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Field Study on Water Absorption Capacity of Pervious Concrete Pavement Under Different Discharge Conditions

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Abstract: Pervious concrete (PC), also called porous concrete, is a special type of concrete with high porosity and low compressive strength, which is used for several applications. Even though extensive research is being carried out on PC, the studies on its field applications are meagre. In the present study, an attempt has been made to investigate the water absorption capacity (WAC) of PC pavement laid in the field under different discharge conditions. A footpath was constructed with PC made of the best mix proportions obtained from the previous study (40% of 20 mm, 30% of 12.5 mm and 30% of 10 mm aggregate, 10% Fly ash with 90% OPC and w/c ratio 0.35) having compressive strength 24 MPa and permeability of 1.56 cm/s. It consists of 15 panels of size 1.2 m × 1.2 m and depth 10 cm. The soil characteristics underneath the PC panels are determined before laying PC over it. WAC of PC footpath is determined by applying the different discharges in the lateral and vertical directions in different seasons in a year. In the first season (August-2018), the discharge is applied only in the lateral direction and it is found that the WAC value is 3315.7 litres/m^3, whereas in the second season (January 2019), it is found as 3064.56 litres/m^3. The reduction in WAC from season 1 to season 2 may be due to the accumulation of sediments. The total amount of rain that occurred during season 1 to season 2 is 400.73 mm and the total amount of sediment accumulated is 44.028 kg. Hence, it is concluded that water absorption of PC is time dependent and also the presence of sediments in the runoff water.

Key words*:* Pervious concrete pavement, water absorption rate, discharge condition, soil conditions, time.

Introduction

Pervious concrete (PC), which is also called porous concrete, permeable concrete, no-fines concrete and porous pavement, etc., is a special type of concrete with high porosity and low compressive strength used for concrete flatwork applications that allows water obtained through precipitation and other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge.

PC is made using large aggregates with little to no fine aggregates. It is an important application for sustainable construction and is one of many low impact development techniques used by builders to protect water quality (Yang & Liang, 2003).

In recent times, there has been a significant focus on providing sustainable and environmentally friendly solutions for urban storm-water management. The high porosity of PC is attained by a highly interconnected void content. Very few attempts have been made to replace the cement binder in the pervious concrete with other supplementary material.

The main significance of PC is to recharge the storm water into the ground by reducing the runoff.

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It eliminates time consuming and costly storm water detention vaults and piping systems. (Eban et al., 2007).

Many researchers focussed on developing PC with different materials to obtain the required compressive strength and permeability. Most of the studies are limited to the laboratory only (Eban et al., 2010; Haselbach, 2007). So, the authors attempted to study the actual recharge rates through the real application of PC by constructing a pavement. So, in the present study, an attempt has been made to investigate the rates of recharge through a pervious concrete pavement made with dimensions of 1.2 m width × 0.1 m thickness × 19 m length (15 panels) and materials of 40% of 20 mm coarse aggregate, 30% of 12.5 mm coarse aggregate and 30% of 10 mm coarse aggregate, 10% fly ash, 90% OPC (53-grade cement of 500 kg/m^3) with a water-binder ratio of 0.35. This pavement is laid on the ground where the soil has a density of 2220 kg/m^3.

Literature Review

The importance of pervious concrete and its benefits in the context of urbanisation has been discussed (Chandrappa et al., 2016). The investigations on mechanical, hydrological, and properties of PC performed in various studies have been reviewed.

Permeable pavement is a key component in reproducing pre-development hydrologic regimes because it can reduce surface runoff, improve water quality and recharge groundwater (Robert et al., 2001).

The w/c ratio being a very important variable is lower compared to those used in the conventional concrete mix and has been historically varied over the range of 0.28 – 0.40 with the main intention to provide sufficient cement coating for the aggregates (Tennis et al., 2004).

The surface infiltration rates of 40 permeable pavement sites were tested in North Carolina, Maryland, Virginia, and Delaware. Two surface infiltration tests (pre and post maintenance) were performed on 15 concrete grid paver lots filled with sand (Eban et al., 2007).

There is a concern that the pores in the PC might clog due to long-term deposition of fine materials in the runoff, or due to catastrophic events such as the failure of upstream erosion control measures or flooding (Haselbach, 2010).

Although specifications are available for the mix design and construction of pervious concrete, there still remains a need for laboratory tests to ensure the anticipated performance of laboratory designed pervious concrete (Dang et al., 2014).

This study was undertaken to compare measured values for methods of NCAT permeameter and ASTM C1701in the field on a variety of permeable pavements used in current practice (Li et al., 2013).

