

Experimental Study of Pervious Concrete in Pavements

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ABSTRACT: Pervious concrete pavement has been increasingly used to reduce the amount of runoff water. However, due to the significantly reduced strength associated with the high porosity, pervious concrete mixtures currently cannot be used in highway pavement but can be used in sub base, low speed pavements etc. The objective of the present investigation is to evaluate the properties of pervious concrete and compared with the normal concrete. This study also focused on the balance between permeability, strength properties and the various mechanical properties, stress – strain characteristics and permeability characteristics of concrete. The mix proportion for the present study is, 1: 0.3: 5.5 and w/c ratio - 0.4, plasticizer -0.6% , SBR polymer -0.2% respectively. The stresses of different thickness of pervious and normal concrete slab were analysed using KENPAVE software. Based on the results, it indicates that such pervious concrete pavements can be used in parking lots, sidewalks etc.

KEYWORDS: Pervious concrete, Mix proportion, Permeability, KENPAVE, sub base, porosity.

I. INTRODUCTION

“In reviewing technology advances through the centuries it is evident that material development plays a key role. Pervious concrete is an innovative material which is a mixture of coarse aggregate, cement, water and little to no sand along with chemical admixtures, containing a network of holes or voids, to allow air or water to move through the concrete. This allows water to drain naturally through it and allow replenishment of groundwater when conventional concrete does not. This innovative material sometimes called as No Fines Concrete also. Absence of sand or fine aggregate permit the properly placed pervious concrete to have about 15 to 30% of void space, the pores can range from 0.08 to 0.32 inches (2 to 8mm), which permit water to pass through without causing any damage to the matrix of the porous concrete.

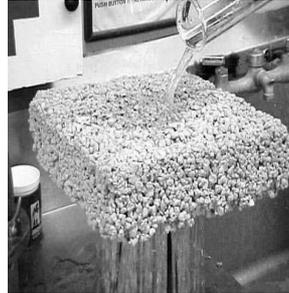
In the recent past due to climatic imbalance land is drying up causing a serious problem. Not only we are experiencing climate change but now 35% to 70% of our construction sites are being covered by paved surfaces and roofs as urban sprawl continues to dominate the landscape. The impervious surfaces block natural water infiltration into the soil, but few of us are ready to give up our paved roads, driveways and parking lots. Rather than building them with conventional concrete or asphalt, more and more communities, municipalities, and businesses are switching to pervious concrete or porous pavement, a material that offers the inherent durability and low life-cycle costs of a typical concrete pavement while retaining storm water runoff and replenishing local watershed systems. Pervious concrete is one such solution for all these problems.

The proper utilization of pervious concrete is a recognized Best Management Practice by the U.S. Environmental Protection Agency (EPA) for providing first-flush pollution control and storm water management as shown in fig. 1.1.

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1.1.APPLICATIONS OF PERVIOUS CONCRETE

Pervious concrete is traditionally used in parking areas, areas with light traffic, pedestrian walkways, and greenhouses as shown in figs. 1.2 and 1.3. It is an important application for sustainable construction. Pervious pavement roadways have seen wider application in Europe and Japan than in the U.S. Properly installed and maintained pervious pavement has a significant life-span, and existing systems that are more than twenty years in age continue to function, because water drains through the surface course and into the sub surface bed. The following are the applications of pervious concrete:

HARDSCAPE

- | | |
|---|-------------------------|
| a) Low-volume pavements | e) Pavement edge drains |
| b) Residential roads, alleys, and driveways | f) Low-water crossings |
| c) Sidewalks and pathways | g) Patios |
| d) Tennis courts | h) Swimming pool decks |

FLOORS

- | | |
|---|--------------------------------------|
| 1.Sub base for conventional concrete pavement | 1.Foundations/floors for greenhouses |
| 2.Slope stabilization | 2.Fish hatcheries, |
| 3.Artificial reefs | 3.Aquatic amusement centres |

