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STUDIES ON CHARACTERISATION OF PERVIOUS PAVEMENT.

[1]Omkar Nevase, [2]Dikshanti Bhalerao, [3]Somnath Ware, [4]Aniket Khandeshe.

Student, Bachelor of Civil Engineering,
Department of Civil Engineering,
Sinhgad Institute of Technology and Science, Pune, India.

Abstract: This study presents the influence of variation of fine aggregate and coarse aggregate content on the properties of concrete. Detailed study of porous concrete is done by changing the aggregate content. Porous concrete is a concrete characterized by a porous structure that allows the water to percolate through it with consequent numerous environmental benefits. However, high drainable characteristics do not generally correspond to high strength and good surface condition when subjected to vehicular traffic, hence applications of permeable concrete are limited.

Index Terms **– Permeable concrete, Permeability, Flexural Strength, Compressive Strength, Porous Concrete, Permeable Pavement.**

I. INTRODUCTION

1.1. Overview :

Permeable pavement surfaces are made of either a porous material that enable storm water to flow through it. Permeable surfaces help to manage the surface runoff through infiltration and help in maintaining the natural water flows. The general feature of Permeable Pavement is to filter, treat and collect surface runoff and enhance the ground water recharge.

Permeable concrete is now used in multiple cities throughout the U.S. and its number of applications has grown drastically over the past ten years, from driveways and sidewalks to commercial and multi-acre spaces.

Permeable Pavement consists of cement, a coarse aggregate, and water, with little to no fine aggregates (sand or clay). That is why permeable concrete has a very rough and uneven appearance. Permeable paving can be one part of green building parking lots, which can also include rain gardens, art, trees, solar covers, and other creative elements. Paving and landscaping choices have a large effect on the environmental impact of parking lots. Increasing Urbanization in cities, rural areas and semi- developed regions creates many problems. One of the major issues is proper water management. It is known to us that at present many parts of city are covered with impervious surfaces due to construction of buildings and other infrastructural facilities.

The reduction in Permeable surfaces along with the traditional drainage systems lead to high water inflows which overwhelm the existing drainage system and causes flooding. The solution for it is Permeable Pavement.

Other terms such as ‘permeable pavement’ or ‘porous pavement’ are used in literature to describe “pervious pavement.” Pervious pavements consist of a surface layer made of either asphalt or concrete (cast-in-place or interlocking concrete units).

1.2. Definition:

Pervious pavements allow stormwater to filter through voids in the pavement surface into an underlying rock reservoir where it is temporarily stored and infiltrated into the surrounding materials. While pervious pavement designs may vary, they all have a similar structure consisting of a surface pavement layer with an underlying reservoir layer.

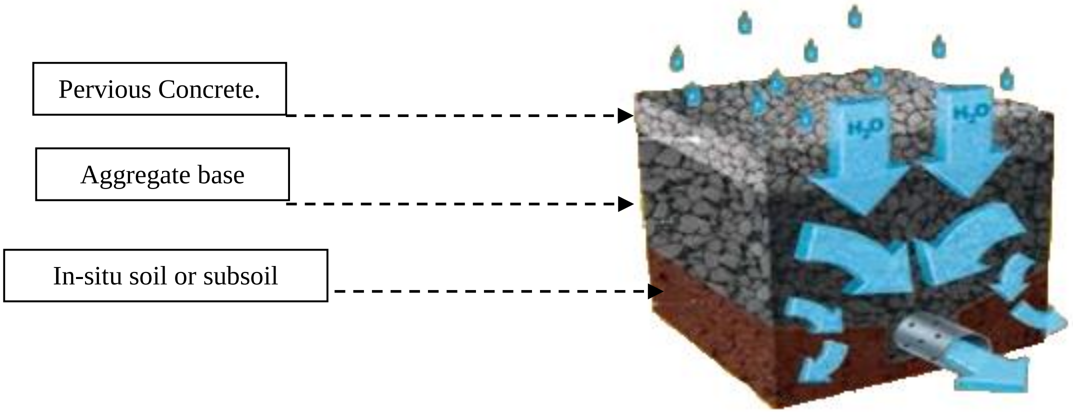


Figure 1. A Typical Permeable Pavement System

1.3. Types Of Infiltration.

Generally, Infiltration of Percolated water through Permeable pavement depends upon underlying Sub-Grade. Infiltration classifies as :

a. Full Infiltration: In that underlying sub-grade allows all the water to infiltrates through sub-grade towards underlying soil.

b. Partial Infiltration : In that underlying sub-grade partially allows all the water to infiltrates through sub-grade towards underlying soil and remaining water is stored in the pavement and must be removed by a discharge pipe.

c. No Infiltration : No water is allowed to infiltrate through the sub-grade but stored in the pavement and must be removed by a discharge pipe.

