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DEVELOPMENT OF MIX DESIGN OF PERVIOUS CONCRETE

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Abstract: An experimental investigation is conducted to develop a standard procedure of the mix design of pervious concrete for strength and permeability aspects.The design is carried out by first fixing the % void that the required and then finding a method to control the voids in pervious concrete while casting samples. The compressive strength and permeability graphs with water cement ratios are developed for determination of the proper water cement ratio for the preparation of mix to get the requisite strength and permeability. The same thing is repeated with superplasticizer to get the mix design of pervious concrete with superplasticizer and study its effects on compressive strength, permeability, density of sample and % voids. At the end both the mix designs with superplasticizer and without superplasticizer are compared and conclusions are drawn.

This research investigates the effects of varying water-cement ratios and the addition of a polycarboxylate-based mid-range water reducing (MRWR) superplasticizer on the properties of pervious concrete. Mixes were prepared with water-cement ratios of 0.300, 0.325, 0.350, and 0.375 without superplasticizer and with water-cement ratios of 0.270, 0.300, 0.320, and 0.350 with the superplasticizer.

Compressive strength increased with the addition of the superplasticizer, reaching peak values at lower water-cement ratios compared to mixes without the superplasticizer. Permeability and void ratio showed a complex relationship with water-cement ratio, with optimized compaction and hydration occurring at specific ratios.

Keywords: Mix Design, Concrete Strength, Superplasticizer, Mid-Range Water Reducing (MRWR), Water Cement

1. Introduction

Ground water is a renewable resource, its availability is progressively declining worldwide, depletion and with rapid urbanization we are on one hand increasing the demand of fresh water and on the other hand we are also depleting the rate of recharge of ground water by making more and more land impermeable by covering it with concrete..

Pervious concrete (porous concrete, permeable concrete), also called no fines concrete is a special type of concrete that has percentage voids between 15% to 25% (normally)

The design of pervious concrete is influenced simultaneously by compressive strength and permeability.

1.1 Pervious Concrete

One material that is intended to be water-permeable is called pervious concrete. This is accomplished by creating a concrete mix with a low water-binder ratio. Large gaps are created as a result, and the concrete begins to permeate quickly. Low strength and variable durability conditions are also the result of this.

1.2Advantages over traditional concrete:

1. Significantly reducing the risk of hydroplaning and road glare caused by damp surfaces.
2. Minimizing noise levels resulting from the contact of a car's tires with the pavement.
3. The ground absorbs any storm water runoff, hence reducing the demand for water-retention zones.

1.3 Disadvantages over traditional concrete:

1. longer curing periods because of early drying brought on by the open structure and low w/c.
2. it causes poor workability and makes it harder to place and compact concrete.
3. traditionally, a lack of standardized testing procedures has resulted from little utilization of the content.
4. Poor performance when using road salts in freeze/thaw situations.

1.4 Construction of pervious pavements

To ensure that the water that percolates through the concrete is directed away from the construction rather than staying in the layer of concrete, the use of pervious concrete necessitates a sub-base with an appropriate percolation rate. The process of installing a pervious concrete pavement begins with the preparation and installation of a sub-base and sub-grade, that can drain the necessary volume of water as specified by the designer.

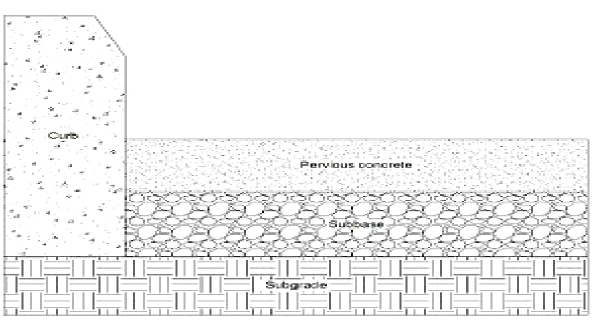

Figure 0:1 Construction of a permeable pavement

Additionally crucial are the pervious concrete's placement and compacting. Because the material's binder-coated grains have a somewhat dry surface This means that the effectiveness of pervious concrete is greatly influenced by the proper management of the material.