A binder drainage test is proposed to determine the critical w/c ratio to prevent the flow of cement paste to the lower layers of concrete under the action of vibration or compaction (Dang et al., 2014).

The clogging potential of pervious concrete mixtures made up of different aggregate sizes was investigated by using fine and coarse sand as clogging material (Deo, 2010).

The score of benefits has undoubtedly supported the use of pervious concrete in pavement applications in the various regions of the world over the last seven years (Huang et al., 2009). Additionally, the porous structure in the pervious pavement can preliminarily purify the rain water, leading to positive environmental effects (Magusveri & Narsimha, 2013; Starke et al., 2011). However due to the high porosity, the two main types of permeable pavement (PC and permeable asphalt mixture pavement) are also suffering from several performance issues including concrete loose, pore clogging, lower strength and durability, and difficulty in maintenance (Dang et al., 2014).

Research on long-term surface permeability has shown that clogging particles asymptotically reduce the permeability, even though an infiltration rate is still considered to be high (Ebam et al., 2007). On-site experience has also shown that clogging can be successfully minimized with proper installation and maintenance using vacuum sweeping or pressure cleaning (Schaefer & Kevern, 2011).

The porosity of the PC varies from 15% to 30%, by volume, and it depends on the size, type of the aggregates and compaction (Neithalath et al., 2010). The pressure washing is ineffective because the pervious concrete, even when clogged with sand and clay, represents a very small fraction of the overall head loss in this study, although it should be noted that the PC was shown to be the infiltration-limiting layer in a recently published field study (Chopra, 2010).

Aiming a solution towards the current deficient strength, durability and inconvenient maintenance in pervious concrete pavement, an innovative high strength pervious concrete was designed and prepared. Where the clogging dust were excluded from bottom to top. This innovation high strength pervious concrete has the potential to allow for a wider application of this material.

Objectives of the Present Research Work

1. To make a study on the water absorption rates corresponding to various discharge conditions of pervious concrete foot path at different seasons.
2. To analyse the effect of the rate of sediment trapped into the panels of PC foot path on water absorption capacity (WAC).

Materials and Methods

The best mix proportions are taken by considering max compressive strength as criteria with required permeability and the details are provided in Table 1 (Vinay et al., 2019). A foot path of size 1.2 m (width) × 0.25 m (thickness) × 19 m (length) is selected for laying PC panels. The schematic line diagram of the footpath is shown in Figure 1.

Table 1: Overall best results of permeability and compressive strength

Aggregate ratio	*Fly ash %*	*Permeability (cm/sec)*	*Compressive strength (MPa)*	*W/c ratio*
40-30-30	10	1.56	24	
50-20-20	25	1.11	14.40	0.35
60-20-20	25	1.70	4.60	
20-40-40	25	1.50	18.80	

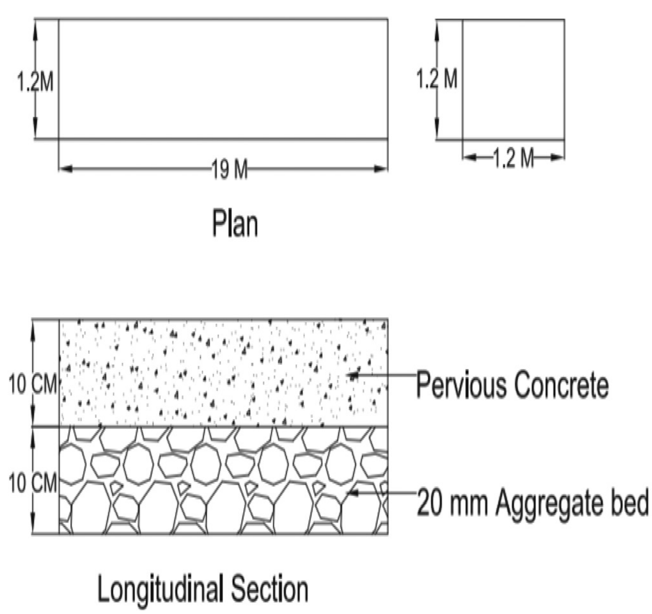

Figure 1: Line diagram of foot path pavement made with PC.

The materials used for making PC panels are described below.

1. Coarse aggregate of different sizes (40% of 20 mm, 30% of 12.5 mm and 30% of 10 mm)
2. Ordinary Portland Cement (53 grade)
3. Fly ash (Class - F)
4. Normal Water

Steps in Making PC Foot path in the Field

1. A site besides a rigid pavement (footpath) is selected and made level and excavated to a depth of 20 cm (Figure 2).
2. Then the soil characteristics of the site are determined. Soil is excavated to a depth of 25 cm to collect the sample (Figure 3).

