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Study on Pervious Concrete

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Abstract- Concrete is homogeneous mixture of cement, fine aggregate, coarse aggregate and water with or without admixtures, which is always regarded as impermeable. Now a days the major issue is to reduce surface runoff and enhance the ground water level, this is the problem wherein areas having concrete pavements. So, the pervious concrete is adopted as one of the best alternative to avoid this. In this paper we have only a brief study of properties of Pervious concrete, its behavior with admixtures and also its mix-design.

Index Terms*:* Pervious concrete, admixtures, strength, permeability, properties, mix-design.

1. INTRODUCTION

Pervious concrete is a zero-slump, open-graded material consisting of hydraulic cement, coarse aggregate, admixtures and water. Because pervious concrete contains little or no fine aggregates such as sand, it is sometimes referred to as “no-fines” concrete. When the cement and water are combined, it forms a paste that binds the coarse aggregate together in a hardened product with connected pores that allow water to pass through easily. The pores can range from 0.08 to 0.32 inches (2 to 8 mm), and the void content usually ranges from 15% to 25% with compressive strengths of 400 to 4000 psi (2.8 to 28 MPa). However, strengths of 600 psi to 1500 psi (2.8 to 10 MPa) are more common. Many of the void spaces are interconnected, forming channels that let water and air pass through the pavement. The draining rate of pervious concrete pavement will vary with aggregate size and density of the mixture, but will generally fall within the range of 2 to 18 gallons/minute/foot2 (81 to 730 liters/minute/m2). The density and flow rate depends on the properties and proportions of the materials used. Therefore, mix designs must take into account the different aggregates used in each geographic locality.

The Clean Water Act and other EPA regulations (e.g. EPA Storm water Phase II Final Rule) were introduced, in part, to create more stringent standards for storm water runoff control. According to EPA (Environmental Protection Agency’s) storm water runoff can send as much as 90% of pollutant such as oil and other hydrocarbon. In an attempt to cease the further degradation of these water resources viable alternatives to current construction and other development practices need to be considered.

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

1.1. *History of Pervious concrete*

In Europe, pervious concrete, most commonly referred to as Gap graded concrete, has been used in the construction industry for approximately 150 years. The initial usage of this type of concrete in Europe was in applications such as prefabricated panels, steam-cured blocks or cast-in-place load bearing walls for single and multi-story houses and, in some instances, in high-rise buildings.

In 1852, Richard Langley used a predecessor of pervious concrete for the construction of two concrete houses on the Isle of Wight in the United Kingdom. This concrete consisted of only coarse gravel and cement. It is not mentioned in the published literature again until 1923, when a group of 50 two-story houses were built with clinker aggregate in Edinburgh, Scotland.

In the late 1930s, the Scottish Special Housing Association Limited adopted the use of pervious concrete for residential construction. By 1942, pervious concrete had been used to build over 900 houses. A larger amount of pervious concrete was used after World War II when sufficient volumes of building brick could not be produced to support housing needs. Less expensive building construction methods were explored and pervious concrete was one of them. In some countries, coarse aggregate was used for the production of pervious concrete and in other countries, brick rubble was utilized. Over time, the brick rubble was exhausted and replaced by crushed or natural coarse aggregate. Lower production costs led to the acceptance of pervious concrete as a building material. Pervious or gap graded concrete was mostly used in construction housing applications. Many new houses were built using pervious concrete in the United Kingdom, Germany, Holland, France, Belgium, Scotland, Spain, Hungary, Venezuela, West Africa, the Middle East, Australia, and Russia. Before World War II, the use of pervious concrete had been limited to two-story housing but after World War II, the pervious concrete technology had advanced and could be used in buildings up to ten stories high. The reason that the usage of pervious concrete in the

United States falls far behind the European countries is due to the fact that no building material shortages have been experienced in the United States, therefore little effort has been made to explore and develop new alternative materials. Current applications are not as focused on building construction as they were in the past but today, pervious concrete is primarily used for the paving of parking lots, driveways or sidewalks.