1.5 Objective of Study

- The present study aims to establish a method to control the % voids in the pervious concrete within the permissible concrete.
- It also aims to develop readily available data (compressive strength and permeability curves with water cement ratios) for designing pervious concrete mix at a particular percentage of voids.
- The presents study also aims to study the effect of water reducers (super plasticizer) on the mix design (compressive strength, permeability and void ratios) and compare them with the results of mix without super plasticizer.

2. Literature Review

(Muttuvelu & Kjems, 2021) [1]This work reviews the literature with an emphasis on permeable pavements, particularly those made of permeable subbase material. Traditionally, surface runoff is allowed to pass through a drainage system, keeping the roads dry. The infrastructure is under pressure from excessive rains and intense rainfalls brought on by climate change. Water in subbase materials has historically been shown to shorten pavement design lifespans and resilience E-moduli. Research indicates that a conventional subbase material's bearing capability decreases with increasing saturation.

(Sonebi et al., 2016)[2] States that specifically, increased precipitation is probably occurring in many geographic places as a result of the effects of urbanization and the growing threat of global warming. As a sustainable urban drainage system (SUDS), Portland cement pervious concrete (PCPC) has been significantly improving environmental conditions for a number of years. By absorbing pollutants, this kind of porous concrete can lessen the likelihood of flooding, replenish groundwater, lessen runoff and peak flows, lessen the amount of precipitation that strains overworked drainage systems, and enhance water quality. The advantages of adopting PCPC to reduce stormwater issues are particularly important in metropolitan settings.

(Ćosić et al., 2015)[3] This research looks into how the size and kind of aggregates affect the characteristics of pervious concrete. Five distinct concrete mixtures were made: one thick concrete mixture, typical; four pervious concrete mixtures with different aggregate types (steel slag or dolomite) and different proportions of 4–8 mm to 8–16 mm aggregate fractions (30:60 or 60:30). The findings imply that concrete mixtures with higher densities and greater flexural strength were produced .

Offenberg (2009)[4] proposed a lab test to evaluate the surface durability of pervious concrete, detailed in his paper "Demonstrating the Durability of Pervious Concrete." He noted that raveling in conventional concrete often results from poor batching, handling, or curing, but can still occur in pervious concrete even with proper procedures. He examined various ASTM test methods for assessing pervious concrete's surface durability and found most unsuitable, except for ASTM C131 (2006), the Los Angeles Abrasion Test. The research team believed a similar, less rigorous method could assess pervious concrete's surface durability. They modified ASTM C131 (2006) to develop a protocol: a 4-inch high by 4-inch diameter cylinder is rotated 50 times in the steel chamber without steel balls. Mass is recorded before and after to calculate mass loss.

2.1 Research Gap

1. Most studies have not established any method for controlling the voids in the pervious concrete.
2. None of the above studies provide a complete method for designing a pervious concrete mix for a particular compressive strength and permeability at particular %voids.
3. The role of superplasticizer on water cement ratio and compressive strength is not studied.

3. Material Used for Experimental Purpose

3.1 Various materials used as per I.S. Code specifications.

3.1.1Cement

The study used ordinary Portland cement grade 43, which complies with (IS 8112, 1989) for the Jaypee cement brand.

Table 0:1Physical properties of Ordinary Portland Cement

S.No.	Properties	Results
1.	Unitweight	3.15
2.	Specific gravity	1.20
3.	Normalconsistency	35%
4.	Initialsettingtime	52min.
5.	Finalsettingtime	280min.
6.	Soundness	2mm
7.	Fineness	6%

3.1.2 Water

The water used in the preparation of mix as well as in the curing of test specimen is fresh tap portable water.

3.1.3 Superplasticizers

Because the new polycarboxylate-based MRWR is an excellent cement dispersion that enables the production of pervious concrete with low water to cementitious material ratios, a polycarboxylate-based mid-range water reducing (MRWR) additive has been used.

3.1.4 Aggregates

Fine aggregate in the preparation of test specimens has not been used (IS 383, 1970). We only have used coarse aggregates of size 20mm and 10mm having fineness modules 7.12 and 5.54 respectively.