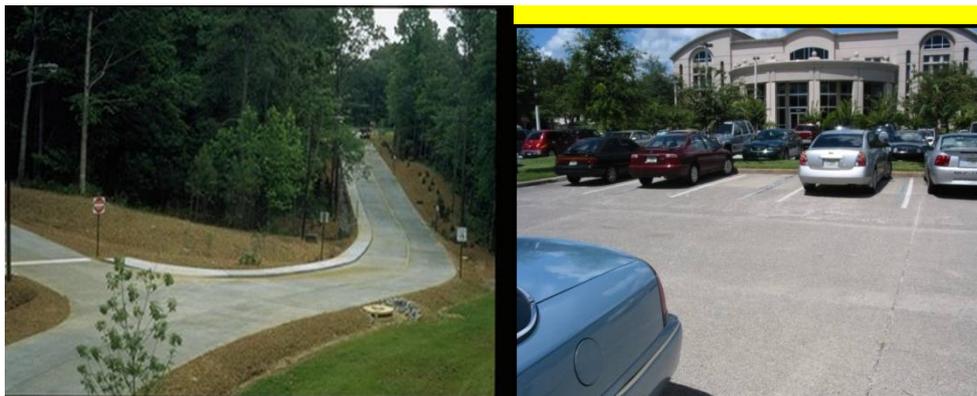


Fig. 1.2 Pervious Pavement Walkways Fig. 1.3 Pervious Pavement Parking Lots

1.2.Advantages

In India, the study of pervious concrete pavement has not been thrown light on it yet, in spite of the following advantages of it:

- Environmental - reduced storm water runoff, recharge groundwater, efficient land use by reducing the need for retention ponds
- Economic - the management effort made in preventing excess runoff during heavy rainfall is prevented. Reduces cost to maintain large detention ponds

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- Safety - increased safety for drivers, improves driving in wet weather conditions, reduces night time glare and lessens the risk of hydroplaning
- Reduced Surface Temperatures, Minimizes the Urban Heat Island Effect
- Extended Pavement Life Due to Well Drained Base and Reduced Freeze-Thaw
- Less Lighting Needed Due to Highly Reflective Pavement Surface

1.3. Limitations: The following are the limitations of the pervious concrete pavement:

- Requires Routine (Quarterly) Vacuum Sweeping
- Requires a Certified Pervious Concrete Craftsman On-site During Installation
- Proper Soil Stabilization and Erosion Control are required to Prevent Clogging
- Quality Control for Material Production and Installation are Essential for Success
- Concrete Must Cure Under Plastic for 7-Days After Installation

1.4 LITERATURE REVIEW:

1. **Jing et al. (2002)** ^[9] used smaller sized aggregate, silica fume (SF) and super plasticizer (SP) in the pervious concrete can enhance the strength of pervious concrete greatly. The compressive strength of the composite can reach 50 MPa and the flexural strength 6MPa.

2. **Baoshan Huang et al. (2009)** ^[2] evaluated the effects of latex, natural sand and fiber on the pervious concrete. Laboratory test such as air void test, permeability test, compressive strength test, split tensile strength test were conducted.

3. **Hao Wu et al. (2011)** ^[6] evaluated the performance of latex-modified pervious concrete with a particular focus on abrasion resistance, Air voids permeability, compressive and splitting tensile strength, and two abrasion resistance tests (Cantabro and APA abrasion tests) were performed for the investigation and evaluation.

4. **Nader et al. (1995)** ^[15] discuss thickness design of no-fines concrete parking lot pavements. Based on the engineering properties of the no-fines concrete mixtures developed in the laboratory, and various traffic conditions and sub grade characteristics, the thickness requirement of no-fines concrete pavements was determined.

5. **Xiang Shu et al. (2011)** ^[20] evaluated the performance of laboratory and field produced pervious concrete mixtures as well as field cores and compared through laboratory performance tests, including air voids, permeability, compressive and split tensile strengths, as well as Cantabro and freeze-thaw durability tests. Two types of coarse aggregate, limestone and granite, with two grading, No. 8 and No. 89 specified in ASTM C33, were used to produce the mixtures.

II. RELATED WORK

2.0 MIX DESIGN:

The various methods available are ACI mix design method, USBR mix design method, British mix design method and Indian Standard method. In this study mix design was done as per Indian Standard guidelines in IS: 10262-2009.

