

**EFFECT OF ADDITION OF STEEL FIBERS ON THE PROPERTIES OF  
PERVIOUS CONCRETE**

A Dissertation Submitted  
in Partial Fulfillment of the Requirements  
for the degree of

**MASTERS OF ENGINEERING  
IN  
CIVIL INFRASTRUCTURE ENGINEERING**

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JULY 2016**

## DECLARATION

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I hereby declare that this thesis titled “**Effect of Addition of Steel Fibers on the Properties of Pervious Concrete**” is an authentic record of the work carried out as per the requirement for the award of degree of **Masters of Engineering in Civil Infrastructure Engineering** in the Civil Engineering Department of **Thapar University, Patiala** under the guidance of **Dr. Prem Pal Bansal, Associate Professor** and **Mr. Tanuj Chopra, Assistant Professor**, Department of Civil Engineering, Thapar University, Patiala during July 2015 to July 2016. The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.


Date: 15<sup>th</sup> JULY 2016

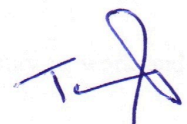
  
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## CERTIFICATE

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This is to certify that the above statement made by the student concerned is correct and true to the best of my knowledge and belief.

  
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## **ACKNOWLEDGEMENT**

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I wish to express my sincere appreciation and profound gratitude to my respected supervisors Dr. Prem Pal Bansal, Associate Professor, CED and Mr. Tanuj Chopra, Assistant Professor, CED, for their intuitive and careful guidance, perpetual inspiration and continued encouragement in completion of this design project. This work reflects their clear ideas, thoughts and concepts. I am highly indebted to them for their valuable suggestions and of course their precious time during the period of the work.

I wish to express my sincere thanks to Dr. Naveen Kwatra, Associate Professor and Head, CED, Thapar University, Patiala, who has been a constant source of inspiration for me throughout this thesis work.

I am extremely thankful to Dr. Heaven Singh, Assistant Professor, CED, for his timely guidance and support.

I owe my sincere thanks to Sh. Ram Simran, Sh.Virender and other laboratory colleagues, who helped me in my experimental work. I highly appreciate the cheerful support of my friends and colleagues who stood by me during all ups and downs.

My sincere thanks go to Thapar University, Patiala who gave me an opportunity to work and successfully complete this project.

I thank my parents for giving unconditional support and encouragement to pursue my current study.

I am thankful to all the people who have encouraged and inspired me to achieve higher goals.

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## ABSTRACT

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In recent years, several areas of the country are facing the problem of reduced ground water table which is directly affecting the production of crops. This is a very serious situation for the country as the production of crops is reduced and the cost is increased. Also, due to inadequate drainage facilities, the storm water runoff is not drained properly in the event of a flood. This results in flash flooding, destruction of fertile land and the functioning of roadways and pathways gets blocked. Since it is not very cost effective to provide an expensive storm water management solution in rural areas so there is a need to develop a sustainable design to reduce the strain on our environment and for the well-being of the society. Pervious concrete is a relatively new concept in the field of pavements and is a mixture of coarse aggregate, water and cement. Due to the presence of a large number of voids, it has a high permeability and thus allows water to pass through it at a high rate. It has widespread pavement applications in Europe where it is being used in parking lots, walkways, sidewalks and low volume traffic roads. In a developing nation like India, it can be a very useful tool to reduce frequent floods and manage storm water runoff.

Due to its open graded structure, pervious concrete suffers from the drawback of low flexural strength. In this research work, attempts have been made to enhance the flexural strength of pervious concrete without significantly affecting its permeability. The present study is divided into three phases. The first phase involves development of a suitable mix design which has good mechanical properties. In the second phase steel fibers are added to the normal mix design in different percentages, i.e., 1%, 1.5% and 2% by volume of concrete to check for its effect on mechanical properties and permeability. Two types of steel fibers are used in this study, i.e., Hooked End (4-D) and Crimped steel fibers with an aspect ratio of 67 and 50 respectively. The third phase involves the design of a pervious pavement to check for its adequacy in field applications. An attempt has been made to check the increase in durability of steel fiber reinforced pervious concrete with water absorption.

The pervious concrete is checked for its compressive strength, flexural strength, durability, water absorption and permeability at different percentages of steel fibers. The compressive strength and flexural strength tests are conducted as per the relevant Indian Standards whereas the permeability test is done by using Falling Head Method which is a common test for obtaining

permeability of soil samples in laboratory. The crimped fiber modified concrete exhibited a maximum increase in compressive strength of 4.19% and maximum increase in flexural strength of 11.19% at a dosage of 2% fiber by volume of concrete without any major change in permeability. For the addition of hooked end (4-D) fiber, the maximum increase of 19.03% in flexural strength and 5.11% in compressive strength is observed on addition of 1.5% fiber without any significant effect on the permeability. Compressive and flexural strength decreased on addition of 2% hooked end fiber. The test results also show that durability increases with decrease in water absorption for all fiber types and fiber proportions or percentages.

It can be concluded from the final results that hooked end (4-D) fibers impart best flexural strength to the pervious concrete. The outcome indicates that pervious concrete with hooked end fibers can be used for the design of low-volume traffic roads. Thus, more efficient land use can be made and water can be directly transmitted to the underground surface and thus recharging the ground water table.

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### **1.1 Introduction to Pervious Concrete**

Pervious Concrete may be defined as a mixture of cement, water and a single sized aggregate combined to produce a porous structural material. Due to its permeability requirement, Pervious Concrete Pavement (PCP) is typically designed with high void content and thus suffers from significantly reduced strength. It is a special type of concrete in which no fine aggregates are used and crushed gravel has been used in place of the coarse aggregate. Pervious Concrete is also called as no-fines concrete or porous concrete. This type of concrete is commonly used in low volume pavements, parking lots, residential roads, driveways, sidewalks and pathways.

The main purpose of this research project is to assess the suitability for no-fines concrete to be used for the construction of road pavements with low traffic volume. This assessment will include conducting some mix designs and standard concrete testing by using steel fibers to evaluate the mechanical properties and structural integrity of PCP. Figure 1.1 shows the visible difference in the physical structure of pervious concrete and conventional concrete.



*Figure 1.1: Laboratory sample of Pervious and Conventional Concrete cylinder*

## **1.2 Historical Background**

Pervious Concrete is a relatively new concept for developing nations like India. However, the earliest known application of zero-fines concrete occurred in England in 1852 with the construction of two residential houses and a sea groyne 61m long and 2.15m wide (Francis 1965). It became very useful in Europe after the World War II due to the scarcity of cement for applications such as cast-in-place load bearing walls of single and multi-storey buildings (Monahan 1981). It gained popularity in the US in early 1970s. In India it became popular in 2000.

In the recent years, the researchers are focusing on sustainable construction designs to reduce the strain on our environment for the well-being of the society. Thus, the concept of no-fines concrete for pavement applications is gaining popularity. The use of pervious concrete has been named as one of the Best Management Practices (BMP) of the Environmental Protection Agency (EPA) (Joung 2008) as it has the ability to reduce the surface runoff by capturing the rain water and remove trace pollutants. Pervious Cement Concrete Pavement has been put into use by a number of states like Illinois, Utah, Florida and California. Currently, full-depth Portland Cement Pervious Concrete is used in the United States for parking lots, pathways, and, in some cases, low-volume roads for storm water applications (Tennis et al. 2004).

## **1.3 General Engineering Properties of Pervious Concrete**

The physical properties of the materials to be used and the pervious concrete as a whole should be properly studied as they contribute to the strength, void ratio and other important properties. Thus, the assessment and complete understanding of these properties is essential to make a choice for the most appropriate application.

### **1.3.1 Structure**

The structure of no-fines concrete varies significantly from conventional concrete in the sense that a small fillet of cement paste holds the materials together. The no-fines concrete has an open structure with a high void ratio. The strength relies on the bonding of aggregate with the cement paste. The use of sand is totally eliminated to ensure that the mix has a high permeability.

### **1.3.2 Shape**

The shape of the particles should be such that they produce the greatest number of bonding points, so, we can say that the ideal shape of the particles to be used for pervious concrete should be spherical. Flaky or elongated particles should be avoided.

### **1.3.3 Mix Proportions**

The mix proportions for pervious concrete vary according to its applications. In buildings, a leaner mix with high void ratio is required to prevent capillary transport of water, so the aggregate-cement ratio generally ranges from 6:1 to 10:1. However, in pavement applications the aggregate-cement ratio is kept as low as 4:1 to achieve higher bond strength to withstand heavy loads (Harber, P. 2005).

### **1.3.4 Water Content**

The water content must be adequate to ensure a proper bond between the cement paste and the aggregate. It varies as 0.27 to 0.43 by mass of cement as per the guidelines of NRMCA. If water content is less than the optimum then cement paste will not form sufficient bond with the aggregates. However, if the water content is higher than the optimum then it will cause the cement paste to run off the aggregate particles.

### **1.3.5 Aggregate Grading**

A single sized aggregate is generally used for making pervious concrete. The aggregate usually ranges from 10mm to 20mm. A large number of small size aggregates should be avoided as they tend to fill up the void spaces reducing permeability.

### **1.3.6 Density**

The density of pervious concrete is dependent upon the void content in the concrete. In place densities of the order of 1600 kg/m<sup>3</sup> to 2000 kg/m<sup>3</sup> are common, which is in the upper range of light weight concrete. This density of pervious concrete depends on the shape, size and density of the aggregate and the aggregate-cement-water ratio and on the compaction procedures used in placement (Tennis et al. 2004).

### **1.3.7 Permeability**

The flow rate through pervious concrete depends on the materials and placing operations. The typical flow rates for water through pervious concrete are 0.2cm/s to 0.54cm/s. However, rates up to 1.2cm/s and higher have been obtained in laboratory (Crouch 2004).

### **1.3.8 Compressive Strength**

The compressive strength of pervious concrete varies from 3.5MPa to 28MPa which is suitable for a wide range of applications. Typical values are about 17MPa. It depends upon the properties of the materials and the mix proportions used and also the compaction and placement techniques adopted in the field (Tennis et al. 2004).

### **1.3.9 Flexural Strength**

The flexural strength of pervious concrete varies from 1MPa to 4MPa. It will particularly depend on the aggregate-cement-water ratio, porosity and the degree of compaction (Tennis et al. 2004).

## **1.4 Fiber Reinforced Concrete**

Concrete is one of the most widely accepted construction material due to its large number of applications. The primary aim of an engineer is to make full use of its compressive strength as concrete is very strong when subjected to compressive forces but is very weak in tension. Steel reinforcement in the form of iron rods has been used in conventional concrete for building purposes since the ancient times to improve the behaviour of concrete in tension. These days the steel reinforcement is also used in concrete pavements which transfer the load by beam action.

Generally, reinforcing bars are only used at locations required. Due to the presence of steel bars large form sections, especially for columns, are required for building works. Shrinkage of steel bars can cause crack development and thus loss of strength. Owing to the above mentioned issues, the architects and engineers nowadays prefer the use of fibers as they distribute throughout the cross-section. If used in proper dosages and sizes, they also help to resist cracking of concrete and control shrinkage. Pervious Concrete or zero-slump concrete, however, is a special type of concrete which was initially used in buildings. But these days, pervious concrete

has some useful applications in low volume traffic roads, parking lots, sideways/pathways etc. The introduction of steel fibers leads to an increase in compressive strength, flexural strength and splitting tensile strength of concrete. The addition of 3D, 4D and 5D-hooked end steel fibers to the reference mix showed a pattern of increase in compressive strength and flexural strength of concrete due to increasing number of hooks at the ends without showing a significant change in porosity and permeability (Tan et al. 2015).

## **1.5 Pervious Concrete Pavement Construction, Inspection and Maintenance**

This section includes brief details on the construction and maintenance of pervious concrete. Pervious concrete pavement differs considerably from a conventional rigid pavement in its hydrological design, the materials used for its construction and maintenance techniques. The various steps involved in its construction are as follows:

### **1.5.1 Preparation of Subgrade and Sub-base:**

The very first and the most important step in the design of any pavement is the availability of a sound subgrade with a granular or cement treated sub-base. However, the installation of a pervious concrete pavement requires a subgrade of uniform character and free from expansive soils. The top 150mm of subgrade shall be made of a free draining granular material with little or no amounts of silt and clay. The subgrade should have a minimum percolation rate of 2.5mm/hour as prescribed by the guidelines of Stoney Creek Materials, L.L.C. for no-fines pavement. The subgrade shall be in a moist state before the placement of sub-base to achieve proper strength and durability. In the absence of a gravelly material for the preparation of subgrade, non-woven geotextile fabric shall be introduced to prevent the solids from rising up in the pavement and separate the sub-base layer from subgrade.

The aggregate to be used for the preparation of sub-base shall be clean and free from fines. The thickness of sub-base generally ranges from 100mm to 250mm depending upon the traffic and water retention requirements. The sub-base should have voids in the range of 20% to 40%. No. 57 stone (3/4 inch) is the most widely used aggregate for the construction of pervious concrete sub-base.

### **1.5.2 Batching, Mixing & Transportation of Pervious Concrete:**

This is a very important phase in the preparation of porous concrete. The water content is usually managed so that it maintains a zero slump. The water content shall be properly monitored because absorption of water by the aggregates and supply of excessive moisture by aggregates will significantly affect the strength characteristics of no-fines concrete. The equipments used for mixing are same as those for conventional concrete. However, the mixing time shall neither be too small nor should it be too large. Admixtures may also be used to improve the strength and reduce water cement ratio. Pumping of no-fines concrete to the site is not possible as the mixes produced are certainly stiff. Special attention should be given to the transportation and placement of pervious concrete mixes as it has low water content and slump. The transit mixers should have large openings for faster rate of discharge of porous concrete mix. The pervious concrete mixes should be discharged fully within 60 minutes after initial mixing. Hydration stabilizers or chemical admixtures may be used for increasing the discharge time to 90 minutes or even more.

### **1.5.3 Placement, Consolidation & Finishing of Pervious Concrete Pavement:**

The placement technique for pervious concrete depends on the site under consideration. Before placing, the sub-base and forms should be checked for rutting, irregularities and misalignment, if any. Placement should be continuous, and spreading and strike-off should be rapid (See Figure 1.2). Vibrating screeds are generally preferred because manual screeds can cause tears in the surface if the mixture is very stiff. The frequency of vibrating screed shall be carefully controlled to avoid over-compaction which may block the voids and significantly affect permeability. For pavements, it is recommended to strike off about 15mm to 20mm above the forms to allow for compaction. It can be obtained (Paine 1992) by attaching a temporary wood strip above the top form to achieve the required height. After strike-off, the strips are removed and the concrete is consolidated to the height of the form. Edges near forms are compacted using a 300mm by 300mm steel tamp, a float, or other similar device to prevent raveling of the edges. Vibratory plate compactors and rollers are used to compact the surface of a pervious concrete pavement. Longitudinal rolling is considered better than cross rolling as it gives better compacting effort. The consolidation should be finished within 15 minutes of the placement. The finishing step for pervious concrete pavement is compaction as it gives a rougher surface and better traction.

Figure 1.2, Figure 1.3 and Figure 1.4 show the different techniques involved in the process of placing, finishing and compacting the slab of a pervious concrete pavement.



*Figure 1.2: Pervious Concrete is placed and finished with a vibrating screed  
(Image Source: Tennis et al. 2004)*



*Figure 1.3: Compaction by steel roller  
(Image Source: Tennis et al. 2004)*



*Figure 1.4: Compaction by longitudinal roller (Image Source: Tennis et al. 2004)*

#### **1.5.4 Joint Placement:**

Joints are installed in pervious concrete pavements to control shrinkage. The recommended joint spacing is 6m (GCPA 1997). Some installations have had joint spacing of 13.5m or higher without uncontrolled cracking (Paine 1992). The joints are provided at a depth of one-fourth of slab thickness. The joints are installed soon after the construction with a roller joint tool commonly referred to as a pizza cutter as shown below in Figure 1.5.



*Figure 1.5: Roller joint tool (Image Source: Tennis et al. 2004)*

### **1.5.5 Curing & Protection of Pervious Concrete Pavements:**

Due to open graded structure, more surface area of the cement paste is exposed to evaporation, thus increasing water loss due to shrinkage. Retarders may also be used to prevent surface water loss. Since the pervious concrete mix is relatively stiff, thus it is highly susceptible to plastic shrinkage cracking. The curing process begins even before the placing of concrete. The subgrade shall be properly moistened so that it does not absorb moisture from concrete. Once the slab is laid, fog misting followed by plastic sheeting is the recommended procedure for curing as shown in Figure 1.6. The sheet shall remain in place for atleast seven days. Use of sand or dirt shall be avoided to hold the sheets in position as it may clog the voids due to spilling. Rebar and stakes can be placed over the sheeting to hold it in position. Curing shall begin soon after placing, compacting and jointing. The maximum time recommended to begin curing is 20 minutes after the completion of above processes.



*Figure 1.6: Plastic sheeting to cover Pervious Concrete (Image Source: Tennis et al. 2004)*

### **1.5.6 Opening to traffic:**

The pavements shall not be opened to traffic for seven days after it is installed. During this period, continuous curing shall be done to prevent the rapid evaporation of water from cement paste due to its open matrix.

### **1.5.7 Inspection:**

Unlike conventional concrete, slump and compaction tests are not the general practice to assess the quality of pervious concrete pavements. Instead, a unit weight test assures the quality of pervious concrete. For this, core samples should be taken (as per ASTM C42) after seven days and tested for thickness and unit weight. No core shall be less than 13mm than the design thickness.

### **1.5.8 Maintenance:**

The pervious concrete pavements do not require maintenance like traditional concrete roads. The primary concern is the prevention of clogging of voids. Before preparing the site for construction, drainage features of neighbouring landscapes should be analyzed and facility should be designed to prevent the flow of materials on the pavement surface. Soil, leaves and debris may seep along with water and decrease the usefulness of pavement. Local materials such as topsoil and sand should not be loaded on pervious pavements, even temporarily, as they will clog the voids. Pressure washing is a common practice to restore the permeability in some cases. Vacuuming can be done periodically to remove debris from the pavement surface. However, the maintenance practices for porous concrete are still being developed.

## **1.6 Applications of Pervious Concrete in India**

Currently, India is facing a lot of problems related to the fall of ground water table due to a reduction in the recharge of rainwater in the subsoil and also due to improper techniques used for agriculture and unplanned pumping in industries. Further increasing urbanization has increased the risk of floods in many metro cities. For example, floods faced in Mumbai are perfect example of how pervious concrete can be utilized. A few years ago, Mumbai faced its worst floods ever which not only handicapped the city but also killed many. As the scope of urban cities will increase, pervious concrete can provide a solution to this rapid growth of cities.

The use of no-fines concrete for the construction of parking lots, low volume traffic roads and walkways can improve the situation by recharging the groundwater. It can also become a part of the rain water harvesting schemes adopted in India.

Pervious Concrete can also be used in the rural areas by replacing the impervious surfaces such as driveways, sidewalks and parking lots etc. The water falling on impervious surfaces is not soaked into the soil which creates an imbalance in the natural ecosystem and causes problems such as erosion, floods, ground water level depletion and pollution of rivers. Pervious Concrete can thus prove beneficial as it captures the rain water in a network of voids and allows it to percolate into the underlying soil.

### **1.7 Advantages of Pervious Concrete:**

- 1) Decreases flooding possibilities, especially in urban areas.
- 2) Recharging the groundwater level.
- 3) Reducing puddles on the road.
- 4) Improving water quality through percolation.
- 5) Sound absorption
- 6) Reduction of surface temperature.
- 7) Supporting vegetation growth.
- 9) Reduce temperature.
- 10) Glaring of road pavement can be eliminate.

### **1.8 Disadvantages of Pervious Concrete:**

- 1) Many engineers and contractors lack expertise with pervious concrete technology.
- 2) Low strength due to high porosity.
- 3) High maintenance requirement.
- 4) Limited use as a load bearing unit due to its low strength.
- 5) Some building codes may not allow for its installation due to its low strength and consequently higher probability of failure.

### **1.9 Aims & Objectives**

The use of no-fines concrete has generally been limited to non-pavement applications with a very little use in pavement applications due to low flexural strength. The main purpose of this project is to develop a pervious concrete with a minimum compressive strength of 20MPa and a minimum flexural strength of 3.0MPa so that it can be suitably used for low volume traffic roads

and pathways. This study will include the analysis of the current literature and performing some standard tests on pervious concrete using steel fibers in order to evaluate its properties. The steel fibers used are Double Hooked End (Aspect Ratio: 67) and Round Crimped (Aspect Ratio: 50).

In order to achieve these aims, the following objectives had to be met:

- i. Study of literature and the research work available on the use of no-fines concrete for pavement as well as non-pavement applications.
- ii. Initial mix design tests with different water/aggregate/cement ratios to achieve a control mix (0% fiber) satisfying compressive and flexural strength requirements.
- iii. Experimental investigations to evaluate the mechanical properties, durability and permeability of zero-fines concrete doped with steel fibers, and;
- iv. To study the effect of different shapes i.e. crimped and hooked end (4-D) and proportions (1%, 1.5% and 2%) of steel fibers on the mechanical properties of pervious concrete.