Table 0:2Sieve analysis of coarse aggregate of 20 mm and10mm size

ISSieve	Cumulative Retained (inkg)	Cumulative retained (20mm)	Cumulative Retained (10mm)
20 mm	0.240	12	0
10 mm	2	100	1.85
4.75mm	2	100	56.85
2.36mm	2	100	96.85
1.18mm	2	100	98.25
600µ	2	100	100
300µ	2	100	100
150µ	2	100	100
<150µ	-	-	-
Total		712	553.8
Fineness Modulus		7.12	5.538

Table 0:3Propertiesofaggregatesused

Aggregate size	Fineness Modulus	Unitweight (in gm/c.c.)	Specific gravity
20 mm	7.12	1.75	2.6
10 mm	5.54	1.89	2.6

3.2 Mix Proportion Details

4 batches of Concrete mixes with w/c ratio of 0.300, 0.325, 0.350 and 0.375 are prepared to cast 3 cubes for each batch first without superplasticizer and then with super plasticizer for w/c ratio of 0.27, 0.30, 0.32 and 0.35. Proportion of 10- and 20-mm aggregates is taken as 1:1 as this ratio has given us the maximum rodded aggregate density so we need least cement paste for this to get the maximum strength. Mix is prepared to get the void % of 20%

3.21**Mix without superplasticizer**

Table 0:4Mix proportion for the mix without superplasticizer for 20% void (Consumption per m^3)

w/c	Water (inkg)	Cement (in kg)	C.A. (10mm)	C.A. (20mm)	Proportions W:C:CA(10):CA(20)	Slump (mm)
0.300	96.90	323	767	767	0.300:1:2.37:2.37	78
0.325	104.98	323	767	767	0.325:1:2.37:2.37	87
0.350	113.05	323	767	767	0.350:1:2.37:2.37	95
0.375	121.12	323	767	767	0.375:1:2.37:2.37	105

3.2.2Mix with superplasticizer

We use Master Glenium SKY8566 (0.3% by weight of cement) in all batches by dissolving it in water that is then added to the mixer for mixing.

Table 0:5Mix proportion for the mix with superplasticizer for 20% void (Consumption per m^3)

w/c	Water (in kg)	Cement (in kg)	C.A. (10mm)	C.A. (20mm)	Proportions W:C:CA(10):CA(20)	Slump (mm)
0.270	87.21	323	767	767	0.270:1:2.37:2.37	97
0.300	96.90	323	767	767	0.300:1:2.37:2.37	115
0.320	103.36	323	767	767	0.320:1:2.37:2.37	124
0.350	113.05	323	767	767	0.350:1:2.37:2.37	135

3.3 Test on concrete

After mixing the mixture is taken out and poured in a big tray for check workability by slump test and for filling of molds.(IS:456, 2000)

3.3.1 Permeability test

1. First of all a neat and clean pipe of rectangular cross section (150mmx150mm) made of transparent material is taken.
2. Then the concrete specimens are fitted into the pipe through one end and the corners, gaps and the interface of the pipe and concrete edges is sealed withclay so that the water is made to pass through the concrete only
3. The pipe is then made to stand up side down with specimens on lower side
4. The water is then filled in the pipe with the face of concrete covered with plastic sheet to block the water in pipe as shown in figure 3.4.
5. Afterfillingthewatertosufficientheightthepla sticsheetisremovedsuddenly and the water starts flowing through the concrete as shown in figure 3.5.
6. The time taken by water to fall through a height say h (h1– h2) is noted and then the permeability is found by Darcy law, that is

$$v=K*i$$

$$\text{Permeability (K)} = ((2.3*H*\log_{10} * (\frac{h1}{h2}))/t)$$

7. The above method is based on falling head permeability test.

3.3.2 Compressive strength test

1. A compression testing machine and with a capacity of 2000 KN, is used to measure the specimens' compressive strength (IS 516, 1959).
2. Weight of the specimens is taken one by one just before compressive testing.
3. The bearing surfaces or plates of the machine are cleaned.
4. Subsequently, the stress is applied steadily and gradually until the specimen fails, at which point the final load is recorded from the display.

4. Result & Discussions

4.1 Without Superplasticizer

Below table displays the mix's compressive strength, permeability, and void ratio.