2.1. Data Required for Concrete Mix Design

The various data required for concrete mix design were summarised below:

- | | | |
|--|---|---------------|
| ▪ Specific Gravity of Cement | : | 3.10 |
| ▪ Specific Gravity of Fine Aggregate | : | 2.63 |
| ▪ Specific Gravity of Coarse Aggregate | : | 2.77 |
| ▪ Maximum Size of Coarse Aggregate | : | 20 mm |
| ▪ Fineness Modulus of Fine Aggregate | : | 2.2 |
| ▪ Quality Control | : | Good |
| ▪ Exposure Condition | : | mild exposure |

2.2. Mix Design Procedure – M30

Step – 1: Determination of Target Mean Strength $f'_{ck} \rightarrow f'_{ck} + 1.65 S$

where, f'_{ck} = Characteristic Compressive Strength at 28 day – (30 MPa)

Standard deviation, $S = 5$

$$f'_{ck} = 30 + 1.65 \times 5$$

$$f'_{ck} = 38.25 \text{ MPa}$$

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Step – 2: Selection of Water Cement Ratio:Water cement ratio corresponding to M30 grade for mild exposure conditions was selected. The maximum value of water cement ratio for M30 grade concrete subjected to mild exposure condition is 0.45. Water cement ratio 0.40 was selected for the mix design.

Step – 3: Selection of Water content: Maximum water content for 20mm aggregate = 186 litre

As super plasticizer is used, the water content can be reduced up to 20% and above.

Hence, the water content = 186 x 0.75 = 140 litre
Total water content = 140 litre

Step – 4: Calculation of Cement Content

Water cement ratio = 0.40

Cement = 140 / 0.40 = 350 kg

From Table 3, IS 456, minimum cement content for mild exposure condition is 300 kg/m³
=350 kg/m³ > 320 kg/m³

Step – 5: Proportion of Volume of Coarse Aggregate and Fine Aggregate Content : From Table 3, IS 10262:2009, Volume of coarse aggregate corresponding to 20mm size aggregate and fine aggregate (Zone III) for water cement ratio is 0.5 = 0.64.

In the present case water cement ratio is 0.40. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water cement is lower by 0.10 the proportion of volume of coarse aggregate is increased by 0.02.

The Volume of Coarse aggregate for the water cement ratio of 0.40 = 0.66

The Volume of fine aggregate content = (1 – 0.66) = 0.34

Step – 6: Mix Calculation: The mix calculation per unit volume of concrete shall be as follows:

- Volume of Concrete (a) = 1 m³
- Volume of Cement (b) = (Mass of cement / Specific gravity of cement) x (1 / 1000)
= (350 / 3.15) x (1 / 1000)
= 0.111 m³
- Volume of water (c) = (Mass of water / Specific gravity of water) x (1/1000)
= (140 / 1) x (1 / 1000)
= 0.140 m³
- Volume of all in aggregate (d) = [a – (b+c)]
= 1 – (0.111+ 0.140)
= 0.749 m³
- Mass of Coarse Aggregate (e) = d x Volume of Coarse Aggregate x specific gravity of Coarse Aggregate x 1000
= 0.749 x 0.66 x 2.77 x 1000
= 1369.32 kg
- Mass of Fine Aggregate (f) = d x Volume of Fine Aggregate x Specific Gravity of fine aggregate x 1000
= 0.749 x 0.34 x 2.63 x 1000
= 669.76 kg

Therefore total quantity of fine and coarse aggregate = 1369 + 670 = 2039 kg

For pervious concrete only 5% of sand is considered for the mix design = (0.05 x 2039) = 102 kg.

Hence the final mix proportion per m³ of pervious concrete is as follows

Water	Cement (kg)	Sand (kg)	Coarse Aggregate (kg)
140	350	102	1937

Mix ratio of pervious concrete for the experimental study is **0.4: 1: 0.3: 5.5**

III. EXPERIMENTAL SETUP

In engineering practice the strength of hardened concrete are determined by:

- a) Compressive strength
- b) Split tensile strength
- c) Flexural strength
- d) Permeability
- e) Poisson's Ratio Test



Fig.1 Compression Test Subjected to Compression

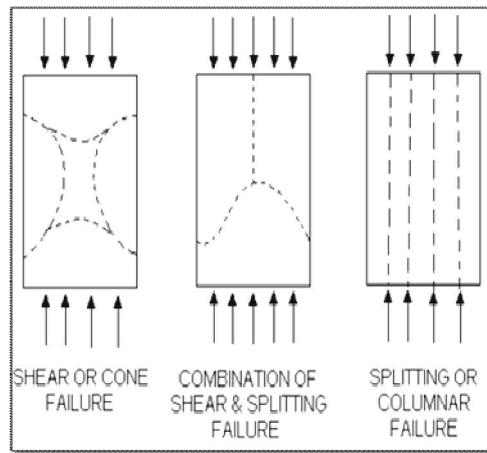


Fig.2 Failure Pattern of Specimen on Pervious Concrete Cubes

The test for determining compressive strength for concrete employs a cube specimen of 150mm size and cured for 3, 7, and 28 days which is subjected to compression in a compression testing machine as shown in fig.3. The use of 150mm cubes have been made as per IS: 516-1959 & IS 456-2000.



