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Field Application of Pervious Concerte for Recharge of Groundwater

Vinay V, Adiseshu S, Chandramouli S

***Abstract:** In the present study, an attempt has been made to investigate strength and permeability of pervious concrete made with different combinations of aggregate sizes (20mm,12.5mm and 10mm) and different mix proportions using flyash and super platiciciser). The main objective of this investigation is to apply the pervious concrete through a footpath to improve groundwater recharge by finding out the best combination of grading of aggregates and also the mix proportion with fly ash for obtaining optimal permeability and strength. The effect of partial replacement of cement with fly ash and super plasticizer on the compressive strength and the water permeability of pervious concrete are investigated. The analysis of the test results indicated that the proposed combination of materials have increased the compressive strength significantly and also, the water permeability. Even though, the individual performances (maximum strength and maximum permeability) of some of the combinations obtained are good, but it is expected in the study to have reasonable values for both to use pervious concrete in the field. Hence, in this study, it is considered the intersection point on the strength versus permeability graph as the best combination. So, the combination with 40% of 20mm, 30% of 12.5 mm and 10mm and 10%flyash with 90% opc (53 grade) without super plasticizer considered as the best which gives 24 MPa and 15.6 mm/s permeability.. A footpath of size 1.2 m (width) x 0.25 m (thickness) x 19 m (length) is selected for laying pervious concrete in the form of number of panels. A constant discharge is applied on to the footpath in lateral direction and it is found that the absorption capacity of the laid mix in the field is 115.52 litres/ m length.*

***Key words:** Pervious concrete, supplementary cement materials, fly ash, permeability, compressive strength*

I. INTRODUCTION

Pervious concrete (also called as porous concrete, permeable concrete, no fines concrete and porous pavement) is a special type of concrete with a high porosity used for concrete flat work applications that allows water from precipitation and other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge. The pervious concrete can only be applied to squares, footpaths, parking lots, and paths in parks.

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Vinay V*, Assistant Professor, Department of Civil Engineering, MVGR College of Engineering (Autonomous), Vizianagaram, Andhra Pradesh, India. E-mail: vinay.vailada@gmail.com

Adiseshu S, Professor, Department of Civil engineering, University College of Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India

Chandramouli S, Professor, Department of Civil Engineering, MVGR College of Engineering (Autonomous), Vizianagaram, Andhra Pradesh, India.

The use of pervious concrete may reduce flooding risk, recharge ground water, reduce surface runoff, reduce noise when in contact with vehicle tires, and prevent glare and skidding during rainy season by allowing water to infiltrate freely through its pores.

The aggregate usually consists of a single size and is bonded together at its points of contact by a paste formed by the cement and water. The result is a concrete with a high percentage of interconnected voids that, when functioning correctly, permit the rapid percolation of water through the concrete. Pervious concrete characteristics are different from that of conventional concrete in terms of compressive strength, permeability etc. Compared to conventional concrete the Pervious concrete has more permeability and less compressive strength and also lower unit weight, approximately 70% of the conventional concrete. The research on pervious pavement materials has begun in developed countries such as the US and Japan since 1980s. However, the strength of the material is relatively low because of its porosity ranging from 0.15 to 0.35 with a density of approximately 1800 kg/m^3 [1].

The water to cement 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 to 0.4 with the main intention to provide sufficient cement coating for the aggregates [2]. The pore structure of pervious concrete is mainly air voids, which have a larger size than gel pores or capillary pores. These large pores in pervious concrete might be connected and affected by aggregate grading and compaction. Since the pervious concrete is highly permeable, the voids between aggregate particles cannot be entirely filled by cement paste. Use of smaller size aggregate 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. Pervious concrete designed and proportioned in the laboratory were cast in 150 x 150 x 150 mm cubes for the determination of cube compressive strength under uni-axial compression testing machine.[3] The compressive strength of the material can only reach about 20 – 30 MPa. Such materials cannot be used as pavement due to low strength. Using selected aggregates, fine mineral admixtures and organic intensifiers and by adjusting the concrete mix proportion, strength, and abrasion resistance can improve the pervious concrete greatly [4]. Performance characterization indicates both satisfactory strength and desirable permeability in high strength pervious concrete [5]. The influence of aggregate type and size on the compressive strength as well as those of aggregate size on the dynamic modulus of elasticity needs to be demonstrated and further research has to be carried out [6].