Table 0:6Permeability, percentage of void ratio, and compressive strength of all four batches without super plasticizer

Water Cement Ratio (w/c)	Weightofthe specimen(Kg)		Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Average Permeability (mm/s)	Average% void (by volume)
0.300	7.10	7.23	14.60	14.90	6.80	19.36
	7.50		15.55			
	7.10		14.57			
0.325	7.20	7.33	16.00	16.74	5.48	20.84
	7.40		17.11			
	7.40		17.11			
0.350	7.50	7.46	20.22	19.62	4.58	20.84
	7.90		19.11			
	7.00		19.55			
0.375	7.70	7.40	17.33	16.41	5.17	22.29
	7.20		15.20			
	7.30		16.71			

1. The permeability of the specimens of same batch is measured multiple times and average is reported.
2. The weight of the specimens is taken just before compressive strength test.
3. The second column of weight represents the average weight of the three specimens of that w/c ratio

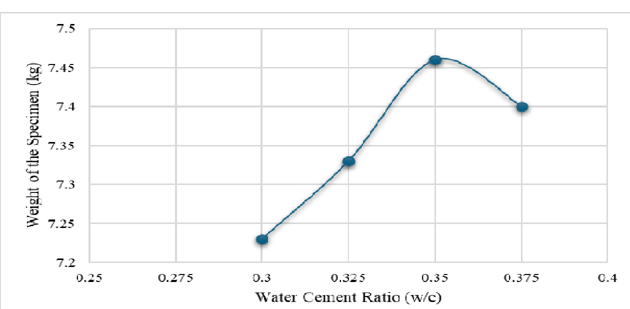

Figure 0:1Weight of the specimen vs w/c for mix without superplasticizer

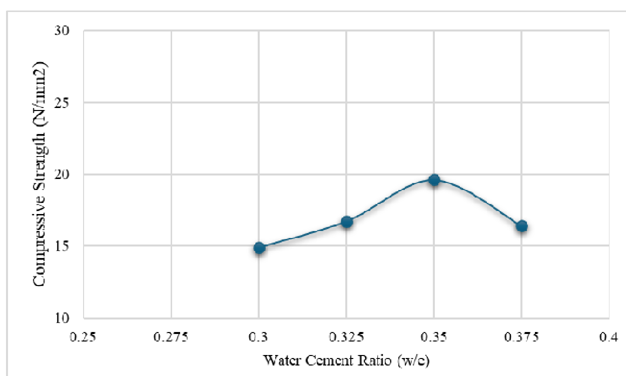

Figure 0:2 Compressive strength vs w/c for mix without superplasticizer

The compressive strength of the mixes as can be seen in the figure 4.2 first raises and after reaching a peak value falls subsequently. It can be explained by referring the figure 4.1 of weight and water cement ratio which follows the similar pattern of the compressive strength graph by first increasing and then decreasing.

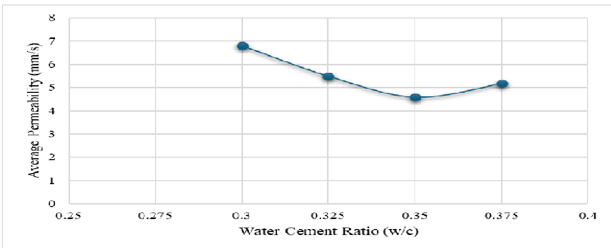

Figure 0:3 Permeability vs w/c for mix without superplasticizer

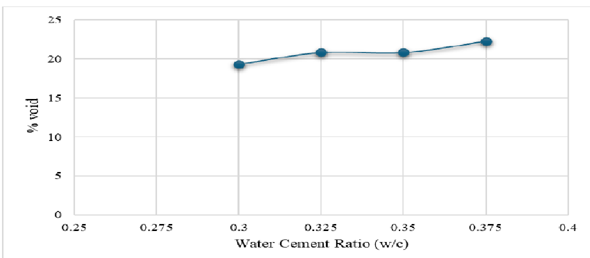

Figure 0:4 % void vs w/c for mix without superplasticizer

The trend of permeability is just opposite of the compressive strength. It first decreases sharply with increasing water cement ratio and then increases after reaching the minimum as shown in figure 4.3.

Permeability has higher value for low water cement value because of improper compaction which gives less dense concrete (lower weight of the specimen) leading to more interconnected voids resulting in higher permeability. But as the water cementratio is increased the degree of compaction increases leadingto dense concrete (higher weight of specimen) having less interconnected voids resulting in lower permeability.