Fig. 3 Split Tensile Test on Pervious Concrete Cylinders

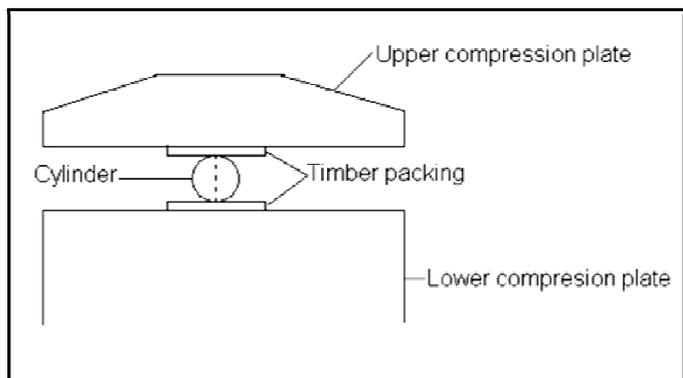


Fig.4 Split Tensile Test Arrangement

This is an indirect test for tensile strength of concrete. The cylinder specimen having 150mm diameter and 300mm length made and cured in the same manner as similar to compressive test. The tensile strength computed in this manner is apparently about 15% higher than that determined by direct tension tests. The test setup is shown in fig.3.

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Fig.5 Flexural Test on Pervious Concrete Prism

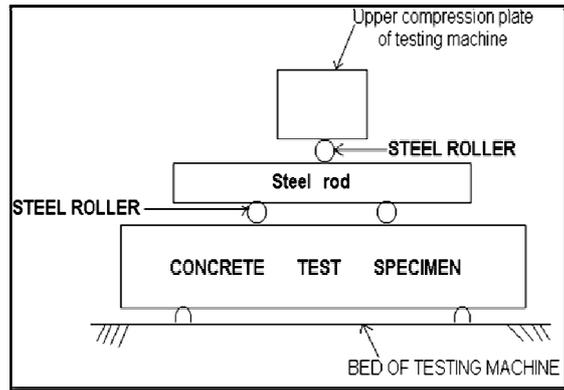


Fig.6 Flexural Test Arrangement

When concrete is subjected to bending, tensile, compressive stresses and in many cases direct shearing stresses occur. The most common example of concrete structure subjected to flexure are highway pavements and the strength of concrete for pavements is commonly evaluated by means of bending tests on 100x100x500mm beam specimens. Flexural strength is expressed in terms of “Modulus rupture” which is the maximum tensile (or compressive) stress at rupture. The setup for the flexural test is given in fig.5.

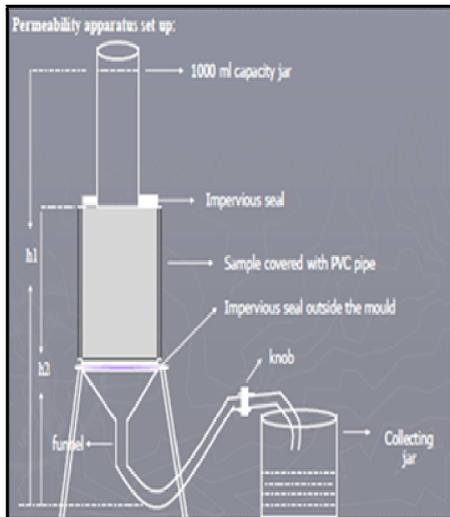


Fig.7 Permeability Test Arrangement



Figure8 Poisson's Ratio Test Arrangement



Fig.9 Pervious Concrete



Fig. 10 Normal concrete Cubes



Fig.11 Pervious Concrete Cylinders



Fig. 4.13 Normal Concrete Cylinders

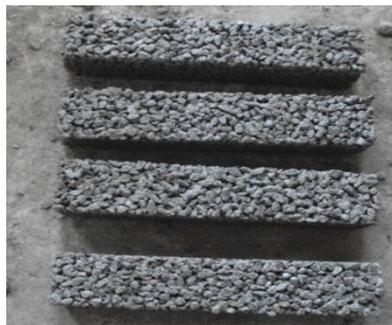


Fig. 4.14 Pervious Concrete Prisms



Fig. 4.15 Normal Concrete Prisms

IV.RESULTS

- The result of the study made on pervious concrete (PC) and normal concrete (NC) and their strength characteristics calculated in accordance with IS 456:2000 requirement are presented under various headings and tabulated in various tables and graphs