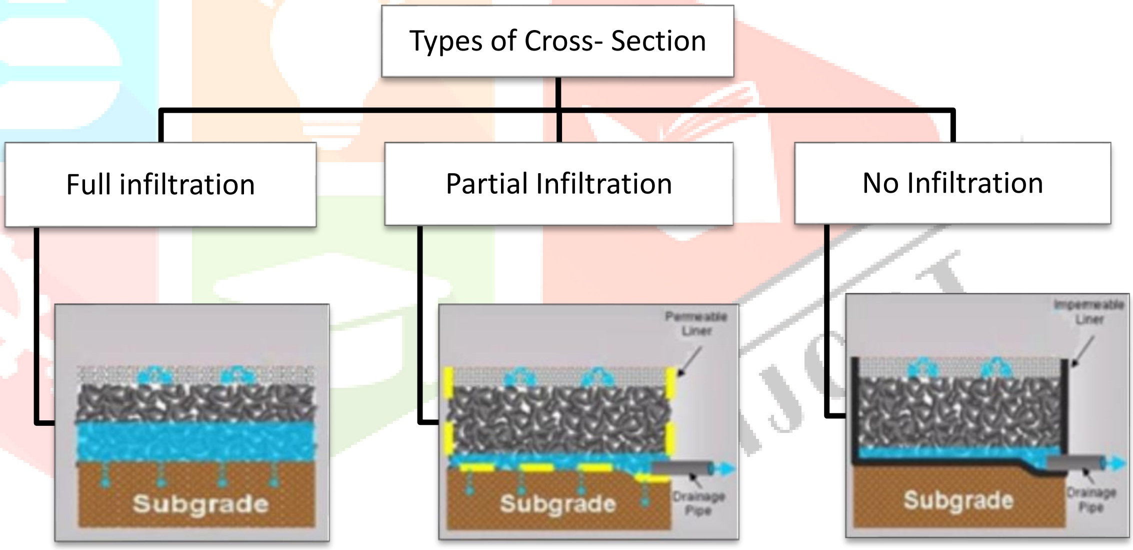


Figure 2. Types of Infiltration

II. PROBLEM STATEMENT

Flooding and water scarcity are a major challenge today. Hence, it is necessary to develop proper ground water management. Also flood control in the city is a major issue. Pervious concrete is a potential solution to manage this issue. The main focus of this project is to develop a suitable previous pavement system for road as per standard codes.

III. RELEVANCE

In various developing countries, Flood management is a major issue. Coastal cities are highly prone to flooding due to inadequate drainage systems. Also, concretization has led to reduced permeable surfaces. This situation can be effectively managed if Permeable concrete is used instead of conventional concrete.

IV. OBJECTIVES

- To study different Permeable Pavement systems.
- To study the properties of different Permeable materials that help to reduce surface runoff and increase ground water level.
- To study the feasibility of pervious pavements in road construction for better storm water management

V. EXPERIMENTAL PROGRAM.

5.1 Materials and properties

Two sizes of single-sized crushed limestone will be used in this project. All of the coarse aggregate used in the study will be sieved to obtain only single-sized aggregate. Coarse Aggregate Size 12.5 mm- with 100% passing the 16mm and 100%retained on 12.5mm sieve is used in the mix design. Fine aggregate with Specific gravity 2.63and Fineness modulus 3.0shall be used. For Concrete to be considered as pervious or porous, Maximum Proportion of Volume of Fine aggregate is 10% to 20% of Volume of All Aggregate.

If the Proportion by Volume is greater than 20%, the concrete is considered as traditional or conventional concrete.

Table 1. Physical properties of materials

Properties	Value
Specific gravity of Coarse aggregate	2.74
Specific gravity of Fine aggregate	2.63
Specific gravity of Cement	3.15

5.2 Mix Proportion Design.

5.2.1 Mix Proportion for porous concrete.

a.) Grade Designation : M30
b.) Type of Cement : OPC 43 grade.
c.) Maximum Nominal size of Aggregate : 20mm.
d.) Minimum cement content : 280kg/m^3
e.) Maximum Water-cement ratio : 0.40
f.) Workability : 100mm (Slump)
g.) Exposure condition : Extreme (for Plain Concrete)
h.) Type of Aggregate : Crushed angular aggregate.
i.) Specific Gravity of Cement : 3.15
j.) Free Surface Moisture:
(1.) Coarse aggregate : Nil (absorbed moisture also nil)
(2.) Fine aggregate : Nil(absorbed moisture also nil)

Step1: Target Strength for Mix Proportioning

$\bar{F}_{ck} = F_{ck} + 1.65 \times s$

$\bar{F}_{ck} = 30 + 1.65 \times s$

$\bar{F}_{ck} = 38.25$ N/mm^2……………….for M_{30}, s =5 N/mm^2

Where,

'$\bar{F}_{ck}$' is the mean compressive strength at 28days in N/mm^2

'F_{ck}' is the characteristic compressive strength at 28days in N/mm^2

's' is the standard deviation.

Step2: Selection of Water Cement Ratio.

For extreme condition,

Water Cement ratio = 0.40.

Adopted Water Cement ratio = 0.40.

Step3: Selection of Water Content.

$$Maximum\ Water\ Content\ for\ 20mm\ Aggregate\ =\ 186\ litre\ (for\ 25\ to\ 50mm\ Slump\ Range)$$

$$Estimated\ Water\ Content\ for\ 100\ mm\ Slump$$

$$= 186 + \frac{6}{100} \times 186$$

$$= 197\ litre$$

Step4: Calculation for Cement Content.