4.2 With Superplasticizer

The Permeability, percentage of void ratio, and compressive strength of mix are as shown in table 4.2

Table 0:7 Permeability, percentage of void ratio, and compressive strength of each of the four batches using super plasticizer (0.3%)

Water Cement Ratio (w/c)	Weightofthe specimen(Kg)		Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Average Permeability (mm/s)	Average %void (by volume)
0.270	7.30	7.36	16.85	17.19	7.30	19.24
	7.30		17.15			
	7.50		17.57			
0.300	7.30	7.43	20.00	20.43	5.98	20.16
	7.30		20.75			
	7.70		20.55			
0.320	7.80	7.67	24.75	24.38	4.93	20.56
	7.60		24.17			
	7.60		24.22			
0.350	7.10	7.27	19.63	20.15	5.67	21.76
	7.40		20.72			
	7.30		20.11			

1. The permeability of the specimens of same batch is measured multiple times and average is reported.
2. 0.3% of the superplasticizer by weight of the cement is used.
3. Polycarboxylicether based mid-range water reducer is used as superplasticizer.

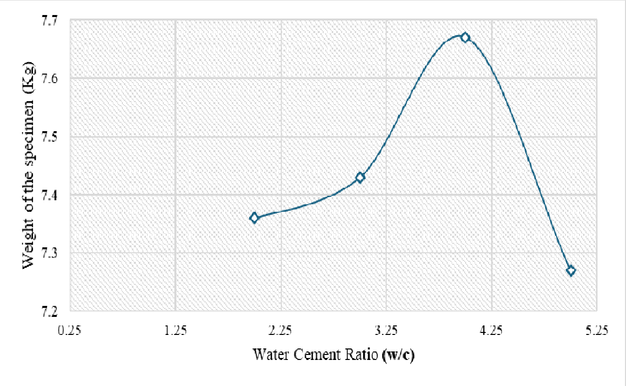

Figure 0:5Weight of the specimen vs w/c for mix with superplasticizer

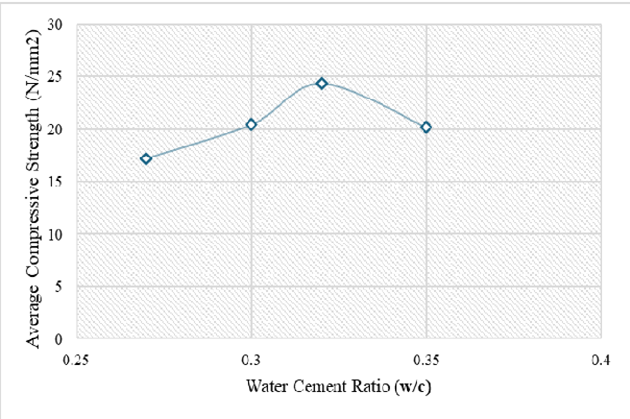

Figure 0:6 Compressive strength vs w/c for mix with superplasticizer

As it can see from figure 4.5 and 4.6 that the mix with mid-range water reducer (superplasticizer) is showing results which are very much similar to the nature and pattern of results shown by the mix without water reducer except for the effect that the mix with superplasticizer is getting the peak compressive strength and weight of the specimen a little earlier than the mix without superplasticizer. The pattern of the results and reason for it has been the same as explained in the earlier section.It can also be noticed from figure 4.5 and 4.6 that the compressive strength and weight of the specimens of the mix with superplasticizer is considerably higher than the compressive strength and weight of the specimen without superplasticizer.