## **1.10 Dissertation Overview**

This research has the following structure:

- Chapter 1 gives an introduction and a discussion on the construction and maintenance of pervious concrete and the objectives of this study.
- Chapter 2 provides an insight on the relevant literature needed to conduct this research.
- Chapter 3 covers the details on the various materials used and explains the tests adopted with some preliminary results to carry out this research.
- Chapter 4 explores the detailed test results and achievement of the objectives.
- Chapter 5 discusses if the test results are in acceptance with objectives set initially. Conclusions are made and future scope of work is discussed.
- Appendix – I gives the recommended structural and hydrological design procedure for the pervious concrete pavements.

## **2.1 Introduction**

The study of literature on this topic revealed that there is limited information available on the development and use of pervious concrete in pavement applications. Further, though considerable research has been done on pervious concrete with different fibers like cellulose and poly propylene split fibers but very little guidance is available for the use of steel fibers in pervious concrete. The following sections relate to the properties of no-fines concrete that have already been investigated.

## **2.2 Literature Review on Pervious Concrete**

In Europe, no-fines concrete has been used in the construction industry for approximately 150 years. The earliest known application of zero-fines concrete occurred in England in 1852 with the construction of two residential houses and a sea groyne (Francis 1965). Gap graded concrete became very useful in Europe after the World War II when sufficient number of housing blocks could not be prepared due to the scarcity of cement. The use of pervious concrete was not promoted in USA due to the sufficient amount of building material available for construction. Initially, the use of zero-fines concrete was limited only to building works but these days it is mostly preferred for pavement purposes such as parking lots and low volume traffic loads.

**Wang et al (2006)** evaluated the strength, porosity, permeability and freeze-thaw durability of Portland Cement Pervious Concrete (PCPC) mixes when made with different types and quantities of cementitious materials, aggregates, fibers and chemical admixtures. The test results indicated that the PCPC mixtures made with single-sized aggregates have low strength but high permeability. Incorporation of sand by approximately 7% by weight of total aggregates to the mixes enhanced the strength and freeze-thaw resistance while maintaining the necessary permeability. It was also observed that addition of small amount of fibers improved the strength and freeze-thaw resistance while maintaining adequate permeability needed for the design of pervious concrete.

**Alaica et al (2010)** focused on developing an optimal mix with suitable tensile strength and porosity from different pervious concrete mixtures. Out of the three different crushed limestone aggregate sizes namely 9mm-13mm, 13mm-16mm, 16mm-19mm, the desired mix was achieved using 10mm-13mm with an aggregate to cement ratio of 4 and a ternary blend of slag and silica fume. The study of failure plane revealed that the splitting failure occurs along the paste but not through the aggregates. The use of Wollastonite natural fibres and polypropylene macro-fibres resulted in improved paste strength. The permeability was evaluated by modifying the ACI522R test procedure for pervious concrete. It was observed that permeability decreases with decrease in aggregate size and addition of supplementary cementitious materials.

**Maguesvari and Narasimha (2013)** studied the influence of different sizes of aggregates on the properties of pervious concrete. The different sizes of coarse aggregates used were 4.75mm to 9mm, 9mm to 12.5mm, 12.5mm to 16mm, 16mm to 19.5mm. The fine aggregate corresponded to grading II and the cement used was OPC Type I. The cement-aggregate ratio was 1:4.75, the water cement ratio was kept as 0.34 and the replacement of fine aggregate with coarse aggregate was in the range of 50-100% by weight. Different mechanical properties like compressive strength, flexural strength and splitting tensile strength were evaluated. The compressive strength varied between 10 N/m<sup>2</sup> to 26 N/m<sup>2</sup> depending on the mix proportion. Falling head permeability method was used to evaluate the co-efficient of permeability. The permeability values varied from 0.4cm/sec to 1.26cm/sec and increased with increase in aggregate size.

**Shah and Pitroda (2014)** investigated the Flexural Strength and Compressive Strength of pervious concrete. The various cement-aggregate ratios used were 1:6, 1:8 and 1:10. Two different sizes of gravel such as 18.75mm and 9.375mm with OPC 53 Grade and PPC 53 Grade cement were used to check these two parameters of gap-graded concrete. Table 2.1 shows the physical properties of OPC 53 grade and PPC 53 grade cement. The compressive strength test will be carried out on the pervious concrete cubes of size 150mm×150mm×150mm according to IS:516-1959 at the end of 7 days, 14 days and 28 days of curing. The test results for OPC 53 are shown in Table 2.2 whereas the test results for PPC 53 are shown in Table 2.3. The tabular results are further illustrated in the form of graphs as shown in Figure 2.1 and Figure 2.2 for OPC 53 & PPC 53 grade cement respectively.

Table 2.1: Physical Properties of OPC 53 grade and PPC 53 grade cement

Property	Value for cement for OPC	Value for cement for PPC	IS Code Recommendations IS:12269 – 1987
Specific gravity	3.15	2.93	3.10 – 3.15
Consistency (%)	28%	31.5%	30 – 35%
Initial setting time (min)	35 minutes	35 minutes	30 minutes (minimum)
Final setting time (min)	178 minutes	230 minutes	600 minutes (maximum)
Compressive strength at 7 days (N/mm <sup>2</sup> )	38.49 N/mm <sup>2</sup>	38.49 N/mm <sup>2</sup>	43 N/mm <sup>2</sup>
Compressive strength at 28 days (N/mm <sup>2</sup> )	52.31 N/mm <sup>2</sup>	51 N/mm <sup>2</sup>	53 N/mm <sup>2</sup>

Table 2.2: Compressive strength test (N/mm<sup>2</sup>) on cubes with OPC 53 grade cement

Sizes of gravel	Concrete mix	7 Days	14 Days	28 Days
A (18.75 mm)	A1(1:6)	3.91	5.27	5.96
	A2(1:8)	3.78	4.10	4.33
	A3(1:10)	2.55	3.00	3.45
B (9.375 mm)	B1(1:6)	9.44	11.36	12.71
	B2(1:8)	6.02	8.34	9.29
	B3(1:10)	3.44	5.06	6.49

Table 2.3: Compressive strength test (N/mm<sup>2</sup>) on cubes with PPC 53 grade cement

Sizes of gravel	Concrete mix	7 Days	14 Days	28 Days
A (18.75 mm)	A1(1:6)	3.87	5.21	5.92
	A2(1:8)	3.72	4.06	4.28
	A3(1:10)	2.51	2.96	3.41
B (9.375 mm)	B1(1:6)	9.41	11.29	12.68
	B2(1:8)	5.99	8.29	9.26
	B3(1:10)	3.41	5.03	6.47

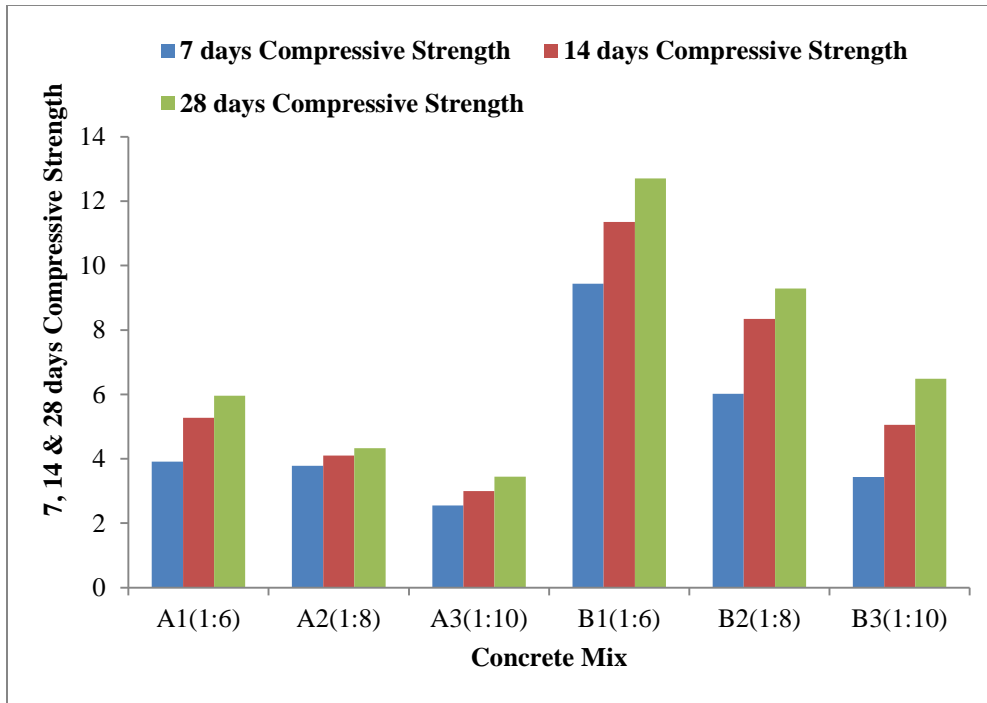


Figure 2.1: Concrete mix v/s compressive strength (N/mm<sup>2</sup>) of Pervious Concrete with OPC 53 at the end of 7, 14 & 28 days

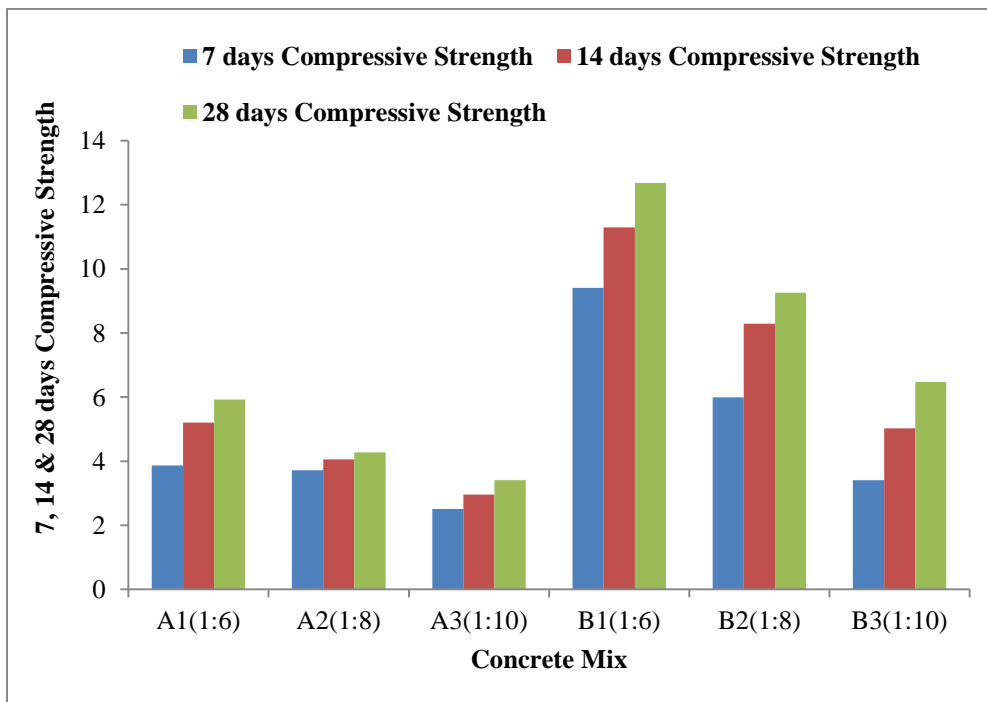


Figure 2.2: Concrete mix v/s compressive strength (N/mm<sup>2</sup>) of Pervious Concrete with PPC 53 at the end of 7, 14 & 28 Days

Flexural Strength test was carried out on beams of size 100mm × 100mm × 500mm according to IS:516-1959 at regular intervals of 7, 14 and 28 days. In this test pervious concrete beam is loaded with one-point loading (central point loading) method at the midpoints of the beam. Equal loads are applied at the distance of one-half from both of the beam supports. It induces equal reaction same as the loading at both of the supports. The test results for OPC 53 are shown in Table 2.4 whereas the test results for PPC 53 are shown in Table 2.5. The tabular results are further illustrated in the form of graphs as shown in Figure 2.3 and Figure 2.4 for OPC 53 & PPC 53 grade cement respectively.

Table 2.4: Flexural strength test ( $N/mm^2$ ) on beams with OPC 53 grade cement

Sizes of Gravel	Concrete mix	7 Days	14 Days	28 Days
A (18.75 mm)	A1(1:6)	1.44	1.56	1.85
	A2(1:8)	1.04	1.12	1.32
	A3(1:10)	0.83	0.96	1.14
B (9.375 mm)	B1(1:6)	1.54	1.66	1.91
	B2(1:8)	1.38	1.52	1.65
	B3(1:10)	1.28	1.38	1.46

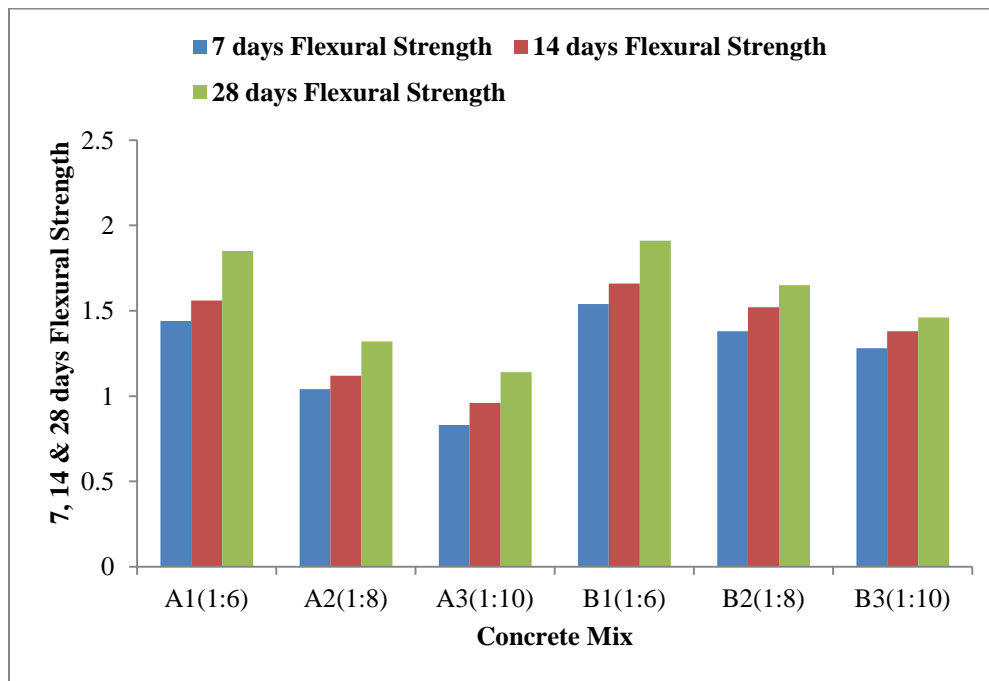


Figure 2.3: Concrete mix v/s flexural strength ( $N/mm^2$ ) of Pervious Concrete with OPC 53 at the end of 7, 14 & 28 Days

Table 2.5: Flexural strength test ( $N/mm^2$ ) on beams with PPC 53 grade cement

Sizes of Gravel	Concrete mix	7 Days	14 Days	28 Days
A (18.75 mm)	A1(1:6)	1.30	1.42	1.73
	A2(1:8)	1.00	1.06	1.24
	A3(1:10)	0.77	0.79	1.04
B (9.375 mm)	B1(1:6)	1.38	1.54	1.77
	B2(1:8)	1.22	1.40	1.53
	B3(1:10)	1.14	1.22	1.36

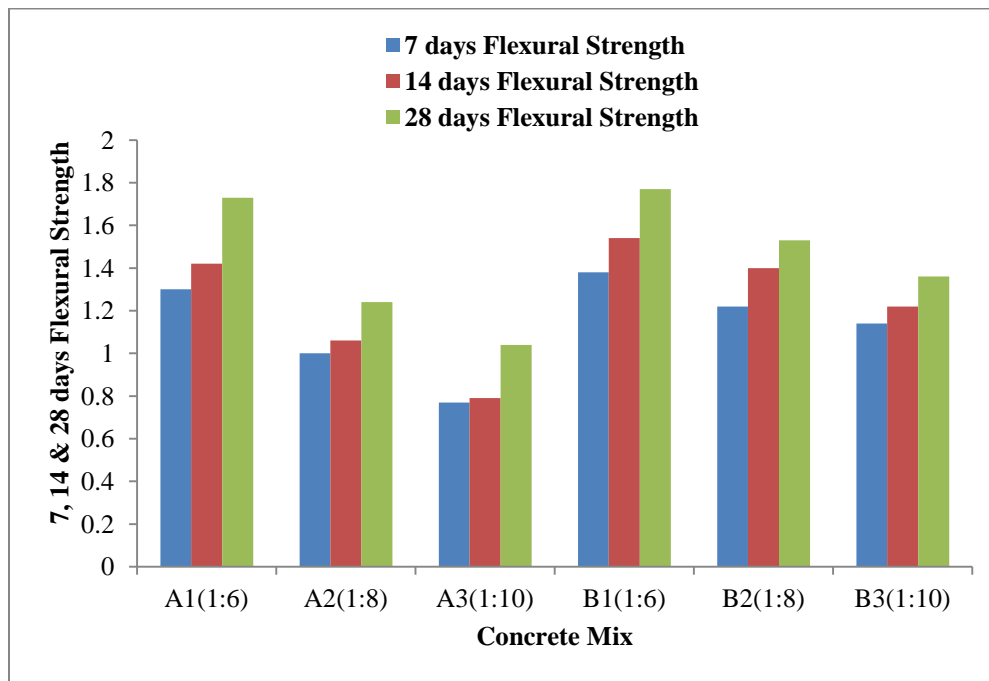


Figure 2.4: Concrete mix v/s flexural strength ( $N/mm^2$ ) of Pervious Concrete with PPC 53 at the end of 7, 14 & 28 Days

The test results showed that the smaller size of gravel, i.e., 9.375mm has more Flexural Strength ( $1.91 N/mm^2$ ) and Compressive Strength ( $12.71 N/mm^2$ ) with concrete mix proportion of 1:6 and for OPC 53 Grade cement.

**Shah and Pitroda (2014)** established that there exists an inverse relationship between water absorption and durability of pervious concrete. To investigate these two properties, cylinders of 100mm diameter and 200mm height were prepared.

The various cement-aggregate ratios used were 1:6, 1:8 and 1:10. Two different sizes of gravel such as 18.75mm and 9.375mm with OPC 53 Grade and PPC 53 Grade cement were used to check these two parameters of gap-graded concrete. Table 2.6 shows the physical properties of OPC 53 grade and PPC 53 grade cement.

*Table 2.6: Physical Properties of OPC 53 grade and PPC 53 grade cement*

<b>Property</b>	<b>Value for cement for OPC</b>	<b>Value for cement for PPC</b>	<b>IS Code Recommendations IS:12269 – 1987</b>
Specific gravity	3.15	2.93	3.10 – 3.15
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Compressive strength at 7 days (N/mm <sup>2</sup> )	38.49 N/mm <sup>2</sup>	38.49 N/mm <sup>2</sup>	43 N/mm <sup>2</sup>
Compressive strength at 28 days (N/mm <sup>2</sup> )	52.31 N/mm <sup>2</sup>	51 N/mm <sup>2</sup>	53 N/mm <sup>2</sup>

The water absorption test was conducted on cylindrical samples after 28 days of curing in water and durability test was conducted by immersing the specimen for 28 days in Sodium Chloride solution (NaCl) after 28 days of curing in water. The results obtained from water absorption test

for OPC 53 and PPC 53 is shown in Table 2.7 and Table 2.8. These test results are further represented graphically in Figure 2.5.

*Table 2.7: Water absorption test results for cylinder with OPC 53*

<b>Sizes of gravel</b>	<b>Concrete mix</b>	<b>28 days average % of water absorption</b>
A (18.75mm)	A1 (1:6)	0.65
	A2 (1:8)	0.92
	A3 (1:10)	1.08
B (9.375mm)	B1 (1:6)	0.29
	B2 (1:8)	0.55
	B3 (1:10)	0.68

*Table 2.8: Water absorption test results for cylinder with PPC 53*

<b>Sizes of gravel</b>	<b>Concrete mix</b>	<b>28 days average % of water absorption</b>
A (18.75mm)	A1 (1:6)	0.55
	A2 (1:8)	0.88
	A3 (1:10)	1.04
B (9.375mm)	B1 (1:6)	0.25
	B2 (1:8)	0.48
	B3 (1:10)	0.56

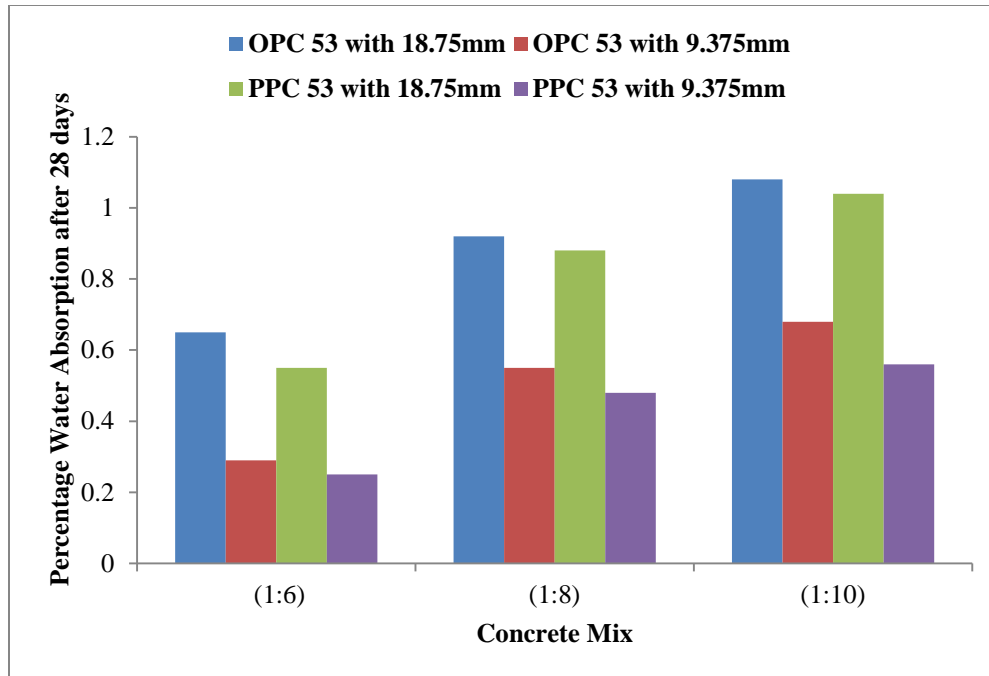


Figure 2.5: Water absorption test results for cylinders with OPC 53 and PPC 53

The test results obtained from Figure 2.5 show that pervious concrete with 1:10 concrete mix has more water absorption, i.e., water absorption increases with increase in concrete mix. The results obtained from the durability test are tabulated in Table 2.9 and Table 2.10 and the same has been graphically represented in Figure 2.6. It can be clearly seen that the durability is decreasing with increase in mix proportion. The pervious concrete with 1:10 concrete mix has the least durability.