1.2. *Advantageous of Pervious Concrete Pavement*

The pervious concrete pavement possesses many advantages that improve city environment as follows:

[1.] Its property of permeability enriches the groundwater resources in time.
[2.] As the pavement is air permeable and water permeable, the soil underneath can be kept wet.
[3.] The pervious concrete pavement can absorb the noise of vehicles, which creates quiet and comfortable environment.
[4.] 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.
[5.] 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.
[6.] Allows storm water to infiltrate into the ground to replenish ground water aquifers.
[7.] Retains storm water so that retention ponds are not needed for parking lots.
[8.] Keeps pavement surfaces dry even in wet situations, such as greenhouses.
[9.] Aerobic bacteria that develop within the pavement and base can break down oil and remove other pollutants from the water that washes off the surface.

1.3. *Properties of Pervious concrete*

1.3.1. Strength

The disadvantages of a pervious concrete pavement are perceived to be lower strength and durability that can sometimes occur in these systems, which may lead to a service life that is shorter than that of the designed life (Schaefer, et al., 2006; EPA, 1999). However, several studies have shown that adequate strength can be achieved for a variety of applications in which porous pavements would be useful, specifically low-volume traffic areas such as parking lots (e.g., Ghafoori and Dutta, 1995; Schaefer, et al., 2005). In these areas the benefits of porous pavement systems can outweigh the perceived limitations, as low-volume areas have a smaller strength demand and act as point sources for storm water pollution.

Laboratory studies have shown a wide range of values for 28-day compressive strengths of porous concrete. Some studies have reported that strengths of about 21 MPa (3,000 psi) or more are readily attainable with the proper water-cement ratio and densification process (Ghafoori and Dutta, 1995). Other studies have found compressive strengths that range from about 4 MPa to 25 MPa (600 psi to 3,600 psi) (Chopra and Wanielista, 2007; Schaefer, et al., 2006). Several factors have attributed to this wide range of reported strengths. The first of which is the effect of compaction or densification on the sample. It has been shown that in general, as the compaction energy or densification effort on the sample increases, there is corresponding increase in the compressive strength of the sample (Chopra and Wanielista, 2007; Schaefer, et al., 2006). The issue that arises when applying too much compaction or densification on a porous concrete is that these efforts may reduce the air voids of the sample significantly and as such may reduce its permeability significantly. As achieving adequate permeability for storm water control is generally the main goal of a porous pavement system, compacting concrete until it reaches adequate strength is not always an option, and a balance must be achieved between strength and void ratio (Ferguson, 2005).

The water-cement ratio (W/C), aggregate-cement ratio (A/C), unit weight of the mix and their effects on the overall strength of porous concrete have also been studied. The W/C ratio alone does not affect the overall strength, but may cause cement to settle on the bottom of the sample thereby reducing permeability (Chopra and Wanielista, 2007). The A/C ratio does have a direct effect on the compressive strength of the system, and as this ratio increases the strength of the concrete decreases (Chopra and Wanielista, 2007). The unit weight of the mix also has a direct effect on the compressive strength of porous concrete, and as the unit weight increases the strength also increases (Chopra and Wanielista, 2007; Schaefer, et al., 2006).

1.3.2. Permeability

The primary goal of any porous concrete system is to achieve adequate porosity so that water can readily pass through the system and into the sub-base. The creation of air voids is achieved by limiting or completely eliminating fine aggregates (FA) such as sand from the mix design, and using a well-sorted coarse aggregate (CA). With no fines in the mix, the CA is bound together only by a thin layer of cement creating air voids. The use of a uniform CA ensures that smaller pieces do not settle in the pore spaces decreasing the porosity of concrete (Ferguson, 2005).

Several methods for determining the permeability of porous concrete systems have been proposed. Most studies utilize a falling-head apparatus adapted from soils testing, although other methods have been used to measure permeability both in the laboratory and in-situ. In their laboratory study, Schaefer, et al. (2006) utilized a falling-head permeameter in testing 7.62 cm (3”) diameter porous concrete specimens prepared using several mix designs and different compaction energies. The measured hydraulic conductivity ranged between about 0.01 cm/s and 1.5 cm/s (14.4 in/hr to 2,000 in/hr). Their results also indicated that permeability increased exponentially with increasing void ratio and that an increase in compaction energy corresponds to a decrease in permeability.