Water-Cement ratio =0.40

Cement Content = $\frac{197}{0.40} = 492.5\ kg/m^3$

Minimum Cement Content = 280 kg/m^3

492.5 kg/m^3 > 280 kg/m^3

Hence, Okay.

Step5: Proportion of Volume of Coarse Aggregate and Fine Aggregate.

Maximum Proportion of Fine Aggregate = 10% to 20%

Adopted Volume of Fine Aggregate = 15% = 0.15

Volume of Coarse Aggregate = 85% = 0.85

Step6: Mix Calculation.

a) Volume of Concrete= 1m^3

b) Volume of Cement =$\frac{Mass\ of\ cement}{Specific\ Gravity\ of\ Cement\ \times 1000}$

Volume of Cement =$\frac{492.5}{3.15\times 1000}$

Volume of Cement = 0.156m^3

c) Volume of Water =$\frac{Mass\ of\ Water}{Specific\ Gravity\ of\ Water\ \times 1000}$

Volume of Water =$\frac{197}{1\ \times 1000}$

Volume of Water = 0.197m^3

d) Volume of All Aggregate

= (Total Volume of Concrete) – (Volume of Cement+ Volume of water)

= 1 – (0.156+ 0.197)

= 0.647m^3

e) Mass of Coarse Aggregate

$$= (Volume\ of\ All\ Aggregate \times Proportion\ of\ Voume\ of\ Coarse\ Aggregate \times Specific\ Gravity \times 1000)$$

= 0.647$\times$ 0.85 $\times$ 2.74 $\times$ 1000

= 1506.86 Kg

f) Mass of Fine Aggregate

$$= (Volume\ of\ All\ Aggregate \times Proportion\ of\ Voume\ of\ fine\ Aggregate \times Specific\ Gravity \times 1000)$$

= 0.647$\times$ 0.15 $\times$ 2.63 $\times$ 1000

= 255.24 Kg

Step6: Mix Proportion for Trial per m^3 of Concrete.

Cement = 492.5 Kg/m^3

Water = 197 kg/m^3

Fine Aggregate = 255.24 Kg/m^3

Coarse Aggregate = 1506.86Kg/m^3

Water Cement Ratio = 0.4

Cement: Fine Aggregate: Coarse Aggregate = 1: 0.5: 3

5.2.2 Mix Proportion for Conventional Concrete.

a.) Grade Designation : M30

b.) Type of Cement : OPC 43

c.) Maximum Nominal size of Aggregate : 20mm.

d.) Minimum cement content : 280kg/m^3

e.) Maximum Water-cement ratio : 0.40

f.) Workability : 100mm (Slump)

g.) Exposure condition : Extreme (for Plain Concrete)

h.) Type of Aggregate : Crushed angular aggregate.

i.) Specific Gravity of Cement : 3.15

j.) Free Surface Moisture:

(1.) Coarse aggregate : Nil (absorbed moisture also nil)

(2.) Fine aggregate : Nil(absorbed moisture also nil)

Step1: Target Strength for Mix Proportioning

$\bar{F}_{ck} = F_{ck} + 1.65 \times s$

$\bar{F}_{ck}$= 30 + 1.65 $\times s$

$\bar{F}_{ck}$= 38.25 N/mm^2……………….for M_{30}, s =5N/mm^2

Where,

'$\bar{F}_{ck}$' is the mean compressive strength at 28days in N/mm^2

'F_{ck}' is the characteristic compressive strength at 28days in N/mm^2

's' is the standard deviation.

Step2: Selection of Water Cement Ratio.

For extreme condition,

Water Cement ratio = 0.40.

Adopted Water Cement ratio = 0.40.

Step3: Selection of Water Content.

$$Maximum\ Water\ Content\ for\ 20mm\ Aggregate\ =\ 186\ litre\ (for\ 25\ to\ 50mm\ Slump\ Range)$$

$$Estimated\ Water\ Content\ for\ 100\ mm\ Slump$$

$$= 186 + \frac{6}{100} \times 186$$

$$= 197\ litre$$

Step4: Calculation for Cement Content.

Water-Cement ratio =0.40

Cement Content = $\frac{197}{0.40} = 492.5\ kg/m^3$

Minimum Cement Content = 280 kg/m^3

492.5 kg/m^3 > 280 kg/m^3

Hence, Okay.

Step5: Proportion of Volume of Coarse Aggregate and Fine Aggregate.