   The values of moisture content and density of soil beneath the footpath at the time of laying are presented in Table 2.
3. Then a layer of sub base of coarse aggregate 20 mm size is laid for a depth of 10 cm for each panel (Figure 4).
4. The entire length of footpath is divided into 15 panels of length 1.2 m by partitioning with thermocol sheets (Figure 5).

Figure 2: Site for laying PC footpath.

Figure 3: Soil Sample collection at the site.

Table 2: Moisture content, density of soil beneath foot path at the time of laying

S.No	*Moisture content (%)*	*Density (kg/m^3)*
1	12.80	2228.67
2	12.06	2210.36
Average value	12.70	2219.52

Figure 4: Filling of 20 mm aggregate for 10 cm depth.

Figure 5: Pervious concrete foot path panels after laying.

Test Setup for Lateral Discharge of Water

A test setup (refer Figure 6) for applying different discharges on to the PC panels in the lateral direction is fabricated.

Specifications:

Diameter of the pipe = 200 mm; Length of the pipe = 1.3 m; No of inlets of the pipe = 1

Diameter of the inlet = 20 mm; No of outlets of the pipe = 3; Diameter of the outlet = 10 mm

Test Setup for Vertical Discharge of Water

A test setup (refer Figure 7) for applying different discharges onto the PC panels in the vertical direction is fabricated.

Figure 6: Test set up for lateral discharge.

Figure 7: Test set up for vertical discharge.

Specifications:

Length of the iron panel = 1.3 m; Width of the iron panel = 1.2 m

Height from the ground = 0.8 m

Results and Discussions

In the present study, two seasons are considered, one is in the month of August-2018 and another season is February-2019. The PC footpath is laid on August 1, 2018. In season-1, only lateral flow is applied whereas in season-2, both lateral flow and vertical flows are considered.

In order to calculate the rate of sedimentation, the rainfall data from the period of August 1, 2018 to January 31, 2019 is considered. The number of rainy days and the total amount of rainfall in this period are collected from Collector Office, Vizianagaram and the same is presented in Table 3. A rainy day is considered as a day with a depth of rainfall > 2.5 mm. The total amount of rainfall during the above period is observed to be 400.73 mm and the total number of rainy days is 74. So, the average rate of rainfall during the period from August 1, 2018 to January 31, 2019 is 5.415 mm/day. The sediment accumulated during a period of six months from August to February 2019, is collected by opening the panels and the data is presented in Table 4. The total amount of sediment is 44.028 kgs.

Table 3: Rainfall data from August 1, 2018 to January 31, 2019

Month	*No. of rainy days*	*Total rainfall (mm)*
August-2018	19	84.70
September-2018	23	82.13
October-2018	12	161.10
November-2018	9	11.50
December-2018	8	60.10
January-2019	3	1.20
TOTAL	74	400.73

Table 4: Sediment accumulation in each panel

PC Panel	*Total weight of the sample (kg)*
1	12.860
2	7.260
3	2.214
4	2.320
5	1.123
6	1.141
7	1.162
8	1.194
9	1.162
10	1.034
11	1.141
12	2.876
13	2.488
14	2.875
15	3.178
TOTAL	44.028

Water Absorption Rate for Lateral Flow Conditions

The water absorption by the panels to recharge the groundwater is estimated by simulating the field conditions like lateral flow (Runoff in lateral direction) and vertical flow (Rainfall directly falling in footpath) and the details of the calculation are presented in this section.

Season-1:

Discharge calculations:

The discharge through the pipe is calculated as follows:

Capacity of collecting tank = 10 litres.

Time taken to fill the tank = 10.88 seconds.

Discharge through the pipe = (capacity of the collecting tank)/(time taken to fill the tank)

= 10/10.8 = 0.919 litres per second (lps)

Water Absorbed and Velocity of Flow in Panels

The time taken to absorb the water through the panels of pervious concrete of various lengths is noted down and shown in Table 5. Also, the velocity through each panel is calculated and also the water absorption is expressed in litres per unit length, these values are also shown in Table 5.

The volume of water that is absorbed by the pervious concrete panel and velocity through the panel is calculated as follows:

- Volume of water absorbed through pervious concrete panels = 1148.75 litres
- Velocity through the panel = 10.24 mm/sec

Water absorption capacity = (time/discharge)/length

- The average water absorption capacity = 137.29 s/lps/m

Total volume of water absorbed = 3315.7 litres/$m^3$of PC.