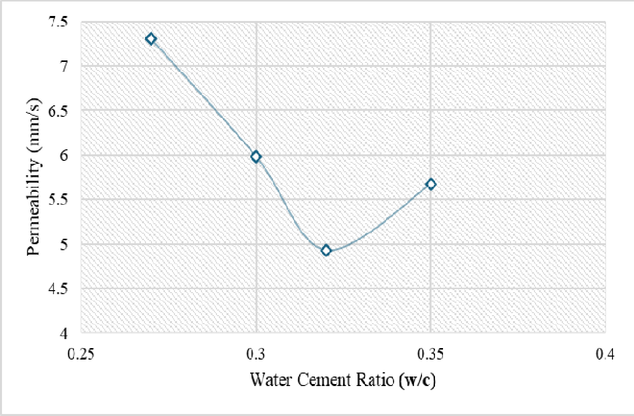

Figure 0:7Permeability vs w/c for mix with superplasticizer

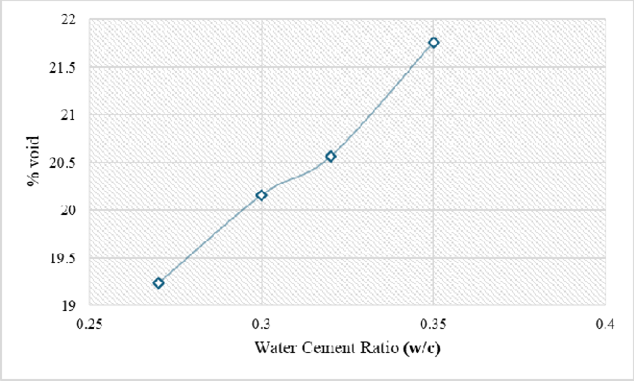

Figure 0:8 % voids vs w/c for mix with superplasticizer

As we can observe from the figure 4.7 that the permeability of the mix with superplasticizer is higher than the permeability of the mix without superplasticizer also the minimum permeability is achieved a little earlier.For voids also, it can seen from figure 4.8 that the % voids of the mix with superplasticizer is little lower than the mix without superplasticizer.

4.2.1 Comparison

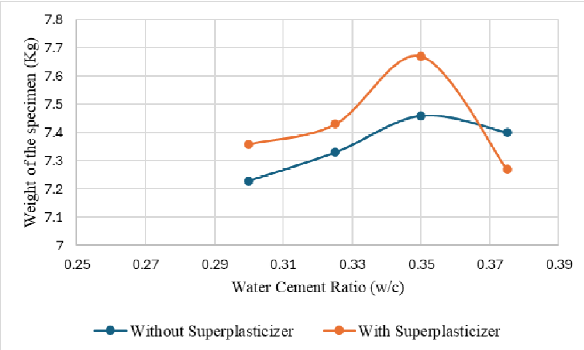

Figure 0:9 Comparison of weight of the specimen with and without superplasticizer

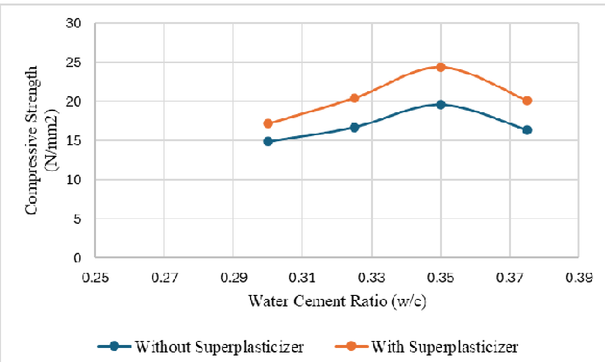

Figure 0:10 Comparison of compressive strength of the concrete with and without superplasticizer

The leftward shifting of the peaks of the compressive strength and weight of the specimens as shown in figure 4.9 and 4.10 can be explained by the fact that when water is added to the concrete, cement particles form the flocs around the water, trapping the air and the water.

When superplasticizer is added to the concrete, it disperses the cement particles thus prevents the formation of flocs around the water particles. This results in the concrete mix of more compressive strength and more dense concrete than the concrete mix without superplasticizer at same water cement ratio. Also when we add superplasticizer, the same workability and compaction can be achieved in the concrete at low water cement ratio as that will be achieved with higher water cement ratio in the concrete without superplasticizer.

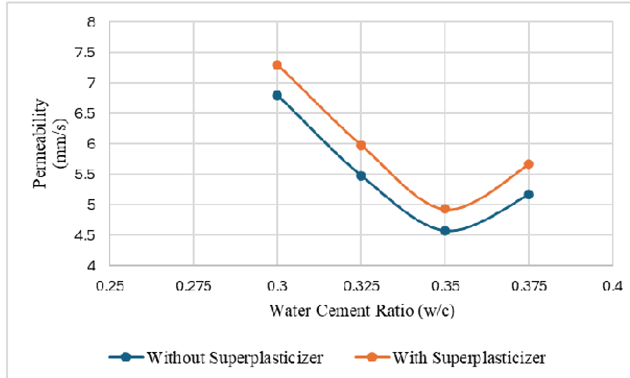

Figure 0:11 Comparison of permeability of pervious concrete with and without superplasticizer