Volume of Fine Aggregate = 40% = 0.40

Volume of Coarse Aggregate = 60% = 0.60

Step6: Mix Calculation.

a) Volume of Concrete= $1m^3$

b) Volume of Cement =$\frac{Mass\ of\ cement}{Specific\ Gravity\ of\ Cement\ \times 1000}$

Volume of Cement =$\frac{492.5}{3.15 \times 1000}$

Volume of Cement = $0.156m^3$

c) Volume of Water =$\frac{Mass\ of\ Water}{Specific\ Gravity\ of\ Water\ \times 1000}$

Volume of Water =$\frac{197}{1 \times 1000}$

Volume of Water = $0.197m^3$

d) Volume of All Aggregate

= (Total Volume of Concrete) – (Volume of Cement+ Volume of water)

= 1 – (0.156+ 0.197)

= $0.647m^3$

e) Mass of Coarse Aggregate

$$= (Volume\ of\ All\ Aggregate \times Proportion\ of\ Voume\ of\ Coarse\ Aggregate \times Specific\ Gravity \times 1000)$$

= 0.647× 0.6 × 2.74 × 1000

= 1063.67 Kg

g) Mass of Fine Aggregate

$$= (Volume\ of\ All\ Aggregate \times Proportion\ of\ Voume\ of\ fine\ Aggregate \times Specific\ Gravity \times 1000)$$

= 0.647× 0.40 × 2.63 × 1000

= 709.11 Kg

Step7: Mix Proportion for Trial per m^3 of Concrete.

Cement = 492.5 Kg/m^3

Water = 197 kg/m^3

Fine Aggregate = 709.11 Kg/m^3

Coarse Aggregate = 1063.67 Kg/m^3

Water Cement Ratio = 0.4

Cement: Fine Aggregate: Coarse Aggregate = 1: 1.44 : 2.16

Table 2. Mix Proportions for Trial

Mix No.	Type of Concrete	Aggregate Size (mm)	Binder cement (kg)	Water Cement Ratio	Coarse Aggregate Quantity (kg)	Fine Aggregate Quantity (kg)	Water (kg)	Coarse Aggregate Percentage	Fine Aggregate Percentage
1	Permeable	12.5	492.5	0.4	1506.86	255. 24	197	85	15
2	Conventional	12.5	492.5	0.4	1063.67	709.11	197	60	40

5.2.3 Preparation of Specimen.

All materials shall be brought to room temperature, preferably 27 ± 3 °C before commencing the test. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material ,Can being taken to avoid the intrusion of foreign matter. The cement shall then be stored in a dry place, preferably in air-tight metal containers. Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. In general. the aggregate shall be separated into fine and coarse fractions and recombined for each concrete batch in such a manner as to produce the desired grading.

For Mixing of concrete, the mixing drum is charged by the power loader, all the mixing water shall be introduced into the drum before the solid materials the skip shall be loaded with about one half of the coarse aggregate, then with the fine aggregate, then with the cement and finally with the remaining coarse aggregate on top. (If all in aggregate used, the skip shall be loaded first with about one-half of the aggregate then with the cement and finally with the remaining aggregate on top.) Where the mixing drum is hand loaded it shall he charged with the dry materials in a similar manner, and the water shall be added immediately before the rotation of the drum is started. The period of mixing shall be not less than 2 minutes after all the materials are in the drum, and shall continue till the resulting concrete is uniform in appearance. When using pan mixers, the concrete shall be heaped together before sampling.

Pervious Concrete and conventional concrete samples of Cube(15cm x 15cm x 15cm), Beam(15cm x 15cm x 70cm) and Cylinder (15cm x 30cm) shall be prepared using mix for test. The test specimen shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 3°e for 24 hours ± l hour from the time of addition of water to the dry ingredients, After this period, the specimens shall be marked and removed from the molds and, unless required for test within 24 hours, immediately submerged in clean, fresh water or saturated lime solution and kept there until taken out just prior to test. The water or solution in which the specimens are submerged shall be renewed every seven days and shall be maintained at a temperature of 27° ± 3°C. The specimens shall not be allowed to become dry at any time until they have been tested.

5.2.4 Testing.

Testing plays an important role in controlling the quality of cement concrete work. Systematic testing of the raw materials, the fresh concrete and the hardened concrete is an inseparable part of any quality control program for concrete which helps to achieve higher efficiency of the materials used and greater assurance of the performance of the concrete in regard to both strength and durability.

1) Compressive Strength

Compressive strength is one of the most important properties of concrete and mortar. The strength of the binder (cement) therefore has a significant effect on the performance characteristics of the mixture and ensures the overall quality of the finished product.

Cubical specimens(15cm x 15cm x 15cm) with 2 different mix proportions are cast and tested on Day1, Day7 and Day28. Compressive loading is applied on the cubes on a UTM(Universal Testing Machine) or CTM(Compression Testing Machine). The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression platens. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied at the opposite sides of the cubes as cast that is not to the top and bottom surfaces. The axis of the specimen shall be carefully aligned with the center of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and the steel platen of the testing machine.

As the spherically seated block is brought to bear on the specimen. the movable portion shall be rotated gently by hand so that uniform seating may be obtained. The load shall be applied without shock and increase constantly until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features In the type of failure shall be noted. The effect of change in proportion of materials and addition of cementitious material on the compressive Strength of the Permeable Concrete specimens shall be studied.

The strength value was reported as the average of three samples.

2) Flexural Strength

Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending. The results of flexural test on concrete expressed as a modulus of rupture which denotes as in MPa.