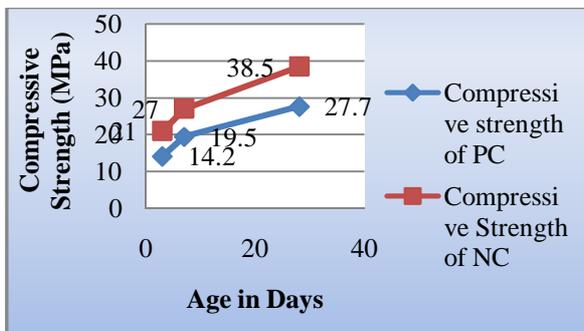


Fig.4.1 Compressive Strength vs. Age Plot

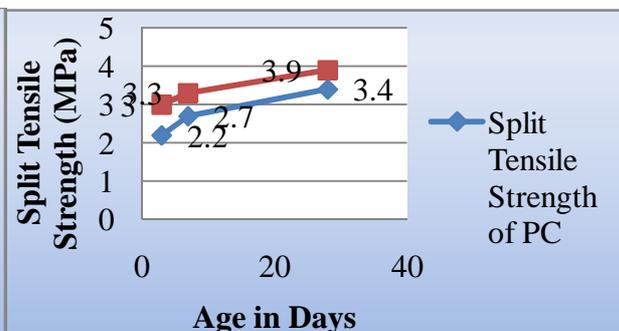


Fig.4.2 Split Tensile Strength vs. Age Plot

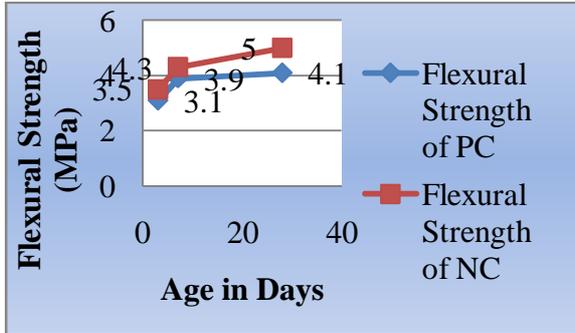


Fig. 4.3 Flexural Strength vs. Age Plot

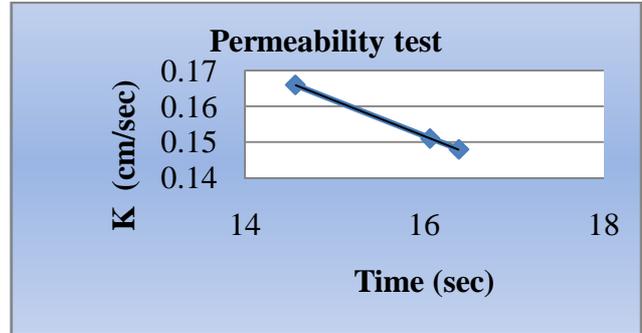


Fig. 4.4 Co-efficient of Permeability vs. Time

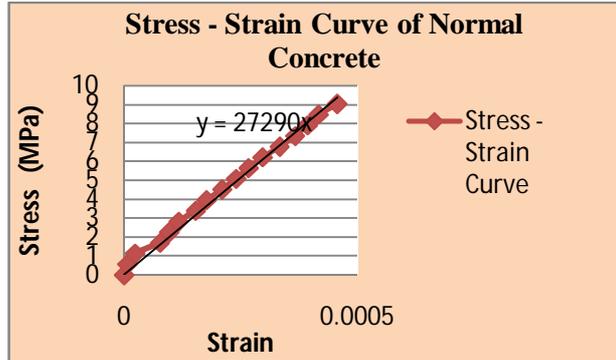
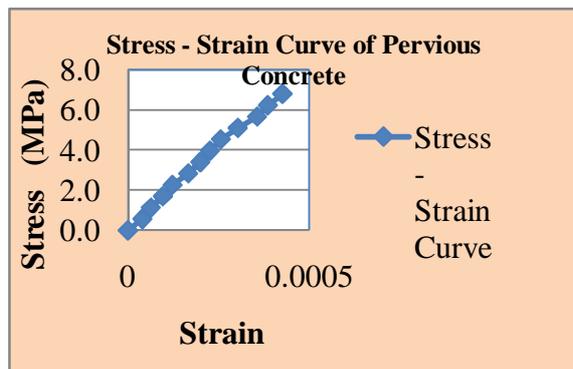