Table 2.9: Durability test results for cylinder with OPC 53

Sizes of gravel	Concrete mix	28 days average % of durability
A (18.75mm)	A1 (1:6)	0.34
	A2 (1:8)	0.30
	A3 (1:10)	0.26
B (9.375mm)	B1 (1:6)	0.36
	B2 (1:8)	0.34
	B3 (1:10)	0.32

Table 2.10: Durability test results for cylinder with PPC 53

Sizes of gravel	Concrete mix	28 days average % of durability
A (18.75mm)	A1 (1:6)	0.30
	A2 (1:8)	0.26
	A3 (1:10)	0.25
B (9.375mm)	B1 (1:6)	0.32
	B2 (1:8)	0.29
	B3 (1:10)	0.27

The test results showed that the mix ratio of 1:6 had more durability and less water absorption and pervious concrete with a mix ratio of 1:10 had more water absorption and less durability. Thus it can be quoted that water absorption and durability are inversely proportional to one another.

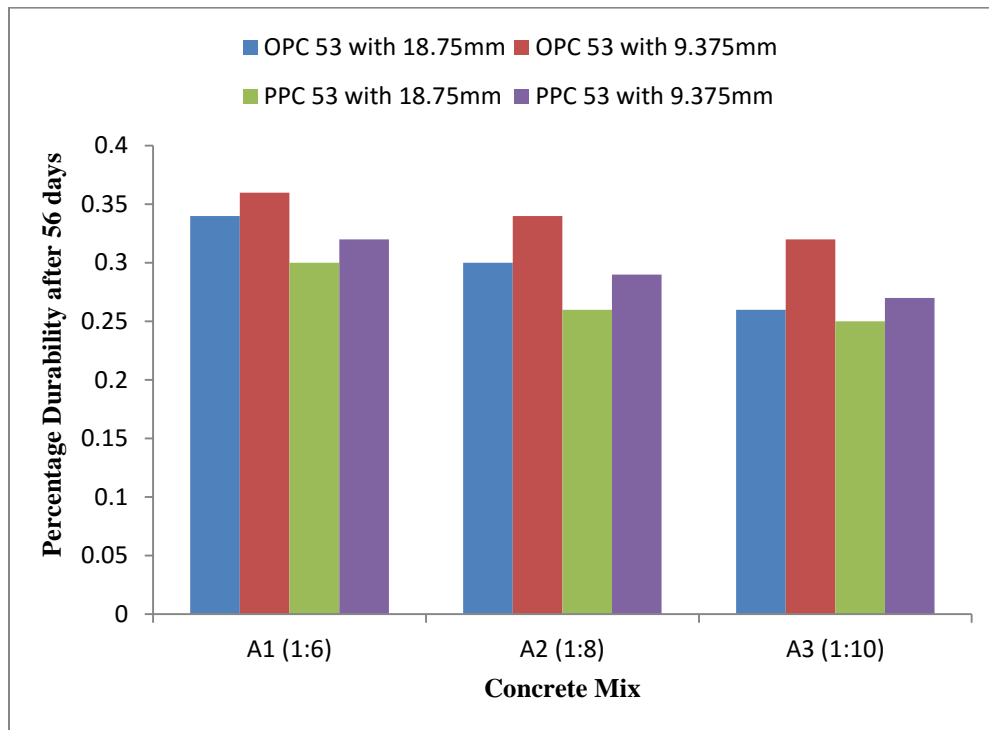


Figure 2.6: Durability test results for cylinders with OPC 53 and PPC 53

After studying the graphs plotted in Figure 2.5 and Figure 2.6, one main result is found out, i.e., water absorption and durability are inversely proportional to each other.

**Abite et al (2014)** investigated the structural integrity of a Pervious Concrete Pavement (PCP) when subjected to traffic loads using a Falling Weight Deflectometer (FWD). The average unit weight of the cored samples obtained from the field installation was  $1,792\text{kg/m}^3$  with a compressive strength of  $11.5\text{MPa}$ . Depending upon the characteristics of sub-base, the PCP sections showed a deflection of about 1.7 to 4 times than the impervious concrete sections at the point of application of load. Back-calculation analysis showed that the sub-base layers which were loosely compacted had lower elastic modulus and higher deflection which leads to a PCP section with poor structural integrity when subjected to traffic loading.

**Arhin and Madhi (2014)** conducted tests on five design mixes of pervious concrete using three different methods of compaction, i.e., self-consolidating, half rodding and standard proctor hammer to establish a mix of appropriate flexural strength with an acceptable rate of permeability for the District of Columbia. The mix consisted of 200 lbs. of #8 Stone (Millville), little to no fine aggregates, cement type I-II, and macro/micro fibers. Certain admixtures like Viscosity Modifying Agent (VMA), an air-entraining agent and High Range Water Reducers (HRWR) were used to potentially improve the bond between the cement and the coarse aggregate, and to improve workability as well as flexural properties of the pervious concrete. A retarder was also included since the low water content of porous concrete pavement mixes causes them to dry quickly. The sand content was varied for all mixes. The optimum mix had a coefficient of permeability of 57.80 inches per hour ( $0.0407\text{cm/sec}$ ) and a compressive strength of 3500 pounds per square inch ( $24.13\text{MPa}$ ) and a modulus of rupture of 565psi ( $3.89\text{MPa}$ ). After the installation of the optimal mix at three different locations in the District of Columbia, the in-situ infiltration tests yielded average infiltration rates between 86.1 inches per hour ( $0.0607\text{cm/sec}$ ) to 208.7 inches per hour ( $0.147\text{cm/sec}$ ).

**Ketcheson et al (2014)** examined the impact of sodium chloride and sand on the movement of chlorides and water in pervious concrete under frozen and thawed conditions. In order to simulate the cold-climatic urban environment in lab, brine solution (23% salt solution), fresh

water and varying sand additions were used. Performance testing was conducted via infiltration capacity. The transportation of chloride was rapid through pervious concrete under all experimental conditions. It was analyzed that the freezing of pore water within the matrix reduced the water and salt passage through pervious concrete slab. Further, the application of sand delayed the peak flow and reduced the movement of water through pores. From the considerations of groundwater management, the test data also indicated that ground water may be contaminated by chlorides if the pervious concrete structures are used in areas vulnerable to salts and groundwater recharge zones.

**Teraiya et al (2015)** carried out compressive strength, void ratio and permeability tests on pervious concrete cubes and cylinders. The average value of compressive strength was found out to be in the range of 7-12MPa and the average value of permeability was found in the range of 15-24mm/sec. Void content was nearly in the range of 20% to 29.8%. It was found that the permeability increases with the increase in void content and vice-versa whereas with the increase in permeability, the compressive strength decreases and vice-versa. Thus, it was observed that void content is directly proportional to permeability.

**Talsania et al (2015)** used Rice Husk Ash (RHA) as a partial replacement of OPC 53 Grade Cement in pervious concrete. RHA can be used to develop an eco-friendly concrete with improved strength and durability. He conducted his research study by replacing the OPC 53 Grade Cement by RHA in the range of 10% and 20% by weight of cement. The three different water/cement ratios used were 0.30, 0.35, and 0.40. Compressive strength tests were performed on compression testing machine using cube samples. Flexural strength tests were performed on testing machine using beam samples. The flexural strength and compressive strength tests were carried out at the end of 7, 14 and 28 days. The experimental results depicted that these two properties increase with increase in water/cement ratio. The highest value of compressive strength and flexural strength were reported at a w/c ratio of 0.40 and 10% replacement of cement with RHA. Thus, it was seen from the test results that the compressive strength and flexural strength increased up to 10% replacement of cement with RHA beyond which it is starting to decrease. Hence, it can be said that use of rice husk ash in pervious concrete is a possible alternative for its safe disposal.

**Tan et al (2015)** investigated the use of discrete hooked end steel fibers to enhance the flexural strength of pervious concrete without affecting the porosity and permeability significantly. The target porosity and permeability were 20 percent and 10mm/sec respectively and the flexural strength was 3.6MPa. The steel fibers were added to the reference mix in the dosages of 1 to 2.5 percentages by volume of concrete in steps of 0.5%. There were a total of 39 different mixes covering the different coarse aggregates and type and dosage of steel fibers.

The reference mixture proportion of the pervious concrete, determined from a previous study (Lim et al., 2013), consisted of cement at  $367\text{kg/m}^3$ , coarse aggregates at  $1560\text{kg/m}^3$  and water at  $110\text{kg/m}^3$ . The water-to-cement ratio was thus 0.3, and the ratio of coarse aggregate to cement content was 4.25. ASTM Type I ordinary Portland cement was used. The coarse aggregates were natural crushed granite complying with size 89 (9.5 to 1.18mm) and size 67 (19.0 to 4.75mm) of ASTM C 33-11a and having a specific gravity of 2.65, were separately used in different mixes. To improve workability and enhance the bond between the paste and aggregates, a comb polymer super-plasticizer meeting the requirements of ASTM C494 was added at a dosage of 800ml/ 100 kg of cement. The different properties of steel fibers like aspect ratio and tensile strength are summarized in Table 2.11.

*Table 2.11: Properties of steel fibers*

<b>Steel Fiber Type</b>	<b>Length (mm)</b>	<b>Diameter (mm)</b>	<b>Aspect Ratio</b>	<b>Tensile Strength (N/mm<sup>2</sup>)</b>
3D – S	30	0.50	60	1130
3D – L	60	0.75	80	1100
4D	60	0.92	65	1500
5D	65	0.92	65	2250

The samples for permeability and porosity tests had a diameter of 150mm and a height of 50mm. Concrete cubes of 100mm side dimensions were used to study the compressive strengths of the mixes; whilst prisms 100mm by 100mm in cross-section and 400mm in length, were used for the flexural tests. After casting, the samples were covered with a non-absorptive, non-reactive sheet of tough, durable impervious plastic for 24 hours, after which they were removed from the molds

and cured in a fog room for 28 days. Three samples were used in each test to obtain the average values.

The NUS constant head permeameter (Singapore Patent number 67286, 2001) was used to determine the permeability coefficient of the specimens. Porosity test was based on Archimedes principle and determined from the difference in weight between the oven-dry and water saturated submerged samples.

The Avery Denison compression and flexural machine was used to test the compressive and flexural strengths. The compressive strength test was done according to BS EN 12390-3: 2009 while the flexural strength test was done according to ASTM C78-10.

Figure 2.7 shows the results of the mixes in terms of flexural strength and permeability. Regardless of the size of coarse aggregates and fiber type, the permeability in general decreased with increasing flexural strength. It is however noted that mixes with smaller coarse aggregates and steel fibers of multiple hook ends performed better than the others.

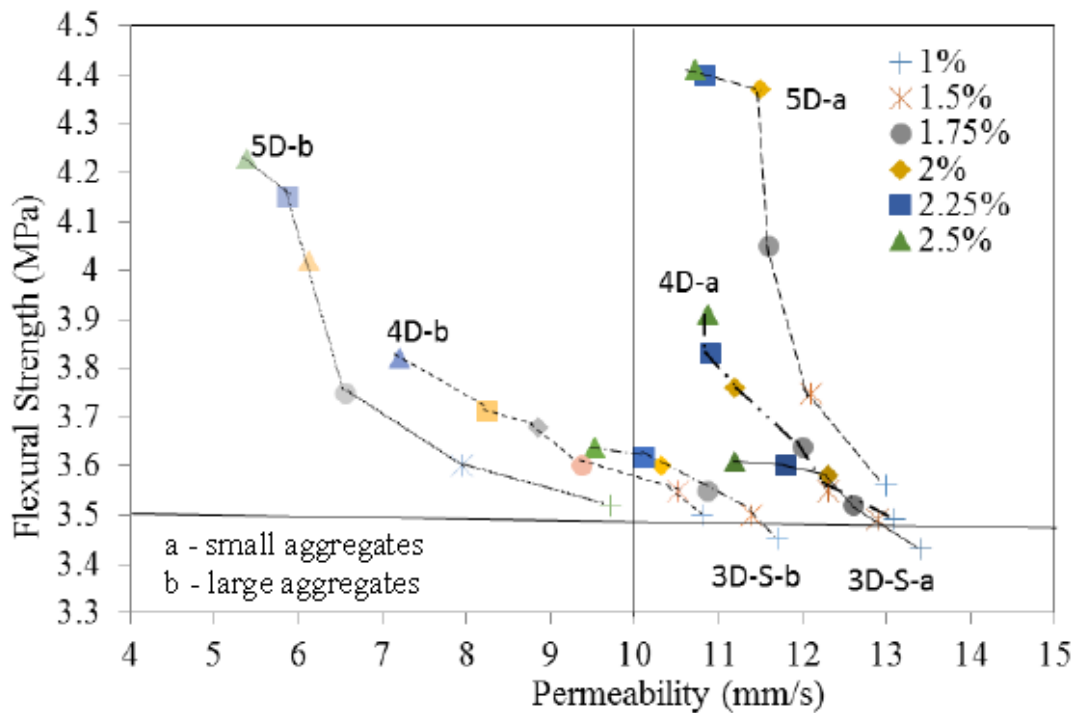


Figure 2.7: Flexural strength and permeability

The target permeability of 10mm/s and flexural strength of 3.5MPa, as recommended by AASHTO (2009) for road pavements, are also indicated in the Figure 2.7. It is seen that mixes satisfying the target performance were those using small coarse aggregates with a dosage of at least 1.5% for 3D fibers and 1% for 4D and 5D fibers. For mixes using large coarse aggregates, the mixes meeting the targets had a dosage between 1.5 and 2.25% of 3D fibers, or between 1% and 1.5% of 4D fibers.

Figure 2.8 shows the results for the compressive strength and porosity. In general, the compressive strength decreased with increasing porosity of the mix. The target porosity is 20% and compressive strength is 12MPa. These were achieved in mixes with small coarse aggregates having 3D or 4D fibers up to 2.25% or 5D fibers up to 2%. For mixes using large coarse aggregates, the target compressive strength and porosity were achieved if the fiber dosage is not more than 1.75%, 1.5% and 1%, respectively, for 3D, 4D and 5D fibers.

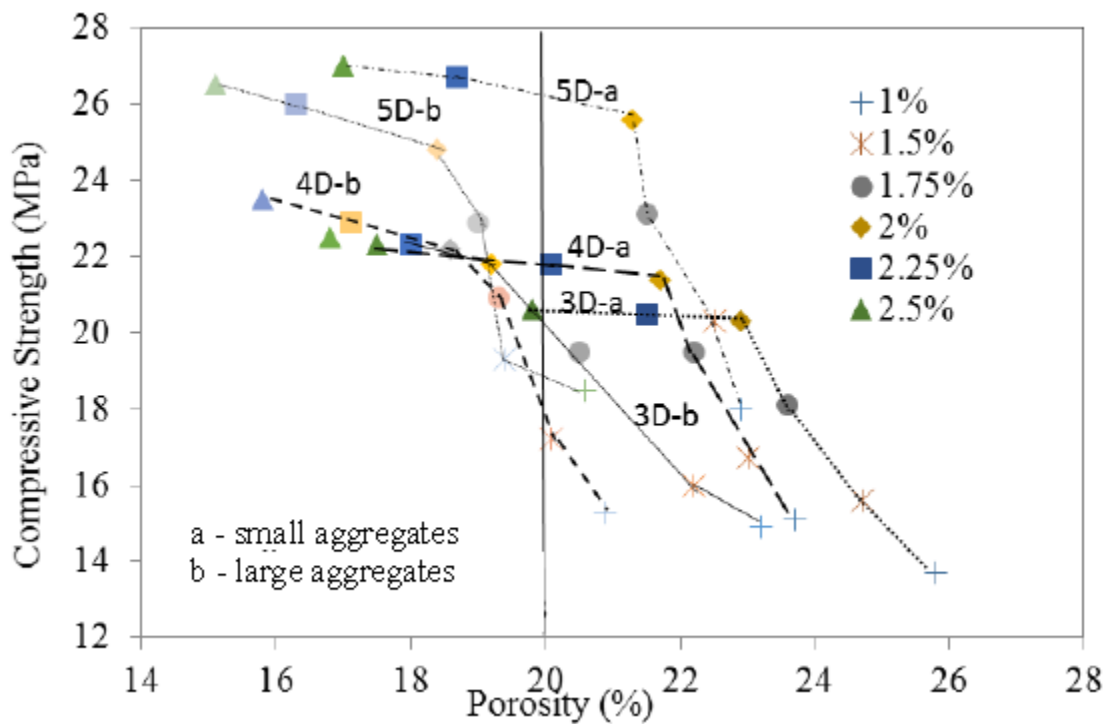


Figure 2.8: Compressive strength and porosity

The inclusion of steel fibers resulted in increasing compressive and flexural strengths without compromising the permeability and porosity. No significant difference in permeability, porosity,

compressive strength and flexural strength was observed between mixes reinforced with short or long 3D steel fibers. The use of 3D, 4D and 5D hooked end steel fibers however did not show significant differences in permeability and porosity. With increasing number of hooks at the ends of the steel fibers, the flexural and compressive strengths were found to increase due to further interlocking between the fibers and cement paste, up to fiber dosage up of 2.25%. Higher fiber content did not provide improvement in strengths, permeability and porosity, due to the balling effect and the uneven spread of the fibers. The most adequate combination was the addition of 1.5% steel fiber by volume of concrete to the reference mix.

**Gao et al (2015)** conducted compressive test, flexural test, splitting tensile test, porosity and permeability tests on pervious concrete by incorporating small amount of Polypropylene Split Fiber (PPSF). He measured the basic indexes such as flexural strength, compressive strength, splitting strength, permeability and porosity. The test results indicated that the incorporation of 3kg PPSF in 1m<sup>3</sup> of pervious concrete was best. The compressive strength, flexural strength and splitting tensile strength of pervious concrete were increased whereas the porosity and permeability were found to be decreased. He also deduced that the PPSF does not agglomerate easily like the ordinary polypropylene fiber and shows better resistance to rust unlike ordinary steel fiber.

**Shinde and Valunekar (2015)** studied the variation of compressive strength, void ratio and infiltration rate of pervious concrete with different mix proportions such as 1:5, 1:6, 1:1:5 and 1:4:5 with different gravel sizes such as 9mm and 12mm. Cubes of 150mm × 150mm × 150mm size were used to evaluate these properties. It was observed that with increase in void ratio, the infiltration rate increased but compressive strength decreased and vice-versa. The average void ratio was 14% and average compressive strength was reported as 12MPa.

### **2.3 Summary**

It can thus be concluded that the pervious concrete has building as well as pavement applications. Though, the compressive and flexural strengths of pervious concrete are lower as compared to the conventional concrete, its mechanical properties can be improved if certain admixtures, super plasticizers or fibers of suitable aspect ratio are added to it in the right dosages.

The water content is critical to form an adequate bond between the aggregates and the cement paste.

The following chapter deals in the materials and the methods adopted for preparation of no-fines concrete.

### **3.1 Introduction**

This chapter deals with the materials, their properties and test procedures adopted to design and evaluate pervious concrete. Pervious Concrete is a special type of concrete that contains coarse aggregates, Portland cement and water. The most critical property of no-fines concrete is its high permeability. Generally, a single-sized aggregate is used to form a matrix of large number of interconnected voids which results in percolation of water through it.

Pervious Concrete should have good mechanical properties like compressive strength and flexural strength so that it can be used for pavement applications as well. With an improvement in mechanical properties, the permeability is expected to decrease. Steel fibers have been used in this study to enhance these properties and to learn their effect on permeability.