Portland cement pervious concrete (PCPC) is a special type of concrete characterized by an interconnected pore structure and high void content/porosity typically in the range of 15 to 35% by volume.
In addition, PCPC is produced at low cost, thus it can be considered among the most attractive sustainable urban drainage systems. PCPC requires, however, regular maintenance to prevent any clogging of the pores by sediments and vegetation which might change its high permeability [7]. A decrease in aggregate size increases the strength of pervious concrete. This is attributed to the increased total bond area between neighboring aggregates [8]. Fly ash (FA) and Bottom ash (BA) are waste materials derived from the coal-fired power plants. In general, FA is a by-product of burning pulverized coal in an electrical power generation plants. This unburned residue is carried away from burning zone in the boiler by flue gases and later to be collected through a mechanical or electrostatic separator.BA had a density of 1466 – 1502 kg/m^3 and compressive strength of 5.7 – 8.6 MPa which are suitable for an environmentally friendly application [9]. The pervious concrete is highly permeable, having water flow rate typically around 0.34 cm/s [10].
In this study, three types of single-sized limestone aggregates (12.5 mm, 9.5 mm, and 4.75 mm) were used, and one type of polymer (SBS latex) was considered to make the pervious concrete mixture. The properties of pervious concrete were evaluated through air void test, permeability test, compressive strength test, and split tensile strength test[11]. In order to expand the use of fly ash geopolymer binder, pervious geopolymer concretes (GPCs) were prepared from alkali activated lignite high-calcium fly ash binder and coarse aggregate. The void content, water permeability, compressive strength, and splitting tensile strength of PGCs were determined. The compressive strengths between 5.4 and 11.4 MPa and splitting tensile strengths between 0.7 and 1.4 MPa were obtained [12]. This study investigated the effects of NH concentration, partial replacement of FA with OPC, and curing temperature on the properties of fly ash-based pervious geopolymer concrete containing bottom ash as coarse aggregate. The results indicated that the increase from 10 to 15 M in NH concentration and from 0% to 15% in OPC replacement, increased the strengths of PGCs. The incorporation of 15 M NH and 15% OPC replacement gave the highest strength PGC. In addition, the pulse velocity of UPV test was found to relate to the compressive strength[13].
Increasing the aggregate amount of pervious PCC results in higher effective void contents at equal compactive efforts, as well as a decrease in both compressive strength and modulus of elasticity. This is the opposite of normal PCC and is a result of the role of paste in pervious PCC [14]. Extreme storm events which deposit large quantities of clay on pervious concrete pavements substantially reduce the infiltration capacity of the system and may even temporarily “clog” the area. The reduction rate increases with the density of the clay suspensions[15]. The range of compressive strength varies between 10 N/mm2 to 26 N/mm2 when the angularity number varied from 8 to 4. Increasing the aggregate size increases angularity number. Coefficient of permeability increases from 0.4 cm/sec to 1.26 cm/sec when the angularity number is in the range of 4 to 8. The optimum mixes in each coarse aggregate size are identified based on the compressive strength, Void present in aggregate (based on angularity number) and permeability are M1F30, M2F30, M3F20 and M4F20[16]. Using these permeability–porosity relationships and the vertical porosity distributions generated from surface compacted specimens, an accurate vertical permeability distribution within a specimen was created and experimentally verified. From this, an effective permeability was calculated which had a much higher correlation with the actual permeability of the specimen than a prediction of the specimen’s permeability using only the average porosity [17].Use of combination of SP and cohesive agent could produce acceptable HPPC with good workability and strength properties. The addition of cohesive agent to HPPC mixture could decrease the total void ratio and permeability and significantly increase the compressive and flexural strengths [18]
Based on the above facts, an attempt has been made in the present study to determine strength and permeability values of pervious concrete with various mix proportions to obtain best combination of materials. Also to use that obtained mix in the field for study on groundwater recharge through a footpath. So in order to execute the study, the following objectives are set to achieve reasonable values of strength and permeability of pervious concrete.

- To find new combination of materials for formation of pervious concrete.
- To obtain best compressive strength and permeability values of various combinations of pervious concrete.
- To work on field by constructing a footpath with the best mix of pervious concrete to study about the water absorption rates under the given soil density.

II. MATERIALS AND METHODS

The methodology followed for executing the stated objectives in the previous section is described below.

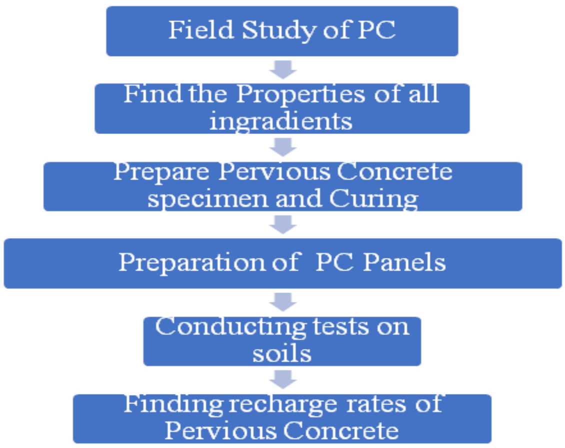

Fig.1 Flow chart describing the Methodology

a. Selection of materials

Based upon the literature, the materials that make suitable pervious concrete are selected to study the strength and permeability properties of PC. The materials selected are

1) Coarse aggregate of different sizes (20mm, 12.5 mm and 10 mm) - from Stone Crusher @ Jami
2) Ordinary Portland Cement (53 grade) – Ultra Tech Cement
3) Flyash (Class - F) from NTPC Thermal Power Plant, Visakhapatnam
4) Superplasticiser (Conplast – SP4)

b. To find the basic physical properties of the selected materials of PC.