Table 5: Time taken for water absorption through panels of various lengths for lateral flow (during August 2018)

S.No	*Time (minutes:seconds)*	*Length (m)*	*Discharge through the pipe in lps*	*Volume of water absorbed (litres)*	*Velocity through the panel (mm/s)*	*Water absorbed in litres per meter length*
1	20:50	12.8		1148.7	10.24	89.74
2	17:32	9.6	0.919	966.8	9.41	100.70
3	12:12	6.4		661.7	8.89	103.39
4	9:46	3.2		538.5	5.92	168.28

Season-2 : Discharge calculations:

The discharge through the pipe is calculated as follows:

Capacity of collecting tank = 20 litres.

Time taken to fill the tank = 25.2 seconds

Discharge through the pipe = (capacity of the collecting tank)/(time taken to fill the tank)

= 20/25.2

= 0.7936 litres per second (lps)

Water absorbed and Velocity of flow in panels:

The time taken to absorb the water through the panels of pervious concrete of various lengths is noted down and shown below in Table 6.

- Volume of water absorbed through pervious concrete panels = 1148.97 litres
- Velocity through the panel = 12.29 mm/s

The average water absorption capacity = 105.76 s/lps/m.

Total volume of water absorbed = 3064.56 litres/$m^3$of PC.

The water absorption capacity is reduced by 21.6% when compared to season -1, this is due to the accumulation of sediments during a period of approximately 200 days (74 rainy days). So, it is suggested to clean the panels periodically for better performance.

Water Absorption Rate for Vertical Flow Conditions

Under this case, there are two categories, they are (i) constant discharge and (ii) variable discharge

Case-1: Constant Discharge

The discharge through the pipe is calculated as follows:

Capacity of collecting tank = 20 litres.

Time taken to fill the tank = 27 seconds.

Discharge = (capacity of the collecting tank)/

(time taken to fill the tank)

= 20/27 = 0.741 litres per second (lps).

The time taken to absorb the water through the panels of pervious concrete of various lengths is noted down and shown below in Table 7.

- Velocity through the panel = 9.1 mm/s
- The average water absorption capacity = 139.22

Total volume of water absorbed = 3512.78 liters per m^3 of PC. So, the vertical flow of water has more water absorption capacity when compared to the lateral flow condition.

Case-2: Varied Discharge

Under this case, the discharge is applied at regular intervals representing a hydrograph as shown in

Table 6: Time taken for water absorption through panels of various lengths for lateral flow (during January 2019)

S.No	*Time (minutes:seconds)*	*Length (m)*	*Discharge through The pipe in lps*	*Volume of water absorbed (liters)*	*Velocity through the panel (mm/s)*	*Water absorbed in liters per meter length*
1	24:13	17.8	0.7936	1148.97	12.29	64.548
2	19:53	14.7		929.94	12.54	63.26
3	12:2	9.8		580.91	13.38	59.36
4	8:50	5.1		404.74	10	79.36

Table 7: Time taken for water absorption through panels of various lengths for vertical flow

S.No	*Time (minutes:seconds)*	*Length (m)*	*Discharge through The pipe in lps*	*Volume of water absorbed (litres)*	*Velocity through the panel (mm/s)*	*Water absorbed in litres per meter length*
1	31:40	17.3	0.74	9.100	81.27	9.100
2	20:35	14.7		11.900	62.17	11.900
3	17:20	9.8		9.420	78.53	9.420
4	9:32	5.1		8.916	82.99	8.916

Table 8: Varying discharge and water absorption capacity (for dry and wet condition)

S.No	*Time (minutes)*	*Discharge (liters/second)*	*Water absorption (liters/meter) for dry condition*	*Water absorption (liters/meter) for wet condition*
1	0 – 10	0.2	66.61	66.61
2	10 – 20	0.4	29	18
3	20 – 30	0.74	14	0
4	30 – 40	0.4	7	18
5	40 -50	0.2	0	66.61

Figure 8. The water absorbed during dry and wet conditions is shown in Table 8. Also, it is shown graphically (Figures 9 and 10) for dry and wet conditions, respectively.