Beam specimens(15cm x 15cm x 70cm) with 2 different mix proportions are cast and tested on Day1, Day7 and Day28. During testing, the bearing surfaces of the supporting and loading rollers shall be wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are to make contact with the rollers. The specimen shall then be placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mold.

Point loading is applied to the beam fixed on rollers at a distance of L/3 from both ends. The axis of the specimen shall be carefully aligned with the axis of the loading device. No packing shall be used between the bearing surfaces of the specimen and the rollers. The load shall be applied without shock and increase at constant rate. The load shall be increased until the specimen fails, and the maximum load applied to the specimen during the test shall be recorded.

The effect of change in proportion of materials and addition of cementitious material on the flexural Strength of the Permeable Concrete specimens shall be studied. The strength value was reported as the average of three samples.

3) Permeability

The most distinguished feature of pervious concrete is its high permeability, which is a measure of the ease by which fluid may flow through the material under a pressure gradient.

Cylinders of Size 15cm×30cm are cast to check the permeability by Constant head method. The test is carried out on a permeameter. The water supply or the discharge is kept constant. The water collected in the container with respect to time is measured and permeability is found from formula

$$\text{Permeability} = \frac{Volume\ of\ Water\ collected}{time\ in\ seconds}$$

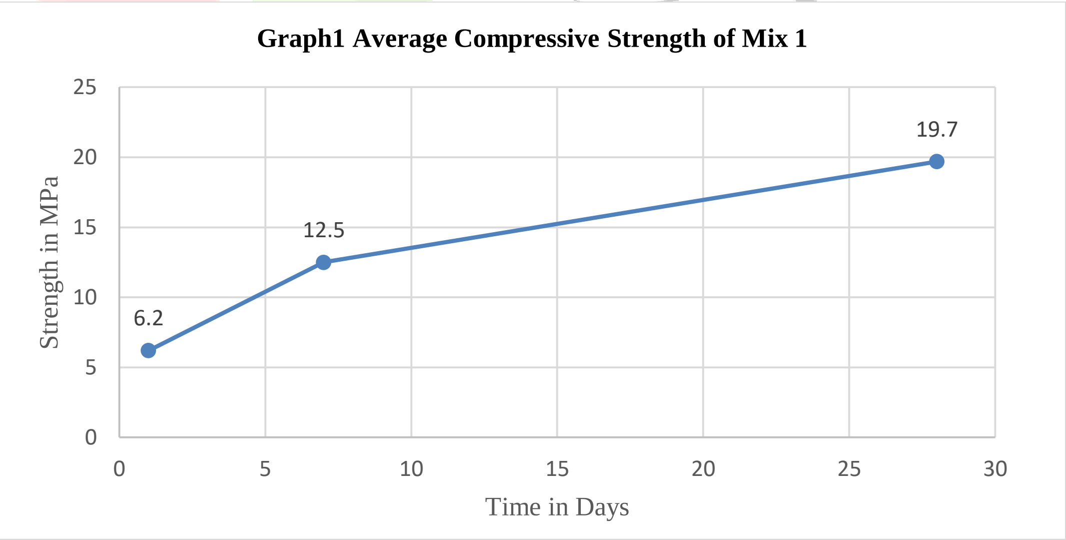
VII. RESULT AND DISCUSSION.

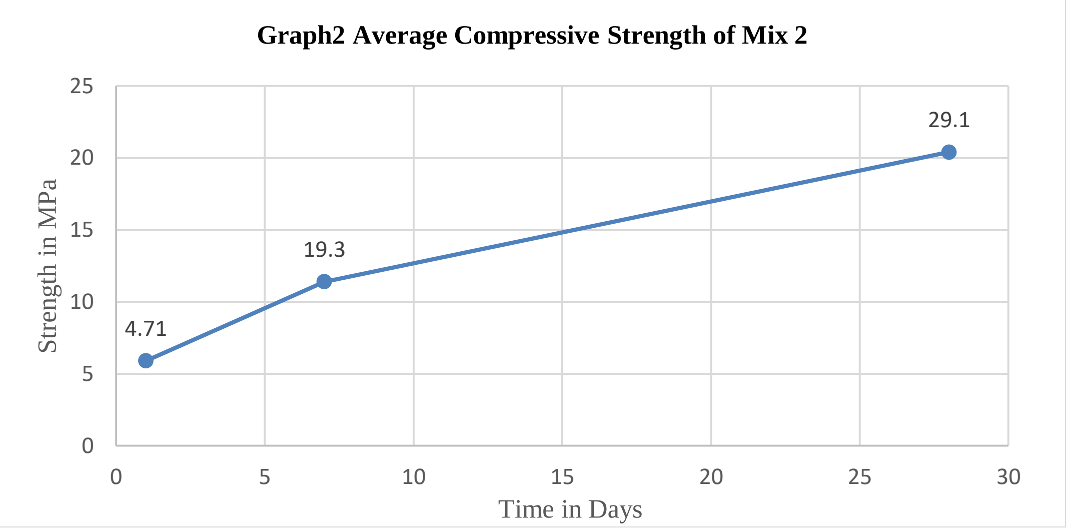
1. For Compressive Strength (in MPa)

The samples were tested according to standard procedure. The following results were obtained. The results indicate overall strength of Mix 2 was greater than that of Mix 1. Average Strength is calculated for both the samples. The strength obtained for porous concrete is lesser than that of the 28-day compressive strength that of conventional concrete.