Montes and Haselbach (2006) also utilized a falling-head apparatus in determining the hydraulic conductivity of porous concrete specimens in the laboratory, which ranged between 0.014 cm/s (about 20 in/hr) and 1.19 cm/s (about 1,700 in/hr). The results showed that the hydraulic conductivity of a porous concrete sample increased exponentially with increasing porosity, and that porous concrete with porosity of less than 15% had limited to no permeability. Ghafoori and Dutta (1995) utilized a constant head permeameter in measuring the hydraulic conductivity of porous concrete samples in the laboratory. The study focused on the effects that compaction energy and the aggregate to cement ratio had on the hydraulic conductivity of porous concrete. Both of these factors were found to play a role in the overall hydraulic conductivity of the concrete, with an increasing compaction energy corresponding to a lower hydraulic conductivity and a larger A/C also yielding a lower hydraulic conductivity.

1.4. *Scope for work*

[1.] An investigation could be done to address the strength and drainage aspects of pervious concrete mixes and also the influence of crushed stone as a fine aggregate.
[2.] A study on resistance of pervious concrete mixes against chemical attack, clogging behavior with the use of geo-textiles etc., could be addressed.
[3.] A detailed study is required to know the effects of aggregate gradation with other types of aggregate to obtain higher strength and adequate engineering properties of pervious concrete.
[4.] Attempts can also be made to improve the 28-day flexural strength of the pervious concrete mixes using different additives like silica fume, keeping the permeability factor in mind.
[5.] A study could be carried out on pervious concrete by varying the percentage of Titanium di-oxide (TiO2) (chemical admixture) and aggregate ratio. (C. Manoj Kumaar, U.K. Mark Vivin Raj and D. Mahadevan Dutta, 2015).

2. MATERIAL PROPERTIES AND MIX-DESIGN OF PERVIOUS CONCRETE

2.1. Cementitious Materials

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. The overall durability of the pervious concrete is increased with the use of silica fume, fly ash and blast-furnace slag due to the decrease in permeability and cracking.

2.2. 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 6.35mm-12.7mm in size. Aggregate can be rounded like gravel or angular like crushed stone and still make for a good mixture. Part of that 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. Coarse aggregate should be kept damp before batching, especially if the weather is very hot with low humidity in order to ensure consistency and uniformity from batch to batch of plastic pervious concrete.

2.3. Water

Water that is potable is generally fine for use in the mix. 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 between 0.27 and 0.30 including any chemical admixtures. Ratios as high as 0.34 to 0.40 have also been used successfully. Unlike the relation between strength and water-to-cement ratios in regular concrete, the relationship for pervious is not as well defined. 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. Needless to say, the water content should be tightly controlled so that the mixture has a sheen to it without it being so soupy that it flows off the aggregate. Optimum water content produces a fully wetted cement paste with a high viscosity that can be described as sticky.

2.4. Admixtures

Some of the same admixtures used in regular concrete can be used with pervious concrete. Many of these admixtures are retarders, or hydration-stabilizing due to the quick setting time with pervious concrete. Some of these include water-reducing admixtures (WRA), retarders, hydration stabilizing admixtures (HSA), viscosity modifying admixtures (VMA) and internal curing admixtures (ICA). Air-entraining admixtures reduce freeze-thaw damage and are used in climates with cold wet winters. A new, proprietary admixture called HydroMax™ facilitates the placement and protection of pervious pavements by significantly speeding up the discharge process while reducing the need for plastic sheeting. HydroMax™ is a viscosity modifying, internal curing admixture that allows an increase in the water: cement ratio without affecting the mix consistency, and while retaining moisture for the curing of the concrete.

As mentioned above, pervious concrete uses the same materials as conventional concrete, except that there is usually little to no fine aggregate. The quality, proportions and mixing techniques affect many of the properties of pervious concrete, in particular the void structure and the strength. Freshly mixed pervious should be plastic and capable of being shaped like modeling clay when squeezed by hand. It should hold its shape without slumping

3. TEST ON PERVIOUS CONCRETE

3.1. Compressive Strength Test

The compressive strength test will be generally carried out on the pervious concrete specimens at the end of 7 days, 14 days and 28 days of curing. After cleaning the bearing surface of the compression testing machine, the concrete block will be placed on its face side having dimension 150 mm × 150 mm. The axes of the specimen are to be carefully aligned with the center of the lower pressure plate of compression testing machine. Then an upper pressure plate is to be lowered till the distance between the pressure plate and the top surface of the specimen achieved. No packing used between the face of the pressure plates and block. The load will be applied without shock and increased gradually at the rate of 35kg/cm until the specimen was crushed. The compressive strength calculated in N/mm^2 from the maximum load sustained by the cube before failure. An average of three values was taken for determining compressive strength of concrete.