The following tests (shown in table 1) are conducted in the laboratory for determination of the basic physical properties of the selected materials of PC.

Table 1: Basic Tests conducted on the ingredients of PC

S.No	Material	Test conducted	IS Code followed
1	Cement	Specific Gravity	IS 2720 (Part III)
		Fineness	IS 4031 (Part I)
		Normal Consistency	IS 4031 (Part IV)
		Initial Setting time	IS 4031 (Part V)
		Final Setting time	IS 4031 (Part V)
2	Flyash (Class -F)	Fineness	IS 4031 (Part I)
		Specific Gravity	IS 2720 (Part III)
3	Coarse Aggregate (20mm, 12.5mm and 10 mm)	Fineness modulus	IS 2386 (Part II)
		Flakiness	IS 2386 (Part I)
		Elongation	IS 2386 (Part I)
		Bulk Density	IS 2386 (Part III)
		Specific Gravity	IS 2386 (Part III)

c. Proportions of materials

In the present study an attempt is made to use different combinations of materials to obtain optimum values of strength and permeability of PC as shown in table 2.The details of mix proportions obtained are presented below in table 3 and table 4.

Table 2: Combinations of Cement and flyash (for replacement of cement by weight, different sized aggregate and percentage of Chemical admixture (Super Plasticiser)

Cement and flyash Combinations	Flyash (%)	Cement (%)	Coarse Aggregare Combination	20 mm (%)	12.5 mm (%)	10 mm (%)	chemical admixture	By weight of cement
FC1	10	90	A1	50	20	30	SP1	0.5 %
FC2	20	80	A2	60	20	20	SP2	1%
FC3	25	75	A3	40	30	30	SP3	1.5 %
FC4	30	70	A4	20	40	40	SP4	2%

Table 3: Mix proportions of Pervious concrete

Mix	OPC/Flyash (kg/m^3)	Coarse aggregate (kg)	Water (kg)	Proportion (Cement:CA)	Water-Cement Ratio
1	450	1916.6	157.5	1:4.26	0.35
2	500	1827.5	175.0	1:3.65	0.35

Table 4 Mix Design Results

1 m^3 of PC	Cement	Water	Coarse Aggregate
	450/450	157.5/450	1916.63/450
	1	0.35	4.26

d. Fabrication of permeability equipment

Falling Head Permeability measuring equipment is fabricated in the laboratory as shown in the fig.1 and fig.2. The procedure followed to find out the permeability using falling head method is described below.

(1) The test specimen consists of a horizontal and vertical arrangement of pipes of different diameters as shown in figures, the elbow portion of 160mm diameter pipe that is horizontally placed the specimen is inserted and so only half of the portion of the specimen is visible outside.
(2) The scale is marked on vertical pipe.
(3) Water is to be filled up to the marked portion on vertical pipe
(4) Then the valve is opened so that the water is allowed to flow into the specimen from a specified height
(5) The time for the drop of water is noted down using stop watch.

(6) The permeability is calculated using the following formula

$$k = \frac{(a \times L)}{(A \times T)} \log\left(\frac{ho}{h1}\right)$$

where k is the coefficient of permeability, cm/sec, a is the cross-sectional area of the pipe (cm^2),L is the length of the specimen (cm),A is the cross-sectional area of the specimen (cm^2),T is the time taken for the head to fall from h0 to h1(sec),h0 is the initial water head(cm), h1 is the Final water head(cm). Falling Head Permeability measuring equipment is fabricated in the laboratory as shown in the figures 2 and 3.

Fig 2: Permeability measuring equipment

Fig 3: Figure showing specimen for testing

e. Field Application

A foot path of size 1.2 m (width) x 0.25 m (thickness) x 19 m (length) is selected for laying pervious concrete.

Line diagram of footpath

A footpath has been chosen to apply the best mix proportions of pc obtained and to find out the absorption. The dimensions and layers are described below in fig. 4.

