sl ow mixer unloading. The Water/Cement and Cement/Aggregate ratios normally range from 0.25 to 0.45 and 1:3.5 to 1:6. The materials that are used in general for the preparation of a pervious concrete are cement, stone chips, water and a suitable admixture if required. The brief descriptions of these materials used in the experimental program are as follows:-

A. Cement

Portland cements and blended cements may be used in pervious concrete. Supplementary Cementitious Materials (SCMs) such as fly ash, pozzalans and blast-furnace slag may also be used. These added materials will affect the performance, setting time, strength, porosity and permeability of the final product. But in this experiment, ordinary Portland cement has been made use of.

B. Aggregate

The size of the coarse aggregate used is kept fairly uniform in size to minimize surface roughness and for a better aesthetic. The use of the pervious concrete will dictate the size of the aggregate used, and sizes can vary from ¼-inch to ½-inch (6.35mm-12.7mm) in size. Aggregate can be rounded like gravel or angular like crushed stone and still make for a good mixture. The decision-making process has to do with the compaction equipment, the availability of materials, the production capabilities and economic concerns. It is good to remember that rounded aggregate requires less compactive effort than angular aggregate, and can produce higher strength pervious concrete. The usage of 10mm size stone chips has been made in this experiment.

C. Water

Water that is potable is generally fine for use in the mix. Coarse aggregate should be kept damp before batching in order to ensure consistency and uniformity. If the aggregate is too dry before being mixed, the mixture will not place or compact well. But excess free water on aggregates contributes to the overall mixing water and will create a wet, soupy mix in which the paste flows off, and the voids are filled. Water to cement ratios should be generally between 0.27 and 0.30 including any chemical admixtures. Ratios as high as 0.34 to 0.40 have also been used successfully. In pervious, the total paste content is less than the voids content between the aggregates, so making the paste stronger may not reliably lead to increased overall strength. Optimum water content produces a fully wetted cement paste with a high viscosity that can be described as sticky. Thus, a water cement ratio of 0.35 has been used based on various tests that are described below.

II. MINIATURE SCALE EXPERIMENT

A miniature scale model is also created in a pragmatic way so that the real time problems which are possible in the future may be realized. Thus, an area is chosen to create that pervious concrete pavement and tests are carried out in that particular area. This depiction of a miniature scale is highly related to the real-time applications in the field. The various procedures and processes are depicted in this section.

A.MARKING THE BORDERS

As a first step, the boundary for the pavement is marked suitably and visibly. In this experimental program, a rectangular section of 1.2m * 0.9m is chosen to depict the real time scenario. Thus, this cross-section is initially marked for proper identification and perfection. Also, the surface to be worked on is cleaned properly with the top surface ripped off the unwanted matter and then levelled. Levelling the surface will make the job of digging easier.

Fig. 1. Digging the area identified

B. DIGGING THE MARKED AREA

The marked area is then dug suitably up to the required depth. In this experiment, based on keeping the depth of the concrete to 6’’, the overall depth of the dug portion was calculated to be 9’’ with the aggregate portion supporting the concrete and finding them for a depth of 3’’.

Overall depth = Depth of Pervious concrete + Depth of Aggregate.

During the process of digging, it was made sure that the sides of the dug portion remained intact and there wasn’t any chance of instability.

C. LEVELLING THE DUG SURFACE

The dug surface, 9’’ beneath the top surface, was first sprayed with water for practical reasons and then the surface was levelled with sand rammer. The surface was levelled because the next step is to fill it with coarse aggregate and thus to ensure the evenness that the aggregates must find them in, the surface was levelled. It also improves the easy and fine transformation of load from the aggregates to the surface.

Fig.2 Levelling the dug surface

The water is sprayed and rammed with sand rammer so that the soil absorbs water initially thus preparing itself for the real time conditions. Before filling the dug surface with the aggregates, it is vital that they are kept in a practical condition thus creating the need for spraying water over the surface. As the soil absorbs water, it is then rammed by sand rammer.

Fig.3.Ramming

D. AGGREGATE LAYER FORMATION

Once the ramming work is done, the surface should be covered with the coarse aggregate. The coarse aggregates used in this experiment for layer formation are 10mm stone chip as mentioned earlier and 20mm aggregate. Firstly, the 20mm aggregate is spread over the surface so that the load distribution will be spread uniformly. This will be the first layer above the soil as it will also allow good infiltration into the soil. Above this layer, 10mm stone chips are spread over it to improve the chances of good infiltration. After each layer, ramming is carried out and levelled for the easy accommodation of the succeeding layer.