### **3.2 Experimental Schedule**

An experimental schedule was developed so as to evaluate the properties of materials to be used for the preparation of concrete specimens of different sizes and shapes and to study their behaviour after casting and curing. The complete experimental schedule is shown in the flowchart in Figure 3.1. The first phase involves the evaluation of different material properties to be used for the preparation of pervious concrete as shown in Section 3.2. The test program consists of:

- 1) Determination of basic properties of constituent materials namely cement, sand, coarse aggregates and steel fibers as per relevant Indian standard specifications.
- 2) Casting of twenty one cubes (150mm × 150mm × 150mm) for compressive strength test, twenty one beams (100mm × 100mm × 500mm) for flexural strength test, twenty one cylinders (76.2mm × 127mm) for permeability test and 42 cylinders (100mm × 200mm) for water absorption and durability test.
- 3) Computation of ultimate failure load of the cube and beam specimens according to the relevant IS codes.

- 4) Computation of permeability of cylindrical specimens according to falling head permeability test and water absorption and durability test.

Figure 3.1 shows the different properties to be investigated in the experimental schedule:

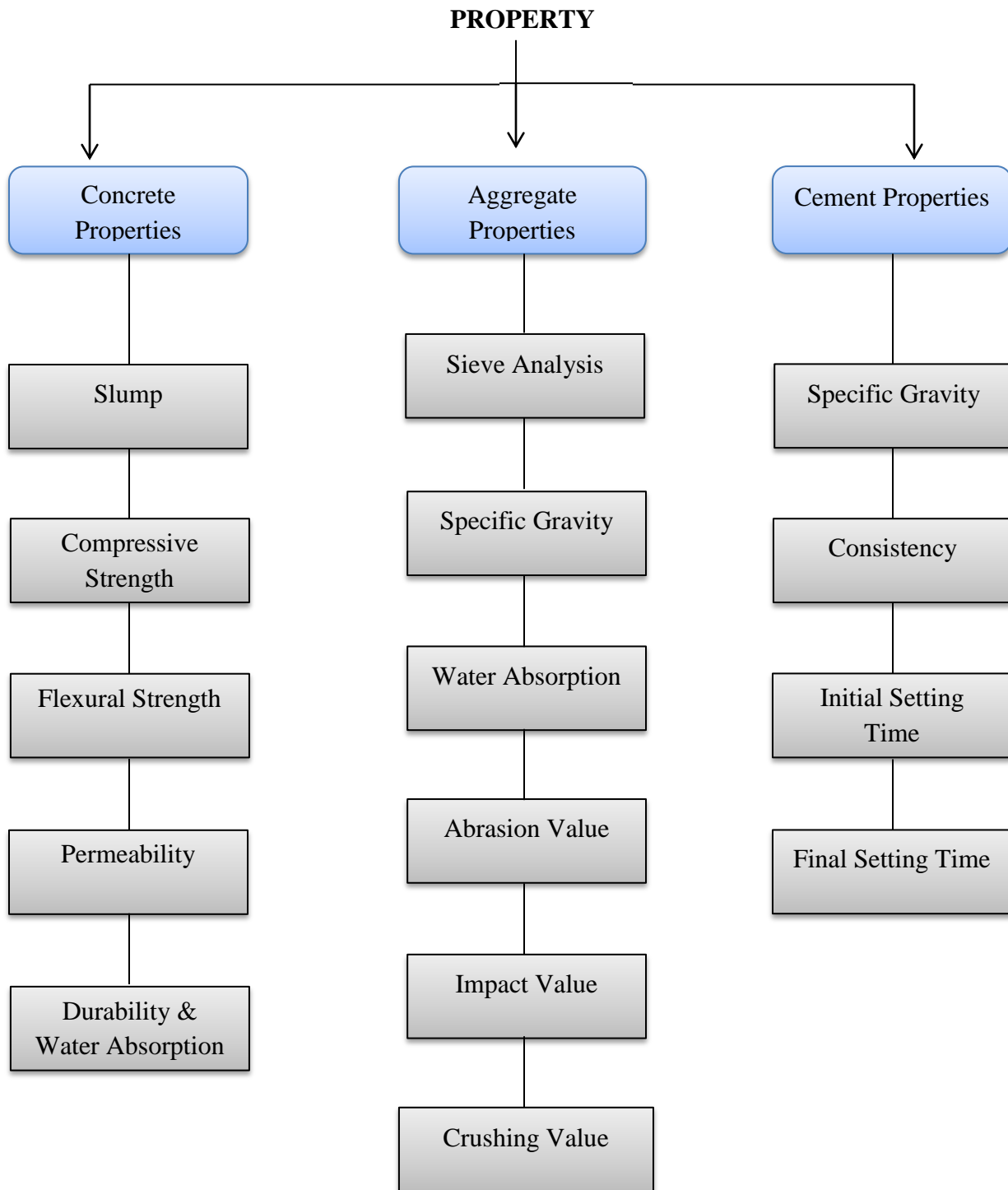


Fig. 3.1: Flowchart showing the properties to be investigated in the experimental program

### **3.3 Materials**

The properties and specifications of the materials used in this study are as follows:

#### **3.3.1 Cement**

Ordinary Portland Cement (OPC 43) of Grade 43 from a single lot is used for the study. IS 8112:2013 provides the specification of OPC 43 Grade. According to IS 8112, Ordinary Portland Cement (43 grade) shall be manufactured by intimately mixing together calcareous and argillaceous and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resultant clinker so as to produce a cement capable of complying with this standard. No material shall be added after burning, other than gypsum (natural mineral or chemical), water, performance improver(s), and not more than a total of 1.0 percent of air-entraining agents or other agents including coloring agents, which have proved not to be harmful. It was fresh and without any lumps. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture. The various tests conducted on cement are as follows:

##### **a) Specific Gravity**

Specific Gravity of cement may be defined as the ratio between the mass of a given volume of cement to the mass of an equal volume of water at that temperature. This test was performed in accordance with IS: 4031 (Part 11) – 1988. Kerosene is used in this test instead of water because kerosene does not react with water. The general value of specific gravity of cement is 3.15.

The specific gravity of cement obtained from test results is 3.11.

##### **b) Consistency**

The standard consistency of cement is defined as the percentage of water by weight of cement required to form a cement paste of viscosity at which the plunger of Vicat's apparatus of 10mm diameter penetrates a depth of 5mm to 7mm, above the bottom of the mould. This test was performed in accordance with IS: 4031 (Part 4) – 1988. It is necessary to find out the consistency of cement paste as the amount of water present in the cement paste may affect the setting time.

The value of normal consistency of cement obtained from the test is 27%.

### c) Initial & Final Setting Time of Cement

The Initial and Final Setting Time of cement test was performed in accordance with IS: 4031 (Part 5) – 1988. Initial setting time is defined as the period elapsing between the time when the water is added to the cement and the time at which needle of 1mm square section fails to pierce the test block to a depth of 5mm to 7mm from the bottom of mould.

Final setting time is defined as the period elapsing between the time when the water is added to the cement and the time at which 1mm needle makes an impression on the paste in the mould but 5mm annular attachment doesn't make any impression.

### d) Compressive Strength

Compressive strength is the capacity of a material to withstand loads tending to reduce size, as opposed to tensile strength, which withstands loads tending to elongate. The cement should satisfy the minimum compressive strength values as per IS (IS 4031 (Part 7) - 1988) so that the strength of mortar is not effected. The properties of cement are arranged in a tabular form below. The above properties are in co-relation with the minimum required values as per different IS codes.

*Table 3.1 Properties of cement*

S. No.	Property	Value for OPC	IS Code Recommendations	IS Code Used
1	Specific Gravity	3.12	3 – 3.25	IS: 4031 (Part 11) – 1988
2	Consistency	27%	3 – 3.15	IS: 4031 (Part 4) – 1988
3	Initial Setting Time	37 minutes	30 minutes (min)	IS: 4031 (Part 5) – 1988
4	Final Setting Time	191 minutes	600 minutes (max)	IS: 4031 (Part 5) – 1988
5	Compressive Strength	–	–	IS 4031 (Part 6) – 1988
	3 days	23.8	23	
	7 days	33.6	33	
	28 days	44.3	43	

### 3.3.2 Aggregates

Coarse aggregates of 10mm size are used which were obtained from a crushing plant. The coarse aggregates used in the present study were obtained locally from a crusher plant on Patiala bypass. The aggregates were thoroughly washed to remove dirt, dust and then dried to surface dry condition. They were then put into the oven for a period of 24 hours so as to remove the excess moisture present. The aggregates taken out were then cooled down to the room temperature to be used in the concrete mix. The aggregates were grey in colour and angular in shape. The different tests performed on aggregates are as follows:

#### a) Sieve Analysis

Sieve analysis which is also known as the gradation test is used to determine the particle size distribution of coarse aggregates. The samples are sieved by using the standard set of IS sieves as shown in the table below.

Table 3.2: Sieve analysis of coarse aggregate (10mm)

S. No.	IS Sieve (mm)	Weight Retained (gm)	% Retained	Cumulative % retained	% Passing
1	80	0	0	0	100
2	63	0	0	0	100
3	40	0	0	0	100
4	20	0	0	0	100
5	16	0	0	0	100
6	12.5	57.4	2.87	2.87	97.13
7	10	176.4	8.82	11.69	88.31
8	4.75	1741.2	87.06	98.75	1.25
9	2.36	23.8	1.19	99.94	0.06
10	Pan	1.2	0.06		0
	Total	2000	Sum	113.31 + 500 = 613.31	
			FM	6.13	

Fineness modulus is an empirical factor which is obtained by adding the total percentage of aggregates retained on each sieve of the specified set of sieves and dividing the sum by 100.

Fineness modulus came out to be 6.13.

### **b) Specific Gravity and Water Absorption**

The specific gravity and water absorption tests were performed in accordance with (IS: 2386 (Part 3) - 1963). The specific gravity test helps us to evaluate the strength of an aggregate. It is an indicator of quality or the density of the rock. Greater the specific gravity, greater is the strength of the aggregate and vice-versa.

The specific gravity of the aggregates as obtained from the test is 2.63.

Water absorption test gives us a measure of the strength of the aggregate but in terms of its porosity. Greater the porosity of the aggregate, greater will be its water absorption and lesser strength.

The water absorption of the aggregates was found to be 0.53%.

### **c) Abrasion Value**

Abrasion value of aggregates may be defined as a measure of aggregate toughness and abrasion characteristics. This test was performed in accordance with (IS: 2386 (Part 4) - 1963). Los Angeles Abrasion test was performed to determine the abrasion value of coarse aggregates. The aggregates should be hard and tough enough to resist crushing, degradation and disintegration from any associated activities including manufacturing, stockpiling, production, placing and compaction. The average abrasion value of three test samples came out to be 23%.

### **d) Impact Value**

The property of aggregates to resist impact is known as their toughness. This test was performed in accordance with (IS: 2386 (Part 4) - 1963) The aggregates used in pavements are subjected to impact due to movement of vehicles and hence should be tough enough to resist disintegration due to impact. The aggregate impact value is thus an indicator of the toughness or resistance of aggregates to sudden shock or impact which may be different from its resistance under gradually applied compressive loads. The average impact value of three test samples is 16%.

### e) Crushing Value

The aggregate crushing value is a measure of the resistance of aggregates to crushing when subjected to gradually applied compressive loads. This test was performed in accordance with (IS: 2386 (Part 4) - 1963). The average crushing value of three test samples is 16%.

The properties of aggregates are further organized in a tabulated form below. Since the above properties satisfy the minimum values as per different IS code specifications and hence, they can be used for the design of pervious concrete mixes.

*Table 3.3: Properties of aggregates*

S. No.	Property	Value for aggregate	IS Code Recommendation	IS Code Used
1	Specific Gravity	2.63	2.5 - 3.0	IS: 2386 (Part 3) – 1963
2	Water Absorption	0.53%	0.1% - 2%	IS: 2386 (Part 3) – 1963
3	Abrasion value	23 %	35% max	IS: 2386 (Part 4) – 1963
4	Impact Value	16%	30% max	IS: 2386 (Part 4) – 1963
5	Crushing Value	13%	30% max	IS: 2386 (Part 4) – 1963

### 3.3.3 Steel Fibers:

The main motive of adding steel fibers to the concrete mix is to prevent and delay the propagation of cracks across the matrix and create a slow cracking propagation stage. The ability of steel fibers to bridge the gaps imparts to the composite a pronounced post-cracking ductility which is not in the case of ordinary concrete. The fiber composite has the ability to withstand repeatedly applied, shock or impact loading and increases the energy absorption characteristics of the material thus leading to a ductile failure. The different shapes of steel fibers available in the market are straight steel fibers, deformed steel fibers and hooked ends steel fibers. In the present study crimped steel fibers (a type of deformed fiber) and hooked ends steel fibers as shown in Figure 3.3 are used which were obtained from Komatko India (P) Ltd., Nagpur. The important properties of different steel fibers used in this research are tabulated in Table 3.4 as shown below:



Figure 3.2: Different fiber types: Hooked end (4-D) fiber (left) and Round crimped fiber (right)

Table 3.4: Properties of steel fibers

S. No.	Property	Shape	
		Crimped	Hooked End
1	Diameter (mm)	1	0.9
2	Length (mm)	50	60
3	Aspect Ratio	50	67
4	Density (kg/m <sup>3</sup> )	7850	7850
5	Tensile Strength (N/mm <sup>2</sup> )	1050	1600

### 3.4 Concrete Mix Design

M20 concrete mix is designed using the above mentioned properties of materials. In pervious concrete mix design, the materials used are the same as that of conventional concrete with an exception that the fine aggregate (sand) is fully eliminated and the grading of the coarse aggregates is kept narrow to maintain the required mechanical properties with high permeability. The trial mix was prepared as per the guidelines for Pervious Concrete mix proportions given by National Ready Mixed Concrete Association (NRMCA) as shown in Table 3.5.

Table 3.5: NRMCA mix proportions

S. No.	Material	Proportions (kg/m <sup>3</sup> )
1	Cement	270 – 415
2	Aggregate	1190 – 1480
3	Water – cement ratio (by mass)	0.27 to 0.34
4	Aggregate – cement ratio (by mass)	4 to 4.5:1
5	Fine – coarse aggregate ratio (by mass)	0 to 1:1

**Trial 1:**

Figure 3.3 shows the procedure adopted to carry out initial mix design in a systematic manner:

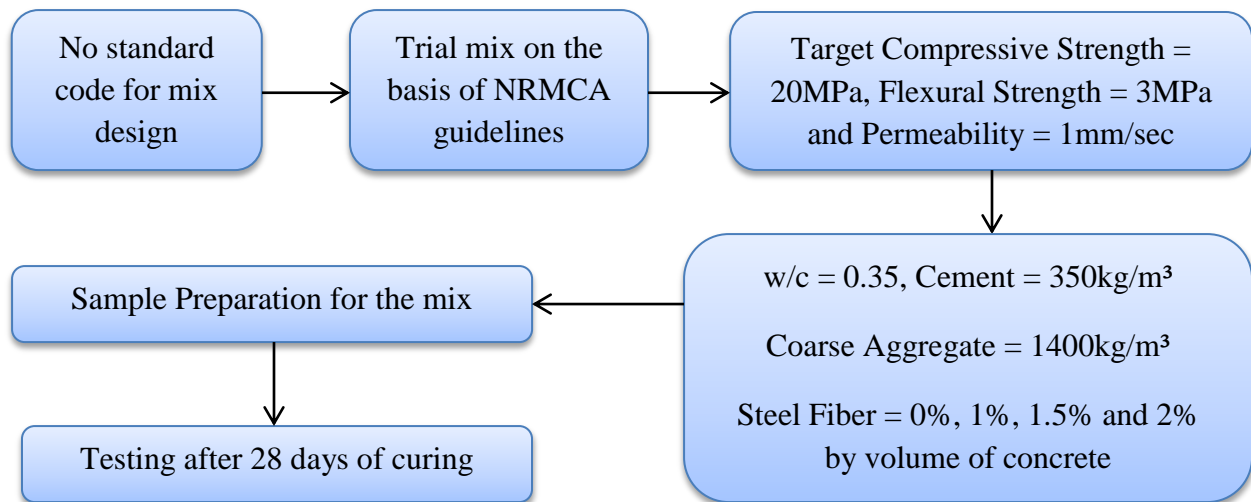


Figure 3.3: Flowchart showing the Pervious Concrete design

Table 3.6 shows the approximate quantity of materials used for mix design:

Table 3.6: Mix design for Pervious Concrete

S. No.	Material	Quantity
1	Coarse Aggregate (10mm)	1400kg/m <sup>3</sup>
2	Cement	350kg/m <sup>3</sup>
3	Water/cement ratio (by mass)	0.35
4	Aggregate – cement ratio (by mass)	4:1
5	Fine – coarse aggregate ratio (by mass)	0

A glance at Table 3.6 gives the aggregate-cement ratio and the quantities of materials used for the preparation of control mix. The fine aggregate content is kept zero and a water cement ratio of 0.35 was used to form a paste of uniform consistency. A set of three cubes of side 150 mm is tested at 7 days and 28 days respectively. The average compressive strength at the end of 7 and 28 days is shown in table below:

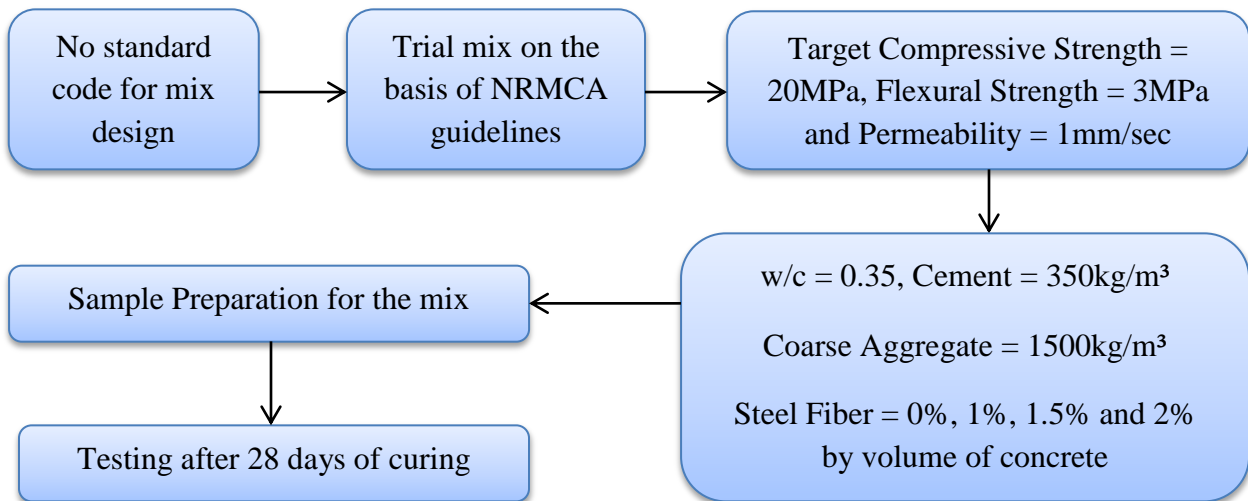
*Table 3.7: Results of Compressive Strength for Trial 1:*

7 Days Strength	12.45 MPa
28 Days strength	17.69 MPa

The compressive strength results obtained from the trial mix 1 were less than the target compressive strength, so there was a need to make changes in the trial proportions. This can be achieved by varying the quantity of cement content or aggregates or water-cement ratio.

**Trial 2:**

Figure 3.4 shows the procedure for the modified mix design of Pervious Concrete. In the second trial mix, the amount of water content and the quantity of cement were kept constant whereas the quantity of aggregates was increased from 1400kg/m<sup>3</sup> to 1500kg/m<sup>3</sup> to check their effect on compressive strength.



*Figure 3.4: Flowchart showing the Pervious Concrete design*

Table 3.8 shows the approximate quantity of materials used for mix design:

*Table 3.8: Mix design for Pervious Concrete*

S.No.	Material	Quantity
1	Coarse Aggregate (10mm)	1500kg/m <sup>3</sup>
2	Cement	350kg/m <sup>3</sup>
3	Water/cement ratio (by mass)	0.35
4	Aggregate – cement ratio (by mass)	4.28:1
5	Fine – coarse aggregate ratio (by mass)	0

A glance at Table 3.8 gives the aggregate-cement ratio and the quantities of materials used for the preparation of control mix. The fine aggregate content is kept zero and a water cement ratio of 0.35 was used to form a paste of uniform consistency. A set of three cubes of side 150 mm is tested at 7 days and 28 days respectively, the results of which are shown in the table:

*Table 3.9: Results of Compressive Strength for Trial 2:*

7 Days Strength	15.27 MPa
28 Days strength	20.75 MPa

The compressive strength obtained in the second trial was a little higher than the target compressive strength. So, after two trial mixes, the control mix had an aggregate-cement ratio of 4.28:1.

### **3.5 Casting of Pervious Concrete**

The stepwise procedure for casting of pervious concrete is given below:

- a) Calculate the quantities of cement, aggregates and water in kg depending on the type and size of sample in m<sup>3</sup>.
- b) Put the dry and clean coarse aggregates in the mixer along with some cement and fibers (if any) and perform dry mixing for about one minute. Now slowly add water and rotate the mixer for about three minutes so that it forms a uniform paste.
- c) The moulds are properly oiled so that the mixture doesn't stick to them.

- d) The moulds are then filled with concrete in three layers and each layer is compacted with help of a tamping rod by giving required number of blows. Each layer is then vibrated for 5 seconds on a vibrator.
- e) After 24 hours, the concrete samples are removed from the moulds and kept for curing in the curing tanks.