Fig. 4.5 (a) Young's Modulus for Pervious Concrete Specimen Fig. 4.5(b) Young's Modulus for Normal Concrete Specimen

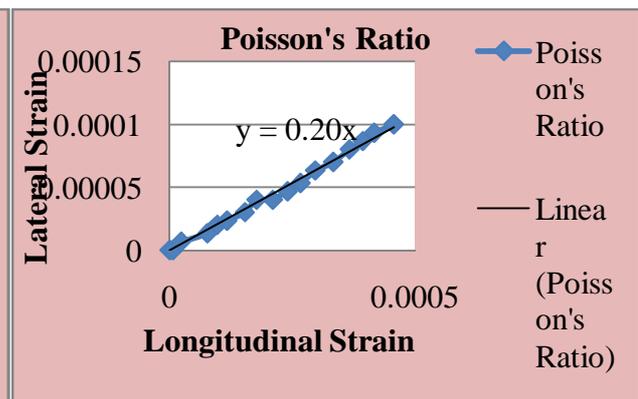
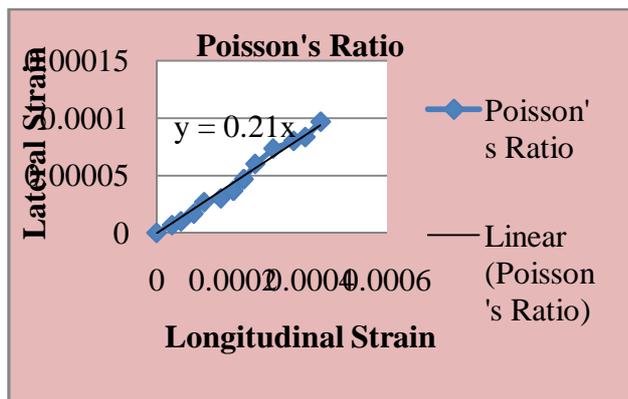


Fig. 4.6 (a) Poisson's Ratio for Pervious Concrete Specimen

Fig. 4.6(b) Poisson's Ratio for Normal Concrete Specimen

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V. RESULTS BASED ON ANALYTICAL STUDIES

4.1 INTRODUCTION: The four separate computer programs, viz. LAYERINP, KENLAYER, SLABSINP, KENSLABS, together with some other graphics programs are combined together to form a software called KENPAVE. KENPAVE was written in visual basic and brief summary of its most important features are presented in this chapter.

4.1.2. Program Description: KENSLABS, together with its input program SLABSINP & graphic programs SGRAPH CONTOUR, is part of a computer package called KENPAVE. In its present dimensions, it can be applied to a maximum of 6 slabs, 7 joints, & 420 nodes. Each slab can have a maximum of 15 nodes in the x-direction & 15 nodes in the y-direction. Damage analysis can be made by dividing each year into a maximum of 12 periods, each with a maximum of 12 load groups. Similar to LAYERINP, a program named SLABSINP can be used to create & edit data files.

4.1.3. INPUT PARAMETERS FOR PERVIOUS CONCRETE SLAB

- 1) Thickness of pervious concrete slab = 4 in (10.1 cm), 6 in (15.2 cm), 8 in (20.3 cm), 10 in (25.4 cm)
- 2) Modulus of elasticity of pervious concrete = 2.4×10^6 psi (1.68×10^5 kg/cm²)
- 3) Poisson ratio of pervious concrete = 0.21
- 4) Contact pressure = 40 psi (2.81kg/cm²)
- 5) Poisson ratio of soil = 0.45
- 6) Contact radius = 4.81 in (12.2 cm)
- 7) Modulus of sub grade of soil= 20000 psi (1460 kg/cm²)

4.1.5 INPUT PARAMETERS FOR NORMAL CONCRETE SLAB

- 1) Thickness of normal concrete slab = 4 in (10.16 cm), 6 in (15.2 cm), 8 in (20.3 cm), 10 in (25.4 cm)
- 2) Modulus of elasticity of NC = 3.95×10^6 psi (2.78×10^5 kg/cm²)
- 3) Poisson ratio of normal concrete = 0.20
- 4) Contact radius = 4.81 in (12.2 cm)
- 5) Poisson ratio of soil = 0.45
- 6) Contact pressure = 40 psi (2.81kg/cm²)
- 7) Modulus of sub grade of soil= 20000 psi (1460 kg/cm²)