When the water percolates through the concrete, it takes time to completely penetrate into the soil. At that instance, this usage of aggregates down the order comes in handy as it avoids water stagnation at the bottom by reducing the time of water to reach the soil. Thus, this layer will serve as the base for the pervious concrete to be created at the top of it.

E. PLACEMENT OF FORMWORK

Above the aggregate layer, the pervious concrete is to be placed. So, to hold the concrete layer, formwork is placed, which gives shape to the concrete to be placed above. Hence, to create the formwork, wooden boards are used to form the sides of the dug layer. 3’’ has been filled by the aggregates. Hence the remaining 6’’ is to be of pervious concrete. Thus the portion of 6” is to be covered with formwork.

F. CONCRETE PREPARATION

Now that the formwork is placed and concrete is to be placed into it, the concrete is prepared as the next process. The concrete is prepared in the ratio of 1:4 for Cement: Coarse aggregate at the side of the model so that the time required for the placement of concrete is less thus avoiding any chances of setting early. To begin with, coarse aggregate is taken initially and then cement is added to it in required proportion. The mixture is then added by water in suitable quantity and thoroughly mixed. It is to be noted that the admixture quantity which may be added if required, is included in the water-cement ratio of 0.35. The workability of the mixture thus prepared is then verified so that there isn’t any problem when the casting of concrete is carried out.

Fig.4. Concrete preparation

G. FINISHING

Once the layers of concrete are placed in the formwork, the top surface of the concrete is levelled using trowel and roller. Also, the reason for levelling the top surface is that, the vehicular movement is possible only when the finish is smooth. This necessitates the need for a smooth finish, which is carried out immediately after the placement of concrete in the formwork.

Without a smooth finish, the top surface may wear a torn look and may be subjected to wear and tear failure in the future. Thus it is necessary that the concrete is finished well at the top to avoid any type of failure in the future and for longer life.

Fig.5. After placement and finishing

From the above figure, it can be seen that the top surface is levelled. Also after levelling, the top surface is made moist by the spraying of water to it, so that the moisture which is prevalent in realistic conditions, is exhibited even here.

G. COVERING THE SURFACE

The top surface is sprayed with water so that the moisture is retained in the pavement. Now, after the spraying of water, the surface is covered using a plastic sheet so that the moisture held by the surface isn’t lost to the atmosphere because of evaporation.

Thus, by covering the surface by a plastic sheet, the moisture is held within itself. This is done for a period of seven days so that curing happens in a proper way, giving strength to the concrete.

Fig.6: Plastic sheet covering

H. SEVEN DAYS CURING

After a period of seven days, the plastic sheet is removed from the surface and allowed to dry. Now the pervious pavement is ready to be used for the purpose of serving as a drive-way as well as for infiltrating water. The performance of the pervious concrete is roughly judged by pouring water over the surface and the water absorption is checked.

The water thus poured over the concrete must not stagnate over the surface as the pervious nature of the concrete drains the water over it by sending it underground and recharging the ground water. The following figure depicts the water draining of the pervious pavement.

Fig.7.Water infiltration

It was seen that the water percolated through the concrete surface, making sure that there was no stagnation of water even on pouring good quantity of water. Thus, this can be a very useful way of solving the water stagnation problems.

III. ASTM INFILTRATION RATE TEST

The American Society for Testing and Materials has technical standards specified for measuring the infiltration rate of the pervious concrete. This test of infiltration is according to ASTM's C1701 and the various stipulations specified in the test are followed accordingly. The ASTM infiltration test requires the following to be present:

- Infiltration ring of suitable diameter
- 5 Gallon (18.92 liters) container
- Water
- Stop watch
- Weighing machine

This infiltration test generally adopts four steps:-

- Installing the infiltration ring
- Prewetting the concrete
- Testing the concrete
- Calculating the results

The first step is choosing an infiltration ring of a suitable diameter. In the inside of that infiltration ring, two lines are marked at a distance of 0.40", the bottom line at a distance of 10mm from the surface bottom. This is according to the ASTM standards, by which the water level should be kept constant by keeping it in between these two lines thus maintaining a constant head.

The infiltration ring is placed in such a manner and covered that the water when poured in to it, shouldn't seep out of the ring. The levels are marked clearly so that the water level is maintained at a constant rate. The test is initially carried on by using 1 gallon (3.78 liters) of water and finally using 5 gallons (18.92 liters) of water.