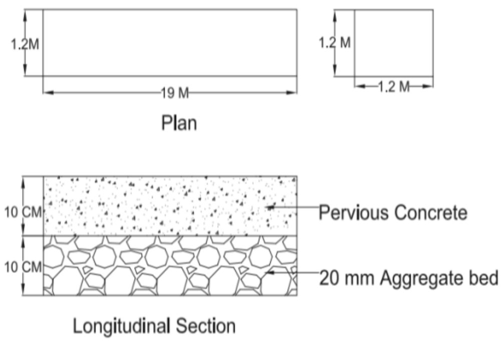

Fig. 4 Line diagram of foot path pavement made with PC

Process of laying of footpath

- Soil is excavated to a depth of 25 cm, length of 19 m and width of 1.2 m. This is shown in fig 5.

Fig. 5 Excavation for refilling of gravel and pervious concrete

- The entire length is divided into panels of length 1.2 m by partitioning with thermocol sheets is done for the whole length into 15 panels.Then a layer of sub base of coarse aggregate 20 mm size is laid for a depth of 10 cm for each panel.
- Mixing of pervious concrete making materials as per the mix proportion shown in fig. 5 to 8 below.(Coarse aggregate of different sizes 20 mm, 12.5 mm, 10 mm is used in the pervious concrete

Fig.6 Filling of 20 mm aggregate for 10 cm depth

Fig. 7 Mixing the raw materials

Fig. 8 water adding to pervious concrete mix

Fig. 9 single panel of size 1.2m *1.2m

- A layer of pervious concrete for a depth of 10 cm is laid and shown in fig.9.

Fig.10 All panels of size of 1.2 m* 1.2 m

Determination of rates of absorption/seepage of water through pervious concrete

After laying of Pervious concrete footpath, it is kept open 28 days for curing. Then a constant discharge is allowed onto the footpath through an arrangement made as shown in the fig 11. The discharge at the inlet is measured and allowed onto the footpath. The time taken to reach the outlet of the footpath is noted down.

Fig.11 Testing of field application

Experimental program

It is planned to use cube specimens (150mmx150mmx150mm) for determining compressive strength and cylindrical specimens (300mmx 150mm) for determining permeability. The total number of cubes (192 no's) and cylinders (128 no's)are casted and tested since 07.12.2017 to 25.06.2018.

III. RESULTS AND DISCUSSIONS

Physical properties of the ingredients of PC viz. cement, Flyash and Coarse aggregate of different sizes obtained by conducting tests in the field are presented below in table 5. All the values are within the range specified by code of practice.

Table 5: Values of Physical properties of ingredients of PC

S.No	Material	Test conducted	Value Obtained	Recommended Value as per IS Code
1	Cement	Specific Gravity	3.15	2.89 – 3.15
		Fineness	90.7%	90%
		Normal Consistency	30%	(26-33)%
		Initial Setting time	35 min	30 min
		Final Setting time	11 hrs	10 hrs
2	Flyash (Class - F)	Fineness	96%	90%
		Specific Gravity	2.38	2.96
3	Coarse Aggregate	Fineness modulus	4.34	6.5- 8
		Flakiness	13	Less than 15 %
		Elongation	11.84	Less than 15%
		Specific Gravity	2.4	2.3 – 2.7

The average compressive strength and permeability values obtained for different combinations are presented below in tables 6 to 9

Table 6: Avearge compressive strength and permeability values of different combinations for Maximum Cement content 450kg/m^3 without superplasticser

Combination	Average Compressive strength in MPa	Permeability in cm/s
MFC1A1450	4.03	2.07
MFC1A2450	3.70	2.95
MFC1A3450	5.30	1.43
MFC1A4450	5.35	1.17
MFC2A1450	6.08	1.93
MFC2A2450	5.40	2.87
MFC2A3450	5.45	1.39
MFC2A4450	7.20	1.17
MFC3A1450	7.90	1.81
MFC3A2450	6.10	2.60
MFC3A3450	5.90	1.34
MFC3A4450	8.20	1.05
MFC4A1450	11.11	1.78
MFC4A2450	8.60	2.48
MFC4A3450	7.15	1.31
MFC4A4450	9.35	1.05

Table 7: Average compressive strength and permeability values of different combinations for Maximum Cement content 500kg/m^3 without superplasticiser

Combination	Average Compressive strength in MPa	Permeability in cm/s
MFC1A1500	12.75	1.69
MFC1A2500	4.20	2.26
MFC1A3500	22.85	1.37
MFC1A4500	13.60	0.54
MFC2A1500	12.55	1.21
MFC2A2500	5.40	2.87
MFC2A3500	6.35	2.09
MFC2A4500	24.15	1.83
MFC3A1500	14.60	1.11
MFC3A2500	4.10	1.90
MFC3A3500	15.60	1.52
MFC3A4500	18.50	1.88
MFC4A1500	21.90	0.84
MFC4A2500	2.15	1.79
MFC4A3500	23.75	1.75
MFC4A4500	15.15	1.35

