Some Aspects on Pervious Concrete

R. Selvaraj, M. Amirthavarshini

Abstract— **Pervious concrete or enhanced porosity concrete has a strictly gap graded coarse aggregate phase and little or no fine aggregates so as to facilitate the formation of an interconnected network of pores in the material. The material is designed with cementitious material content just enough to coat the coarse aggregate particles so that a configuration that allows the passage of water at a much higher rate than conventional concrete. The pervious concrete has many advantages that improves city environment, recharges the ground by rain water and could be used as pavement for light vehicles, pedestrian pathways, parking lots, also it reduces the tire pavement interaction noise etc. the effectiveness of a pervious concrete pavement depends as the intrinsic permeability of the mass, and normally this is defined by the porosity. It has been observed that porosity alone is an inadequate indicator of the permeability of pervious concretes, since the permeability depends on pore sizes, geometry and connectivity also. This paper presents a new method for determining the permeability of pervious concrete and provides design methodology to prepare pervious concrete based on experimental characteristics test values of pervious concretes.**

Index Terms— **Pervious Concrete, Gap Graded, Cementitious material, Intrinsic Permeability, Vacuum sweeping and Sand Clogging.**

I. Introduction

As long as century ago, designers in Europe recognized the value of porous concrete as structural insulation for buildings. And about 80 years ago in Europe, pervious concrete was starting to be used for roads as well. It is only in the past 20 years, that porous concrete has gained a foot hold for general construction purposes in the United States (American concrete institute, 522.1-08). It is one of the leading materials used by the concrete industry in effecting good "green" industry practices and is recognized as a best management practice by the U.S. Environmental Protection Agency (EPA) for providing pollution control, storm water management and sustainable development. In the first two years of twenty first century, the United States renewed interest has been expressed in pervious concrete pavements, mainly due to environmental issues (Schaefer, 2006). According to this same reference, these materials have been actually been used for over 30 years in England and the United States, and also widely in Europe and Japan as a roadway surface course to reduce traffic noise and also to improve skid resistance. Basically, a pervious concrete is simply produced by eliminating fine aggregate from the regular concrete mixture and often using much narrower distribution of coarse aggregates leading to an increased void content, typically in the order of 15 to 35%. These voids are interconnected so that the pervious concrete not only has dramatically increased permeability to allow water penetration and filtration but also lower strength and potentially lower durability. ACI Committee 522 was formed in the year 2001 to develop and report information on pervious concrete, and ASTM International's subcommittee C09.49, pervious concrete has recently formed to deal exclusively with pervious concrete issues (Bentz, 2008). Pervious concrete studies have focused mainly on experimental measurements of the strength and flow properties (Montes, 2006, Neithalath, 2006).

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The major application of pervious concrete includes.

(i) Applications with relatively light and low frequency loading (parking lots, bike paths, sidewalks, areas with light traffics, platforms, pavements to help in storm water conservation).

(ii) Pavement to reduce the tire-pavement interaction noise (road noise).

(iii) A pervious concrete reduces/ decreases road erosion, no channeling on road shoulders.

(iv) The pervious concrete pavements absorb carbon dioxide (CO_2) from the atmosphere

$$CO_2\ (g) + Ca\ (OH)_2\ (s) \longrightarrow \quad O\ (I) + CaCO_3\ (s) \quad (1)$$

(v) Rigid drainage layers exterior mall areas (Tennis, 2004).

Pervious concrete is one of the fast growing markets of concrete construction. As emphasis on environmental protection and building green is continuing to increase, the demand for pervious concrete will increase as well.

The effectiveness of concrete pavement to transport water through it depends on the intrinsic permeability of the system. However, this characteristic is defined interims of the porosity of the material. It has been observed (Neithalath, 2006) that porosity alone is an inadequate indicator of the permeability of the pervious concretes, since permeability depends on pore size, geometry and connectivity also.

Pervious concretes are open-graded material consisting of hydraulic cement, coarse aggregates, chemical admixtures and water. It contains little or no fine aggregates. Therefore 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 in the previous concrete can range from 2mm to 8mm, and the void content ranges from 15% to 30%, with compressive strengths in the range 2.8 MPa to 28 MPa. However, the compressive strength in the range 2.8 MPa to 10 MPa is more common in Europe. 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 generally fall in the range of 81 to 730 liters/min/m^2. It is evident that better understanding of the relationships between the microstructure and transport properties of pervious concrete will allow for better mixture proportioning and material selection.