Table 4.2 Corner Loading Stress for Different Table 4.3 Edge Loading Stress for Different

Pervious Concrete Thickness of Slab (mm)	Corner Loading Stresses (MPa)			
	X direction		Y direction	
	Max -ve	Max +ve	Max -ve	Max +ve
101	0.001	0.168	0.785	0.311
152	0.000	0.163	0.391	0.263
203	0.000	0.141	0.227	0.201
254	0.000	0.118	0.148	0.151

Pervious Concrete Thickness of Slab (mm)	Edge Loading Stresses (MPa)			
	X direction		Y direction	
	Max -ve	Max +ve	Max -ve	Max +ve
101	1.389	0.284	0.473	0.187
152	0.892	0.172	0.216	0.129
203	0.621	0.103	0.123	0.090
254	0.459	0.066	0.079	0.065

4.4 OUTPUT: The output from the KENPAVE analysis is taken and the results are arrived.

4.5 Edge Loading Stress for Different Thickness of NC & Interior Loading Stress for Different NC

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Table-4.6 Edge Loading Stress for Different Thickness of NC **Table-4.7 Interior Loading Stress for Different**

Normal Concrete Thickness of Slab (mm)	Edge Loading Stresses (MPa)			
	X direction		Y direction	
	Max -ve	Max +ve	Max -ve	Max +ve
101	1.629	0.345	0.473	0.230
152	1.010	0.168	0.214	0.148
203	0.689	0.104	0.122	0.100
254	0.503	0.068	0.079	0.070

Normal Concrete Thickness of Slab (mm)	Interior Loading Stresses (MPa)			
	X direction		Y direction	
	Max -ve	Max +ve	Max -ve	Max +ve
101	1.102	0.122	1.189	0.122
152	0.619	0.053	0.658	0.050
203	0.401	0.030	0.423	0.021
254	0.284	0.019	0.297	0.009

Fig. 4.6. Comparison of Max -Ve Stress of PC and NC in X Direction

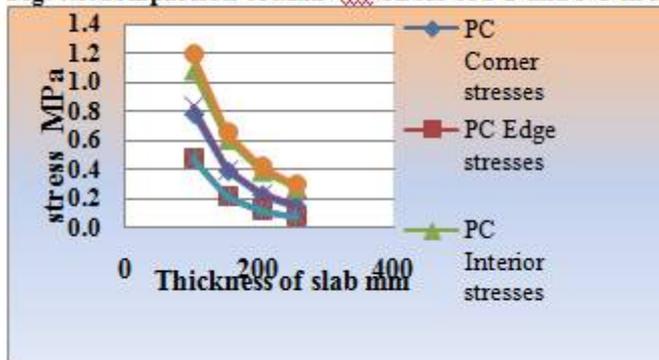


Fig. 4.7 Comparison of max +ve stress of PC and NC in X direction

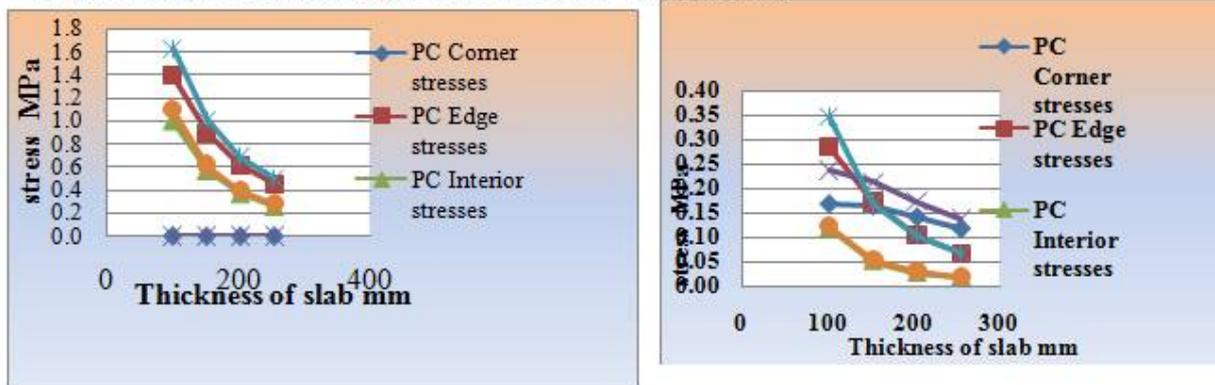


Fig. 4.8 Comparison of Max -Ve Stress of PC and NC in Y Direction

Figs. 4.6, 4.7, 4.8, and 4.9 show that with the increase in thickness of slab stress in both normal and pervious concrete slab decreases.