Table 8: Average compressive strength and permeability values of different combinations for Maximum Cement content 450kg/m^{3}with superplasticiser

Combination	Average Compressive Strength in MPa	Permeability in cm/sec
MFC1A1SP1450	12.70	4.07
MFC1A2SP2450	17.35	1.52
MFC1A3SP3450	24.85	1.24
MFC1A4SP4450	17.90	1.62
MFC2A1SP1450	23.20	2.87
MFC2A2SP2450	9.00	1.09
MFC2A3SP3450	7.10	1.08
MFC2A4SP4450	22.10	1.52
MFC3A1SP1450	29.15	-
MFC3A2SP2450	23.30	-
MFC3A3SP3450	8.70	-
MFC3A4SP4450	13.40	-
MFC4A1SP1450	-	-
MFC4A2SP2450	-	-
MFC4A3SP3450	-	-
MFC4A4SP4450	-	-

Note: '-' denotes the samples are not tested due to excessive superplasticizer, the sampleswere crumble

Table 9: Average compressive strength and permeability values of different combinations for Maximum Cement content 500kg/m^{3}with super plasticizer

Combination	Average Compressive Strength in MPa	Permeability in cm/sec
MFC1A1SP1500	12.80	1.41
MFC1A2SP2500	23.85	1.62
MFC1A3SP3500	21.20	1.30
MFC1A4SP4500	22.00	1.24
MFC2A1SP1500	25.97	1.66
MFC2A2SP2500	-	1.34
MFC2A3SP3500	21.35	1.42
MFC2A4SP4500	18.00	1.27
MFC3A1SP1500	-	-
MFC3A2SP2500	-	-
MFC3A3SP3500	-	-
MFC3A4SP4500	-	-
MFC4A1SP1500	-	-
MFC4A2SP2500	-	-
MFC4A3SP3500	-	-
MFC4A4SP4500	17.33	-

The maximum compressive strength obtained is 29.15 MPa for 50-20-30 (A1) combination of aggregates with maximum cement content of 450 kg/m^3 with 0.5% super plasticizer and 25%flyash with 75%OPC (53 grade). The maximum water permeability of PC obtained is 4.05 cm/s for 50-20-30 (A1) combination of aggregates with maximum cement content of 450 kg/m^3 with 0.5% super plasticizer and 10% flyash with 90%OPC (53 grade). However, it is good practice to consider PC which gives reasonable values of strength and permeability. Hence, the following analysis is carried out to find out these values. The strength and permeability values obtained for a particular combination (MFC1A1 to MFC4A1) are plotted on a graph, shown below in fig 12 to 20. The intersection point of the two curves is considered as optimal point in the present study.