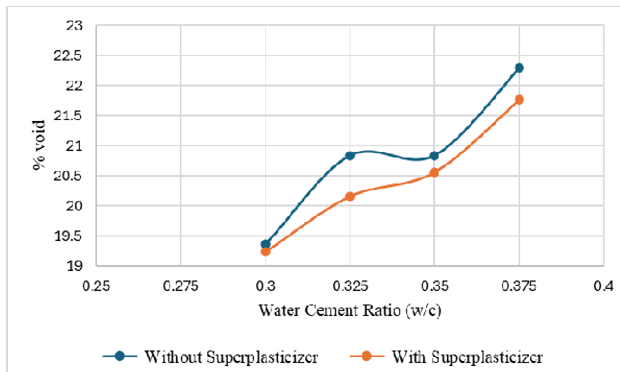

Figure 0:32 Comparison of % air voids in the specimen with and without superplasticizer

In the permeability curve, the leftward shifting of the curve as shown in figure 4.11 can be explained by the similar explanation as above that the dispersion of cement particles due to addition of superplasticizer helps in achieving better compaction and hydration (optimum) at low water cement ratio as compared to concrete without superplasticizerby prevention of formation of flocs of cement particles.

Also addition of superplasticizer reduces the air voids in the cement paste bydispersing the cement particles. Thus helping creating in more interconnected voids resulting in increased permeability as compared to concrete mix withoutsuperplasticizer.It can be seen from figure 4.12 that the % air voids for concrete with superplasticizer is slightly lowered because of the following reasons:

1. Firstly because of low water cement ratio. As it is known that higher water cement ratio induces higher voids in the concrete as the excess water left in the concrete after hydration evaporates leaving the airvoids in its place. It can be seen that with superplasticizer we get the desired results with less water cement ratio resulting in less voids.
2. Secondly addition of superplasticizer disperses the cement particlesresulting in prevention of formation of flocs and relieving the trapped air and water which could otherwise have formed voids leading in reduction of air voids.

4.3 Effect of variation in superplasticizer dose

As it is known that more workability can be achieved at same water cement ratio and also the water content can be reduced at same workability by using superplasticizer. So, the variation in the superplasticizer doses is necessary to study its effect on various parameters of pervious concrete.

4.3.1 0.2% of Cement V/W

Table 0:8 Compressive strength, permeability, and % void ratio of all the four batches with super plasticizer (0.2%)

Water Cement Ratio (w/c)	Weightofthe specimen(Kg)		Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Average Permeability (mm/s)	Average %void (by volume)
0.270	7.20	7.27	16.16	16.29	7.10	19.36
	7.40		17.15			
	7.20		15.57			
0.300	7.40	7.40	18.66	18.55	5.86	20.56
	7.30		17.84			
	7.50		19.15			
0.320	7.60	7.57	22.26	22.26	4.86	20.84
	7.50		21.86			
	7.60		22.56			
0.350	7.20	7.30	19.96	20.83	5.53	21.76
	7.30		20.66			
	7.40		21.86			

4.3.2 Superplasticizer 0.35 % of cement V/W

Table 0:9Compressive strength, permeability, and % void ratio of all the Four batches with super plasticizer (0.35%)

Water Cement Ratio (w/c)	Weightofthe specimen(Kg)		Compressive Strength (N/mm2)	Average Compressive Strength (N/mm2)	Average Permeability (mm/s)	Average %void (by volume)
0.270	7.50	7.40	18.16	17.69	7.34	19.36
	7.20		17.06			
	7.50		17.86			
0.300	7.60	7.53	21.96	21.52	6.14	20.84
	7.50		21.73			
	7.50		20.86			
0.320	7.50	7.60	22.93	23.22	5.26	22.29
	7.80		23.56			
	7.50		23.16			
0.350	7.00	7.14	19.23	19.42	5.95	22.29
	7.20		19.76			
	7.20		19.26			