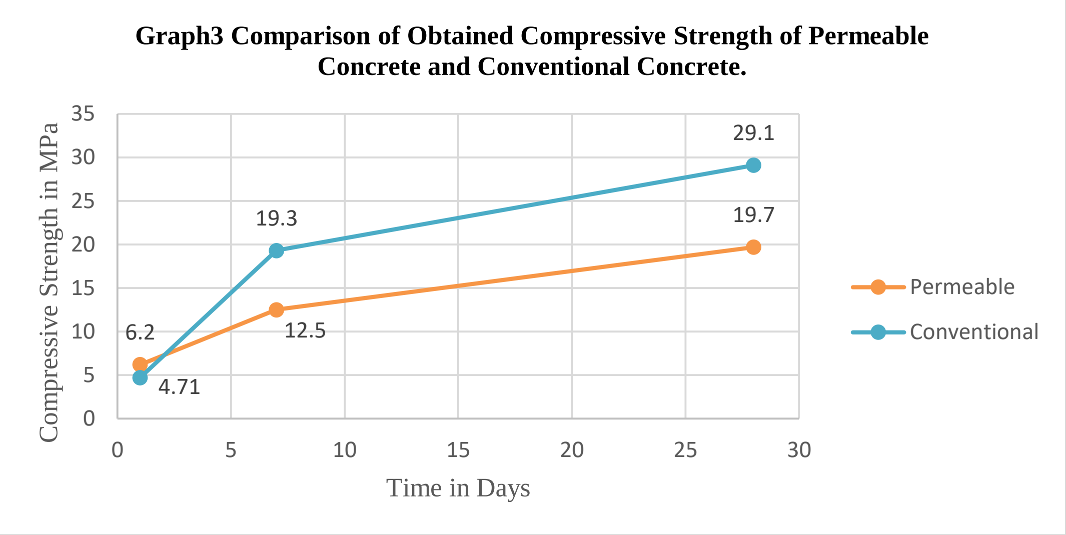
Table 3 Obtained Compressive Strength.

	Compressive strength/No. of Days	1-day Compressive Strength(MPa)	7 days Compressive Strength(MPa)	28 days Compressive Strength(MPa)
1	Average strength for Mix 1	6.2	12.5	19.7
2	Average strength for Mix 2	4.71	19.3	29.1





Graph 1 and 2 show the obtained compressive strength at 1, 7 and 28 days in MPa for Mix 1 and Mix 2 respectively.



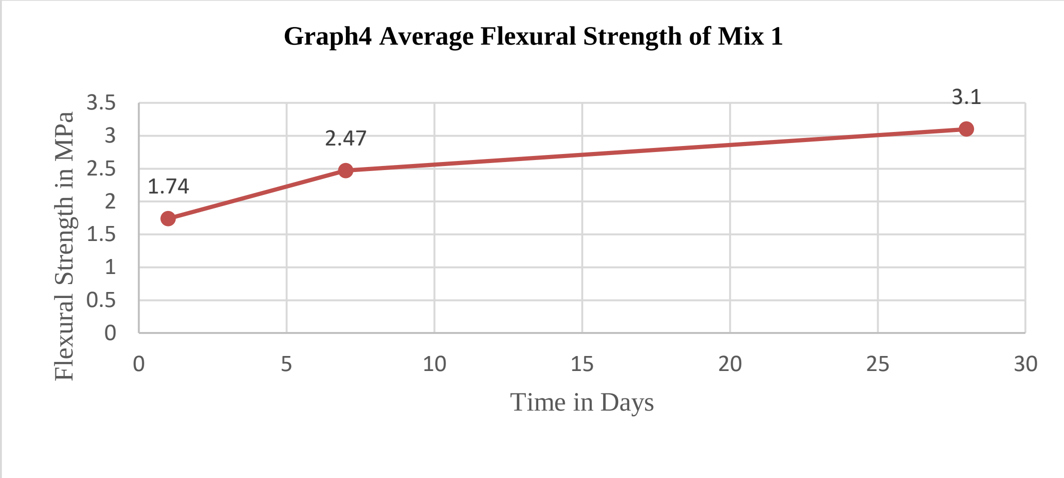
Graph3 shows the comparison of Obtained Average Compressive strength of Permeable Concrete and Conventional Concrete.