Materials	Proportions (Kg/m^3)
Cementious materials	270-415
Coarse aggregate	1190-1480
Water to Cement ratio (by mass)	0.27-0.34
Aggregate : Cement ratio	4 to 4.5 : 1
Fine aggregate ratio	0-1 : 1

Table 1 The typical ranges of materials used in pervious concrete

II. ASPECTS ON MIX DESIGN

Pervious concrete uses the same materials as conventional concrete, except that there is usually little or no fine aggregate. The quantity, proportions, and mixing techniques affect many properties of pervious concrete, in particular the void structure and strength. Usually single sized coarse aggregate upto 20 mm size normally adopted. Larger size aggregates provide a rougher concrete finish while smaller size aggregates provide smoother surface that may be better suited for some application such as pedestrian pathways. Although the coarse aggregate size 6 mm to 20 mm are used, the most common being 10 mm fairly uniform size is used. The aggregates may be rounded like gravel or angular like crushed stone. It is good to remember that round coarse aggregate require less comparative effort than angular aggregates and can provide higher strength pervious concrete.

Since the pervious concrete is highly permeable, the voids between aggregate particles cannot be entirely filled by cement paste. Use of smaller size aggregates can increase the number of aggregate particles per unit volume of concrete. As the aggregate particle increase the specific surface and thus increases the binding area. This results in the improved strength of pervious concrete. However, the major thrust for using pervious concrete stems from its capability to drain and potentially de-pollute enormous amounts of water in short time, thus reducing the runoff rates. The physical and mechanical properties of pervious concretes are reported elsewhere (Onstenk, 1993, Neithalath, 2004, Neithalath, 2005, Neithalath, 2006, Nelson, 1994). The use of larger size aggregates reduces clogging of pores in the pervious concrete (Nelson, 1994).The water permeation capacity or drainage properties are closely related to the porosity with coefficient of permeability to about 0.01m/s is recommended (Belgian Road Research center, 2000). A drainage rate of 100 to 270 lit/m^2/min has been reported for pervious concrete with a porosity ranging from 17% to 28% (Tennis, 2004). Recently (Fanry, 2004, American Concrete Institute ,522R- 06) it is suggested that the aggregate sizes of pervious concrete should be between 9.5 mm and 19 mm and no fine aggregate should be used. The Fig.1 shows the schematic model of pervious concrete.

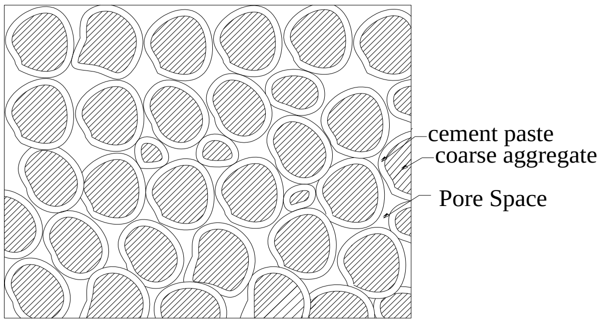

Figure 1 The schematic model of pervious concrete

The binder normally used in ordinary Portland cement (OPC). Pozzolanic materials like fly ash, blast furnace slag and silica fume can also be used. However, use of pozzolanic materials will affect setting time, strength, porosity and permeability of the resulting concrete. Addition of fine aggregate will reduce the porosity and increase the strength of concrete. Chemical admixtures like water reducing admixture, retarders, hydration stabilizing admixtures, viscosity modifying admixtures and internal curing admixtures are used. Placement and compaction of pervious concrete are critical to the overall drainage function of the pervious concrete. The vibration impact must be kept as low as possible for sealing the surfaces from practical point of view.

The pervious concrete pavements shall be cleaned periodically or immediately after rain water runoff to keep open the voids. This can be achieved by vacuum sweeping or pressure washing (Pervious Concrete). It is reported that (Tennis, 2004) the pressure washing restores the clogging of this concrete 80% to 90% of its original permeability. The pervious concretes specimen cast in the laboratory is shown in Fig.2.

Figure 2 The cast specimens of pervious concrete

III. MATERIALS USED

Four different pervious concretes were prepared as indicated in Table 2. The ordinary Portland cement (OPC) of Dalmia make conforming to IS 8112, 43 grade was used. The coarse aggregate used was crushed, angular blue granite stones of uniform sizes namely 8, 10, 12 and 20 mm. No grading of coarse aggregate adopted and no fine aggregate was used, because these factors will increase the strength of concrete and reduce the porosity of concrete drastically. Ordinary tap water was used for mixing. No chemical admixtures used in this study. The water to cement ratio was kept constant for all the mix proportions as 0.35.