3.2. Split Tensile Strength Test

Due to the difficulty in applying uniaxial tension to a concrete specimen, the tensile strength of the concrete is determined by split cylinder test, it is standard to determine the tensile strength of concrete in an indirect way. The test could be performed in occurrence in IS : 5816-1970 the cylinder size 150 mm diameter and 300mm length it is casted and tested to determine the split tensile strength on 7th, 14th and 28th days.

3.3. Permeability

Permeability tests were performed using three separate falling head permeameters, specifically designed to accommodate specimens of three different diameters. However, all three permeameters had similar design. As an example, Figure 1 shows a photograph of the permeameter used for testing 7.62 cm (3”) diameter specimens.

The specimens were enclosed in a mold that was lined with a thin rubber sheet, and tightened with hose clamps to minimize any flow along the sides of the mold that would affect the measurement of hydraulic conductivity. The sample was then connected to a vertical PVC pipe on both the upstream and downstream sides. The apparatus was filled with water from the downstream end, to expel any air voids that may have been present in the porous concrete sample. Once water had reached the top of the specimen, the apparatus was then filled from the upstream side. The system was allowed to reach equilibrium, at which time the water level was recorded, representing the head level on the downstream side. Maintaining the constant downstream head at a higher elevation than the top of the porous concrete sample provided full saturation of the sample throughout the test. The upstream water level was then increased to a height of 30 cm (about 12”) and allowed to fall to a height of 10 cm (about 4”), during which the time it took to fall was recorded. These values were chosen to represent values that could possibly occur for a porous concrete pavement system during a storm event. This head difference was expected to maintain laminar flow for the range of anticipated hydraulic conductivity (Montes and Haselbach 2006).

Fig. 1: Falling head permeameter used for 7.62 cm (3”) diameter porous concrete specimens

The coefficient of permeability (k) was determined by Equation:

$$k = \left(\frac{aL}{At}\right)\left(\frac{h_1}{h_2}\right) \quad \text{......Eq.1}$$

Where, k = coefficient of permeability (in/hr),
a = cross sectional area of the standpipe (in^2),
L = length of the specimen (in),
A = cross sectional area of the specimen (in^2),
t = time for water level to reach from h1 to h2 (sec.),
h1 = initial water level (in),
and h2 = final water level (in).

4. CONCLUSIONS

Pervious concrete pavement is a very cost-effective and environmentally friendly means to support green, sustainable growth. Its ability to capture storm water and allow it to seep into the ground enables pervious concrete to play a significant role in recharging groundwater, reducing storm runoff. Pervious concrete does not contribute to toxic runoff as asphalt does, plus it lessens the heat island effect that asphalt pavement contributes to.

We could develop strong and durable pervious concrete mixes for low-volume roads. It was found that by increasing w/c, strength of pervious concrete is increased. The study reveals that pervious concrete with aggregate size 12.5 to 16mm have much higher compressive strength and tensile strength. And there is a fall in strength on further increased size of aggregate i.e., for pervious concrete with aggregate size 16 to 20mm. For the same w/c, strength of pervious concrete increases with increase in aggregate size.

Compressive strength and tensile strength of four sized coarse aggregate namely, 4.75mm to 9mm, 9mm to 12.5mm, 12.5mm to 16mm and 16mm to 20mm with w/c ratio 0.35, 0.4 and 0.45 are investigated. (Sindhu P K, et al., 2015).

It was found during study that the failure plane during tensile test occurs along the paste rather than through the aggregates. And that the addition of Wollastonite and polypropylene fibres improved the strength of the paste.

Permeability is probably the most critical property in a pervious concrete design. It is important to maintain a high degree of permeability during sampling while trying to enhance other factors. Sacrificing permeability for an increase in strength or durability was not seen as a viable option. Therefore, it was studied that the target void ratio for the different mix designs was a standard 20%. This is an accepted void ratio that allows for adequate amount of free draining through the pervious concrete.

The major priorities of the work are to have a high permeability concrete with good compressive and flexural strength and resistance to various environmental conditions, which could be done using different additives like silica fume, Titanium di-oxide (TiO2) (chemical admixture) keeping the permeability factor in mind.

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