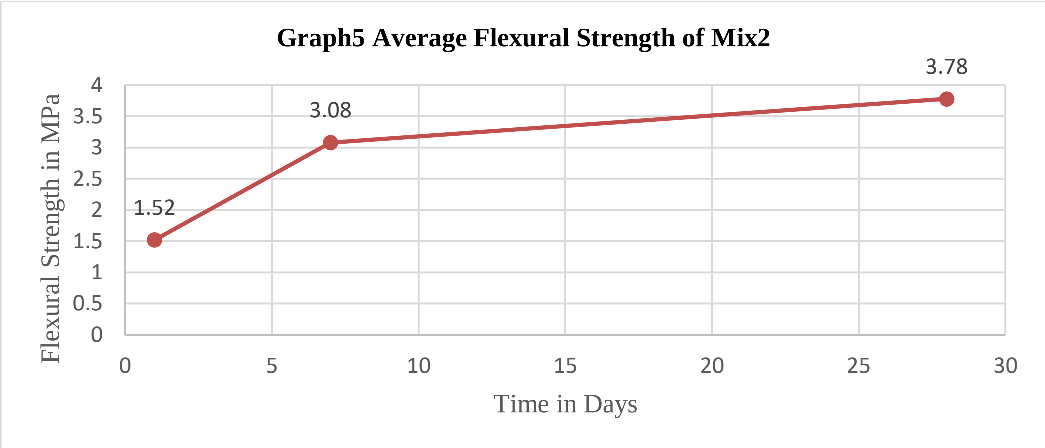
2.For Flexural Strength (in MPa)

The samples were tested according to standard procedure. The following results were obtained. The results indicate overall flexural strength of Mix 2 was greater than that of Mix 1. Average flexural Strength is calculated for both the samples. The strength obtained for porous concrete is lesser than that of the 28-day flexural strength that of conventional concrete.

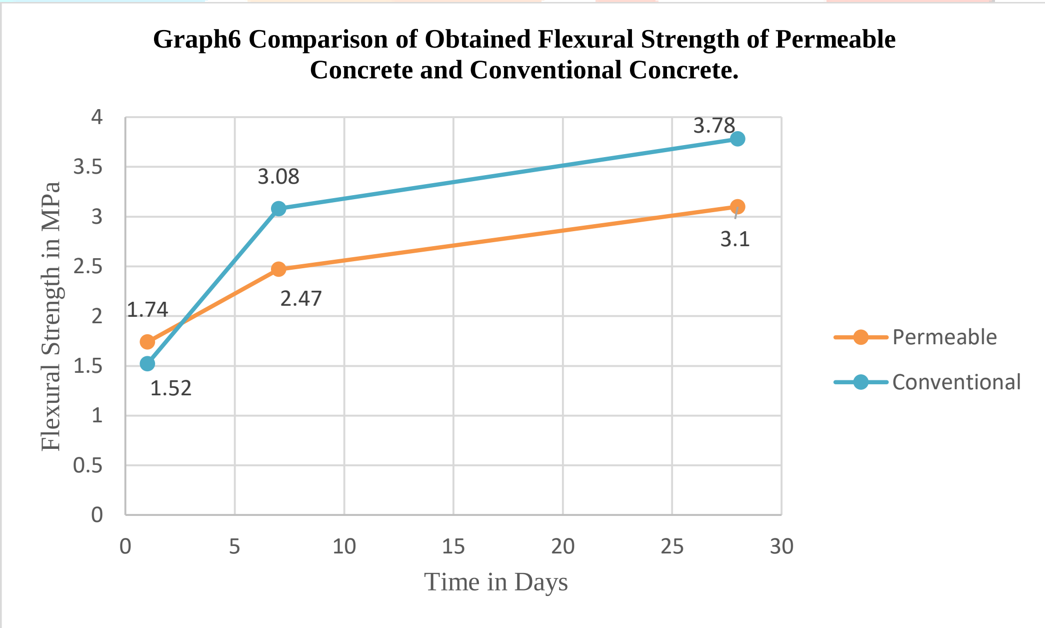
Table4 Obtained Flexural Strength

	Flexural strength / No. of Days	**1-day Flexural Strength(MPa)**	**7 days Flexural Strength(MPa)**	**28 days Flexural Strength(MPa)**
1	Average strength for Mix 1	1.74	2.47	3.1
2	Average strength for Mix 2	1.52	3.08	3.78





Graph 4 and 5 show the obtained Flexural Strength for 1, 7 and 28 days in MPa for Mix 1 and Mix 2 respectively.



Graph 6 shows the Obtained Average Flexural strength of Permeable Concrete and Conventional Concrete.

3. For Permeability (in mm/sec)

The obtained Permeability is measured after 28-days through constant head permeability Method. Mentioned above are the results obtained through testing.

Table5 Permeability of Pervious Concrete.

	Sample	28 Days Permeability (mm/sec)
1	Sample 1	35
2	Sample 2	38

3	Sample 3	38
4	**Average**	**37**

VI. CONCLUSION.

1. **Permeable Concrete:**
   a. For Concrete to be considered as pervious or porous, Maximum Proportion of Volume of Fine aggregate is 10% to 20% of Volume of All Aggregate.
   b. If the Proportion by Volume is greater than 20%, the concrete is considered as traditional or conventional concrete.
2. **Permeability:** The desired Permeability was achievable by considering the above proportions. Permeability of 37 mm/sec was obtained which helped to achieve the desired result.
3. **Reduced Compressive Strength:** Compressive Strength for the Permeable concrete reduced by almost 30% that of the Conventional concrete. Instead of using at Heavy loading areas, porous concrete with this proportion at lightly loaded areas like Parking lots, sideways , running track ,parks ,etc. can be preferably used.
4. **Requisite Flexural Strength:** The Flexural strength of porous concrete is reduce as compared to Conventional Concrete.
5. **Study of Types and application of Permeable concrete:** The study of Permeable Concrete established the effect of variation of Aggregate proportion on the properties of Permeable Concrete.