The Figures 3.5 to 3.10 shows the different steps involved in the preparation of pervious concrete samples. The demoulded cube (Figure 3.7), beam (Figure 3.8) and cylindrical (Figure 3.9) specimens are further cured in a curing tank for 28 days. These samples are then removed from curing tank and tested.



*Figure 3.5: Material preparation*



*Figure 3.6: Mixing of material*



*Figure 3.7: Demoulded cube samples*



*Figure 3.8: Demoulded beam samples*



*Fig. 3.9: Demoulded cylindrical samples*



*Fig. 3.10: Curing of beam samples in curing tank*

### **3.6 Testing Arrangement**

#### **3.6.1 Compressive Strength**

Compressive strength of concrete may be defined as the ability of a material to resist breaking when subjected to compressive loads. This test is performed in accordance with IS: 516 (1959). A total of 21 cube specimens of size 150mm × 150mm × 150mm were cast. The cubes were tested in Universal testing machine (UTM) of 1000KN load capacity after 28 days of curing. The load was applied at a rate of 140kg/cm<sup>2</sup>/min. The testing procedure for all the cube specimens was same. The tests were performed using the setup as shown in the Figure 3.11.



*Figure 3.11: Compressive strength test on Pervious Concrete cube*

### 3.6.2 Flexural Strength

Flexural strength may be defined as the property of a material to resist load under bending. It is the most important parameter for design of a rigid pavement. This test is performed using two point loading according to the provisions of IS: 516 (1959). A total of 21 beam specimens of size 100mm × 100mm × 500mm were cast. The beams were tested in Universal testing machine (UTM) of 1000KN load capacity after 28 days of curing. The load is applied at a rate of 180kg/min. The testing procedure for all the beam specimens was same. The tests were performed using the setup as shown in the Figure 3.12.



*Figure 3.12: Two point loading test to evaluate flexural strength of Pervious Concrete beam*

### 3.6.3 Permeability

Permeability is the most important variable of pervious concrete. It is defined as the rate of flow of fluid such as water through a porous media like pervious concrete. Permeability of pervious concrete is calculated by falling head test method using IS: 2720 (Part 17). The test is performed using Falling Head Permeameter as shown in Figure 3.14. The total numbers of cylindrical specimens cast were 21. The diameter of the tested samples was 76.2mm with a height of 127mm. The testing procedure for all the beam specimens was same.



*Figure 3.13: Pervious Concrete mould*



*Figure 3.14: Permeability test apparatus*

### **3.6.4 Water Absorption and Durability Test (Shah & Pitroda 2014)**

The durability and water absorption tests are conducted on pervious concrete to evaluate their behaviour when exposed to salts like sodium chloride. A total number of 42 cylindrical specimens of height 200mm and diameter 100mm were tested in accordance with the procedure outlined in **Shah & Pitroda 2014**.



*Fig. 3.15: Cylinders after 28 days of curing*



*Fig. 3.16: Cylindrical specimen in curing tank at 85°C*



Fig. 3.17: Oven dried cylindrical specimen



Fig. 3.18: Cylinders immersed in salt solution

## Procedure:

### a) Water Absorption

- 1) The cylinders after casting are immersed in water for 28 days of curing.
- 2) After 28 days, the cylinders are oven-dried at a temperature of 110°C for 24 hours. This weight is noted as dry weight ( $W_1$ ) of the cylindrical specimen.
- 3) Now cylinders are immersed in hot water at a temperature of 85° for 3.5 hours.
- 4) The specimens are again weighed and this weight is noted as wet weight ( $W_2$ ) of the cylindrical sample.
- 5) Mathematically, the water absorption (WA) in percentage is given as:

$$WA (\%) = [(W_2 - W_1) / W_1] \times 100$$

### b) Durability

- 1) The cylinders after casting are immersed in water for 28 days of curing.
- 2) After 28 days, the cylinders are oven dried at a temperature of 110°C for 24 hours. This weight is noted as dry weight ( $W_1$ ) of the cylindrical specimen.
- 3) The oven dried specimens are now immersed in sodium chloride solution (3.5%) for another 28 days.
- 4) The specimens are again weighed and this weight is noted as wet weight ( $W_2$ ) of the sample.
- 5) The percentage change in weight will be determined in the same manner as in water absorption test.

Mathematically, it is given as:

$$\text{Durability (\%)} = [(W_2 - W_1) / W_1] \times 100$$

### **3.7 Summary**

In this chapter, the material specifications, fundamental tests and their procedures involved to test pervious concrete have been explained.

The next section shows the results of the various tests which were used to evaluate mechanical and physical properties of pervious concrete.

## **4.1 General**

This chapter investigates the properties of the no-fines concrete samples. The effect of fibers on the compressive strength, flexural strength, permeability, durability and water absorption is reported in this chapter.

## **4.2 Test Results**

### **4.2.1 Slump**

The slump test of concrete is an empirical test that is used to assess the workability of freshly mixed concrete. This test helps us to evaluate the consistency of concrete for a particular batch. Consistency refers to the ease with which the concrete flows.

The slump is measured as the difference in height between the top of the mould and the highest point of the specimen being evaluated.

The slump value in our case comes out to be zero. This may be attributed to the absence of fine aggregates, which primarily provide workability to the mix.

The plastic pervious concrete mixture is stiff compared to traditional concrete. The primary application of pervious concrete is to allow easier drainage of water through its high permeability. Hence the permeability and not the slump of pervious concrete is generally specified as the acceptance criteria. When placed and compacted, the aggregates are tightly adhered to one another and exhibit the characteristic open matrix that looks like pop-corn.

### **4.2.2 Compressive Strength**

The compressive strength is one of the most important properties used by the design engineers to judge the strength of the material. Three cube specimens were tested for control mix as well as each percentage of fiber. The 28 days compressive strength of each cube specimen of pervious concrete for different percentages and types of steel fibers is given below.

Table 4.1: 28 days average compressive strength of Pervious Concrete

S. No.	Steel Fiber Type	Steel Fiber (%)	28 Days Compressive Strength (MPa)	28 Days Average Compressive Strength (MPa)
1	Control Mix (No fiber)	0	21.20	20.75
			20.35	
			20.71	
2	Crimped	1	21.42	21.19
			21.28	
			20.88	
3	Crimped	1.5	21.33	21.40
			21.06	
			21.82	
4	Crimped	2	21.73	21.62
			21.24	
			21.91	
5	Hooked End (4D)	1	21.24	21.34
			20.93	
			21.86	
6	Hooked End (4D)	1.5	21.82	21.81
			22.12	
			21.49	
7	Hooked End (4D)	2	22.04	21.58
			21.42	
			21.28	

The tabular results are further illustrated in the form of graphs:

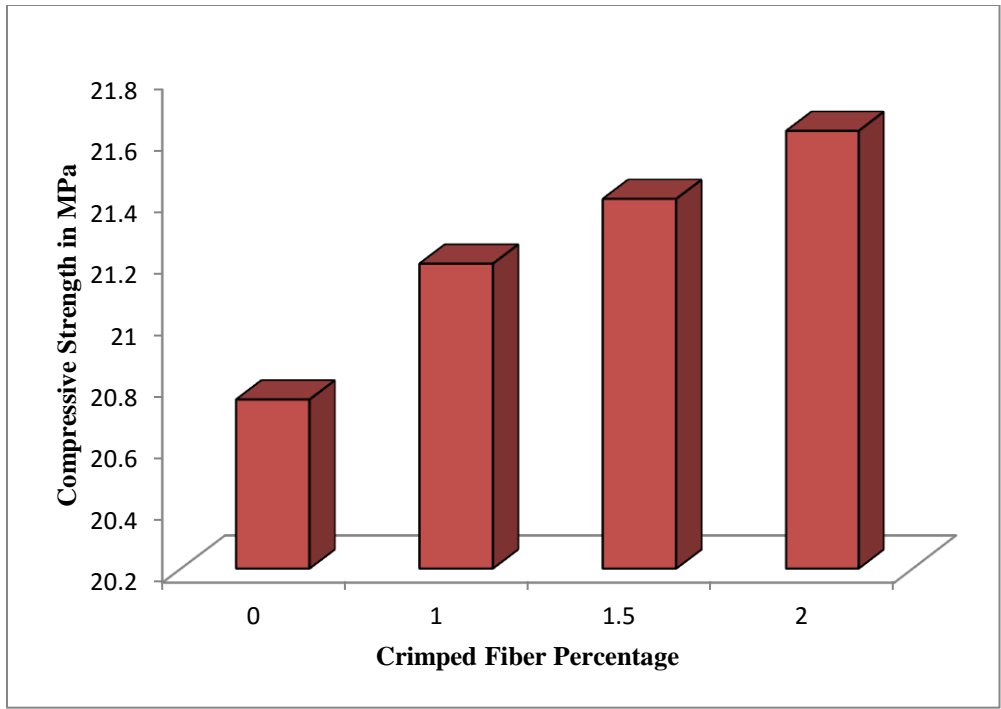


Figure 4.1: Compressive strength at 28 days at different percentage of Crimped fiber

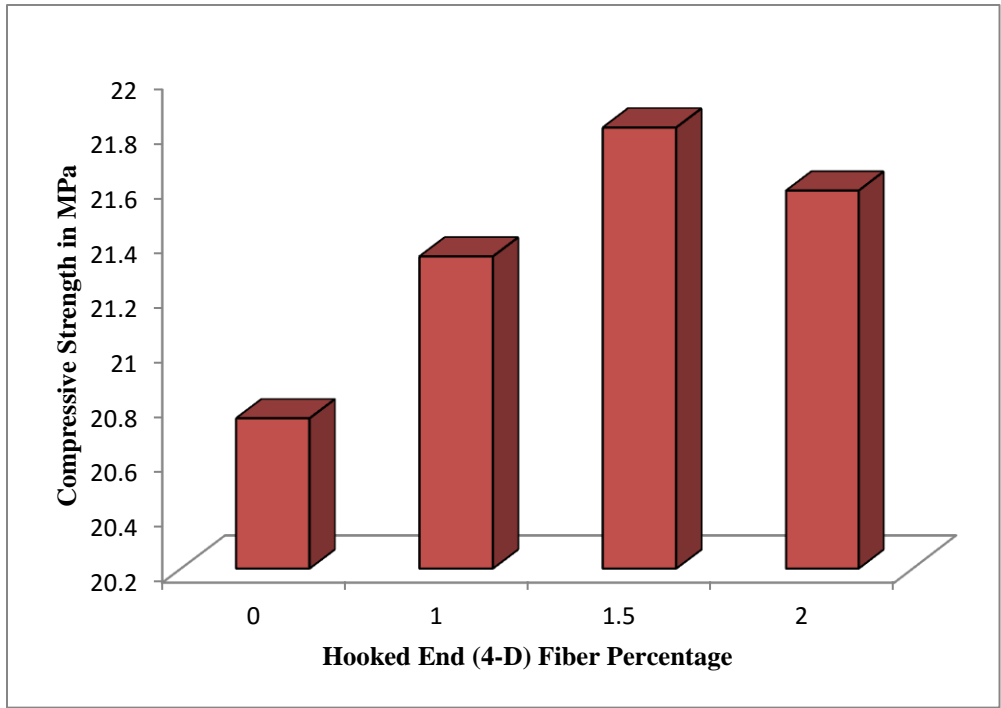


Figure 4.2: Compressive strength at 28 days at different percentage of Hooked End (4-D) fiber

The 28 days average compressive strength of cube specimens without and with different types of steel fibers is given in Table 4.1. Figure 4.1 gives the variation in compressive strength of pervious concrete on adding crimped fibers in percentages of 1%, 1.5% and 2% by volume of concrete. The compressive strength of crimped fiber modified concrete increased and a value of 21.62MPa was recorded as highest at a fiber dosage of 2% by volume of concrete. Figure 4.2 show the change in strength of porous concrete on adding hooked end fiber (4-D) to it. The compressive strength increased when fiber proportion was 1% and 1.5% by volume of concrete but it decreased slightly when 2% 4-D fiber by volume of concrete was added to the mix. The hooked end (4-D) fiber modified concrete exhibited a maximum gain in compressive strength at a fiber dosage of 1.5% and the new value was recorded as 21.81MPa. Thus, it can be stated that there was a very little increase in the compressive strength of the mixes on addition of steel fibers.

The basic motive of adding fibers to a concrete mix was to improve strength of the composite. The crushing of concrete and development of cracks takes place when the externally applied force exceeds the compressive strength of the material. When steel fibers were added to the concrete mix, it resulted in the formation of a number of localized cracks which were distributed throughout the member instead of a bigger crack which was developed when pervious concrete without any steel fiber was tested. The addition of 4-D fiber therefore allows more energy absorption than crimped fiber before failure within the member thus increasing the capacity of the cube under compression. The increase in strength with hooked end fibers was higher as they have higher tensile strength and give better energy absorption than straight steel fibers. It is because extra energy is required to straighten the deformed ends of a hooked end fiber (4-D) to debond the fiber from the matrix. Thus, we can conclude that addition of fibers resulted in failure of the cubes at a slightly higher peak loads when compared to pervious concrete cubes without any steel fiber.

A glance at Figure 4.3 gives us the percentage change in the strength of pervious concrete on addition steel fibers to the mix. The maximum gain in strength was 4.19% when crimped fiber at a dosage of 2% by volume of concrete was added to the mix. The increase in compressive strength was observed as 2.84% and 4% with 4-D fiber dosages of 1% and 2% respectively. The

percentage increase in strength of 5.11% was recorded as maximum at 1.5% with hooked end fiber.

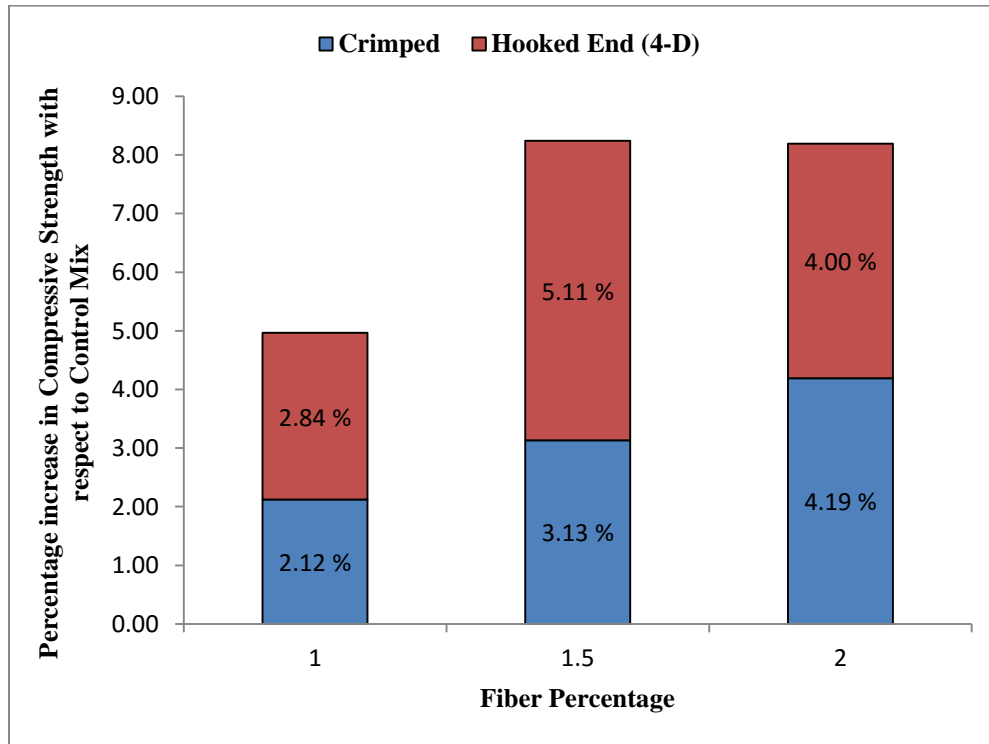


Figure 4.3: Percentage increase in compressive strength for different fiber types with respect to control mix

### 4.2.3 Flexural Strength

The flexural strength test is performed to evaluate the resistance of member when subjected to bending. Flexural strength is the basic criteria to govern the quality of pavement. A pavement when put in use is often subjected to a variety of wheel loads and temperature stresses. The pavement must be able to withstand the flexural stress variations generated due to all such load combinations. Generally, pervious concrete usually suffers from the problem of low flexural strength. In order to enhance the flexural strength of pervious concrete, steel fibers have been added to the control mix. Three beam specimens were casted and tested for each percentage and type of fiber. Two point loading method was used to evaluate the flexural strength of beam specimens. The 28 days average flexural strength of pervious concrete for different percentages and types of steel fibers is given in Table 4.2 below:

Table 4.2: 28 days average flexural strength of Pervious Concrete

S. No.	Steel Fiber Type	Steel Fiber (%)	28 Days Flexural Strength (MPa)	28 Days Average Flexural Strength (MPa)
1	Control Mix (No fiber)	0	2.69	2.68
			2.61	
			2.76	
2	Crimped	1	2.87	2.80
			2.64	
			2.89	
3	Crimped	1.5	2.99	2.90
			2.80	
			2.93	
4	Crimped	2	2.97	2.98
			2.95	
			3.02	
5	Hooked End (4D)	1	2.94	2.99
			3.04	
			2.99	
6	Hooked End (4D)	1.5	3.28	3.19
			3.13	
			3.17	
7	Hooked End (4D)	2	3.14	3.11
			3.07	
			3.12	

The tabular results are further illustrated in the form of graphs:

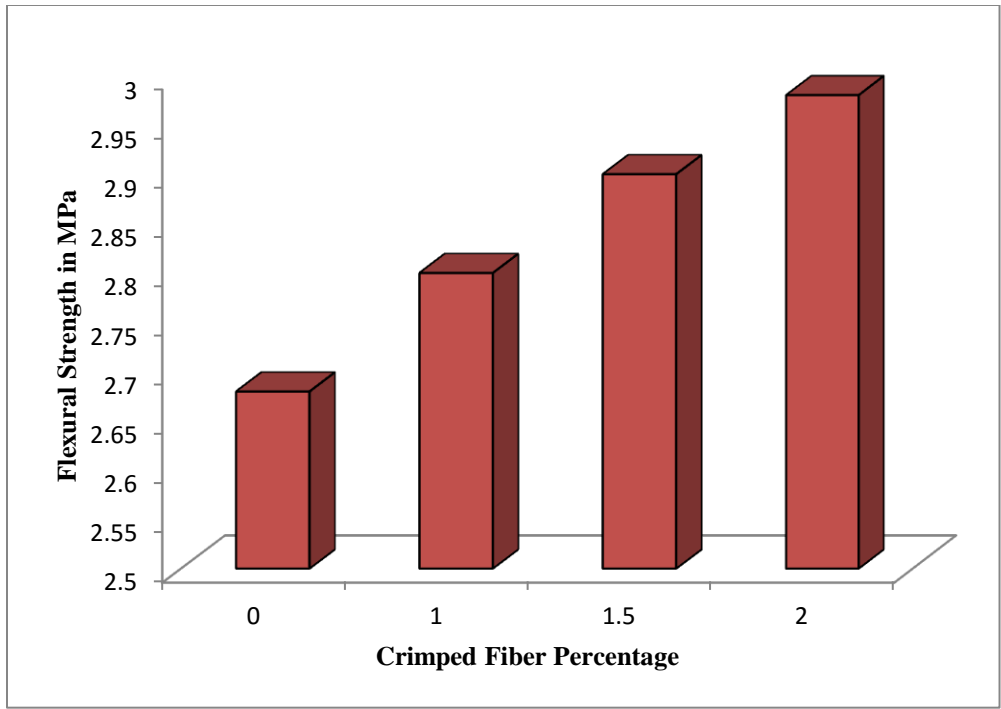


Figure 4.4: Flexural strength at 28 days at different percentage of Crimped fiber

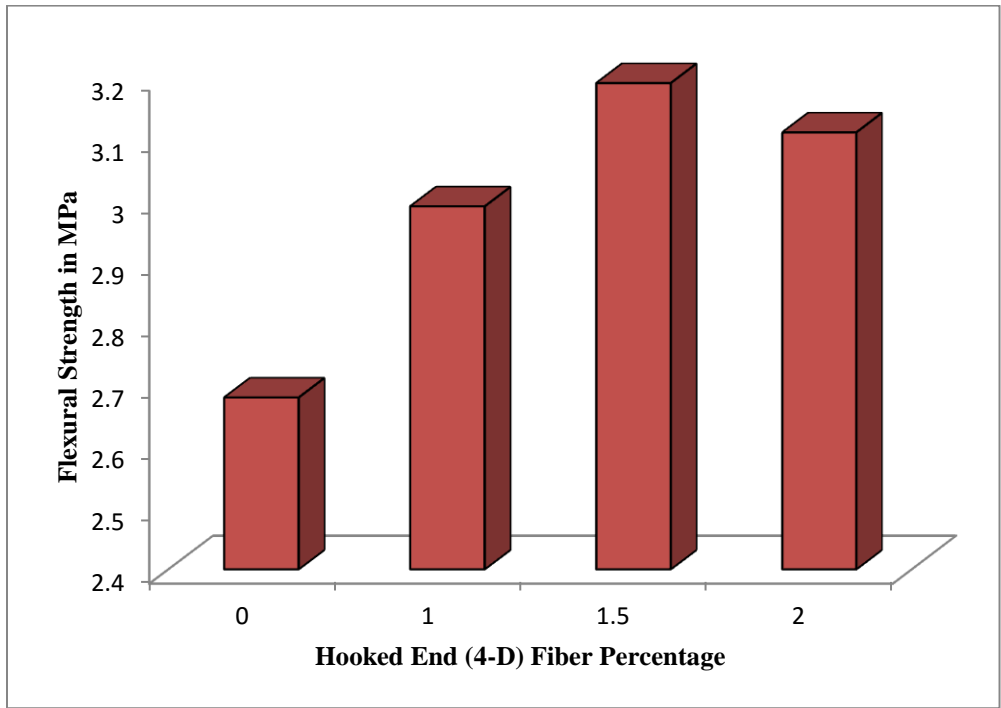


Figure 4.5: Flexural strength at 28 days at different percentage of Hooked End (4-D) fiber

The quality of a pavement is judged by its flexural strength. A pavement once constructed is often subjected to a variety of loads during its life span so it is required that the design considers the wheel loads and stresses which will be generated due to temperature differential in slabs. In this thesis, steel fibers are added in the control mix to increase the flexural strength of gap graded concrete. Figure 4.4 gives the variation in flexural strength of pervious concrete on adding crimped fibers in percentages of 1%, 1.5% and 2% by volume of concrete. The flexural strength of crimped fiber modified concrete increased and a value of 2.98MPa was recorded as highest at a fiber dosage of 2% by volume of concrete. Figure 4.5 shows the modification in strength of porous concrete on adding hooked end fiber (4-D) to it. The flexural strength increased when fiber proportion was 1% and 1.5% by volume of concrete but it decreased slightly when 2% 4-D fiber by volume of concrete was added to the mix. The hooked end (4-D) fiber modified concrete exhibited a maximum gain in flexural strength at a fiber dosage of 1.5% and the new value was recorded as 3.19MPa. The general trend indicated that there was a slight increase in flexural strength of crimped fiber reinforced pervious concrete whereas the increase in flexural strength of hooked end (4-D) fiber reinforced pervious concrete was high.