4.3.3 Comparison

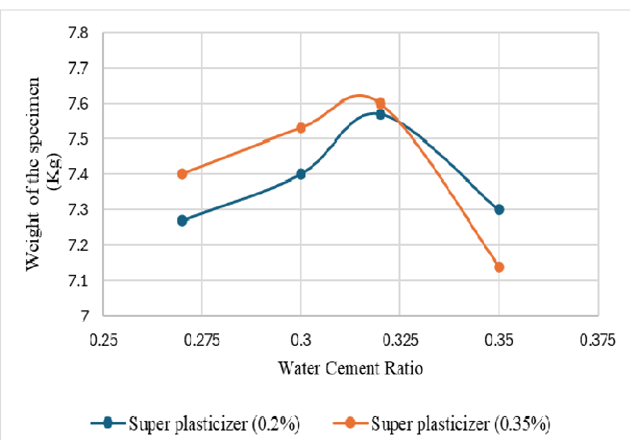

Figure 0:43 Comparison of weight of specimens with different doses of superplasticizer

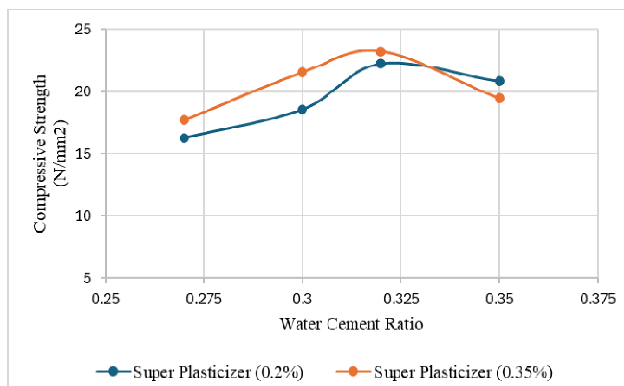

Figure 0:14comparison of compressive strength of specimens with different doses of superplasticizer

As it can be seen from the figure 4.13 and4.14 that when the dose of superplasticizer is decreased the denseness as well as the strength of the pervious concrete specimen falls below. But at high water cement ratios, the settlement of cement paste starts in the specimens with higherdoses of superplasticizer leading to increased rate of rise in strength and denseness of specimens with low doses of superplasticizer as compared to specimens with high doses of superplasticizer.

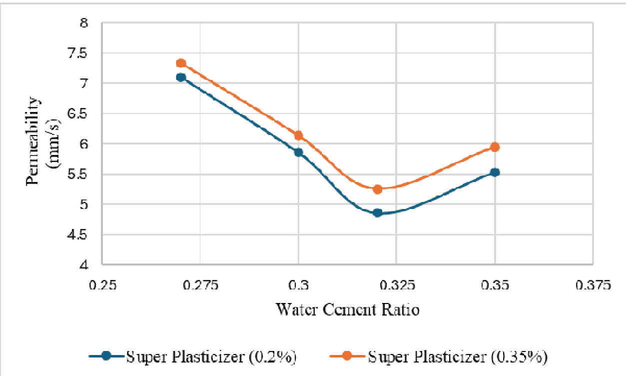

Figure 0:55 Comparison of permeability of specimen for different doses of superplasticizer

The variation in permeability as shown in figure 4.15 can also be explained by similar explanation on as above. When the dose of the superplasticizer is decreased, the permeability of specimens with low doses increases at low water cement ratio as compared to specimens with high doses because of poor compaction due which denseness of concrete decreases.

5. Conclusion

The experimental results (permeability and compressive strength curves with water cement ratio) for pervious concrete mix designs with and without superplasticizer .The following conclusions can be made based on the compressive strength and permeability that it achieves for various water cement ratios.

1. When designing low-capacity pavement, such as parking lots, walkways, paths, tennis courts, zoo areas, shoulders, drains etc. With compressive strengths as high as 20–25 N/mm^2, pervious concrete can be advised.
2. % voids can be controlled in pervious concrete and it can be designed of a particular % voids depending on strength and porosity needs.
3. Permeability of pervious concrete also depends vastly on the permeability of layers beneath it.
4. Optimum compaction plays a very important role in achieving good compressive strength which can be achieved with optimum consistency by added requisite water and superplasticizer in pervious concrete. Less compaction will give more voids to the concrete will more compactions will lead to the settlement of cement paste in the bottom of the mould.

5.1 Further scope of study

1. Along with compressive strength and permeability, other mechanical properties elastic modulus, tensile strength and flexural strength can be evaluated for wider applications of the pervious concrete.
2. Different % of the superplasticizer can be used to get better strength at different water cement ratios.
3. Different size, types and gradations can be used to map their effects
4. Durability study of pervious concrete can be done to establish its use in harsh climatic conditions.

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