VII. BENEFITS.

Benefits of pervious pavements include:
1. Reducing the rate of runoff
2. Maintaining the natural hydrologic function of the site
3. Increasing Ground water level.
4. The project is helpful at controlling the flood situation and preventing the wastage of Potable Water

Permeable pavement is design for stormwater infiltration and reduce stormwater runoff. It is typically designed to capture rainfall on the pavement surface area, but may also accept runoff from adjacent impermeable areas. Pervious pavements infiltrate the water below the pavement surface and eliminate water accumulation issues. This will help to eliminate concerns of mosquito breeding. Some recent studies have also found that permeable pavement can help reduce temperatures on and around pavements which helps reduce urban heat island effect(water percolating through the pavement can exert a cooling effect through evaporation, and convective airflow can also contribute to cooling).

VIII. LIMITATIONS.

- Permeable pavement has limited use in heavy vehicle traffic areas.
- Specialized construction practices are necessary for permeable pavement.
- Curing time is more.
- Special attention required in areas where high groundwater level.
- Special attention and care in design of some soil types such as expansive soils and frost-susceptible ones.

IX. FUTURE SCOPE.

- The effect of addition of Steel Fibres to the concrete mix to further improve the strength of the permeable concrete can be studied.
- How the addition of binders to the concrete mix affects the permeability and the strength of the pavement can be studied in the future
- The effect of different environmental conditions on the material and how it affects its different physical properties can be further studied.

X. ACKNOWLEDGMENT

We express our gratitude to our guide Mr. P. M. Wale for his competent guidance and timely inspiration. It is our good fortune to complete our Project under his able competent guidance. This valuable guidance, suggestions, helpful constructive criticism, kept interest in the problem during the course of presenting this project successfully.

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REFERENCES

1. Long-term Stormwater Quantity And Quality Performance Of Permeable Pavement Systems (Benjamin O. Brattebo, Derek B. Booth) (Water Research 37 (2003) 4369–4376) (July 2003)
2. Introduction To Permeable Bituminous Pavement In Pithoragarh Area Of Uttarakhand (Vipul Kumar Saini, Anuj Upadhyay) (International Journal Of Civil Engineering And Technology) (Volume 8, Issue 4)(April 2017)
3. Studies On Characterization Of Pervious Concrete For Pavement Applications (M.Uma Maguesvaria,c And V.L. Narasimhab) (2013) (Social And Behavioral Sciences 104 (2013) 198 – 207)
4. Development Of A National Asce Standard For Permeable Interlocking Concrete Pavement (David K. Hein, P. Eng. And David R. Smith)(American Society Of Civil Engineers (ASCE))
5. Review Of Permeable Pavement Systems (Miklas Scholz, Piotr Grabowiecki) (20 November 2006)(Elsevier) (Building And Environment 42 (2007) 3830–3836)
6. Environmental assessment of a permeable pavement system used to harvest stormwater for non-potable water uses in a building (Lucas Niehuns Antunes, Enedir Ghisi, Roni Matheus Severis)
7. Permeable pavement design and construction case studies (David K. Hein, P. Eng.)
8. Mix Design Method for Permeable Base of Porous Concrete (Mulian Zheng, Shuanfa Chen, and Binggang Wang)(ISSN 1997-1400 Int. J. Pavement Res. Technol.5(2):102-107)
9. An Experimental Study on Pervious Concrete(Mix-Ratio, Strength and Porous Properties) (Dev Pratap Mani Tripathi, S. M. Ashraf Hussain, Praneet Madhav)((IJERT)ISSN: 2278-0181 Vol. 6 Issue 12, December - 2017)
10. A Review on Mix Design for Pervious Concrete (Salunkhe patil S.S.1, Patil O.D., Dhemare A. M., Jadhav S.A., Bhirud S.V)(8th National Conference on Emerging Trends in Engineering and Techology-2018 ISBN-978-93-87793-03-3)
11. Pervious Pavement Blocks Made from Recycled Polyethylene Terephthalate (PET): Fabrication and Engineering Properties (Byung-Hyun Ryu, Sojeong Lee and Ilhan Chang)(Sustainability 2020, 12, 6356)
12. Experimental Study on Steel Fiber-Reinforced Pervious Concrete (Channappa, Pradeep Kumar Reddy) ((IRJET) e-ISSN: 2395-0056)
13. ACI committee 522 (2006). Pervious Concrete, ACI International, Farmington Hills.
14. IS: 383-1970 Specification of Coarse and Fine Aggregate from Natural Source for Concrete, New Delhi, India: Bureau of Indian Standards