The strength increase on addition of fibers is normally higher in flexure than in compression. When a pervious concrete beam without any steel fibers was tested, it leads to failure at low displacement due to the inherent brittleness of the plain concrete in flexural tension. However, on addition of steel fibers in the pervious concrete mix, the displacement capacity of the member was increased because steel fibers of high tensile strength were able to bridge the gaps which were developed on application of load. When load is applied, part of the load is transferred to fiber along its surface. Shear stress develops along the surface of the fiber due to difference in stiffness between fiber and matrix. Hooked end fibers have a higher stiffness and higher tensile strength than crimped fibers, thus provide good anchorage due to which the increase in peak load was significant.

A glance at Figure 4.6 shows that the percentage increase in flexural strength is higher than the compressive strength. The crimped fiber modified concrete exhibited a maximum increase in flexural strength of 11.19% at a dosage of 2% fiber by volume of concrete without any major

change in permeability. On addition of 1.5% hooked end (4-D) fiber, the maximum increase of 19.03% in flexural strength was observed.

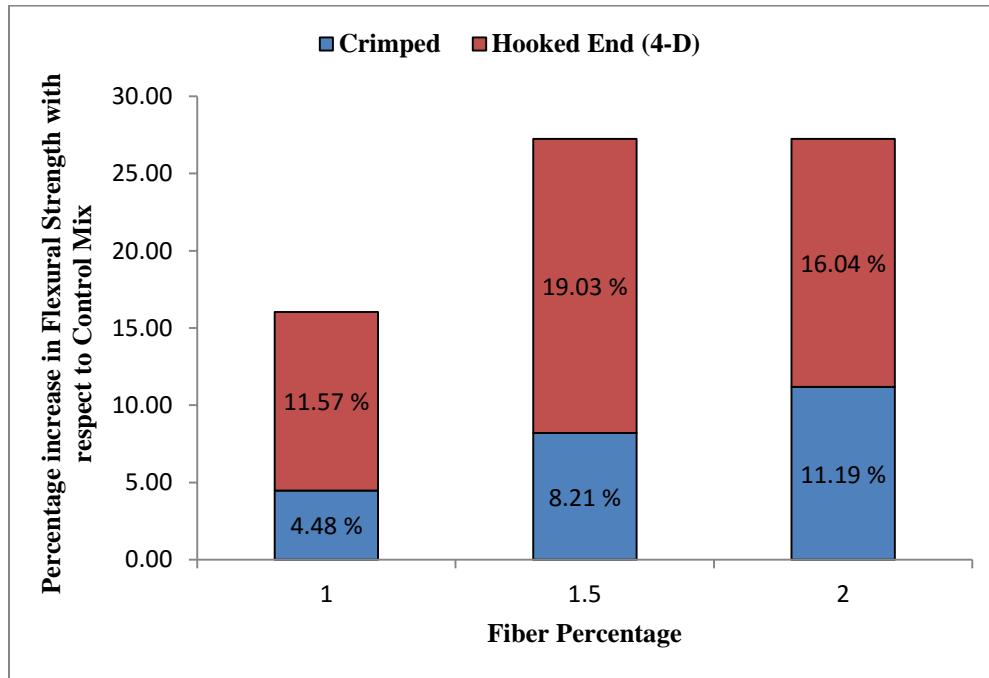


Figure 4.6: Percentage increase in flexural strength for different fiber types with respect to control mix

#### 4.2.4 Permeability

Permeability is the most important property for the design of permeable pavements. The basic function of a permeable concrete pavement is to allow the water to infiltrate through the subgrade to the soil below to recharge the groundwater. The pervious pavements are a strong tool for storm water management. The no-fines concrete has a high permeability than conventional concrete because use of fine aggregates is eliminated for its design. The mixing and compaction techniques used for preparing the pervious concrete specimen play a vital role in its permeability. Three cylindrical specimens were casted and tested for each percentage and type of steel fiber. The permeability tends to decrease with increase in percentage of steel fiber. The 28 days permeability of pervious concrete for different percentages and types of steel fibers is given below in Table 4.3. Also, the 28 days average permeability in cm/sec for each percentage and type of steel fiber is given below:

*Table 4.3: 28 days average permeability of Pervious Concrete*

<b>S. No.</b>	<b>Steel Fiber Type</b>	<b>Steel Fiber (%)</b>	<b>28 Days Permeability (cm/sec)</b>	<b>28 Days Average Permeability (cm/sec)</b>
1	Control Mix (No fiber)	0	0.15	0.16
			0.15	
			0.20	
2	Crimped	1	0.15	0.15
			0.15	
			0.15	
3	Crimped	1.5	0.15	0.14
			0.12	
			0.15	
4	Crimped	2	0.12	0.13
			0.15	
			0.12	
5	Hooked End (4D)	1	0.15	0.14
			0.12	
			0.15	
6	Hooked End (4D)	1.5	0.12	0.12
			0.12	
			0.12	
7	Hooked End (4D)	2	0.12	0.116
			0.11	
			0.12	

The tabular results are further illustrated in form of graphs:

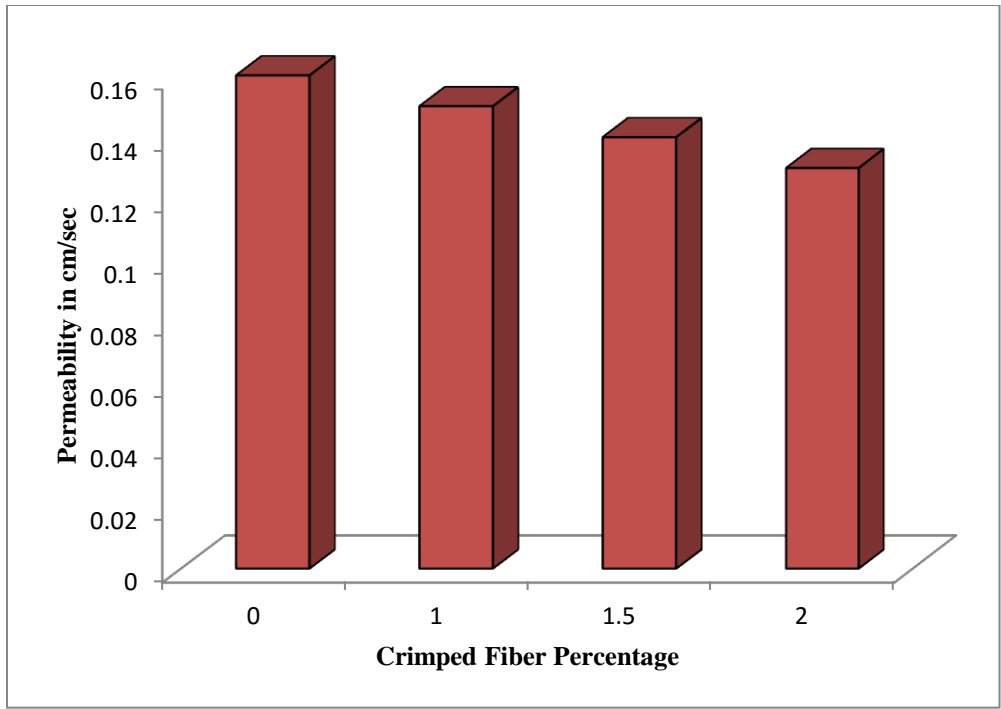


Figure 4.7: Permeability in cm/sec at 28 days at different percentage of Crimped fiber

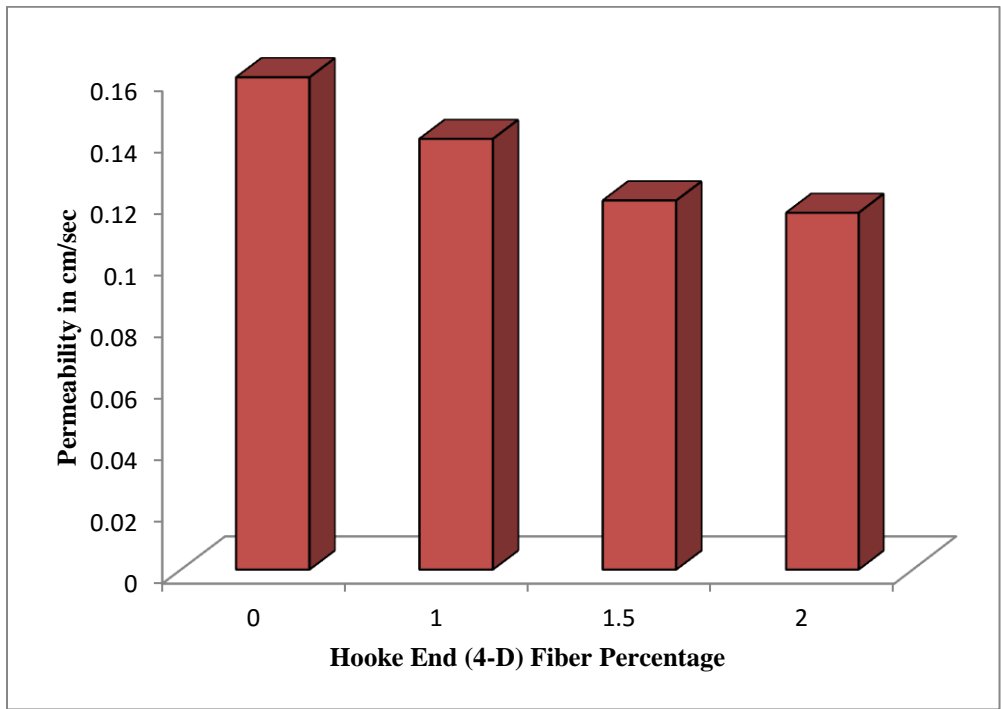


Figure 4.8: Permeability in cm/sec at 28 days at different percentage of Hooked End (4-D) fiber

This section discusses the drop in permeability on addition of steel fibers to the mix. The control mix had a permeability of 0.16cm/sec. With the addition of crimped fiber, the pervious concrete exhibited the lowest permeability of 0.13cm/sec at a fiber content of 2% as shown in Figure 4.7. The hooked end (4-D) fiber exhibited the maximum drop in permeability at a fiber dosage of 2% by volume of concrete and the new value was recorded as 0.116cm/sec as seen in Figure 4.8. The figures also show that permeability decreases with increase in the percentage of fibers for both shapes of fibers and fiber doses studied in this thesis. Thus, it can be quoted that by adding crimped steel fibers at dosages of 1% and 1.5%, the permeability of pervious concrete is decreased. However, the decrease in permeability on addition of hooked end (4-D) fibers at dosages of 1.5% and 2% by volume of concrete was significant.

A glance at Figure 4.9 shows that the permeability of pervious concrete decreases with increase in percentage of steel fibers. The decrease in permeability was recorded lowest at 1% addition of crimped fiber by volume of concrete to the control mix. The percentage decrease of 27.5% was the highest when 2% hooked end (4-D) fiber was added to the control mix.

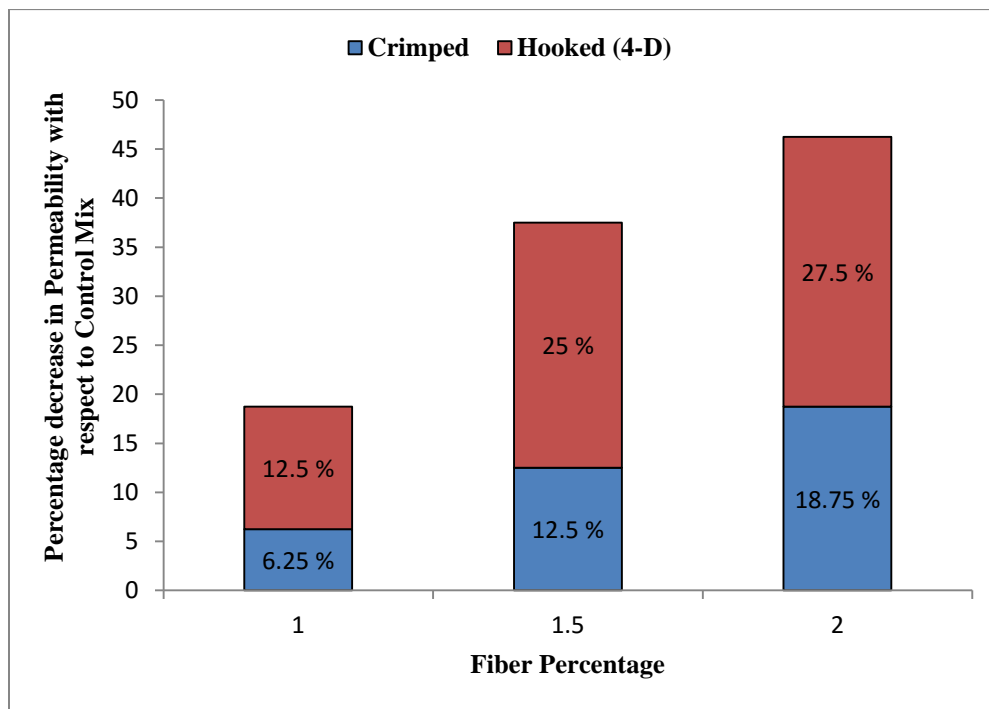


Figure 4.9: Percentage decrease in permeability for different fiber types with respect to control mix

The permeability of the concrete mix decreases slightly with increasing percentages of steel fibers. This may be attributed to the breaking of continuity of pores and interconnectivity of porous channels by the impermeable steel fibers.

### 4.3 Variation of Permeability with Compressive Strength and Flexural Strength

This section discusses the variation of permeability with compressive strength and flexural strength at different percentages and types of steel fibers. The inclusion of steel fibers resulted in an increase in compressive strength and flexural strength of pervious concrete. The use of crimped steel fibers did not show significant variation in permeability. However, the decrease in permeability was high on addition of hooked end (4-D) fibers. The flexural and compressive strength were found to increase with 1% and 1.5% hooked end (4-D) due to better interlocking between aggregates and cement paste but with 2% hooked end fibers both these properties decreased slightly probably due to balling effect and uneven distribution of steel fibers.

Figure 4.10 and Figure 4.11 show the variation of compressive strength and permeability with different types and percentages of steel fibers.

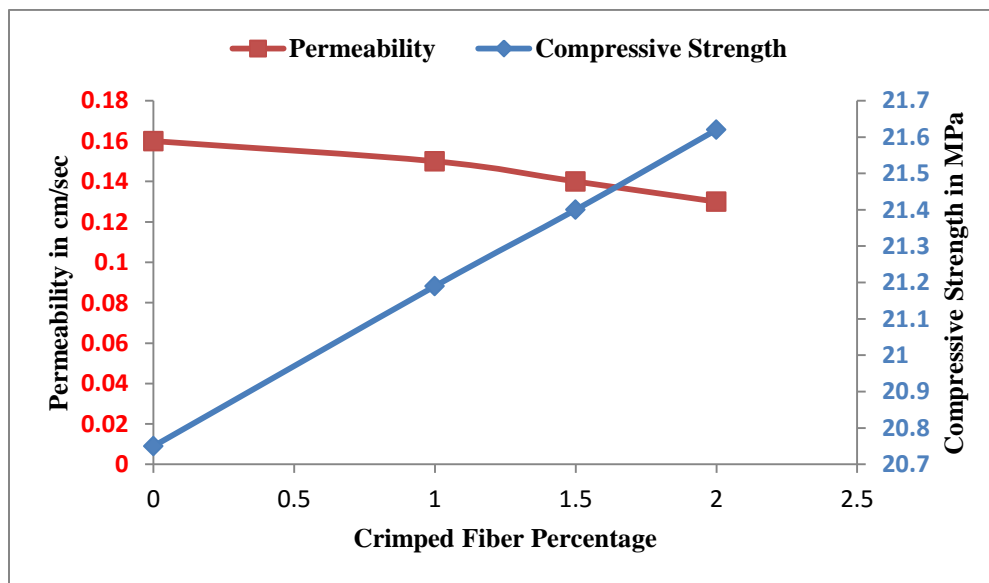


Figure 4.10: Variation of permeability and compressive strength with percentage of Crimped steel fiber

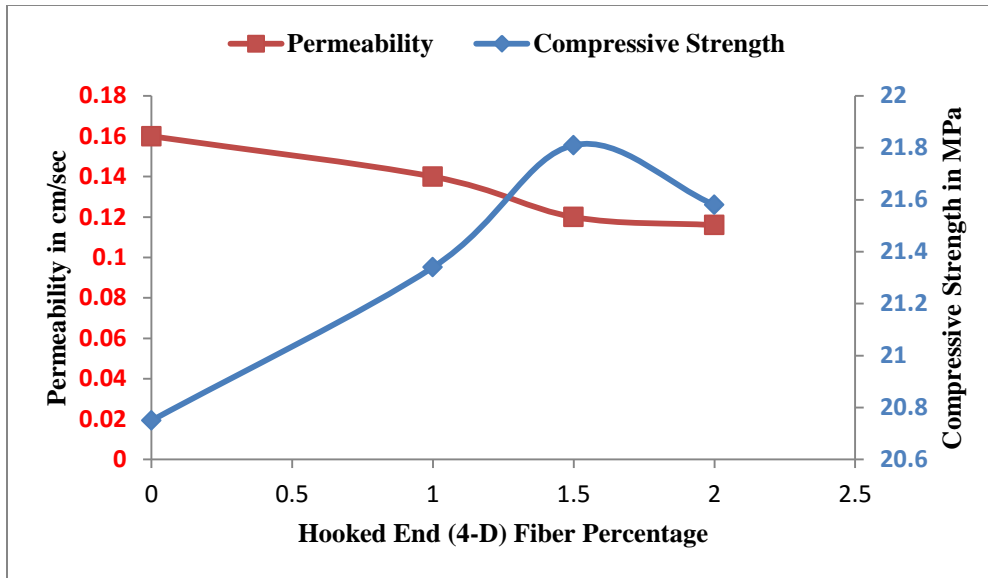


Figure 4.11: Variation of permeability and compressive strength with percentage of Hooked End (4-D) steel fiber

The permeability in general decreased with increase in percentage of steel fibers. The mixes satisfying the target performance with both the fibers were in the dosages 1%, 1.5% and 2%. Figure 4.12 and Figure 4.13 show the variation of flexural strength and permeability with different types and percentages of steel fibers.