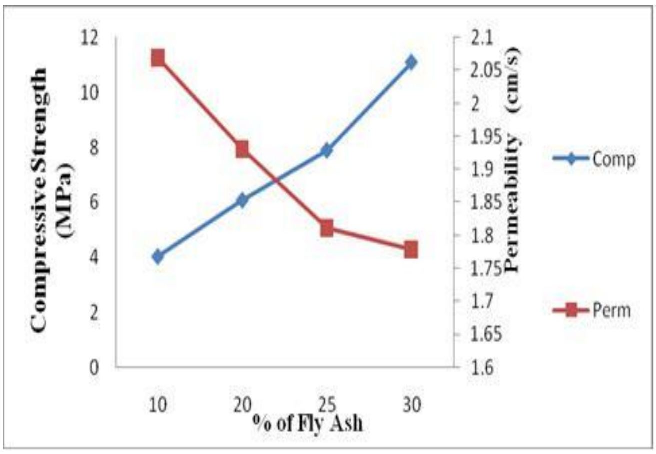

Fig. 12.Variation of strength and permeability for MFC1A1450 to MFC4A1450

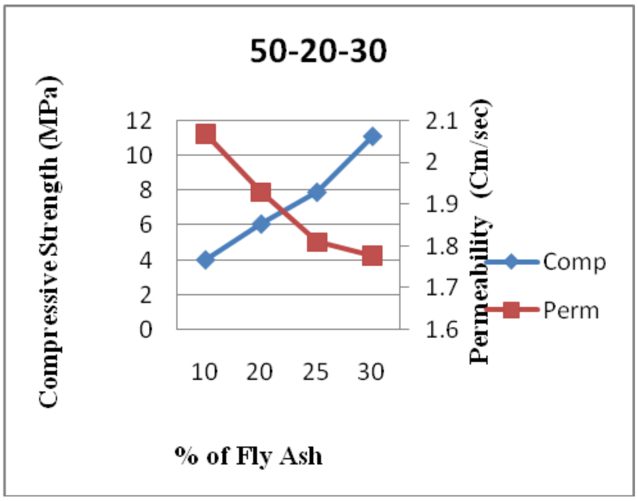

Fig. 13.Variation of strength and permeability for MFC1A2450 to MFC4A2450

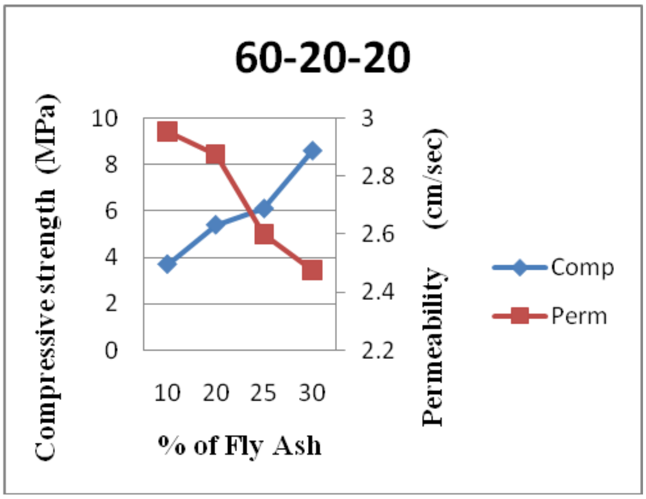

Fig. 14.Variation of strength and permeability for MFC1A3450 to MFC4A3450

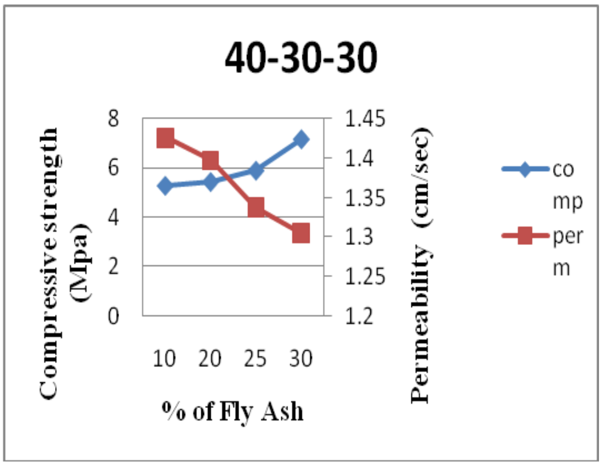

Fig. 15.Variation of strength and permeability for MFC1A4450 to MFC4A4450

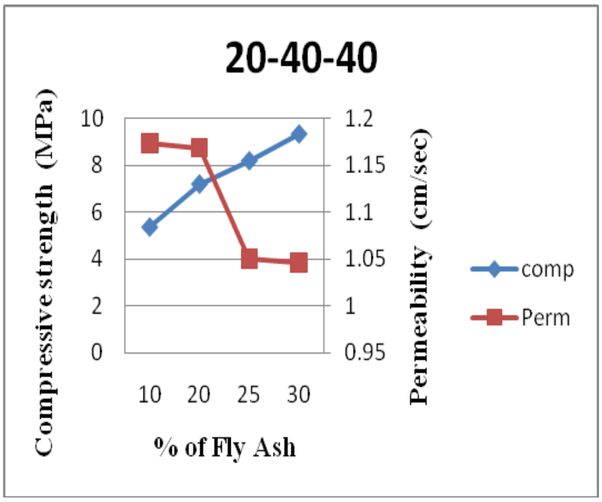

Fig. 16.Variation of strength and permeability for MFC1A1500 to MFC4A1500

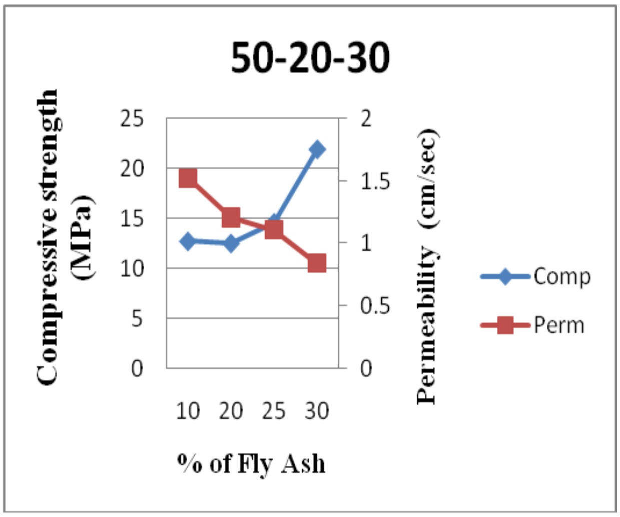

Fig. 17.Variation of strength and permeability for MFC1A2500 to MFC4A2500

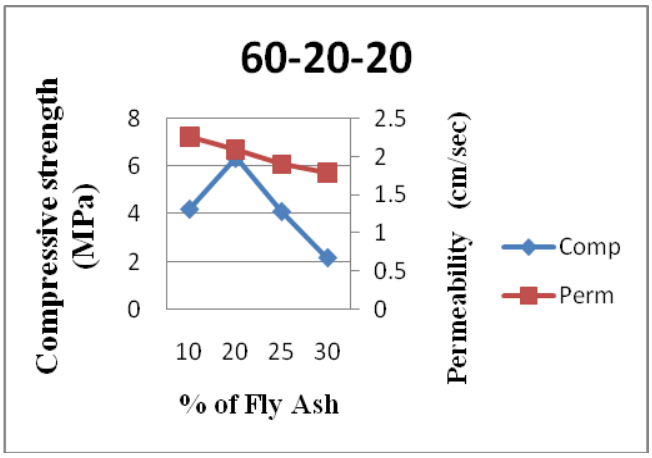

Fig. 18.Variation of strength and permeability for MFC1A3500 to MFC4A3500

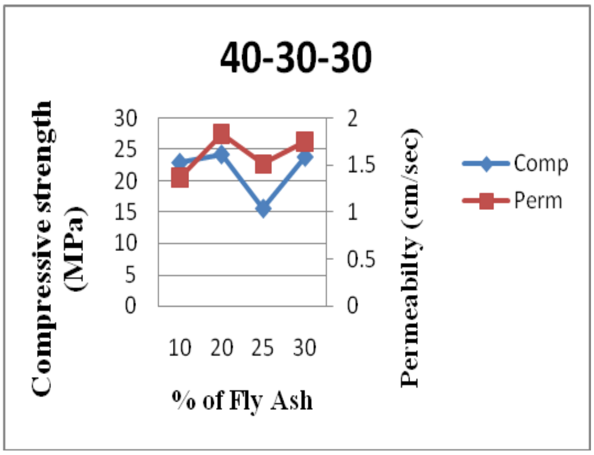

Fig. 19.Variation of strength and permeability for MFC1A1500 to MFC4A1500

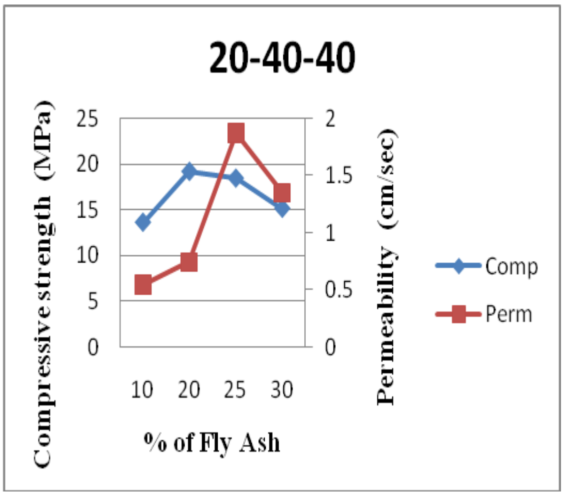

Fig. 20.Variation of strength and permeability for MFC1A1500 to MFC4A1500

Form the data presented in table 10, it is considered as 40% of 20mm, 30% of 12.5 mm and 10mm and 10%flyash with 90% opc (53 grade) the best combination which gives 24 MPa and 15.6 mm/s permeability.

Table 10: The best values from each of the above combinations are listed below in table.

Aggregate ratio mm	Flyash %	Cement content kg/m3	Super plasticizer %	Permeability cm/sec	Compressive strength (MPa)
50-20-30	20	450	0	1.885	6.6
40-30-30	10	500	0	1.56	24
20-40-40	10	450	0.5	1.58	19
50-20-30	20	500	1	1.55	20

Field application:

The discharge through the pipe is calculated and obtained as 0.919 Lps. The time taken to absorb the water through the panels of pervious concrete of various lengths are noted down and shown below in table 11 and 12.The volume of water that is absorbed by the pervious concrete panel and velocity through the panel are calculated as follows,1148.75lts and 10.24 mm/sec respectively.