Table 2 Mix proportions of pervious concrete used

Mix	OPC (Kg/m^3)	Coarse aggregate (Kg/m^3)	Size of coarse aggregate (mm)	w/c ratio
P1	300	1460	8	0.35
P2	300	1440	10	0.35
P3	300	1400	12	0.35
P4	300	1320	20	0.35

IV. EXPERIMENTAL

Pervious concretes designed and proportioned in the laboratory were cast into 150 x 150 x 150 mm size cubes for the determination of cube compressive strength under uniaxial compression testing machine. Specimens of size 50 x 50 x 300 mm long beam were cast to find out the flexural tensile strength of the pervious concretes. Circular specimens of size 100 mm diameter x 150 mm long were used for the determination of hydraulic conductivity (permeability) of pervious concretes. Cube specimens are used for finding total void percentage. The results are given in Table 3.

Table 3 Properties of pervious concretes

Mix	Coarse aggregate size (mm)	Total void ratio (%)	Cube compressive strength (MPa)	Flexural strength (MPa)	Hydraulic conductivity (k) (m/s)
P1	8	17.12	12.61	2.23	0.0012
P2	10	18.63	11.19	1.91	0.0019
P3	12	20.73	10.04	1.08	0.0026
P4	20	28.84	6.13	0.86	0.0061

The total void ratio (%) was calculated using 150 x 150 x 150 mm cube specimens, by taking the difference in weight between a oven dried and sample in water, and it is suggested by Park and Tia (Park, 2004). The relationship for total void ratio is as follows:

$$V_r = [1-(W_2-W_1/\rho_w-V)] \times 100 \quad (2)$$

Where

V_r = Total Void ratio (%)
W_1 = weight specimen in water
W_2 = oven dry weight of specimen
V = volume of specimen
ρ_w = density of water

A. Measurement of Hydraulic Conductivity (permeability)

As it has been stated that the pervious concrete has a large inter connected pore network, and hence the conventional method used for evaluating hydraulic conductivity of normal concrete is not applicable. Therefore to evaluate or to estimate the hydraulic conductivity of pervious concrete, a falling head permeability test apparatus has been fabricated at CECRI as shown in Fig 3. The way by which the water gets percolated through pervious concrete when poured from top is shown in Fig 4.

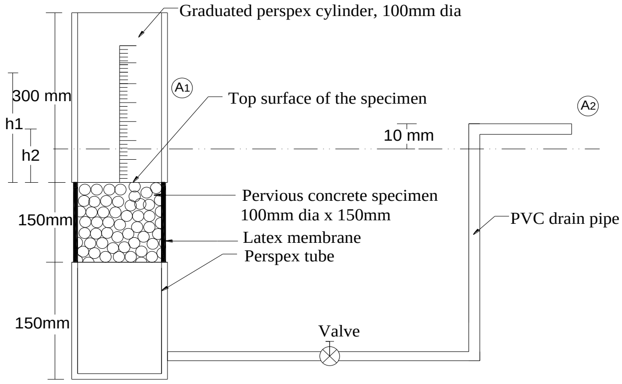

Figure 3 Falling head permeability test setup

Figure 4 Percolation of water through pervious concrete

The pervious concrete of circular specimen size 100 mm diameter and 150 mm long is placed in between Perspex tube and another graduated Perspex tube as shown in Fig 3. The dimensions of the tubes and the placement of drain pipe are shown in the same figure. the specimen to be tested is clamped tightly using rubber sleeve ie latex membrane so that only vertical flow takes place. The graduated top cylinder is used to monitor the water level during the test. The water is added to the graduated cylinder kept at the top of the specimen to fill up specimen and drain pipe.

This eliminates any air pockets in the specimen, and ensures that the specimen is completely saturated. By closing the valve in the drain pipe, the graduated Perspex cylinder is filled with water. The valve is then opened, and the time taken (in seconds, t) for the water to fall from the initial head to a final head (h_1 to h_2) is measured. This procedure is repeated for three times, and an average value of t is taken. The cross sectional area of specimen is A_1 and that of drain pipe is A_2, then according to Darcy's law, the coefficient of permeability (k) is calculated as

$$K = (A1l/A2t) \log (h_2/h_1) \quad (3)$$

Where

l is the length of the specimen. The measured hydraulic conductivity is shown in Table 3.

B. *Computation of Intrinsic Permeability: (k_i)*

The intrinsic permeability (K_i) of a porous medium can be thought of as a measure of frictional resistance to a fluid flowing through it. Therefore, the intrinsic permeability depends on the porosity. Pore size, pore space, pore size distribution, pore roughness, contractions of the pore space, and the tortuosity and connectivity of the internal pore channels (Garboczi, 1990, de lima, 2000). The hydraulic conductivity can be related to intrinsic permeability as

$$K_i = K\,(\rho g/\ \mu\ ) \quad (4)$$

Where

ρ is the density of the fluid, g is the acceleration due to gravity and μ is the dynamic viscosity of the fluid. For water, flowing through the pore system, the above equation is simplified as shown below

$$K_i = K \times 10^7 \quad \text{(in SI Units)} \quad (5)$$

The intrinsic permeability (K_i) of porous medium is typically described by Kozery – Carman equation (Bear, 1972, Chapuis, 2003)

$$K_i = (\phi_p^{3} / F_s\, \tau^2\, S_o^{2}\, (1- \phi_p)^2\,) \quad (6)$$

Where

ϕ_p is the porosity of the medium, F_s is the generalized factor to account for different pore shapes, τ is the tortuosity and S_o is the specific surface area of pores.