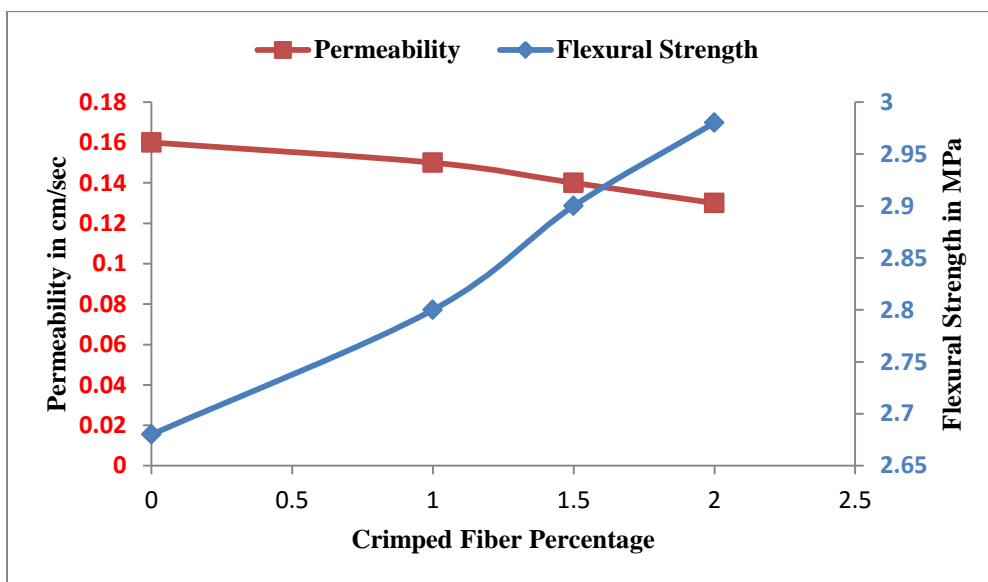


Figure 4.12: Variation of permeability and flexural strength with percentage of Crimped steel fiber

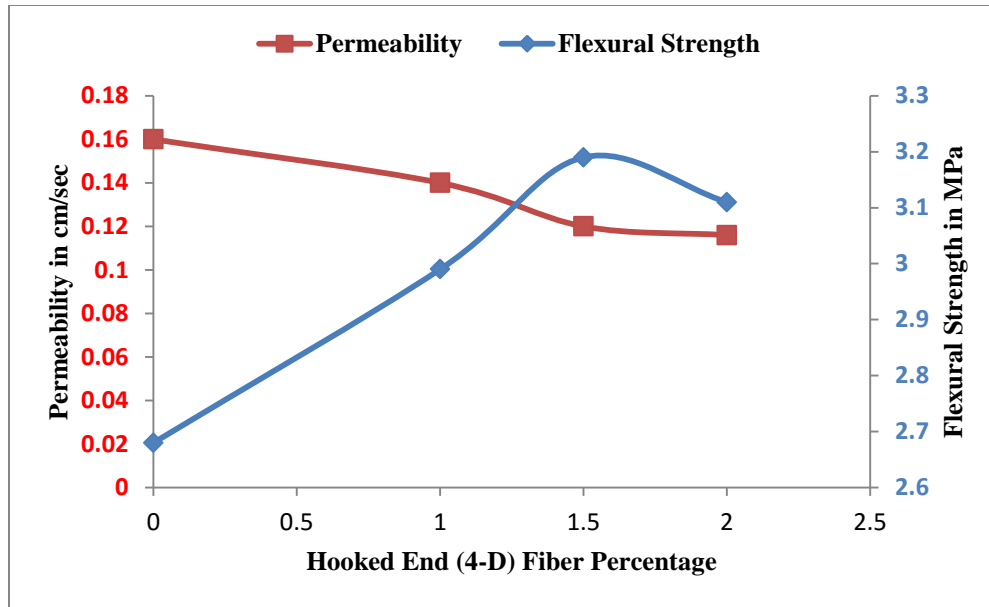


Figure 4.13: Variation of permeability and flexural strength with percentage of Hooked End (4-D) steel fiber

The mixes satisfying the target performance were achieved with 1%, 1.5% and 2% crimped and hooked end (4-D) steel fibers.

As seen from the graphs, permeability was found to decrease with increase in compressive and flexural strengths of the specimen. It can be attributed to the bridging of the voids by steel fibers which break the continuity of voids path and thus reduces permeability. From the above observations, the recommended crimped fiber dosage to ensure target compressive strength and permeability is 2%. However, for hooked end (4-D) fiber, a dosage of 1.5% appears to be optimal.

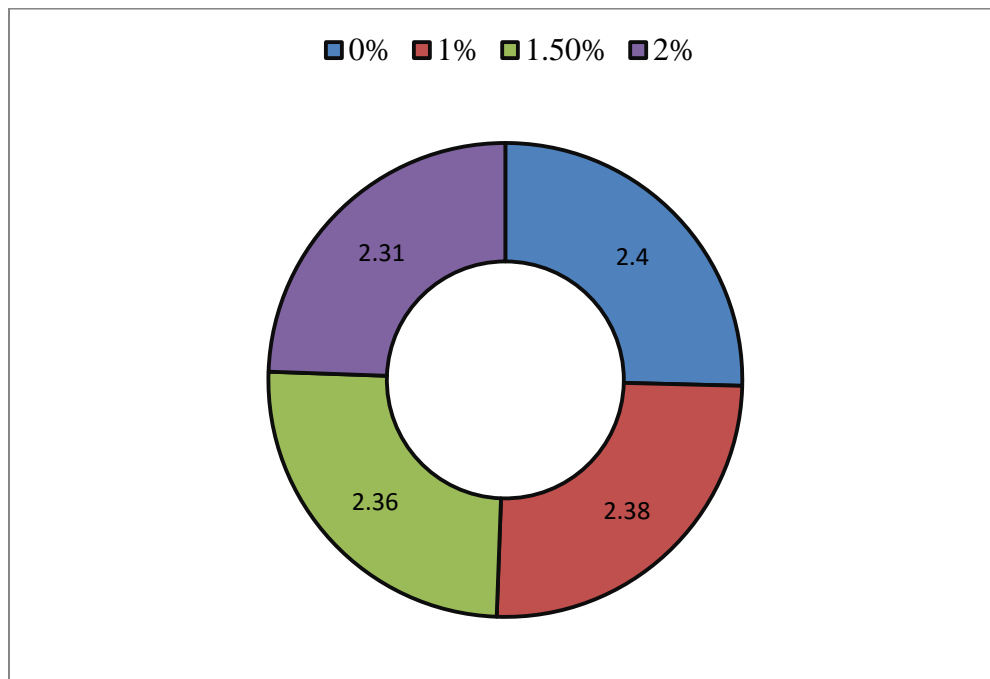
#### 4.4 Durability & Water Absorption

Water absorption and durability play a very important role in the functioning of a pervious concrete pavement. Water Absorption may be defined as a process where concrete absorbs water under specific conditions and is given as percentage of the dry weight of material. Durability on the other hand is the ability of concrete to resist chemical attack, weathering action and other degrading processes while maintaining the necessary engineering properties.

*Table 4.4: Durability and Water Absorption characteristics of Pervious Concrete*

S. No.	Steel Fiber Type	Steel Fiber (%)	28 Days Average Water Absorption (%)	56 Days Average Durability (%)
1	Control Mix (No Fiber)	0	2.40	4.23
2	Crimped	1	2.38	4.35
3	Crimped	1.5	2.36	4.42
4	Crimped	2	2.31	4.49
5	Hooked End	1	2.33	4.44
6	Hooked End	1.5	2.30	4.51
7	Hooked End	2	2.25	4.54

The 28 days average water absorption and 56 days average durability characteristics are tabulated in Table 4.4. The tabular results are further illustrated in the form of graphs.



*Figure 4.14: Water Absorption at different percentage of Crimped steel fibers*

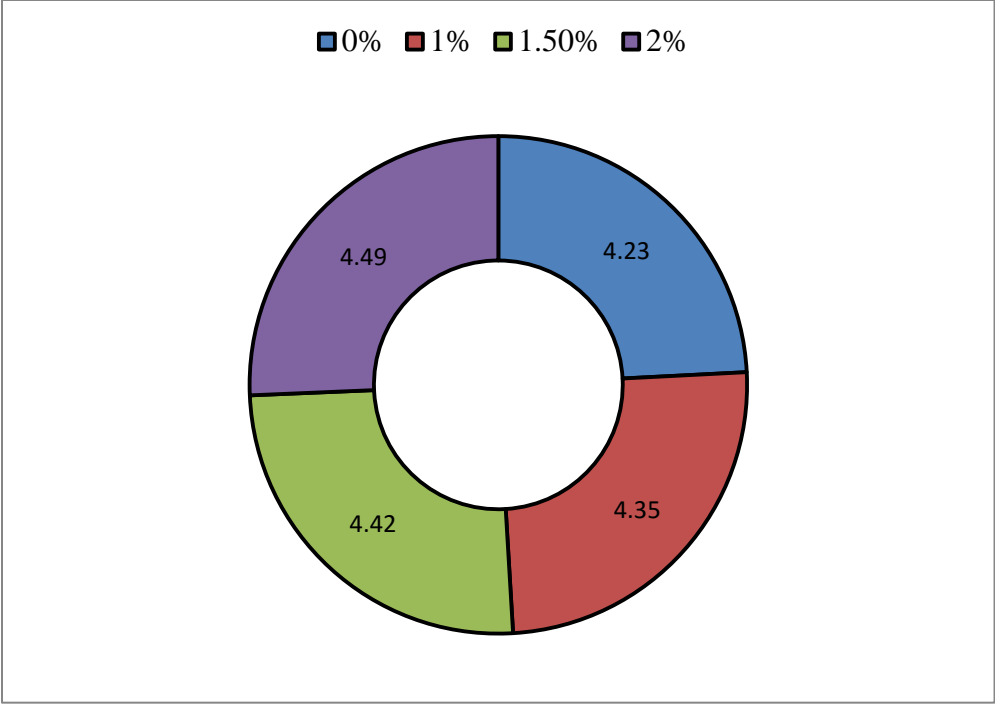


Figure 4.15: Durability at different percentage of Crimped steel fibers

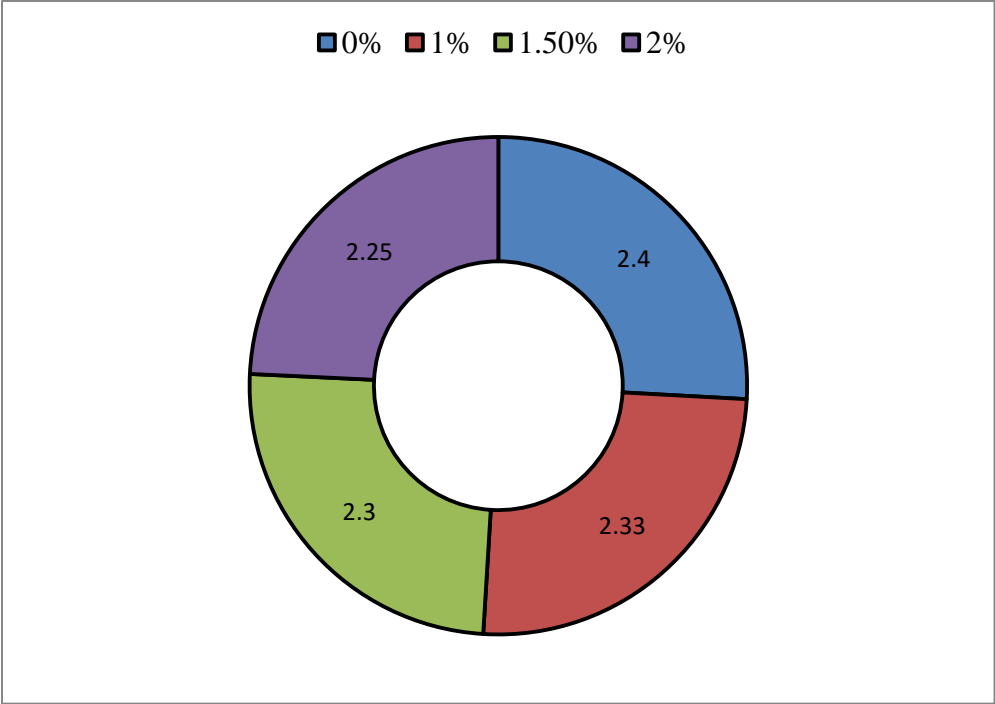
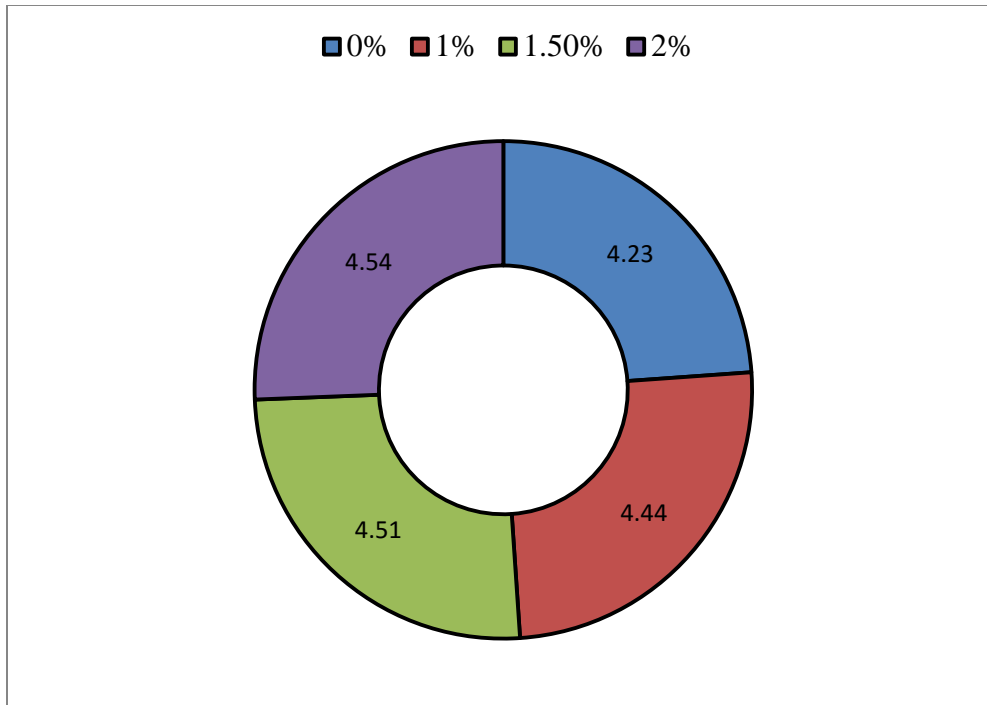


Figure 4.16: Water Absorption at different percentage of Hooked End (4-D) steel fibers



*Figure 4.17: Durability at different percentage of Hooked End (4-D) steel fibers*

As per the work of Shah and Pitroda 2014, the average absorption of the test samples shall not be greater than 5% with no individual unit greater than 7%. Regardless of the use of crimped or hooked end (4-D) fibers in the mixes, the water absorption results of our test fall within the permissible range, so we can say that the pervious concrete so designed is durable. It can also be seen from the Figure 4.14 to Figure 4.17 that durability has increased on addition of steel fibers to the mix with a decrease in water absorption. This can be attributed to the fact that the interconnectivity of porous channels break with addition of steel fibers and thus reduces water absorption and increases durability.

#### **4.5 Variation of Water Absorption & Durability with Fiber Percentage and Type**

The pervious pavement when put in use is often exposed to a variety of salts during the infiltration of water into the subsoil. The salt movement gets restricted in winter due to the freezing of pore water. These salts can have deleterious effects on the quality of ground water and thus effect the functioning of pavement. An attempt has been made through this test to observe the change in water absorption and durability of pervious concrete with addition of steel

fibers. Figure 4.18 and Figure 4.19 show the variation of compressive strength and permeability with different types and percentages of steel fibers.

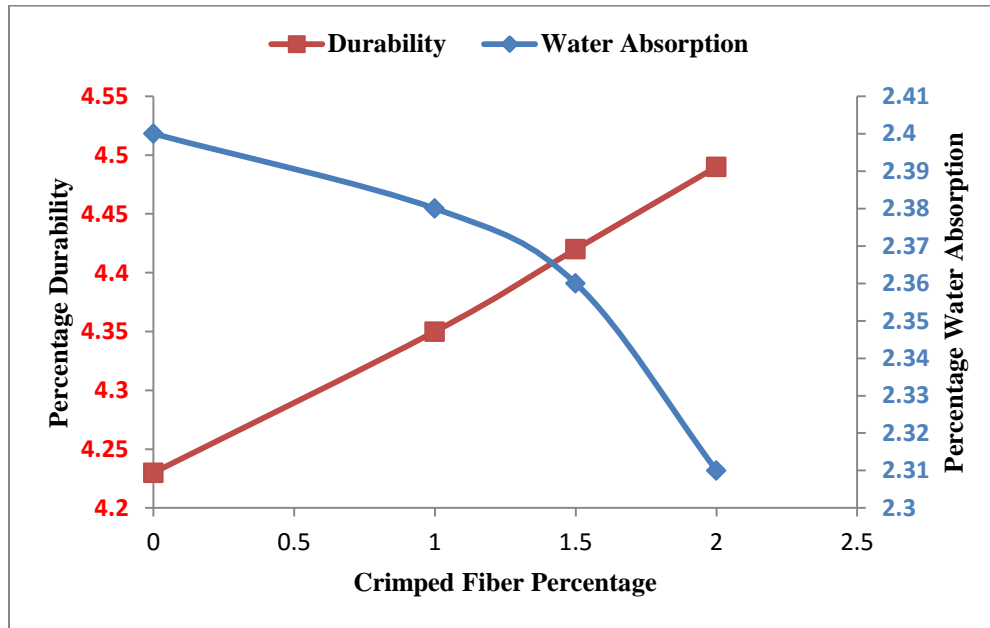


Figure 4.18: Relation b/w durability & water absorption at different percentage of Crimped steel fiber

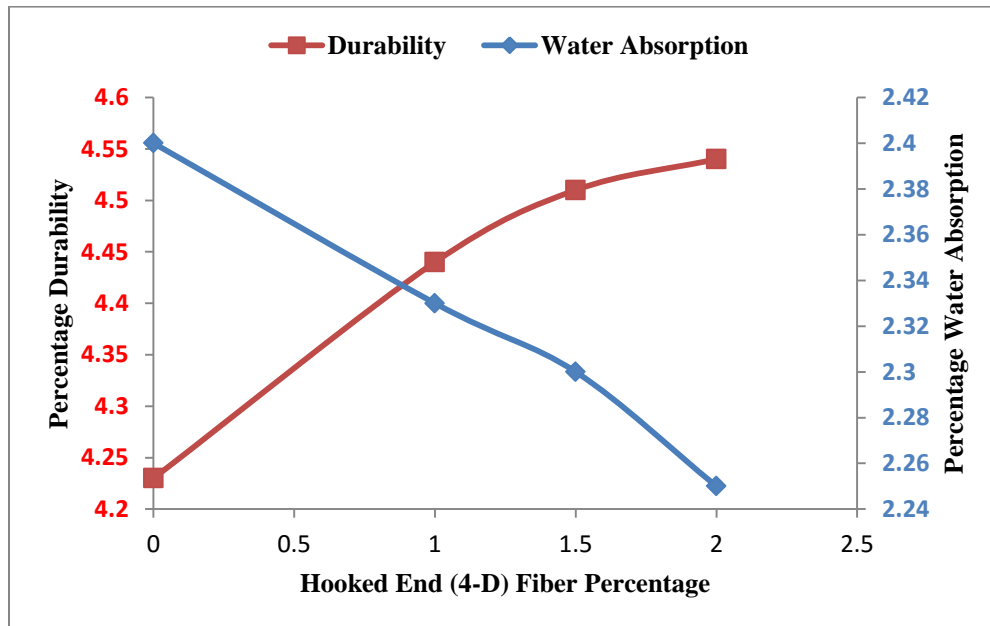


Figure 4.19: Relation b/w durability & water absorption at different percentages of Hooked End (4-D) steel fiber

From the above graphs, it is observed that the average absorption of the test samples is not greater than 5% with no individual unit greater than 7% (Shah & Pitroda 2014). For mixes with hooked end (4-D) fibers, the percentage increase in durability is more because they form a better bond by interlocking between cement paste and aggregates. From these conclusions one main result is found out, i.e., water absorption and durability are inversely proportional to each other.

#### **4.6 Summary**

Based on the test results, we can conclude that the mechanical properties like compressive strength and flexural strength of pervious concrete are increased on adding fibers to the control mix. Water absorption and durability tests give us an inverse relationship between the two properties. Durability increases with decrease in water absorption and vice-versa.

The next chapter deals in the conclusions which are derived from the test results and recommendations have been made on the future scope of this work.

## **5.1 General**

The present research is done to evaluate the flexural strength, compressive strength, permeability durability and water absorption of pervious concrete with different levels of addition of two distinct steel fibers to the concrete mix by its volume.

## **5.2 Conclusions**

Based on the experimental results, following conclusions are drawn:

### 1) Effect of Fibers on Compressive Strength:

- a) Crimped Fiber: The compressive strength was found to increase with increasing percentages of crimped fibers. The compressive strength at 1%, 1.5% and 2% addition of crimped steel fiber to the control mix was increased by 2.12%, 3.13% and 4.19% respectively.
- b) Hooked End (4-D) Fiber: The compressive strength of the mix at 1%, 1.5% and 2% addition of steel fiber to the control mix was increased by 2.84%, 5.11% and 4% respectively. It can be seen that the compressive strength increased at first two increments in the percentage of steel fiber. At 2% steel fiber, a slight reduction in the compressive strength was reported.
- c) Thus, it can be stated that the increase in compressive strength on addition of crimped fibers is not very significant.

### 2) Effect of Fibers on Flexural Strength:

- a) Crimped Fiber: The flexural strength of the control mix increased with increasing percentages of steel fiber. The flexural strength on addition of 1%, 1.5% and 2% steel fiber by volume of concrete was increased by 4.48%, 8.21% and 11.19% respectively. Therefore, the maximum increase in flexural strength with crimped steel fibers was observed at 2% fiber dosage.