Table. 11 : Time taken for water absorption through panels of various length

S.No.	Length (m)	Time (minutes:seconds)
1	12.8	20:50
2	9.6	17:32
3	6.4	12:12
4	3.2	9:46

Table 12: Velocity and water absorbed

Panel length in m	Volume of water absorbed (liters)	Velocity through the panel (mm/sec)	Water absorbed liters per m length
12.8	1148.7	10.24	89.74
9.6	966.8	9.41	100.70
6.4	661.7	8.89	103.39

3.2	538.5	5.92	168.28
Average		8.62	115.52

IV. SUMMARY AND CONCLUSIONS:

The effect of partial replacement of cement with fly ash and super plasticizer on the compressive strength and the water permeability of pervious concrete are investigated. Different combinations of aggregate sizes are used in this study. The analysis of the test results indicated that the proposed combination of materials have increased the compressive strength significantly. Also, the water permeability has got increased with the use of proposed combinations. The groundwater recharge is studied through a footpath by applying pervious concrete with the best mix proportions obtained.

The conclusions of the work have been summarized as follows:

1) The maximum compressive strength obtained is 29.15 MPa for 50-20-30 (A1) combination of aggregates with maximum cement content of 450 kg/m^3 with 0.5% super plasticizer and 25%flyash with 75%OPC (53 grade).
2) The maximum water permeability of PC obtained is 4.05 cm/s for 50-20-30 (A1) combination of aggregates with maximum cement content of 450 kg/m^3 with 0.5% super plasticizer and 10%flyash (53 grade).
3) The individual performances for strength and permeability as explained above may be good, but they should have reasonable values for varied reasons. Hence, In the present method, it is proposed to consider the intersection point of the graph (strength – permeability variation different fly ash and OPC combinations of different aggregate s) as the best combination. So, the combination with 40% of 20mm, 30% of 12.5 mm and 10mm and 10%flyash with 90% opc (53 grade) considered as the best which gives 24 MPa and 15.6 mm/s permeability.
4) From filed application, it is observed that when the rate of flow entering into pervious concrete is 0.919 liters per second and the density of soil is 2220 kg/m^3, then the average rate of water absorption is 115.53 lts and average velocity is 8.615 mm/sec.
5) The advantage of the panels is the highlight in this work because the panels can be easily removed and the sediments accumulated can be removed easily. So that repetitively, the panels can be utilized.
6) This study is completely site specific, however, the results showed that there is a considerable amount of groundwater recharge through the panels of pervious concrete; hence it is recommended that if the panels are maintained properly, then this is the best solution for recharge.

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VI. CONFLICT OF INTEREST

The author has no conflict of interest with any of the research or research or academic organizations. The results presented in this study are purely based on the experimental investigations. This work is solely carried out by me with the support from my college management and students.

VII. DATA AVAILABILITY STATEMENT

All data , model used during the study appear in the submitted article. Any other data which is not mentioned in the article can be provided by the author upon request. No data is confidential in this study.

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AUTHORS PROFILE

Vailada Vinay currently serves as Assistant Professor, Department of Civil Engineering, MVGR College of Engineering, Vizianagaram. He received his M.Tech from Andhra University, Visakhapatnam, in 2011. He is pursuing Ph.D from Andhra University, Visakhapatnam, since 2018. He is working with MVGR College of Engineering since 2011. His research interests are in the Civil Engineering Materials, Concrete & Steel Structures. He has 05 publications in various National and International Journals and Conferences of repute. He has attended more than 10 professional training programmes organized by prestigious institutions in India.

Dr. Sirgam Adiseshu received his B.E. degree in Civil Engineering from Osmania University, Hyderabad, A.P., M.E. degree in Structural Engineering from Andhra University, Visakhapatnam, A.P., and his Ph.D. degree in Civil Engineering from Andhra University, Visakhapatnam, A.P., in 2013. He is currently working as Professor in Civil Engineering at Andhra University, Visakhapatnam, Andhra Pradesh. His research interests are in the Civil Engineering Materials, Self-Compacting Concrete and Durability of Structures. He is Fellow of Institute of Engineers, IIAMBE & ICI member.

Chandramouli Sangamreddi currently serves as Professor, Department of CivilEngineering, MVGR College of Engineering, Vizianagaram. He received his M.Tech. from NIT Warangal in2002. He obtained his Ph.D. in Civil Engineering from Andhra University,Visakhapatnam, in 2013. He has worked in several organizations such as CES(I)Pvt. Ltd., Hyderabad; GVP College of Engineering, Visakhapatnam; and GMRIT, Rajam, for a period of 10 years. He is working with MVGR College of Engineeringsince 2011. He has published more than 70 technical papers in various reputedjournals and conferences. He has attended more than 60 professional training programmes organized by prestigious institutions in India. He is the life member ofISTE and IEI. He has completed one DST project as a co-principal investigator (Co-PI) and currently serves as Co-PI for a WTI project of DST of worth 1.04 crores. Hehas reviewed many journal papers published by prestigious journals and conferences.He has organized many faculty development programmes and studenttraining programmes.He is one of the editors for the two springer books on water resources and environmental Engineering-I and II. He guided 6 M.tech students and one Ph.D student.