It can be seen that the specimen that exhibits the highest permeability neither has the highest porosity, nor the largest pore size. This proves that permeability is not a function of the porosity and pore size alone, rather pore connectivity has to be combined with easily measureable pore structure features like porosity, and pore size to gain a fundamental understanding of the permeability of the system.

While permeability generally increases with an increase in porosity, there is no definitive relationship between these parameters. The reason for such poor correlation can be explained by the fact that porosity is a volumetric property of the material, whereas permeability is a parameter that defines the flow properties through the material that not only depends on the volume of pores but also as the distribution of the pore volume and its connectivity. The Kozery Carman equation is further simplified as

$$K_i = ß_H\ \ (\phi_p /\ (1-\phi_p))^2 \quad (7)$$

The intrinsic permeability (k_i) is therefore represented by a function of porosity (ϕ_p) and the hydraulic connectivity factor($ß_H$).This hydraulic connectivity factor can be thought as a combination of parameters that describe the pore space volume and geometry in such a way that the intrinsic permeability is related to porosity and hydraulic connectivity factor.

C. *Problem of Sand Clogging*

Clogging of sand in the pore system affects the rate of infiltration of rain water adversely, particularly clogging on covering by sand in coastal areas and river areas (Haselbach, 2006). The pervious concrete usually has the porosity range from 15% to 30% and the rate of water flow from 0.3cm/s to more than 1cm/s, depending on the material and placement(Montes, 2005, Tennis, 2004). Initially, it may appear that the system will then be limited for its infiltration capacity of both passive and active runoff by the permeability of the sand. It is suggested (Montes, 2005) that the effective permeability is

$$K_{eff} = (P_{top}/100)\ K_{sand} \quad (8)$$

Where

P_{top} = average porosity of the top quarter of the block as determined by an equation developed from laboratory analysis of other blocks taken from the same slab and given in percentage.

K_{sand} = permeability of sand (cm/s)

K_{eff} = theoretical effective permeability of sand clogged or covered pervious concrete block system (cm/s).

The effective permeability of the system is the limiting flow at this interface, which is the ratio of areas times the unit permeability of sand.

$$K_{eff} = (A_p/A_B)\ K_{sand} \quad (9)$$

A_p is the area of pervious concrete block occupied by pores (cm^2), and A_B is the total surface area of the pervious concrete block (cm^2).

The theoretical effective permeability of sample sand clogged pervious concrete block is also given by

$$K_{eff} = (P_{top}/100)\ K_{sand} \quad (10)$$

Suppose if the pervious concrete is blocked with a 19% porosity near the top surface and which is fully covered with a sand layer that has a permeability of K_{sand} = 0.023cm/s, then the effective system permeability is

K_{eff} = (19/100) x 0.023 = 0.0044 cm/s

A mass balance on steady-state system would dictate that the volumetric rainfall rate minus the volumetric run off rate would equal the infiltration rate, or

$$K_{clog} = \text{(Rainfall rate – Runoff rate) / Area of the block} \quad (11)$$

K_{clog} = experimental permeability of sand – clogged pervious concrete block system.

V. RESULTS AND DISCUSSION

Four types of pervious concrete were prepared with various size of coarse aggregate and no fines are used. From the results shown in Table 3, it can be clearly concluded that as the coarse aggregate size increases, the voids percentage increases but the compressive strength and flexural strength of the material drops down. The hydraulic conductivity of the material (k) increases with increase in total porosity of the mass. This can be attributed to the fact that these pores are well connected since there is no sand is used. The reason for increase in porosity with increase in coarse aggregate is poor packing density and higher pore sizes. The strength of the pervious concrete can be improved by the addition of the pervious concrete can be improved by the addition of five aggregate but this will read to reduction in porosity and subsequently a hydraulic conductivity.

VI. CONCLUSIONS

- This paper gives an in depth study of pervious concrete though it appears a simple method of casting and laying.
- The larger the size of coarse aggregate, the larger the total void ratio.
- Cube compressive strength and the flexural strength of pervious concrete drops down as the size of coarse aggregate is increased.
- Addition of sand will improve the mechanical strengths but at the same time the hydraulic conductivity will be reduced.
- The hydraulic conductivity increases as the size of coarse aggregate is increased.
- The aspect of clogging of pervious concrete is discussed in detail, and expression to compute effective infiltration rate is also given.

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