- b) Hooked End (4-D) Fiber: The flexural strength of the mix at fiber dosage of 1%, 1.5% and 2% by volume of concrete increased by 11.57%, 19.03% and 16.04% respectively. It can be seen that the flexural strength increased at first two increments in the percentage of steel fiber. At 2% steel fiber, a slight reduction in the flexural strength was reported. It was probably due to the balling effect and uneven distribution of steel fibers in the mix.
  - c) Thus, it can be stated that the increase in flexural strength on addition of crimped fibers was not very significant whereas the increase in flexural strength of pervious concrete mix on addition of hooked end (4-D) fibers at dosages of 1.5% and 2% by volume of concrete was high.
- 3) Effect of Fibers on Permeability:
- a) Crimped Fiber: The permeability of the control mix decreased with increasing percentages of steel fiber. The permeability on addition of 1%, 1.5% and 2% steel fiber by volume of concrete was decreased by 6.25%, 12.5% and 18.75% respectively.
  - b) Hooked End (4-D) Fiber: The permeability of the mix at 1%, 1.5% and 2% addition of steel fiber to the control mix was decreased by 12.5%, 25% and 27.5% respectively. It can be seen that the permeability decreased with increase in the percentage of steel fiber.
  - c) Thus, it can be stated that the decrease in permeability on addition of crimped fibers at dosages of 1% and 1.5% was not very significant. However, the decrease in permeability of hooked end (4-D) fiber reinforced pervious concrete was significant at fiber dosages of 1.5% and 2%.
- 4) Based on the above results, it can be concluded that the hooked end (4-D) fiber showed better strength results than crimped fiber. Based on the test results, the optimum percentage of hooked end (4-D) fiber was found to be 1.5% as the pervious concrete mix reflected the highest compressive and flexural strength values at this percentage. After that there was a slight reduction in the mechanical properties of pervious concrete.

- 5) Based on experimental results, the obtained maximum flexural strength on addition of 1.5% hooked end (4-D) steel fiber was 3.19MPa and thus pervious concrete can be used in parking, pathways, sideways and other low volume traffic roads.
- 6) Water Absorption and Durability are found to be inversely proportional to each other. Durability decreases with increase in water absorption or vice-versa.

### **5.3 Future Scope of Work:**

- 1) There is no prescribed method to design pervious concrete pavements, so this is an area where a lot of work needs to be done.
- 2) A very little work has been done in the field of pervious concrete with steel fibers. The properties of pervious concrete vary with different fiber types and their aspect ratio, so this can be further studied.
- 3) Evaluation of the pervious concrete pavements in terms of its rutting and fatigue performance under wheel load should be carried out by casting trial sections of pervious concrete pavement.

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RECOMMENDED DESIGN PROCEDURE FOR PERVIOUS PAVEMENT

**I-I General:**

This appendix gives the design of a pervious concrete pavement. The behaviour of pervious pavements to traffic and other temperature distresses is considered similar to that of rigid pavements. Thus, pavement slab thickness has been calculated on the basis of IRC: SP: 62-2014 which is the code for design and construction of cement concrete pavements for low volume traffic roads. Since there is no accepted fatigue model for the design of pervious pavement, the fatigue equation given in SP: 62 can be used to evaluate the thickness due to fatigue damage. The hydrological design of reservoir layer has been done using rational formulas to check for the required minimum thickness and the detention time to process the entire volume of water.

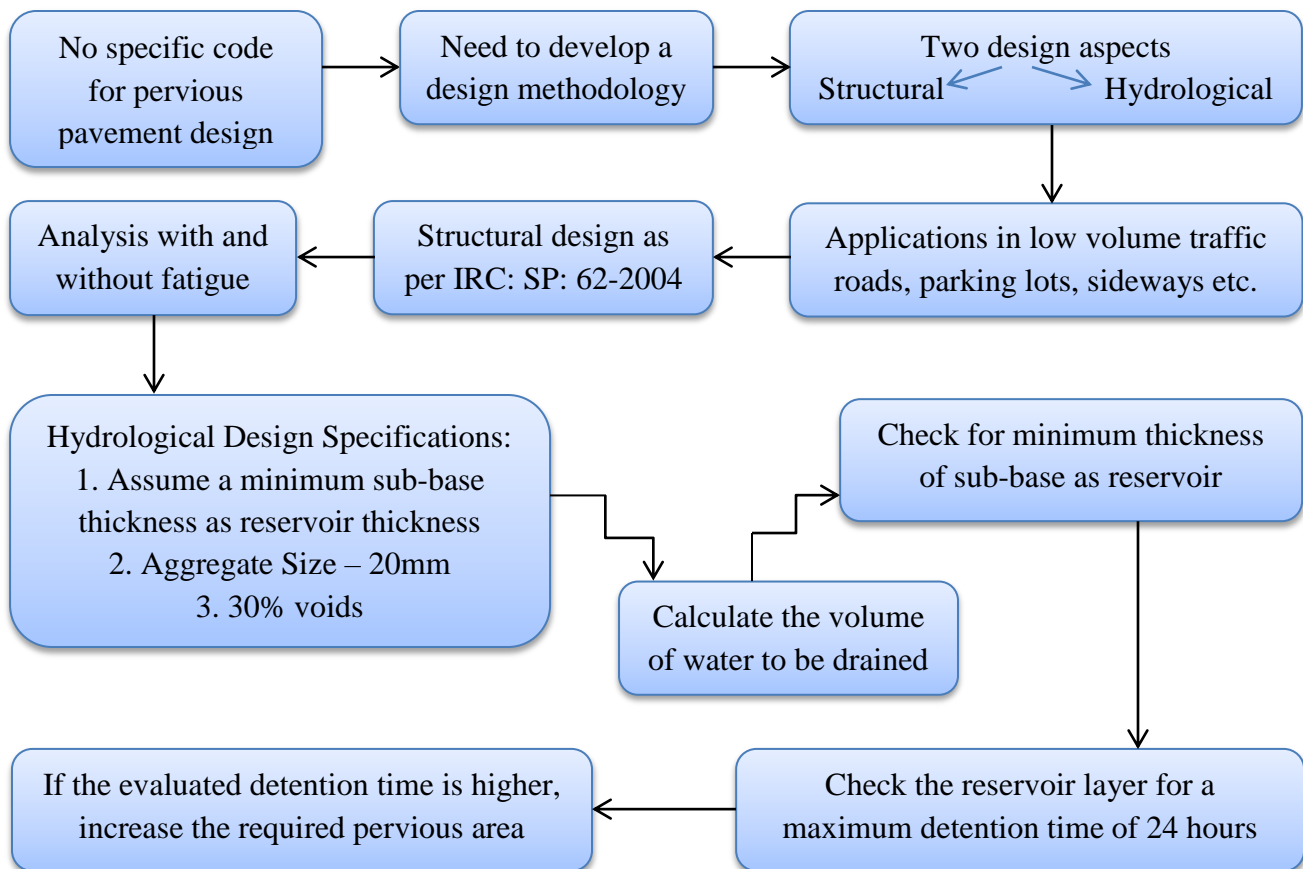


Figure I.I: Flowchart showing the recommended design procedure for Pervious Concrete pavement

## **I-II Design Inputs:**

- Grade of Concrete = M20
- Design Period in years,  $n = 20$  years
- CBR = 8%
- Rate of increase of traffic,  $r = 4\%$  (Assumed)
- Tyre Pressure,  $p = 0.8 \text{ N/mm}^2$  (From IRC: SP: 62 – 2014)
- Load on one wheel of dual set,  $P_d = 50000 \text{ N}$  (From IRC: SP: 62 – 2014)
- Poisson's Ratio,  $\mu = 0.15$  (From IRC: SP: 62 – 2014)
- Modulus of Elasticity of Concrete,  $E = 30000 \text{ N/mm}^2$  (From IRC: SP: 62 – 2014)
- Co-efficient of thermal expansion,  $\alpha = 0.00001/^\circ\text{C}$  (From IRC: SP: 62 – 2014)
- Modulus of Subgrade reaction,  $k = 49 \text{ MPa/mm}$  (From IRC: SP: 62 – 2014, Table 3.1)
- Effective Modulus of Subgrade Reaction,  $k_{\text{eff}} = 58.8 \text{ MPa/mm}$  (From IRC: SP: 62 – 2014, Table 3.2)
- Spacing between centers of dual wheels,  $S_d = 310 \text{ mm}$  (From IRC: SP: 62 – 2014)
- Temperature Differential,  $\Delta T = 13.1^\circ\text{C}$  (From IRC: SP: 62 – 2014, Table 4.1)
- Initial CVPD after completion of the road,  $A = 40$

## **Case I: Analysis and Design of pavement for wheel loads and temperature stresses only:-**

### **Thickness design:**

#### **Step 1: Concrete Strength**

- 28 days Compressive Strength =  $20 \text{ N/mm}^2$
- 90 days Compressive Strength =  $24 \text{ N/mm}^2$  (As per IRC: SP: 62, it is taken as 20% higher than the 28-day compressive strength)
- 28 days Flexural Strength =  $3.2 \text{ N/mm}^2$  (It is taken directly from the test results)
- 90 days Flexural Strength =  $3.52 \text{ N/mm}^2$  (As per IRC: SP: 62, it is taken as 1.10 times the 28-day flexural strength)

Step 2: Total number of cumulative vehicles at the end of design period

$$N = 365 \times A \times \left[ \frac{(1+r)^n - 1}{r} \right] = 434759.9472 \text{ CVPD}$$

Step 3: Radius of Equivalent Surface Area,  $a$  in mm

$$a = \sqrt{\frac{0.8521 Pd}{p\pi} + \frac{Sd}{\pi}} \times \left( \frac{Pd}{0.5227p} \right)^{1/2} = 180.6098988 \text{ mm}$$

**Note:** Here, the value of  $P_d$  is multiplied by 0.5 because  $P_d$  is the load on 1 wheel of dual wheel set.

Step 4: Assume a trial thickness of 220 mm.

Step 5: Assume transverse joint spacing,  $L = 2.75$  m and width of slab,  $B = 3.5$  m

Step 6: Radius of Relative Stiffness,  $I$  in mm

$$I = \left( \frac{Eh^3}{12k(1-\mu^2)} \right)^{1/4} = 824.951639 \text{ mm}$$

Step 7: Edge stress caused by Single or Dual wheel at the edge

$$\sigma_e = \frac{0.803P}{h^2} \left[ 4 \log \frac{I}{a} + 0.666 \frac{a}{I} - 0.034 \right] = 2.281712683 \text{ N/mm}^2$$

Step 8: Bradbury's Co-efficient:

$$C_1 = L/I = 0.2634$$

$$C_2 = B/I = 0.508$$

Therefore,  $C = 0.508$  (higher of  $C_1$  and  $C_2$ )

Step 9: Temperature Stress at Edge

$$\sigma_{te} = \frac{E\alpha t}{2} \times C = 0.99822 \text{ N/mm}^2$$

Step 10: Total Stress (Load Stress + Warping Stress) = 3.279932683 N/mm<sup>2</sup>

**Note:** Total Stress should be less than 90 days flexural strength

Step 11: Corner Load Stress

$$\sigma_C = \frac{3P}{h^2} \times \left(1 - \left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right) = 2.340314954 \text{ N/mm}^2$$

**Note:** Corner Load Stress should be less than 90 days flexural strength

Step 12: According to IRC: SP: 62-2014, when the total CVPD is less than 50, then there is no need for fatigue analysis. Also, the failure of pavement due to wheel loads and temperature stress is very rare as they are least likely to occur simultaneously. But still in this case, we have considered failure due to temperature stress and wheel loads for additional margin of safety.

Since the total stress, i.e., stress due to wheel loads and warping stress is less than the 90 days flexural strength and corner load stress is also less than 90 days flexural strength, so the assumed designed thickness is safe.

**Hydrological Design:**

The hydrological design is based on the Los Angeles County method for the thickness evaluation of reservoir layer.

Step 1: The thickness of sub-base/reservoir layer is assumed as 200 mm.

Step 2: The volume of water to be drained by the pervious concrete pavement can be expressed as:

$$V = [(A_p + A_b) \times I \div 12]$$

Where,

$A_p$  = pervious concrete area in  $\text{ft}^2$

$A_b$  = non-pervious area to be drained in  $\text{ft}^2$

$V$  = volume of water,  $\text{ft}^3$

$I$  = storm intensity in inches = 19 inch (assumed)

Substituting the values we get,

$$V = [(103.60 + 0) \times 19 \div 12] = 164 \text{ ft}^3$$

Step 3: The thickness of sub-base/reservoir layer can be determined as:

$$h_s = [(12 \times V) \div (r_s \times A_p)]$$

Where,

$r_s$  = void ratio of the sub-base/reservoir layer in %

$h_s$  = thickness of the sub-base/reservoir layer in inches.

Substituting the values we get,

$$h_s = [(12 \times 164) \div (30 \times 103.60)] = 0.633 \text{ ft}$$

$$\text{or } h_s = 192.93 \text{ mm}$$

Step 4: It is assumed that the sub-base/reservoir layer will process the entire volume of water, and the maximum detention time is taken as 24 hours. The detention time is then checked to ensure that the pervious concrete pavement structure will be capable of processing the total volume of water in the desired time.

The detention time is given as:

$$t_d = [(12 \times V) \div (A_p \times E)]$$

Where,

$t_d$  = maximum detention time of pervious section (generally 24 hours).

E = permeability/infiltration rate of the soil in inches/hour = 1.5

Substituting the above values we get,

$$t_d = [(12 \times 164) \div (103.60 \times 1.5)] = 12.66 \text{ hours.}$$

The required minimum thickness for sub-base/reservoir is 192.33mm and also since the calculated detention time is less than the maximum detention time, so the provided thickness of 200 mm is safe.

Figure I.I gives the typical section of a pervious concrete pavement.

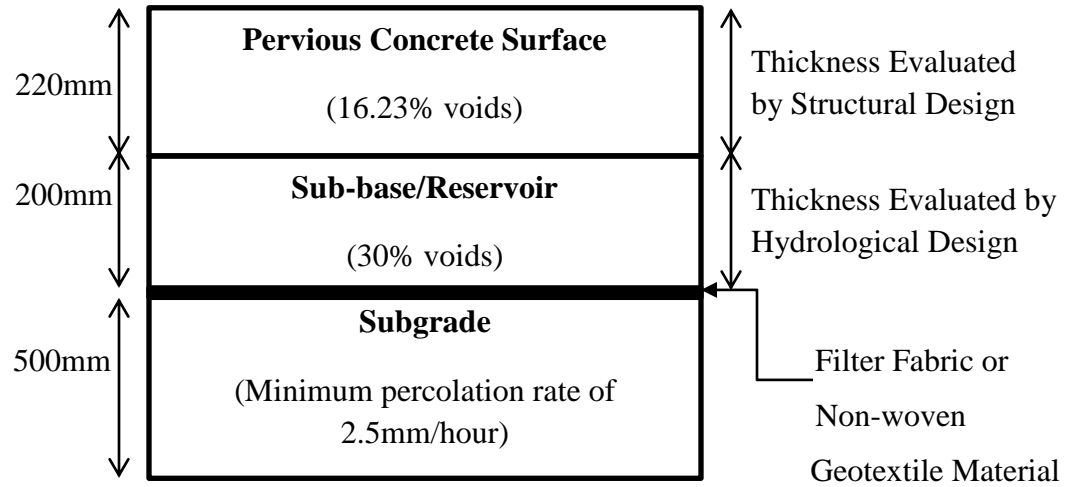


Figure I.II: Typical section of a Pervious Concrete pavement - I

## **Case II: Analysis and Design of pavement for wheel loads and temperature stresses and fatigue:-**

### **Thickness design:**

#### **Step 1: Concrete Strength**

- 28 days Compressive Strength = 20 N/mm<sup>2</sup>
- 90 days Compressive Strength = 24 N/mm<sup>2</sup> (As per IRC: SP: 62, it is taken as 20% higher than the 28-day compressive strength)
- 28 days Flexural Strength = 3.2 N/mm<sup>2</sup> (It is taken directly from the test results)
- 90 days Flexural Strength = 3.52 N/mm<sup>2</sup> (As per IRC: SP: 62, it is taken as 1.10 times the 28-day flexural strength)

#### **Step 2: Total number of cumulative vehicles at the end of design period**

$$N = 365 \times A \times \left[ \frac{(1+r)^n - 1}{r} \right] = 434759.9472 \text{ CVPD}$$

#### **Step 3: Radius of Equivalent Surface Area, a in mm**

$$a = \sqrt{\frac{0.8521 Pd}{p\pi} + \frac{Sd}{\pi} \times \left(\frac{Pd}{0.5227p}\right)^{1/2}} = 180.6098988 \text{ mm}$$

#### **Step 4: Assume a trial thickness of 270 mm.**

#### **Step 5: Assume transverse joint spacing, L = 2.75 m and width of slab, B = 3.5 m**

#### **Step 6: Radius of Relative Stiffness, I in mm**

$$I = \left( \frac{Eh^3}{12k(1-\mu^2)} \right)^{1/4} = 961.9096956 \text{ mm}$$

#### **Step 7: Edge stress caused by Single or Dual wheel at the edge**

$$\sigma_e = \frac{0.803P}{h^2} \left[ 4 \log \frac{I}{a} + 0.666 \frac{a}{I} - 0.034 \right] = 1.65040203 \text{ N/mm}^2$$

#### **Step 8: Bradbury's Co-efficient:**

$$C_1 = L/I = 0.156$$

$$C_2 = B/I = 0.344$$

Therefore, C = 0.344 (higher of C<sub>1</sub> and C<sub>2</sub>)

Step 9: Temperature Stress at Edge

$$\sigma_{te} = \frac{E\alpha t}{2} \times C = 0.67596 \text{ N/mm}^2$$

Step 10: Total Stress (Load Stress + Warping Stress) = 2.32636203 N/mm<sup>2</sup>

**Note:** Total Stress should be less than 90 days flexural strength

Step 11: Corner Load Stress

$$\sigma_C = \frac{3P}{h^2} \times \left(1 - \left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right) = 1.638596096 \text{ N/mm}^2$$

**Note:** Corner Load Stress should be less than 90 days flexural strength

Step 12: Stress Ratio, SR

$$SR = \frac{\text{Flexural Stress due to Wheel Load \& Temp. (Total Stress)}}{\text{Flexural Strength at 90 days}} = 0.660898304$$

Step 13: Allowable Repetition, N<sub>f</sub>

$$\log_{10} N_f = \frac{SR^{-2.222}}{0.523} = 62964.06963$$

Step 14: Expected Repetition, N<sub>e</sub> = 43475.99472

**Note:** the code assumes that expected repetition is 10% of total number of cumulative vehicles at the end of design period.

Step 15: Cumulative Fatigue Damage = 0.690488956 (CFD = N<sub>e</sub>/N<sub>f</sub>)

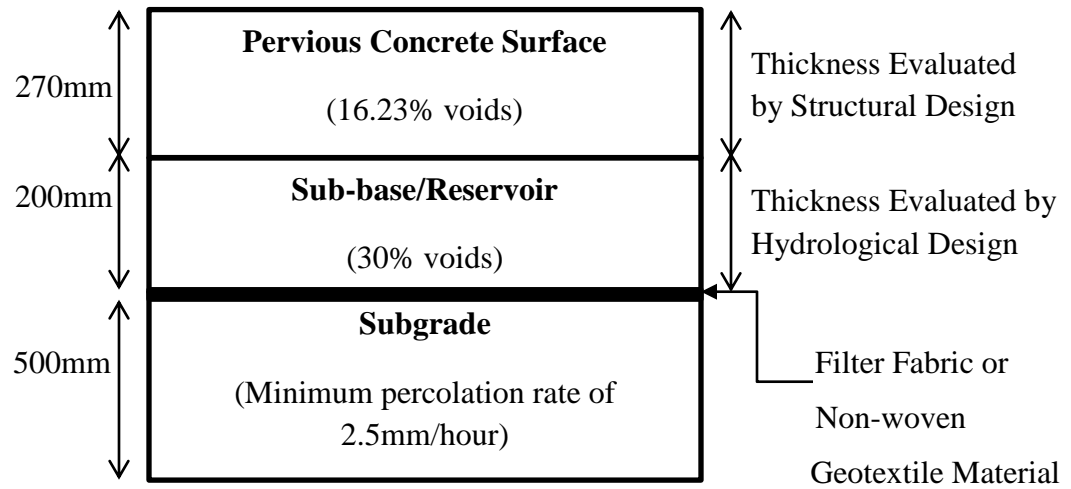
**Note:** CFD should be less than 1 for safety.

Step 16: According to IRC: SP: 62-2014, when the total CVPD is less than 50, then there is no need for fatigue analysis. Also, the failure of pavement due to wheel loads and temperature stress is very rare as they are least likely to occur simultaneously. The fatigue is not considered as there are very low chances of vehicles to pass over such a pavement. But still in this case, we have considered failure due to temperature stress and wheel loads and fatigue for additional margin of safety.

The total stress, i.e., stress due to wheel loads and warping stress is less than the 90 days flexural strength and corner load stress is also less than 90 days flexural strength, so the assumed design thickness in load stress and warping stresses is safe. Fatigue analysis has also been done and the results clearly indicate that is pavement will be safe in fatigue also. So, we can conclude that the provided design thickness is safe.

**Hydrological Design:**

The hydrological design is similar to the design of last case and hence we can provide a sub-base or reservoir layer thickness of 200 mm.



*Figure I.III: Typical section of a Pervious Concrete pavement - II*