As a first step, the time taken for the 1 gallon of water to completely infiltrate the ring is noted, taking care that the head is maintained between the two lines marked in the ring. Then the time taken to completely infiltrate 5 gallons of water is noted.

Fig.8. Infiltration ring is placed

The infiltration rate is then calculated by using the formula below:-

- $I = (KM)/(D^2t)$

Where,
K= 12680 (constant)
M= Mass of infiltrated water (lb)
D= Inside diameter of infiltration ring (in)
t= Time required to infiltrate (s)

A. ASTM INFILTRATION RATE CALCULATION

The results of the experiment pertaining to the infiltration rate of pervious concrete according to ASTM specifications are then found out. This is done by using an infiltration ring of 20.5cm diameter. This infiltration ring is then made the center point of the test by pouring water into it. Before the test is carried out, two rings are marked in the inside of the infiltration ring, the bottom one being at a distance of about 10mm from the bottom and the top one at a distance of 15mm from the bottom. The water is poured into the infiltration ring during the test, in such a way that the head of the water is maintained in between these two rings. There are two quantities of water used in carrying out this test:-

- 1 Gallon of water
- 5 Gallons of water

The time taken by the water to infiltrate the ring is then noted and the results of that are as follows:-

- 1 Gallon = 57.44 seconds
- 5 Gallons = 4.34 minutes

Based on the time taken by the water to infiltrate the ring, the infiltration rate is to be calculated. The formula being:-

I= (KM/ D^2t),

Where,

- K= 12680 (Constant)
- M= 5 Gallons = 41 lb
- D= 20.5cm = 8.07 inches
- t = 4.34 mins= 260 seconds

Hence,

I = (12680 * 41)/ (8.07^{2} * 260)

= > I= 312.64 inches/ hour

Thus the performance of the pervious concrete pavement constructed is based on this, where the infiltration rate is 312.64 inches/ hour. So, in an hour, water infiltrates 312.64 inches. The infiltration rate value of 312.64 inches/ hour suggests that the pervious concrete structure constructed has a good rate of infiltration and can be used for practical purposes such as pavements etc. The American Society for Testing and Materials has no specific range for the infiltration rate as the rate varies depending on the void ratio and the materials used. The reason is that the pervious concrete doesn't have a mix ratio of its own as there is no usage of sand in the preparation of pervious concrete.

Hence, the rate of infiltration largely varies depending on the voids present in the concrete and the size of the aggregates used.

IV. APPLICATIONS

The various applications of pervious concrete are as follows:-

A. Residential roads, alleys, and driveways

Wherever the volume of traffic is less, say for an example, the dead ends in a residential area and light-vehicle movement in a limited manner, the pervious concrete may play a bigger role in these parts.

B. Road Shoulders

Moreover, in heavy traffic areas, the usage of pervious concrete is highly restricted. Still, it can be used in the shoulders of the road with proper camber being provided in the roads so that there is sufficient inclination for the water to drain into the pervious concrete shoulders lining the border of the roads. From the below depiction, it is clear that the pervious concrete may be used in the shoulders of the roads in an efficient way to drain the water that collects in a normal road

Other applications are:-

C. Sidewalks and pathways

Also, the pedestrian sidewalks may be built with pervious concrete so that they let the water pass through them into the ground. For a private purpose, Pervious concrete may be used to surround the house so that it supplements the rain water harvesting scheme by directly draining the water into the ground without having to stagnate them.

Fig.9. Application model

D. Parking areas

Other than this, in Parking lots, pervious concrete has a major role to play these days as there isn't a heavy movement of vehicles.

E. Low-volume pavements

Pavements have a greater advantage in using pervious concrete as their usage leads to easier draining of water at the same time withstanding a decent load.

V. CONCLUSION

The recent consciousness about the environmental protection and the birth of Leadership in Energy and Environmental Design (LEED) has encompassed even the roadways. This novel idea of using pervious concrete has generated huge interest in developing roadways and driveways considering environment as a factor too. By the tests carried out in this project, it is clear that the pervious concrete is capable of infiltrating water at a decent rate. The laying of pervious concrete has shown the practical issues of concreting immediately after the mix. The Infiltration rate of 312.64 inches/ hour is an indication about how useful these can be, if implemented properly adhering to the rules. The potential of pervious concrete as a whole is yet to be tapped. This material indicates just that on how useful socially it can be.

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