For dry conditions of soil the water absorption for varying discharge from 0-50 min, the oozing occurs after 50 min. For the wet condition, of soil the water absorption for varying discharges from 0-50 min, the oozing occurs at 29.1 min. From this, we can understand that water absorption capacity is more for dry conditions of the soil. For dry condition of soil water absorption

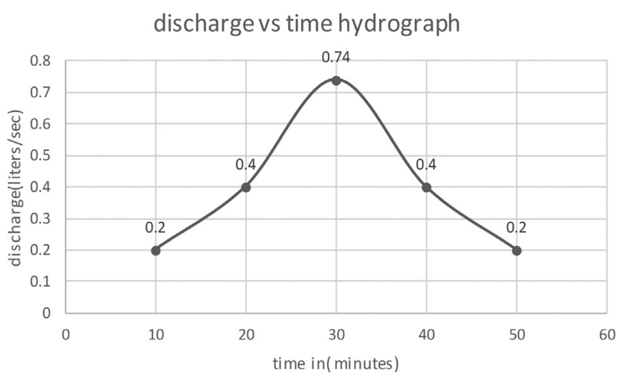

Figure 8: Assumed storm hydrograph.

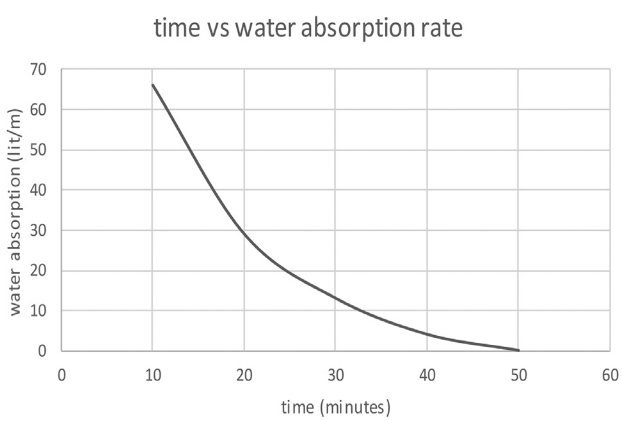

Figure 9: Variation of water absorption capacity with time (Dry).

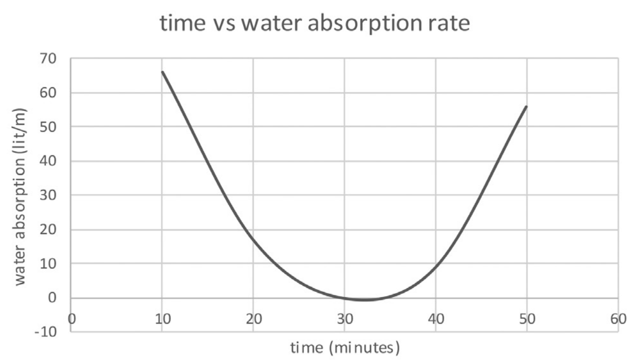

Figure 10: Variation of water absorption capacity with time (wet).

capacity is higher at the initial point of time and reduces at the final point of time; whereas for the wet condition of the soil, water absorption capacity is higher at the start and reduces at the middle of the time of absorption.

Conclusion

1. It is observed that the water absorption capacity of pervious concrete footpath is reduced due to sediment trapped into the panels and regains its capacity by cleaning of those pervious concrete panels through reverse watering or vacuum cleaning process.
2. It is observed that the rate of sediment collected from PC footpath panels is 1.485 (g/mm)/day
3. It is observed that the sediment trapped into the PC footpath panels is characterized as a percentage of sand, silt and clay.
    - The average percentage of sand content is 46.6. It ranges between 37% - 54%
    - The average percentage of silt content is 51.67. It ranges between 44% - 63%.
    - The average percentage of clay content is14.6. It ranges between 10% - 20%.
4. It is observed that after 28 days of PC panels laying process when the rate of flow entering into pervious

concrete is 0.919 litres per second and the average water absorption is 137.29 s/lps/m (3315.7 litres/ m^3) for lateral distribution of water.

5. It is observed that after 200 days of PC panels laid when the rate of flow entering into pervious concrete is 0.79 liters per second and the average water absorption is 105.76 s/lps/m (3064.56 liters/ m^3) for lateral distribution of water.
6. It is observed that after 200 days of PC panels laid when the rate of flow entering into pervious concrete is 0.74 litres per second and the average water absorption is 139.22 s/lps/m (3512.78 litres/ m^3) for the vertical distribution of water.
7. The percentage reduced water absorption capacity is 21.62 for an interval of 200 days in which having 74 rainy days with the rate of sediment collecting is 0.595 kg/day.
8. It is observed that by varying the water discharges with time, the water absorption capacity is higher at initial discharge and lower at final discharge for dry conditions of the soil.
9. It is observed that by varying the water discharge with time, the water absorption capacity is higher at initial discharge and lower at maximum discharge at 0.74 litre/s, and slightly increase at final discharge for wet condition of soil.

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