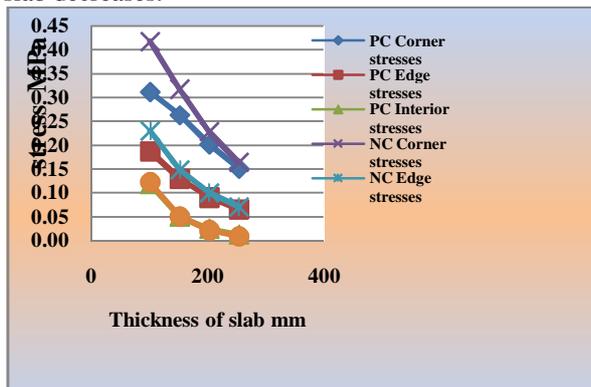


Fig. 4.9 Comparison of Max +Ve Stress of PC and

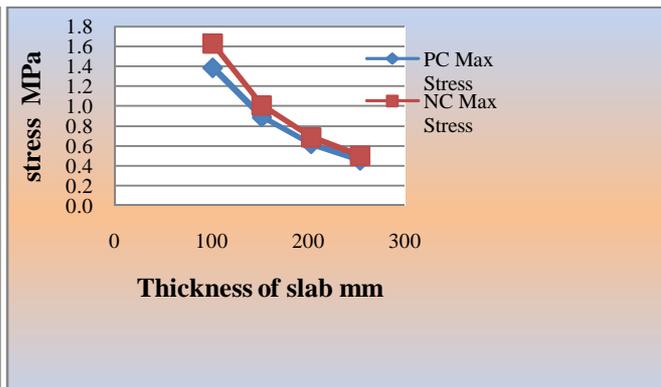


Fig. 4.10 Stress Vs Thickness of Slab NC in Y Direction

Fig. 4.10 shows the normal concrete edge stresses are slightly more compare to pervious concrete edge stresses, but as thickness of slab increases, difference between normal and pervious concrete edge stresses also decreases.

V.CONCLUSION

5.1 SUMMARY AND CONCLUSION:Pervious concrete is a viable material that has the potential to replace the use of traditional concrete pavements in situations where heavy traffic is limited such as car parks, residential streets and driveways. More widespread applications may be possible if methods of reducing the ravelling that occurs within the top surface of pavement. The objective of this thesis was to determine the properties of the pervious concrete and its applicability as a parking lot pavement. The following are the major conclusions of the investigation are:

1. pervious concrete mix proportion obtained after trial mix is :
1: 0.3: 5.5, 0.4. Glenium B233 - 0.6% and Rheomix 141 - 0.2% by weight of cement.
2. Compressive strength of normal concrete is 38.5 MPa, for pervious concrete is 27.7 MPa, which is 39% less than normal concrete.
3. Split tensile strength of normal concrete is 3.9 MPa, for pervious concrete is 3.4 MPa, which is 15% less than normal concrete
4. Modulus of rupture of normal concrete is 5 MPa, for pervious concrete is 4.1 MPa, which is 22% less than normal concrete
5. The experimental observations have shown an average Co-efficient of permeability as 0.155 cm/sec.
6. The Young's modulus of pervious and normal concrete is 16478 N/mm² and 27290 N/mm² respectively.
7. The Poisson's ratio of pervious and normal concrete is 0.21 and 0.20 respectively.
8. Stresses in both normal and pervious concrete slab decreases as thickness of slab increases.
9. Edge stresses are more critical compared to corner and interior stresses.
10. Normal concrete edge stresses are slightly more compared to previous concrete edge stresses, but as thickness of slab increases, difference between normal and pervious concrete edge stresses also decreases.
11. Maximum slab stresses of normal and pervious concrete are 1.629 and 1.389 MPa respectively. The flexural strengths of normal and pervious concrete are 5 and 4.1 MPa respectively. Therefore pervious and normal concrete slab will not suffer structural damage under the design load.

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